New results from the RD52 (DREAM)* project

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Frontier Detectors for Frontier Physics
La Biodola, May 20 - 26, 2012

* DREAM (RD52) Collaboration:
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About RD52

RD52 is a **generic** detector R&D project **not** linked to any experiment

**Goal:**

Investigate + eliminate the factors that prevent us from measuring hadrons and jets with similar precision as electrons, photons

**Method:**

Simultaneous measurement of scintillation light \((dE/dx)\) and Čerenkov light produced in shower development makes it possible to measure the em shower fraction event by event. The effects of fluctuations in this fraction can thus be eliminated  *(Dual-READout Method)*

**Relevance:**

This method provides the same advantages as intrinsically compensating calorimeters \((e/h = 1)\) **WITHOUT** the limitations (sampling fraction, integration time, volume)
Elba 2003: The original DREAM calorimeter
DREAM: Effect of event selection based on $f_{em}$

Entries 78198
Mean 66.1
RMS 12.4

100 GeV $\pi^-$ Č signal

Elba 2006:
Č/S signal ratio measures $f_{em}$ event by event!

→ Eliminate effects of $f_{em}$ fluctuations on performance of hadron calorimeters

Identifying Čerenkov component on the basis of its directionality

\[ n = 2.2, \arccos \theta_C = 1/n \rightarrow \theta_C = 63^\circ. \]

Trigger counters

Calibration: \( L = R \)

Measure \( \frac{L - R}{L + R} \) as a function of \( \theta \)

Experimental results
Elba 2009: First results of new, dedicated DREAM crystals

PbWO$_4$·1\%Mo

Separate Č and S components through:
- spectral characteristics
- time structure

Figure 3: Unraveling of the signals from a Mo-doped PbWO$_4$ crystal into Čerenkov and scintillation components. The experimental setup is shown in diagram a. The two sides of the crystal were equipped with a UV filter (side $R$) and a yellow filter (side $L$), respectively. The signals from 50 GeV electrons traversing the crystal are shown in diagram b, and the angular dependence of the ratio of these two signals is shown in diagram c [6].
Time structure of the DREAM signals: the neutron tail (anti-correlated with $f_{em}$)

**Elba 2009**

**Figure 4:** The average time structure of the Čerenkov and scintillation signals recorded for 200 GeV “jets” in the fiber calorimeter (a). Scatter plot of the fraction of the scintillation light contained in the (20 ns) exponential tail versus the Čerenkov/scintillation signal ratio measured in these events (b) [9].
Outline:

- New results with crystals
- The new fiber calorimeter (SuperDREAM)
  - beam tests of prototype modules
  - final design choices
- Plans for 2012 and beyond
Fiber calorimeters vs crystals

Elements needed for high-resolution calorimetry:

- Elimination of contributions of fluctuations in em shower fraction
  Intrinsic compensation ($e/h = 1$) or dual-readout

- Minimization of contributions of fluctuations in visible energy
  Efficient detection of “nuclear” shower component
  (e.g., energy resolution ZEUS much better than D0)

- Limit contribution of stochastic fluctuations
  These are THE limiting factor for em energy resolution
Measurements with crystals
Tests of Dual-Readout crystal matrices with electron beams

Selection of Čerenkov, Scintillation signals

See poster S. Franchino
Polarization measurements

80 GeV $e^-$

T$_1$, T$_2$, veto
DC1, DC2

Polarizer (HN38)
UV filter (U330)

Cerenkov PMT R8900

Pb sheets

BSO crystal
2.2 cm x 2.2 cm x 18 cm

Scintillator PMT R8900
Yellow filter (GG495)
Polarizer (HN38)

Scintillation

Signal in BSO crystal (a.u.)

Shower depth ($X_0$)

$\text{Čerenkov/scintillation signal ratio}$

Shower depth ($X_0$)
The new fiber calorimeter
The first SuperDREAM module tested at CERN

Pb absorber
9.3 x 9.3 x 250 cm
150 kg
4 towers, 8 PMTs
2 x 2048 fibers

Fiber pattern

Hamamatsu R8900
pc: 85%!

DREAM structure

Copper

23.5 mm

2.5 mm

4 mm

2.54 mm

photo cathode
Comparison of polystyrene/PMMA clear fibers

Numerical aperture:
PS 0.72, PMMA 0.50

However, self absorption in PS (Rayleigh scattering), $\lambda_{att} \sim 3 \text{ m}$

Tested two lead modules, one with PS, one with PMMA
Readout EXACTLY the same

Scintillator: no change
Čerenkov: x 2!

Č light yield was measured for PS module with LED: 32 p.e./GeV
→ twice as high for PMMA
Electromagnetic energy resolution in one (Pb) SuperDREAM module

Čerenkov signals
(beam hits in 4-corner region)

RESOLUTION MUCH BETTER THAN IN DREAM!

Further improvements:
• Combine different modules → better containment for beam in tower centers
• Aluminizing upstream end of (Č) fibers → more light
• Light mixers → eliminate position dependence of response
• Reduce noise contribution of readout electronics

Expect 10%/\sqrt{E} by combining signals from two types of fibers
Absorber choice: Cu vs Pb

- Detector mass: \( \lambda_{\text{Cu}} = 15.1 \text{ cm} \), \( \lambda_{\text{Pb}} = 17.0 \text{ cm} \)
  
  Mass \( 1\lambda^3 \): Cu/Pb = 0.35

- e/mip \( \rightarrow \) Čerenkov light yield Cu/Pb \( \sim 1.4 \)
  
  (Showers inefficiently sampled in calorimeters with high-Z absorber)

- Non-linearity at low energy in calorimeters with high-Z absorber
  
  Important for jet detection
The first copper module

Clear fibers illuminated

Scintillating fibers
The first copper module
First hadrons in SuperDREAM (1 Pb module + n-shield)
Calibration of neutron shield (muon beam)
First results on pion detection in the new fiber calorimeter

Scintillator signal (raw data)

Leakage vs scintillator signals

a) 180 GeV π⁻

C/S vs corrected S signal

After rotation

Corrected total S signal
Time structure signals

Fiber calorimeter: needed for
- precision measurement of start time signals
- neutron tail of S signals

Crystals: needed to separate C and S signals

We use a data acquisition system based on the DRS chip* (Domino Ring Sampler) developed at PSI. An array of 1024 switching capacitors samples the input signal, at a frequency of 5 GHz (DRS-IV). Read out by pipeline 12-bit ADC.

* See NIM A518 (2004) 407
Depth of the light production and the starting point of the PMT signals

- **Particles to starting point shower**
- **Light to PMTs**
- **Start of PMT pulse**

Time (ns) vs. Depth inside DREAM calorimeter (cm)

- 2.55 ns/m
- \( \sim 0.6 \text{ ns/} \lambda_{\text{int}} \)
Measurement of the depth of the light production in module using the DRS timing

80 GeV electrons

\[ \sigma = 0.55 \text{ ns} \]

180 GeV pions

Start of calorimeter signal (in DRS cells = 0.2 ns)

slope 0.8 ns
Check that DRS time measures shower depth

Leakage counters

Depth from leakage counter profile (cm)  Displacement $x_{DWC} - x_{CAL}$ (mm)
Plans for 2012

- We hope to finish construction of a matrix of 12 - 16 fiber modules (2 - 4 Cu, 8 - 10 Pb, + 2 existing Pb)

- Complete the construction of the neutron shield (40 modules)

- Test this matrix + n-shield in November

- Finish our crystal program (polarization measurements, July)

- Further develop MC tools needed for this project
Production of Pb based SuperDREAM modules
Plans for ≥ 2013

- Finish construction of the 5-ton calorimeter
- Tests of full calorimeter with/without em Xtal matrix
- Address issues associated with implementation in experiment
  - Compactness: investigate W option
  - Readout: test SiPM readout of fiber module
  - Projectivity
Backup slides
DREAM: How to determine $f_{em}$ and $E$?

\[ S = E \left[ f_{em} + \frac{1}{(e/h)_S} (1 - f_{em}) \right] \]

\[ Q = E \left[ f_{em} + \frac{1}{(e/h)_Q} (1 - f_{em}) \right] \]

*Example*: If $e/h = 1.3$ (S), 4.7 (Q)

\[ \frac{Q}{S} = \frac{f_{em} + 0.21 (1 - f_{em})}{f_{em} + 0.77 (1 - f_{em})} \]

\[ E = \frac{S - \chi Q}{1 - \chi} \]

with \[ \chi = \frac{1 - (h/e)_S}{1 - (h/e)_Q} \approx 0.3 \]
DREAM: relationship between Q/S ratio and $f_{em}$

**em shower fraction**

**a)**

- **Q/S**
  - Entries: 25121
  - Mean: 0.7806
  - RMS: 0.07532

**b)**

- **$f_{em}$**
  - Entries: 25121
  - Mean: 0.5532
  - RMS: 0.1212
DREAM: Effect of event selection based on $f_{em}$

100 GeV $\pi^-$ Čerenkov signal

From: NIM A537 (2005) 537
DREAM: Signal dependence on $f_{em}$

**Scintillator signals**

$\langle S \rangle = 149.8 + 38.5 \times f_{em}$

**Čerenkov signals**

$\langle C \rangle = 40 + 148 \times f_{em}$

$R(f_{em}) = p_0 + p_1 \times f_{em}$ with $\frac{p_1}{p_0} = e/h - 1$

Cu/scintillator \hspace{1cm} e/h = 1.3

Cu/quartz \hspace{1cm} e/h = 4.7

*From:* NIM A537 (2005) 537
DREAM: Effect of corrections (200 GeV "jets")

Uncorrected:
- Entries: 13507
- Mean: 133.1
- RMS: 18.6

Q/S method:
- Entries: 13507
- $\chi^2$/ndf: 292/158
- Mean: 190.1
- Sigma: 9.69

Čerenkov signal (GeV)