New Results from the DREAM project

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Gabriella Gaudio
INFN-Pavia
on behalf of the DREAM Collaboration

DREAM principle

The Dual READout Method (DREAM) allows to improve the performances of hadronic calorimeters by measuring event-by-event the electromagnetic fraction of the hadronic cascade, thus reducing the effect of its fluctuation and obtaining a better resolution and linearity. The method is based on the separation of the scintillation light due to ionization from Čerenkov light produced almost exclusively by relativistic particles, i.e. the electromagnetic component of the hadronic shower. The DREAM method has been applied to both a fiber calorimeter and homogeneous media (crystals).

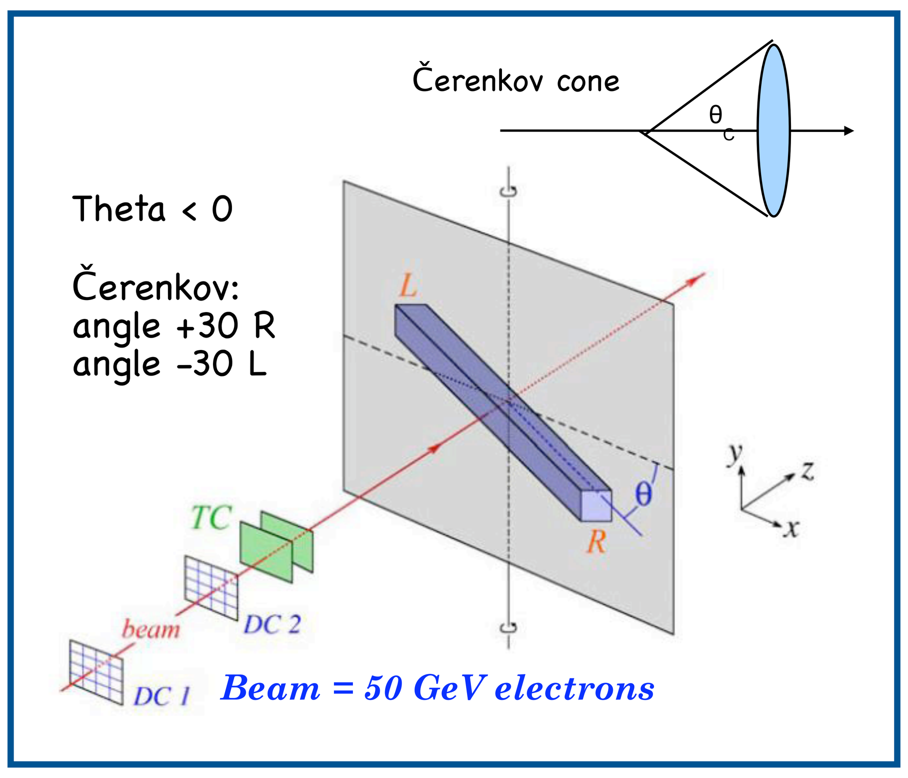
Crystals for Dual Readout technique

Separation of Čerenkov (C) and Scintillation (S) light in crystals can be achieved by exploiting:

Time structure: Čerenkov light is prompt, while Scintillation is characterized by one or several time constants.

Spectral Properties: Čerenkov emission exhibits a λ^{-2} spectrum, while for Scintillation the emission spectrum is characteristic of the crystal type, usually it shows some peaks.

Directionality: Čerenkov light is emitted at a characteristic angle $\theta_C = \arccos(1/\beta n)$, while Scintillation is isotropic (not exploitable in real detectors but useful for quantitative evaluations).



In order to have the best possible separation, a crystal must have a scintillation emission:

- in a wavelength region far from the bulk of the Čerenkov signal
- with a decay time of order of tenths of nanoseconds

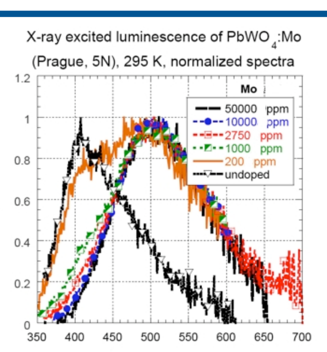
We adopted a readout scheme which consists of two PMTs, one at each side of the crystal, and equipped with a short-pass filter for selecting Čerenkov light, and a long-pass filter for scintillation.

Both lead tungstate ($PbWO_4$) and BGO crystals have been successfully used as homogeneous media for dual readout technique. Studies for crystals optimization have been carried on by the Dream Collaboration.

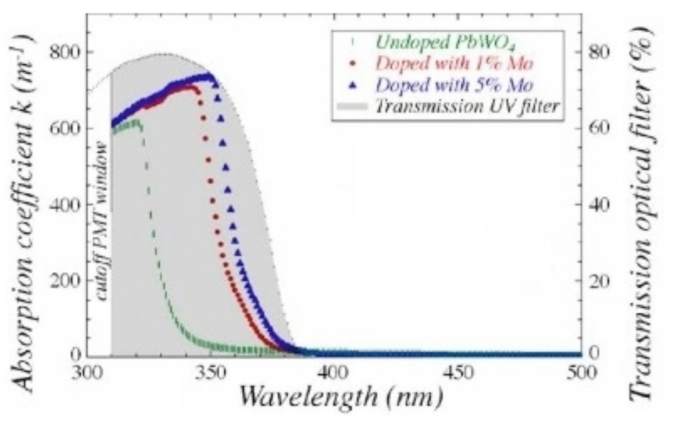
Molybdenum doping in PbW0₄ crystals

Molybdenum (Mo) doping causes:

- a shift of the emission spectra with peak moving from ~420 nm to ~500 nm with respect to the undoped crystal [2]
- an increase the S decay time to about 50 ns
  - ➡ allow to obtain a very good Čerenkov to scintillation light separation.

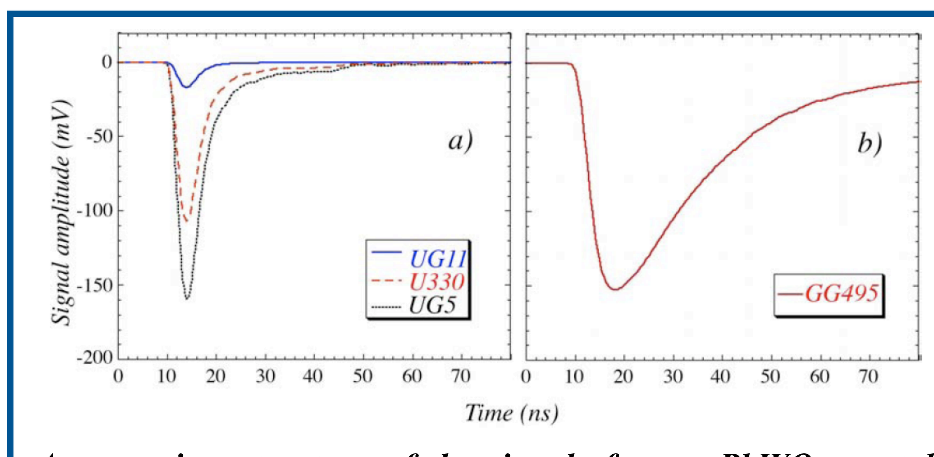


- a shift of the self-absorption cut-off to higher wavelength is observed
  - ➡ crystals are less transparent to Čerenkov light produced
  - ➡ in order to achieve a good S versus C separation, C light has to be collected in a narrow window between self-absorption edge and filter cut-off. This may results in strong light attenuation.

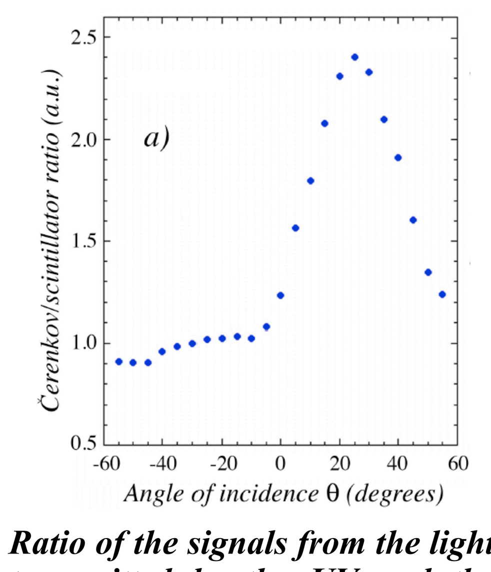


Systematic studies on Mo dopant concentration (0.1% to 5%) and on different short-pass filters have been carried out.

The time structure of the signals, the C/S ratio, the effect of light attenuation, and the Čerenkov light yield are figures of merit to evaluate crystal suitability for Dual Readout Technique.



Average time structure of the signals from a $PbWO_4$ crystal doped with 1% Mo. The angle θ was 30° in these measurements. Shown are the results obtained with different short-pass (a) and yellow (b) filters, respectively.[3]



Ratio of the signals from the light transmitted by the UV and the yellow filters, as a function of the angle of incidence of the beam particles. [3]

Depending on optical filters - Mo concentration combination:

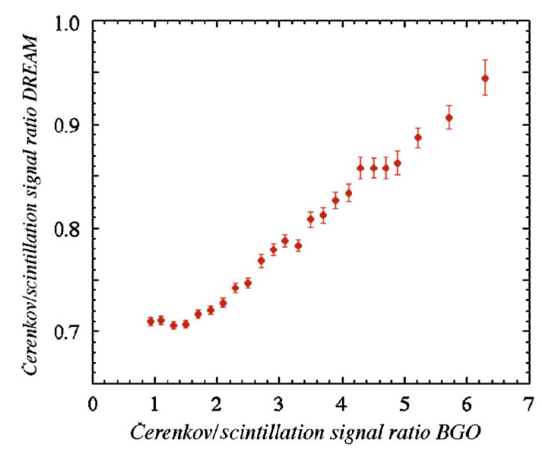
- Čerenkov light yield from 6 p.e./GeV to 60 p.e./GeV have been obtained.
- Attenuation length from 7 cm to 25 cm have been found

Combined calorimetry [4]

The calorimeter during installation in the test beam, which runs from the bottom left corner to the top right corner in this picture. The 100-crystal BGO matrix is located upstream of the fiber calorimeter. [4]

The crucial aspect of the DREAM method is the comparison of the Scintillation and Čerenkov signals produced in hadronic shower development. The ratio between these two signals is a measure for the em shower fraction. In the case of the fiber detector in stand-alone mode, there is a simple one-to-one correspondence between this signal ratio and electromagnetic fraction.

$$\frac{Q}{S} = \frac{R_Q}{R_S} = \frac{f_{em} + 0.20(1 - f_{em})}{f_{em} + 0.77(1 - f_{em})}$$



The Cerenkov/scintillation signal ratio of the DREAM calorimeter, for 200GeV π⁺ starting a shower in the BGO crystal, as a function of the Cerenkov/ Scintillation signal ratio of the BGO signal. [4]

For the combined BGO+fiber system, such a simple relationship does not exist, since the e/h values of the BGO crystal are different from those of the fiber detector, and the energy sharing between these two calorimeter systems varies from event to event. However, also in this case, the ratio of the Čerenkov and Scintillator signals itself turns out to be a good measure for the em shower content.

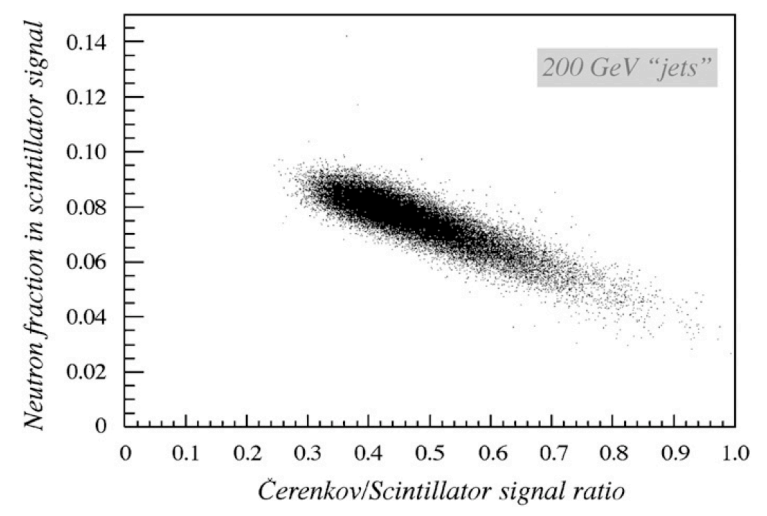
Neutron fraction measurement [5]

Once the contribution to the resolution due to leakage is eliminated, the resolution become dominated by nuclear breakup effects. Fluctuations in the fraction of the total energy needed to release protons, neutrons and heavier nuclear fragments in the nuclear reactions initiated by the shower particles lead to fluctuations of the visible energy, and thus to fluctuations in the calorimeter response.

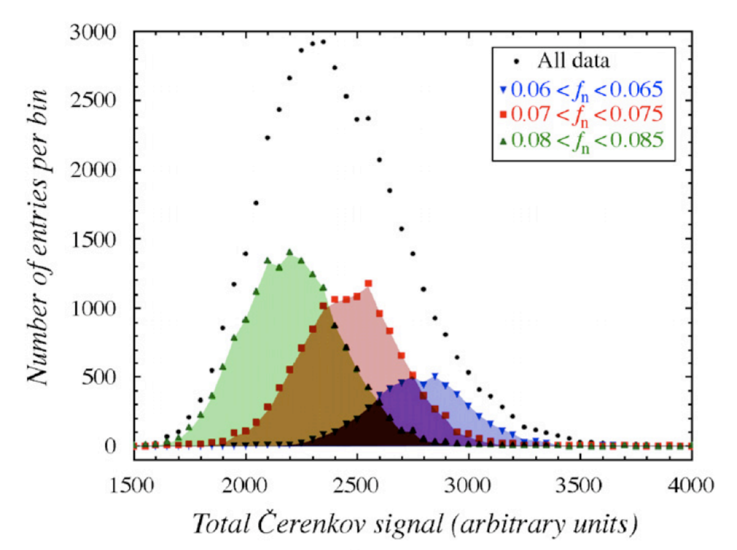
It has been demonstrated previously that a measurement of the total kinetic energy carried by neutrons generated in the shower development is a powerful tool for reducing the effects of these fluctuations, especially in high-Z absorber materials where most of the nucleons released in the nuclear reactions are indeed neutrons.

It is possible to determine the event-by-event relative contribution of the neutron (f_n) by analyzing the time structure of the signal.

This fraction is anti-correlated with the Čerenkov/scintitlation signal ratio and thus with the relative strength of the em shower component.



Scatter plot for 200 GeV "jets"(1). For each event, the combination of the total Čerenkov/scintillation signal ratio and the fractional contribution of the neutrons to the total scintillation signal is represented by a dot. [5]



Distribution of the total Čerenkov signal for 200 GeV "jets" and the distributions for three subsets of events selected on the basis of the fractional contribution of neutrons to the scintillator signal. [5]

Event samples with different neutron fractions (f_n) are selected.

The total Čerenkov signal distribution for all the events turns out to be a superposition of many distributions.

Each of these distributions for the subsamples has a different mean value, is much more Gaussian than the overall signal distribution and shows a resolution that is substantially narrower than that of the overall signal distribution.

An analysis very similar to the one originally used to study the merits of the dual readout method has been carried out.

(1) "jets" are intended as a collimated collection of particles produced by beam interaction in a paraffin target positioned just upstream the detectors.

References

[1] Akchurin N. et al., "New crystals for dual-readout calorimetry" Nucl. Instr. and Meth. **A604** (2009) 512

[2] Nikl M. et al "Complete characterization of doubly doped PbWO4:Mo,Y scintillators", Journal of Applied Physics, **91** (2002), 2792

[3] Akchurin N. et al., "Optimization of crystals for applications in Dual Readout Calorimetry" to be submitted to Nucl. Instr. and Meth. A

[4] N. Akchurin et al., "Dual-Readout Calorimetry with a Full-Size BGO Electromagnetic Section", Nucl. Instr. and Meth. **A598** (2009) 710

[5] N. Akchurin et al., "Neutron Signals for Dual-Readout Calorimetry", Nucl. Instr. and Meth. **A598** (2009) 422