The DREAM module was designed as a proof-of-principle module to test the idea of dual-readout as a means to suppress the large EM fluctuations in hadronic showers. It worked.

The next largest are the binding energy loss fluctuations, and these can be estimated by measuring the MeV neutrons liberated in shower development.

We have modified the DREAM module, measured these neutrons, and estimated the effect of these fluctuations on hadronic energy measurement.

Improvements in these techniques are planned.
Dual-readout DREAM: Structure

- **Some characteristics of the DREAM detector**
  - **Depth** 200 cm (10.0 $\lambda_{\text{int}}$)
  - **Effective radius** 16.2 cm (0.81 $\lambda_{\text{int}}$, 8.0 $\rho_M$)
  - **Mass** instrumented volume 1030 kg
  - **Number of fibers** 35910, diameter 0.8 mm, total length $\approx$ 90 km
  - **Hexagonal towers** (19), each read out by 2 PMTs
Reconfigure DREAM module to sum nearly the entire volume into three scintillation and one Cerenkov channel. Deliver these to a fast oscilloscope.

DAQ was 1 GHz 4-chan digital storage scope

transfer to counting house in fast air-core cables

Scintillating fibers

“Fast 1”

“Fast 2”

“Fast 3”

“Fast 4”

Cerenkov fibers

1● + 6● + 9●
50 GeV e-data events

event #1

event #2

event #3

event #4

(clearly electrons)
300 GeV pi-data events

event #1

event #2

event #3

event #4

(clearly pions)
“neutron signal” defined simply as the integral of the Scintillation pulse over 20-40 ns.
fn = \frac{En}{200 \text{ GeV}}
The neutron fraction is anti-correlated with the Cerenkov signal - as expected.

More interestingly, the total Cerenkov distribution can be decomposed into its constituent parts as a function of \( f_n \).

This is the analog to the same plot decomposed into fEM parts.
Linearly correcting each Cerenkov distribution in an $f_n$ bin to $f_n=0.07$ (arbitrary, middle value) results in the “$f_n$ corrected” distribution.

1. $f_n$-corrected Cerenkov resolution improves with shower energy ... AND ...
2. Its dependence leaves no “constant term”
For fixed EM fractions, the neutron fraction varies by ~15% or more; these are the binding energy loss fluctuations on top of the EM fraction fluctuations.
For fixed EM fraction, the resolution in the Cerenkov signal worsens as the neutron fraction grows larger, and its fluctuations grow larger.

For fixed EM fraction \( \sim 0.55 \) and \( 0.045 < \text{fn} < 0.065 \), the resolution in Cerenkov signal is 4.7%. For a tighter \text{fn}, \( 0.050 < \text{fn} < 0.055 \), the resolution is 4.4%.

Note bene: leakage fluctuations in DREAM are \( \sim 4\% \).
Summary and plans for neutrons in DREAM

- This is a “first cut” analysis.

- The time history of every channel with the Domino Ring Sampler (DRS) will yield the best data we can expect from the DREAM module; this analysis will be repeated and further analyses done with new data next July-August.

- It is not yet clear what hadronic energy resolution we can achieve, but the “ultimate” resolution is about $15\% / \sqrt{E}$. Will it be 15% ... 20% ... 25% ... ?

- It will be a pleasure to be limited in a collider experiment by jet-finding, reconstruction, jet energy scale, and other confusions and systematics ... but not the hadronic calorimeter energy resolution!