New results from the RD52 (DREAM)[*] project

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Frontier Detectors for Frontier Physics
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[*] *DREAM (RD52) Collaboration:*
Cagliari, Cosenza, Pavia, Pisa, Roma, Iowa State, TTU

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

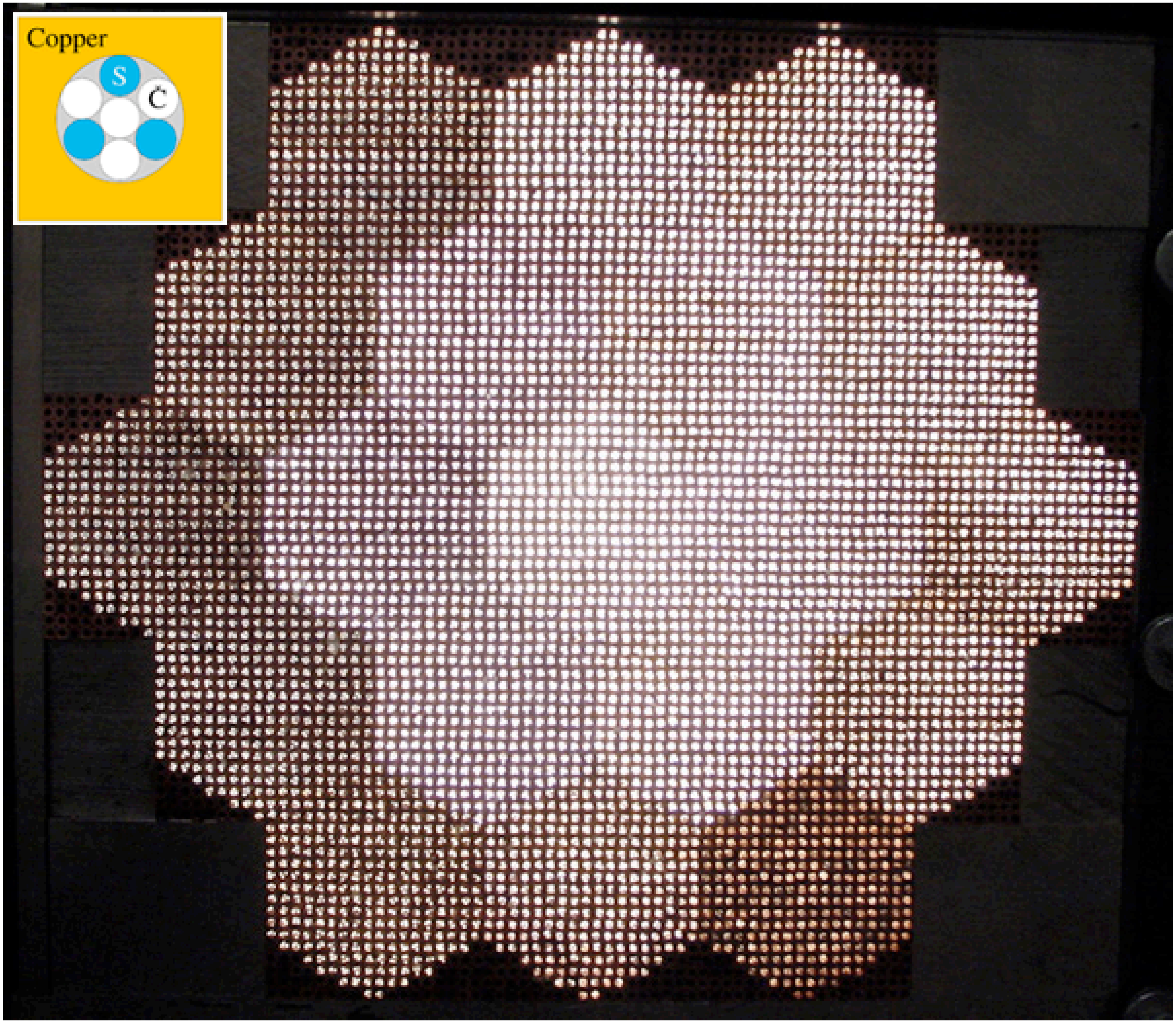
Method:

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)

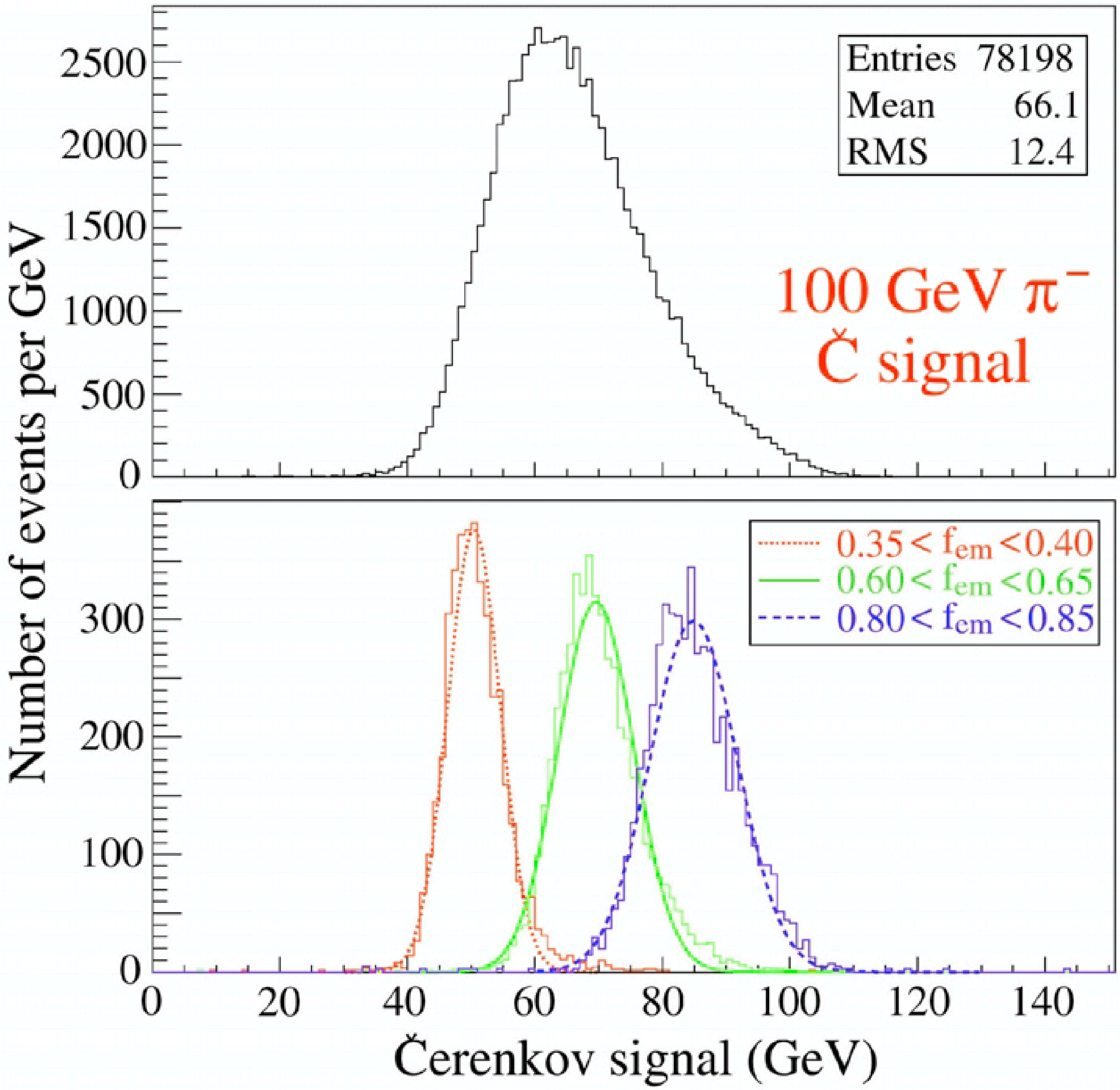
Relevance:

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}



Elba 2006:

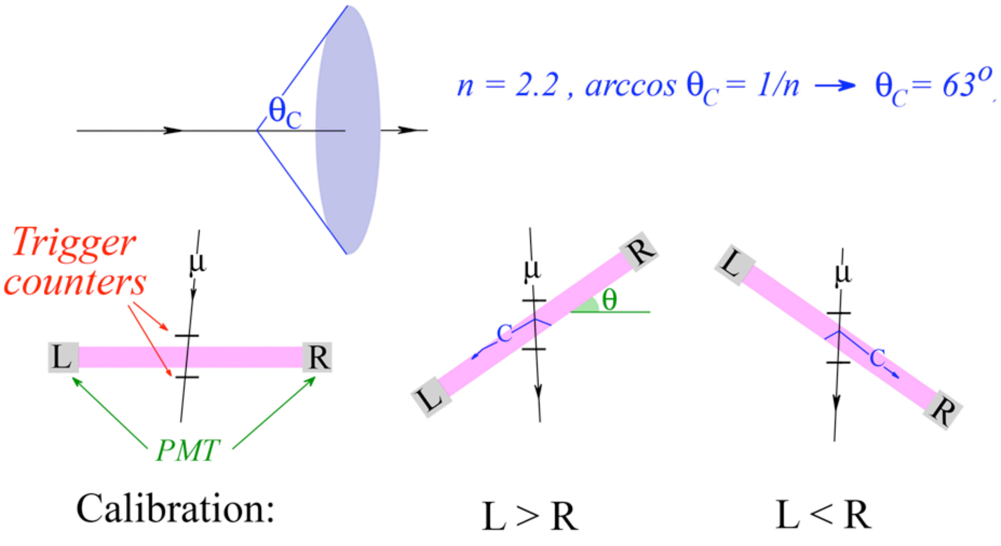
Č/S signal ratio measures f_{em} event by event!

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

Elba 2006: Introduction of the Dual-Readout Method in crystals

(first tried with $PbWO_4$)

Identifying Čerenkov component on the basis of its directionality



$n = 2.2$, $\arccos \theta_C = 1/n \rightarrow \theta_C = 63^o$

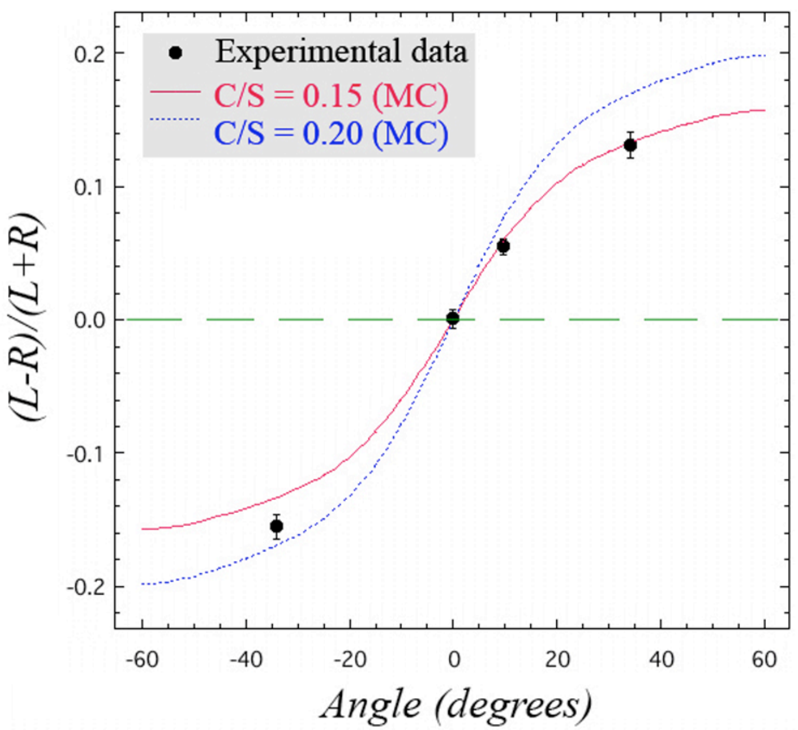
Calibration:
L = R

L > R

L < R

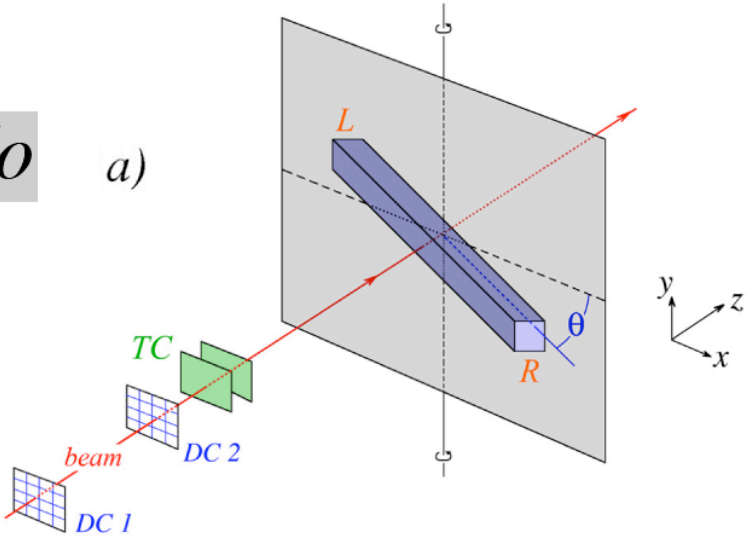
→ *Measure* $\frac{L - R}{L + R}$ *as a function of* θ

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*

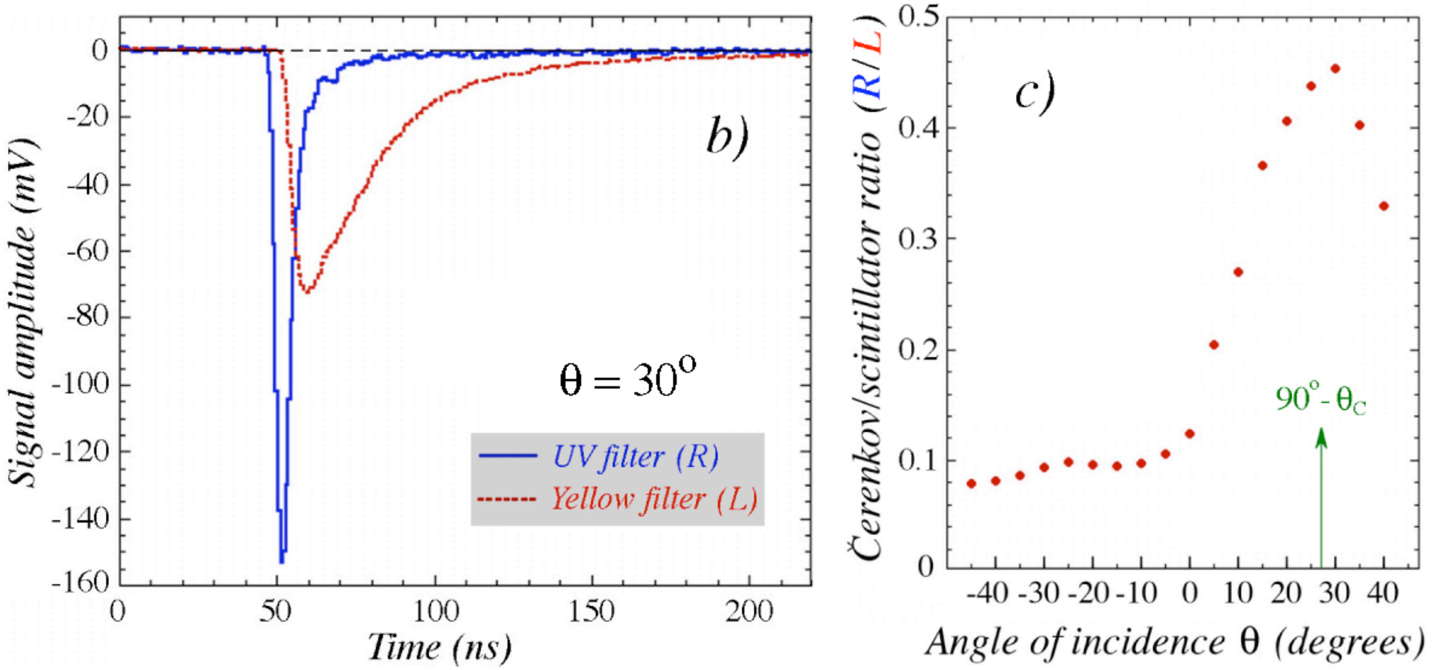
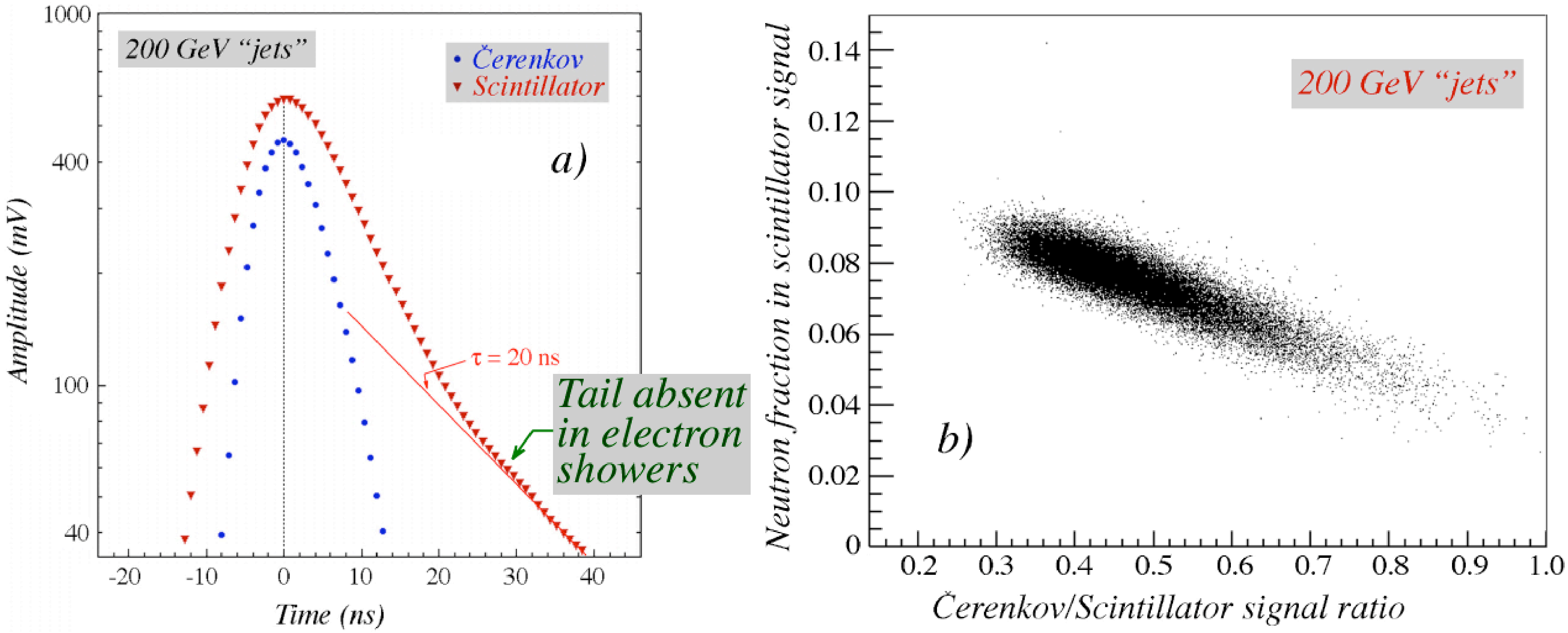


Figure 3: Unraveling of the signals from a Mo-doped $PbWO_4$ crystal into Čerenkov and scintillation components. The experimental setup is shown in diagram *a*. The two sides of the crystal were equipped with a UV filter (side *R*) and a yellow filter (side *L*), respectively. The signals from 50 GeV 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



Tail absent in electron showers

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) exponentional 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

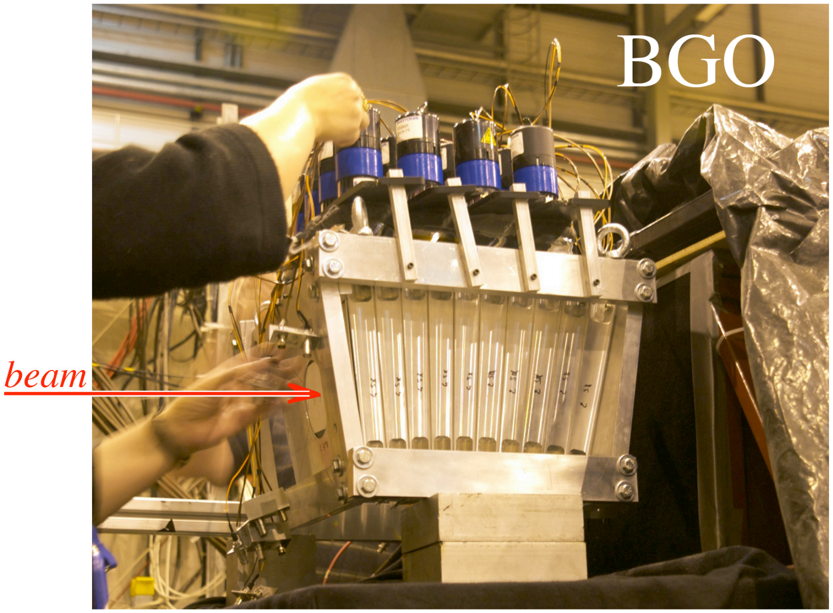
- *Minimization of contributions of fluctuations in visible energy*
  Efficient detection of "nuclear" shower component
  (e.g., energy resolution ZEUS much better than D0)

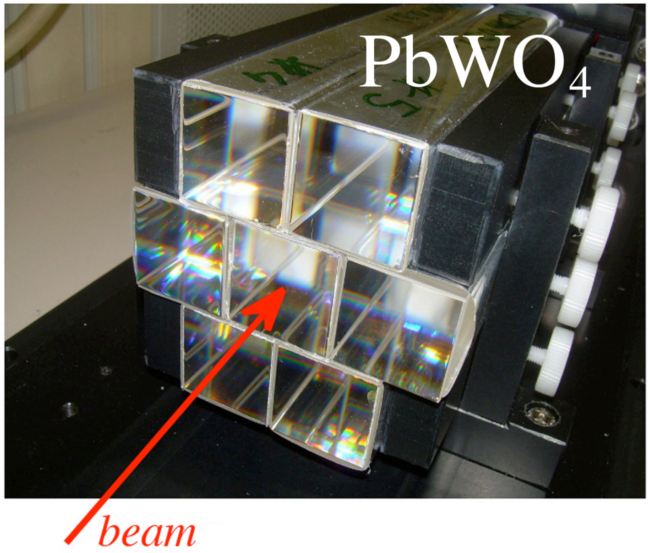
- *Limit contribution of stochastic fluctuations*
  These are THE limiting factor for em energy resolution

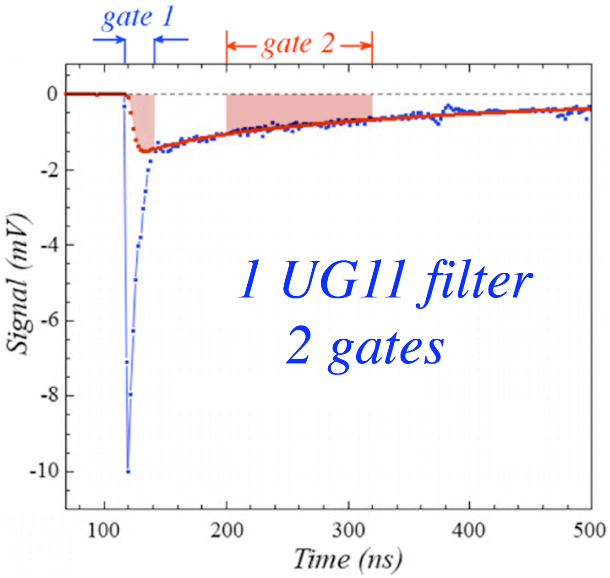
Measurements with crystals

Tests of Dual-Readout crystal matrices with electron beams

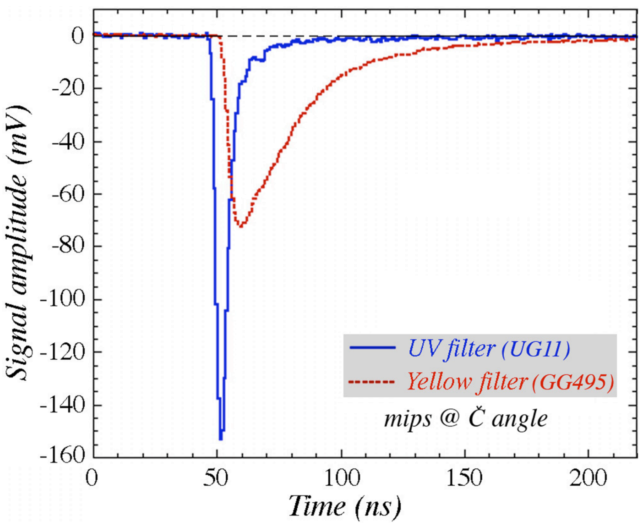
Selection of Čerenkov, Scintillation signals





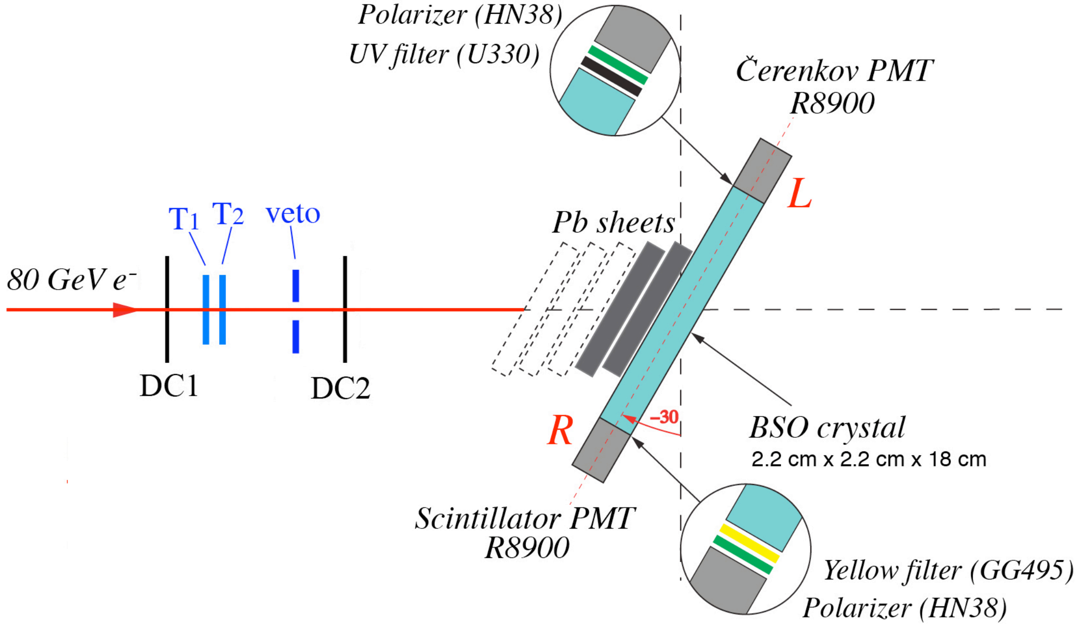


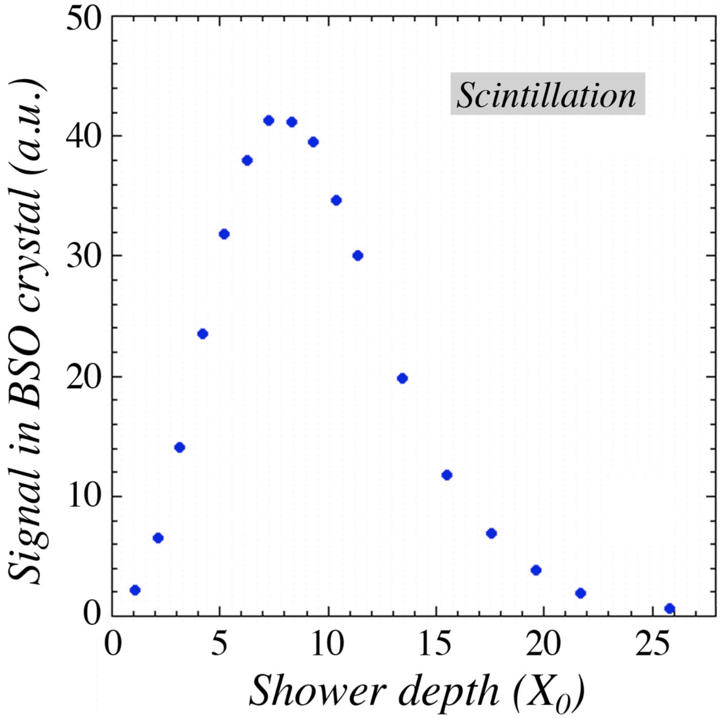
1 UG11 filter
2 gates

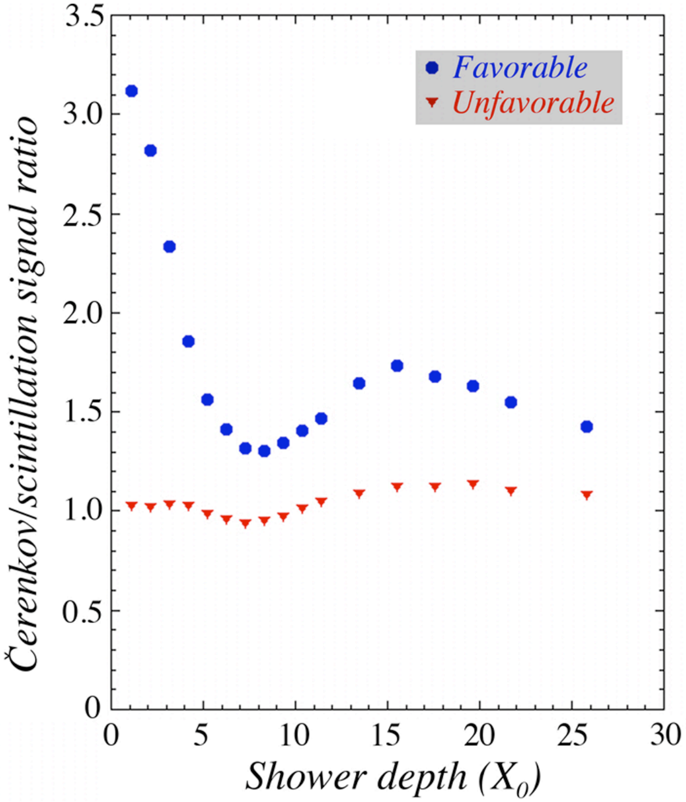


See poster
S. Franchino

Polarization measurements

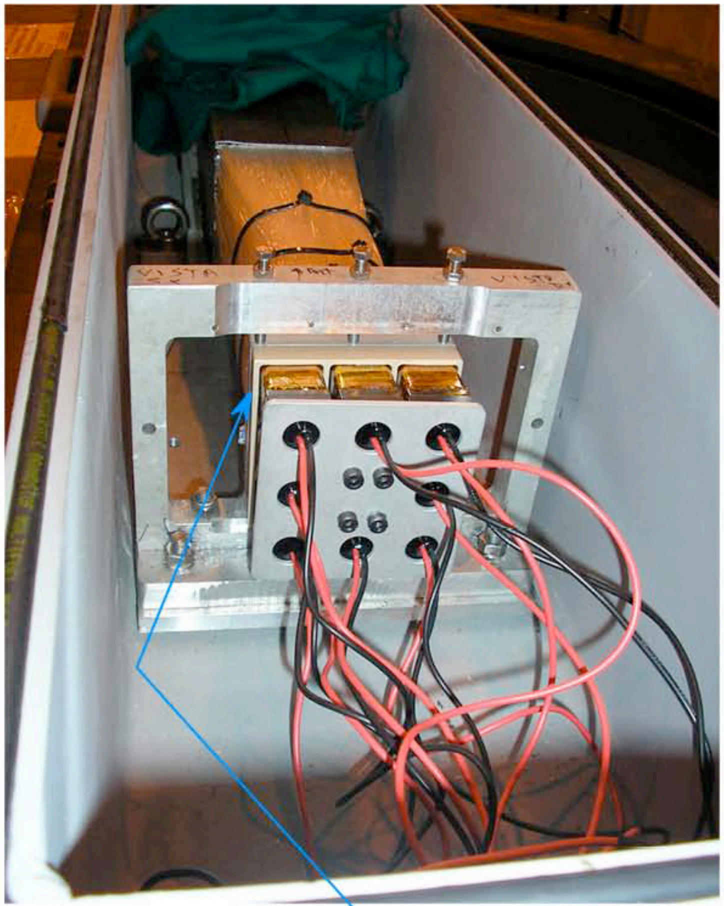




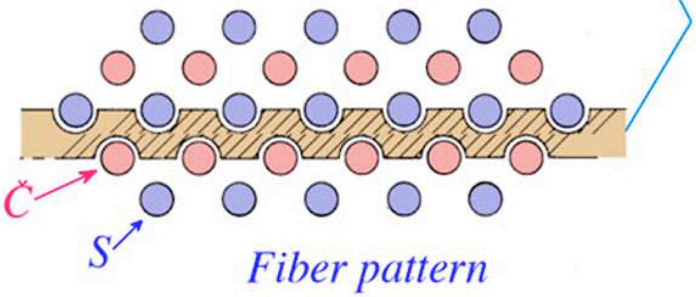


The new fiber calorimeter

The first SuperDREAM module tested at CERN

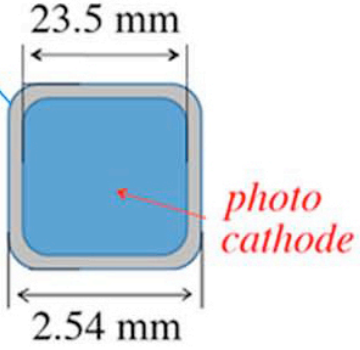


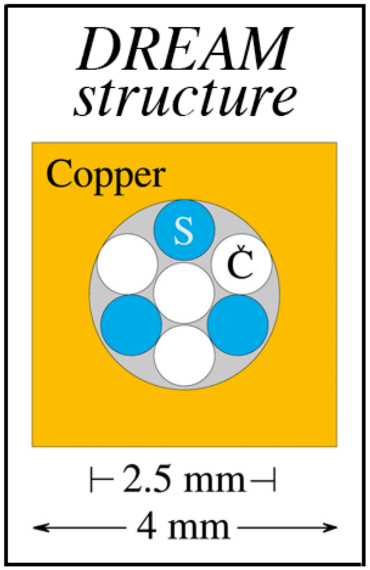
Pb absorber
9.3 x 9.3 x 250 cm
150 kg
4 towers, 8 PMTs
2 x 2048 fibers



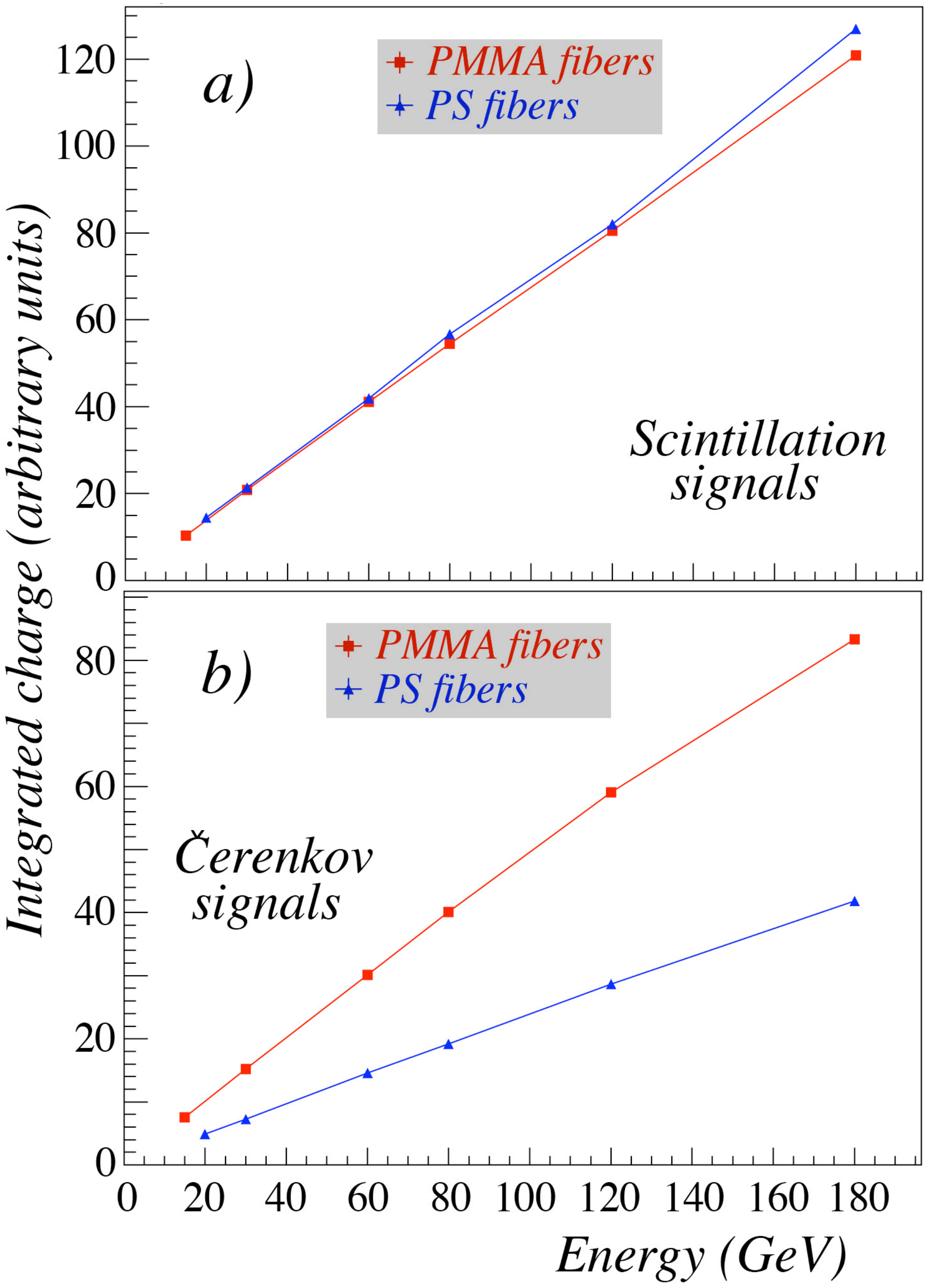
Fiber pattern

Hamamatsu R8900
pc: 85%!





Comparison of polystyrene/PMMA clear fibers



Numerical aperture:
PS 0.72, PMMA 0.50

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

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

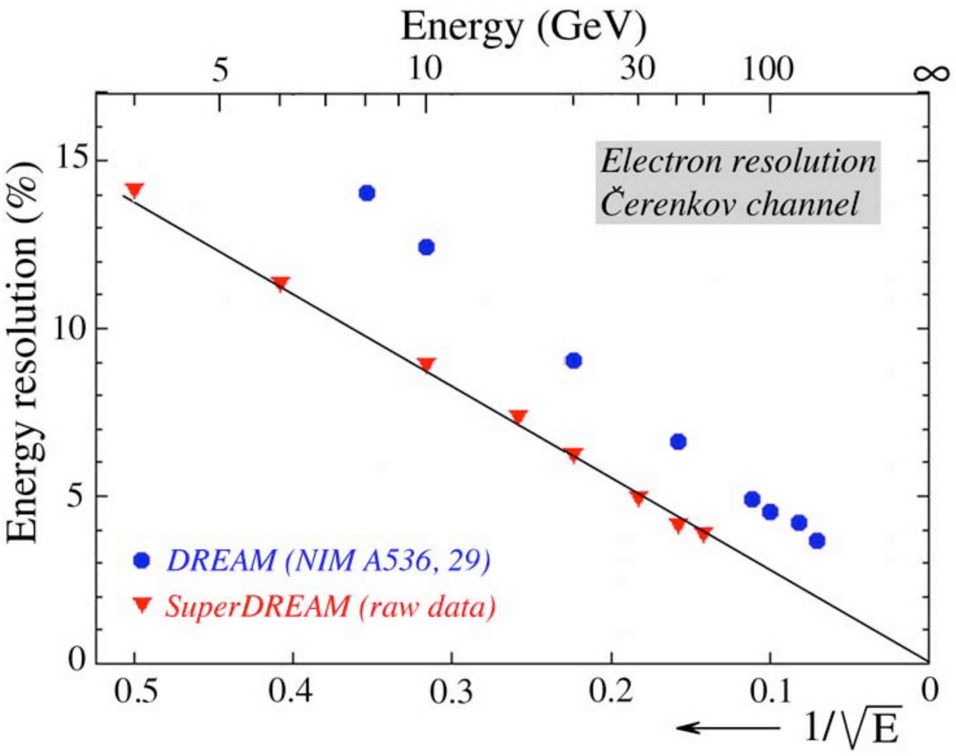
Scintillator: no change
Čerenkov: x 2!

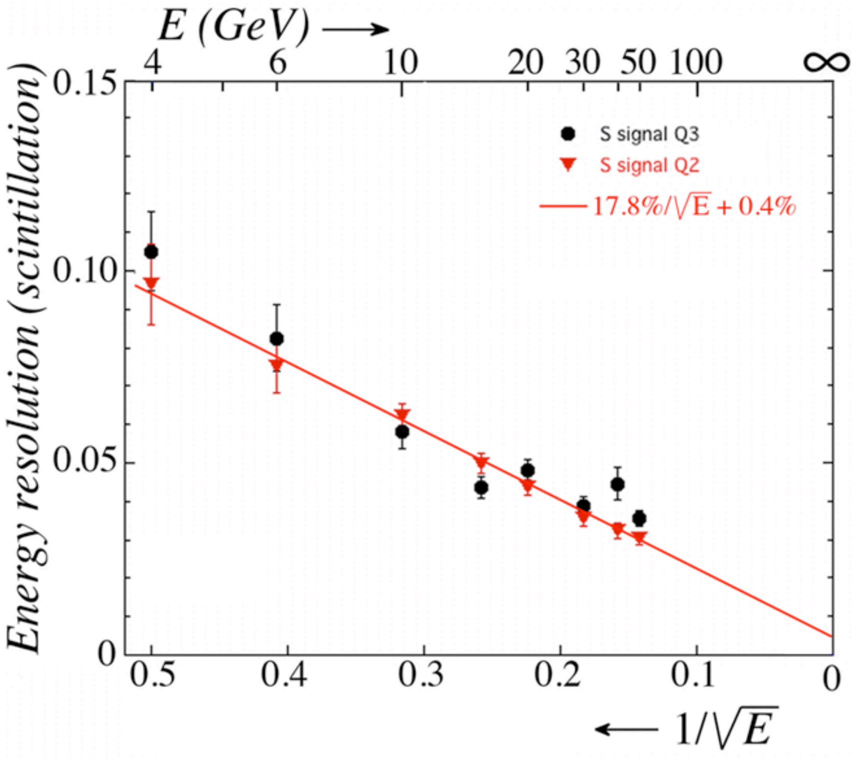
Č light yield was measured for
PS module with LED: 32 p.e./GeV
⟶ *twice as high for PMMA*

Electromagnetic energy resolution in one (Pb) SuperDREAM module

Čerenkov signals
(beam hits in 4-corner region)

RESOLUTION MUCH BETTER THAN IN DREAM!





Scintillation signals
(beam centered on two different quadrants)

Small deviation from $1/\sqrt{E}$ scaling

Further improvements:

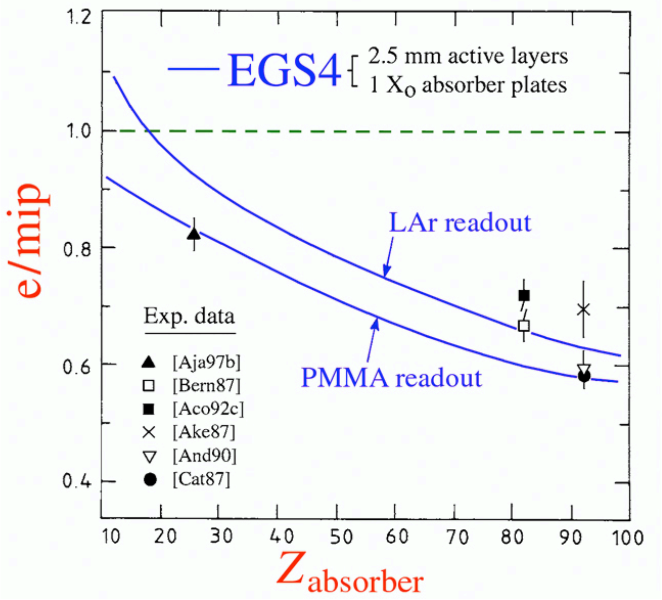
- *Combine different modules → better containment for beam in tower centers*
- *Aluminizing upstream end of (Č) fibers → more light*
- *Light mixers → eliminate position dependence of response*
- *Reduce noise contribution of readout electronics*

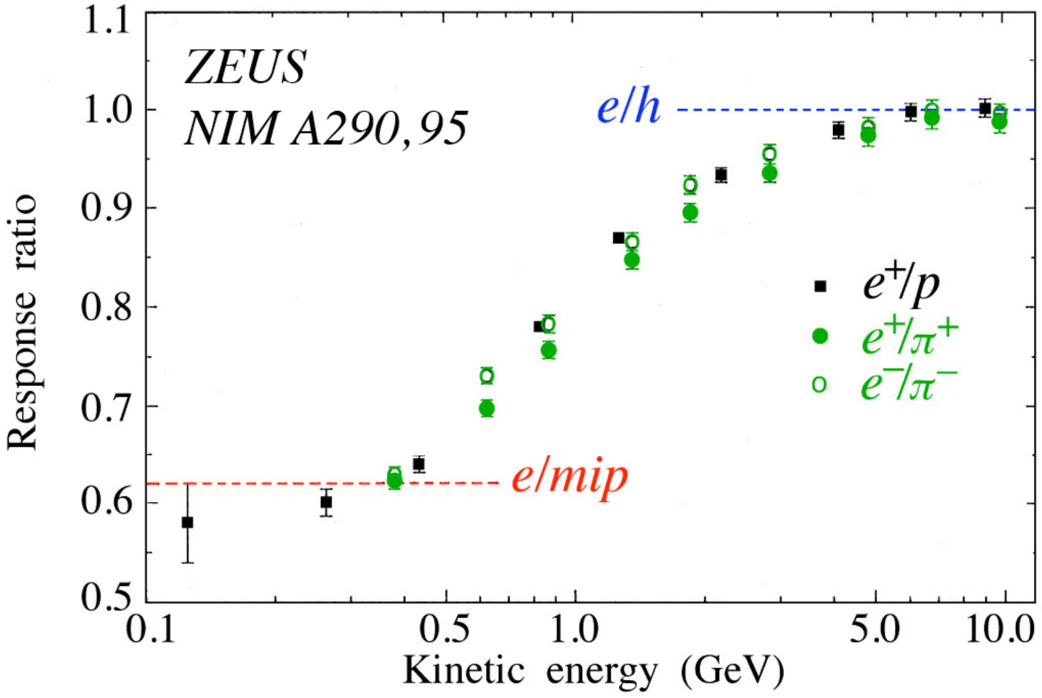
Expect $10\%/\sqrt{E}$ by combining signals from two types of fibers

Absorber choice: Cu vs Pb

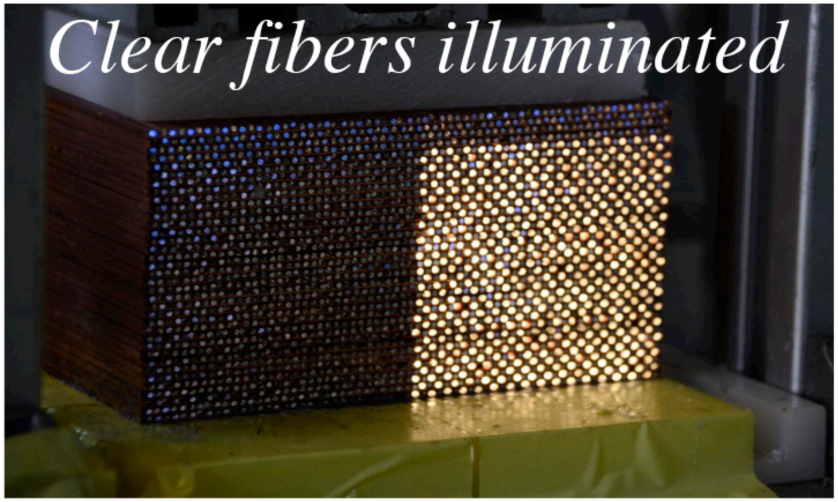
- *Detector mass:* $\lambda_{Cu} = 15.1$ *cm*, $\lambda_{Pb} = 17.0$ *cm*
  Mass $1\lambda^3$ *: Cu/Pb = 0.35*
- *e/mip ⟶ Čerenkov light yield Cu/Pb ~ 1.4*
  (Showers inefficiently sampled in calorimeters with high-Z absorber)
- *Non-linearity at low energy in calorimeters with high-Z absorber*

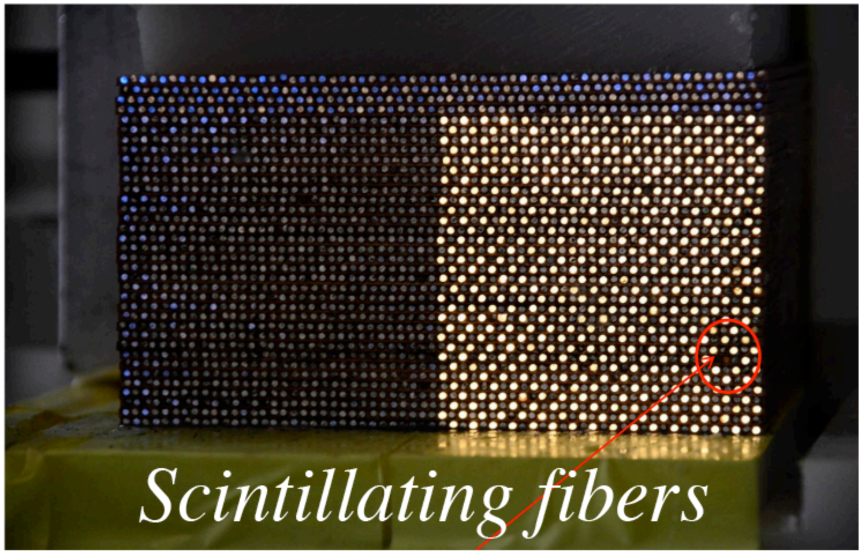
Important for jet detection



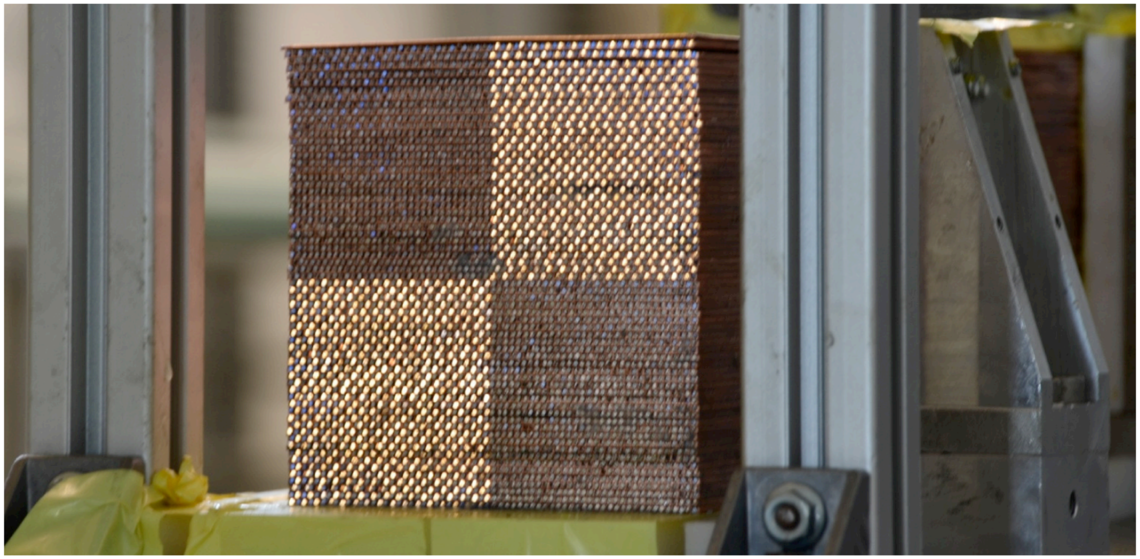


The first copper module



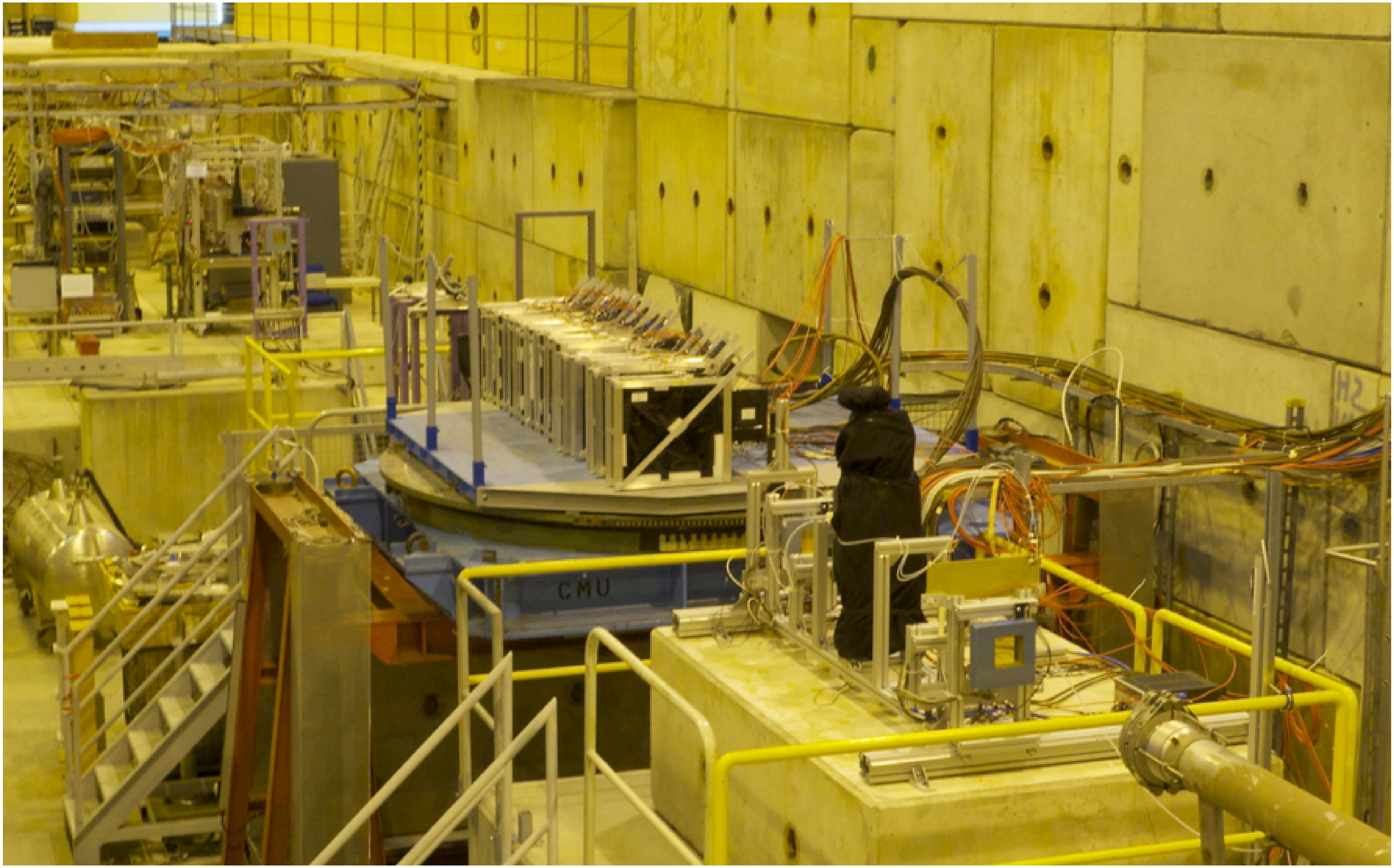


The first copper module



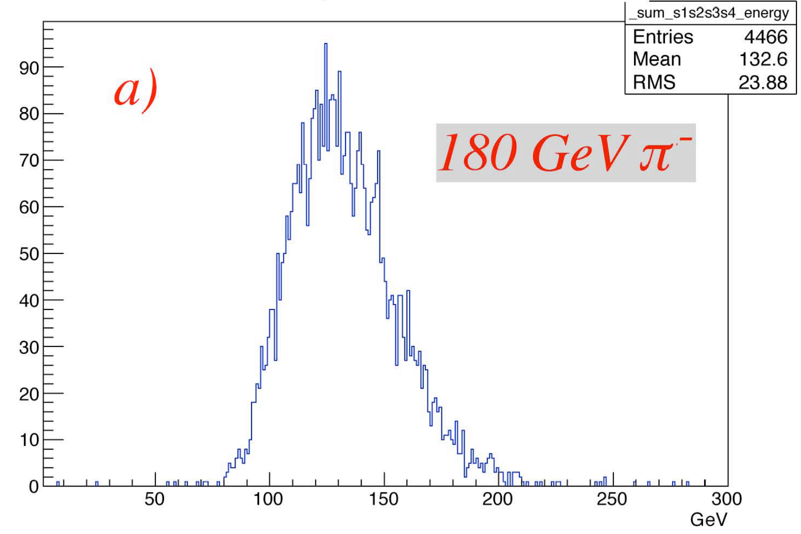
First hadrons in SuperDREAM (1 Pb module + n-shield)

Calibration of neutron shield (muon beam)

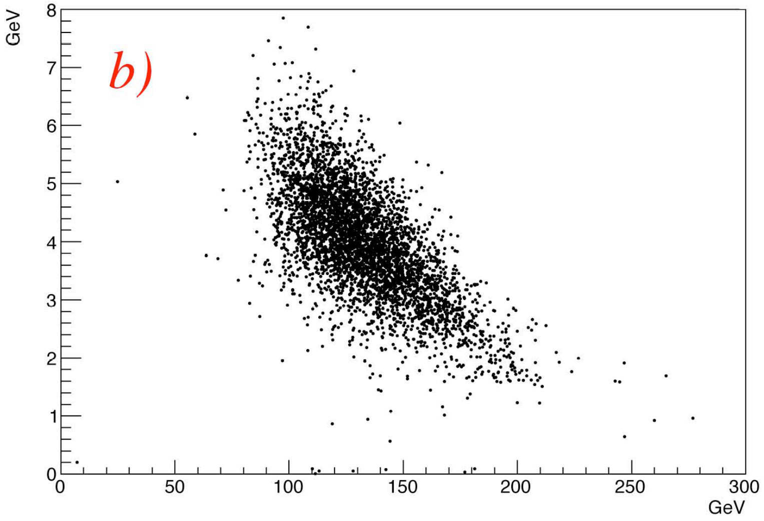


First results on pion detection in the new fiber calorimeter

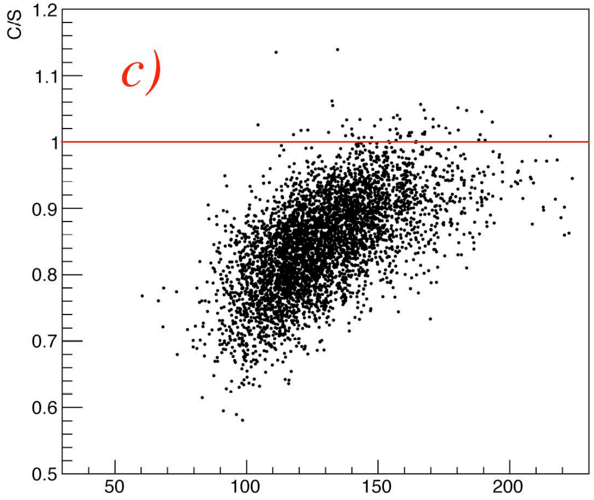
Scintillator signal (raw data)



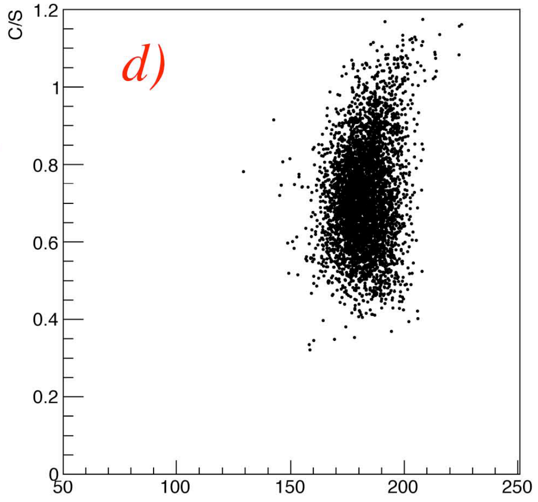
Leakage vs scintillator signals



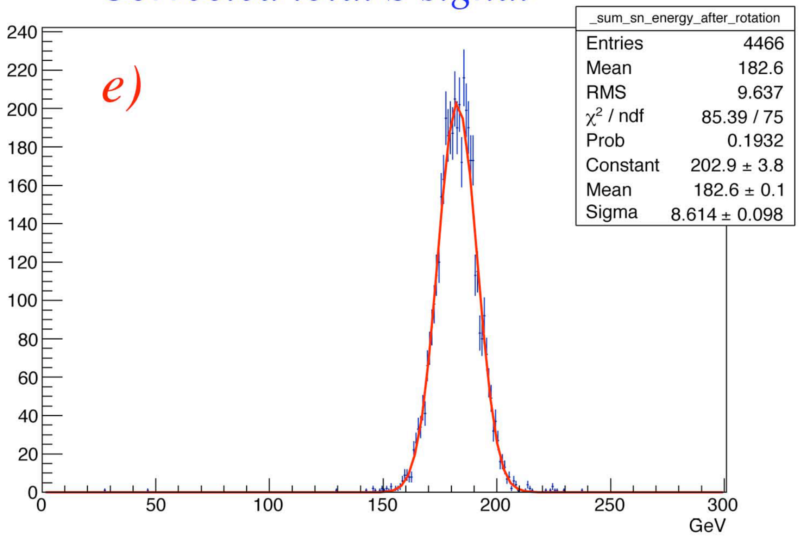
Č/S vs corrected S signal



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.

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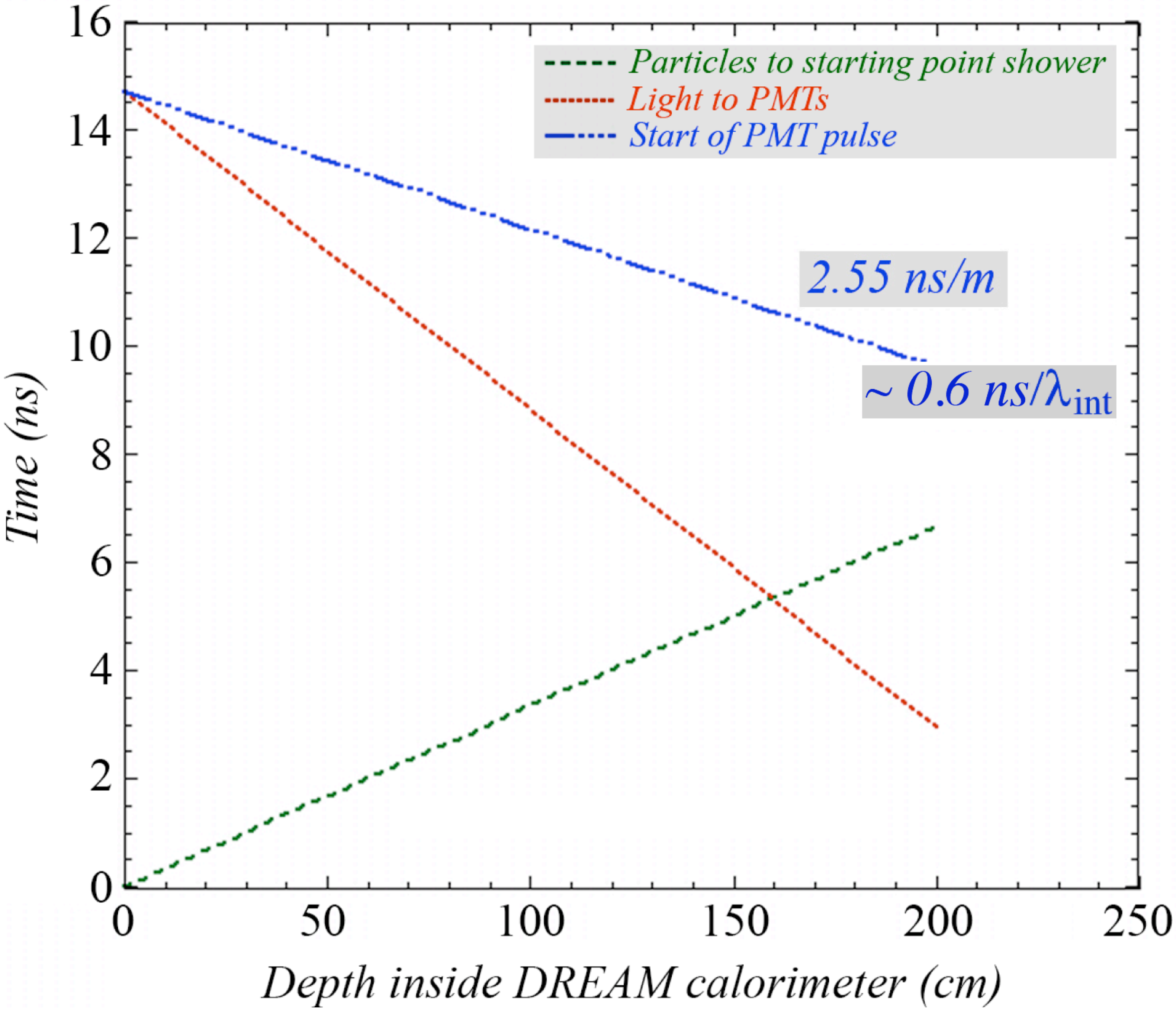
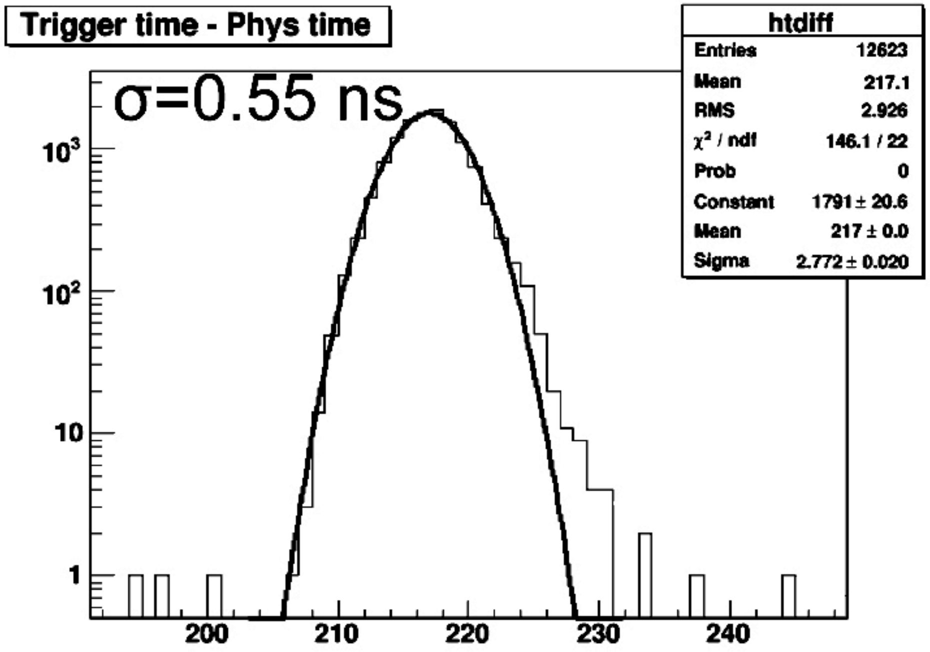
* *See* NIM A518 (2004) 407

Depth of the light production and the starting point of the PMT signals

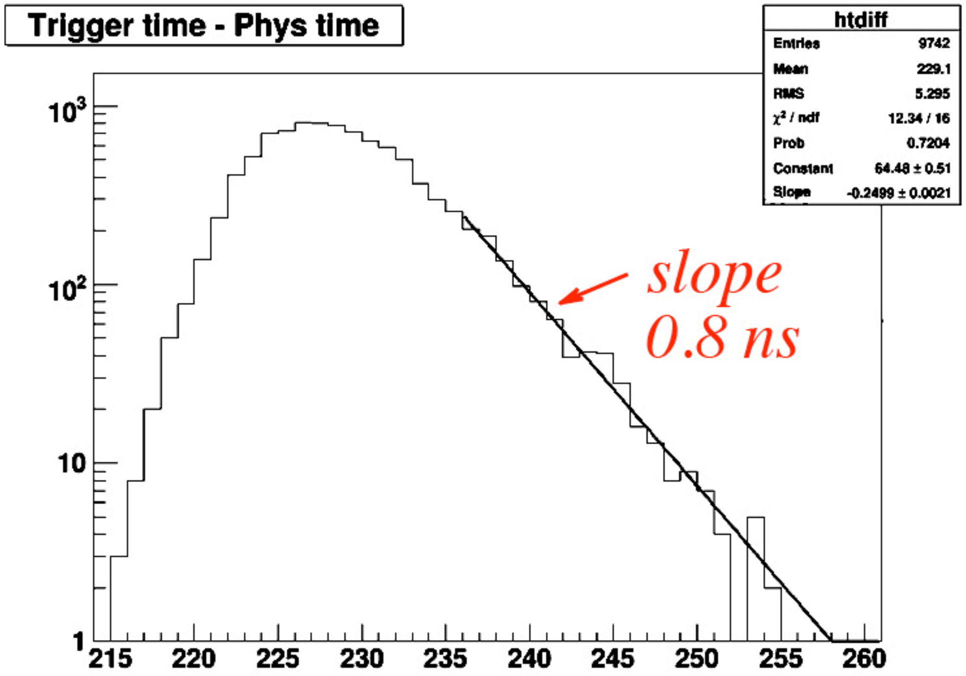


Measurement of the depth of the light production in module using the DRS timing

80 GeV electrons



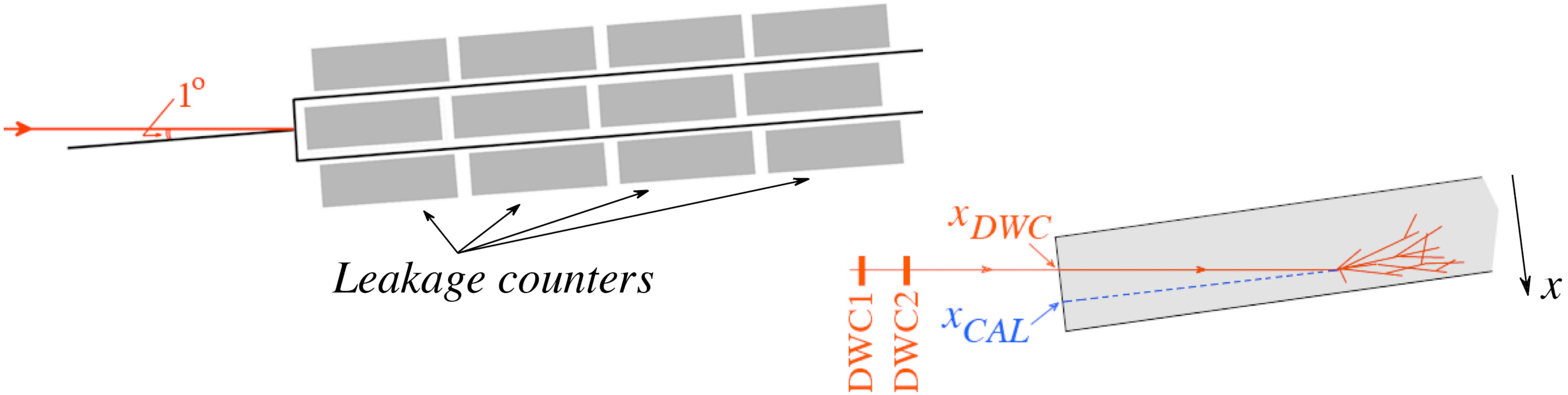
180 GeV pions

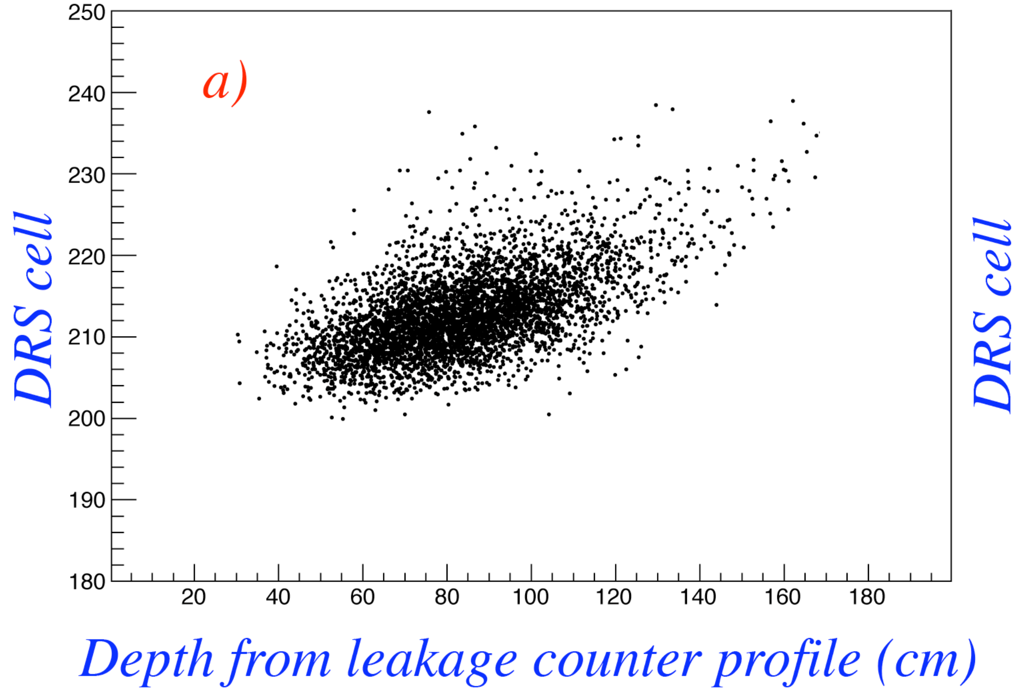


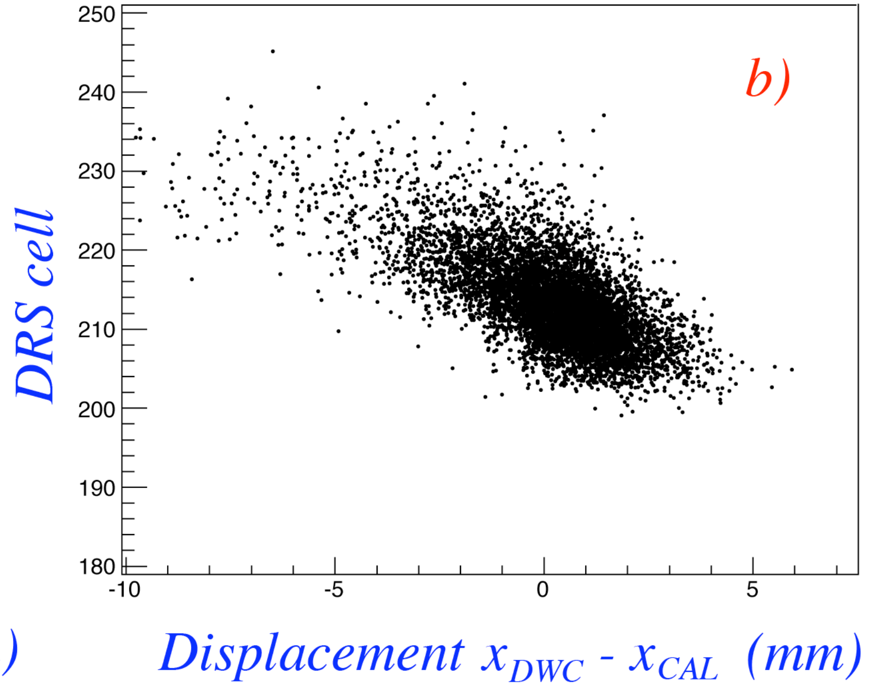
slope 0.8 ns

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

Check that DRS time measures shower depth







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*

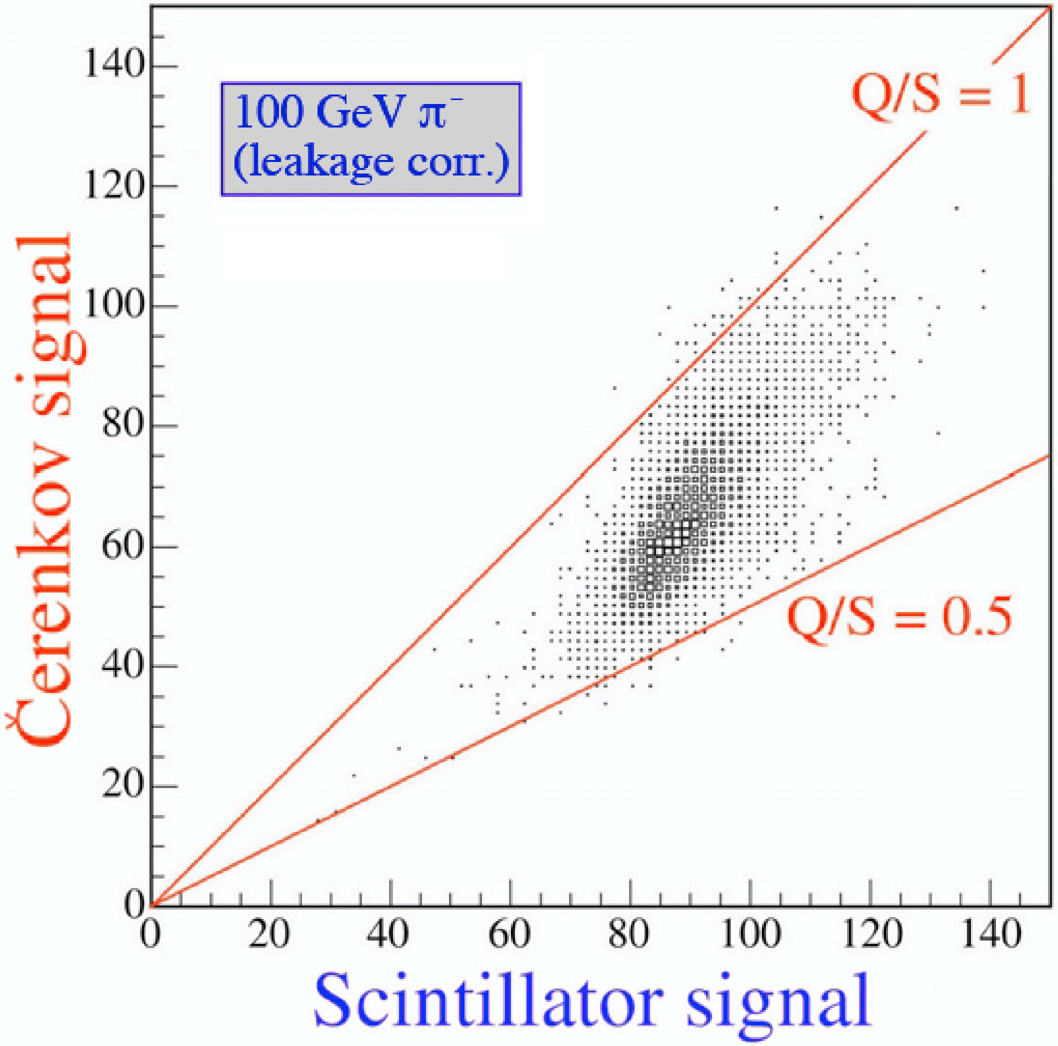
Production of Pb based SuperDREAM modules

Plans for $\geq$ 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 ?



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

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

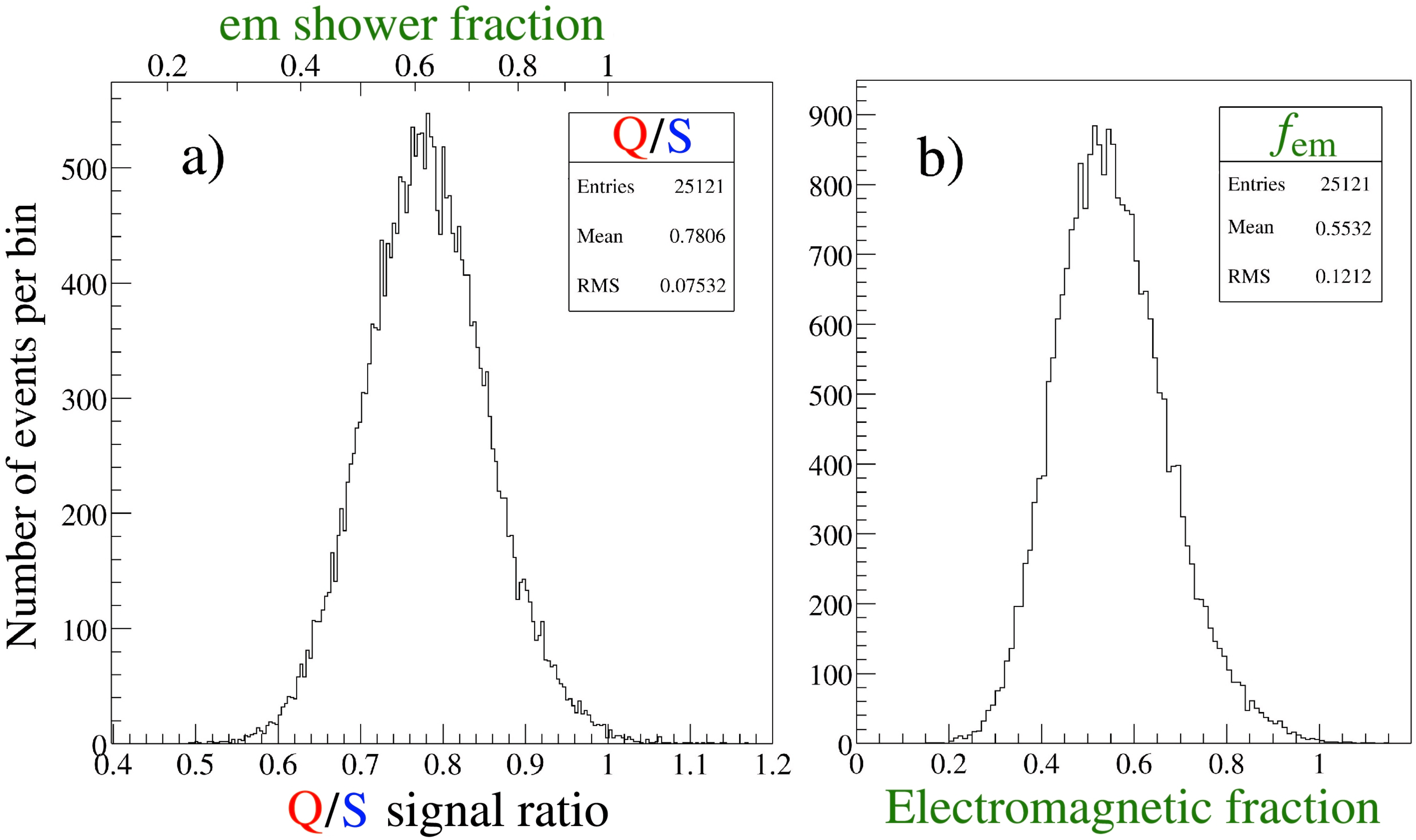
e.g. If $e/h = 1.3$ (S), 4.7 (Q)

$$\boxed{\frac{Q}{S} = \frac{f_{\rm em} + 0.21\,(1-f_{\rm em})}{f_{\rm em} + 0.77\,(1-f_{\rm em})}}$$

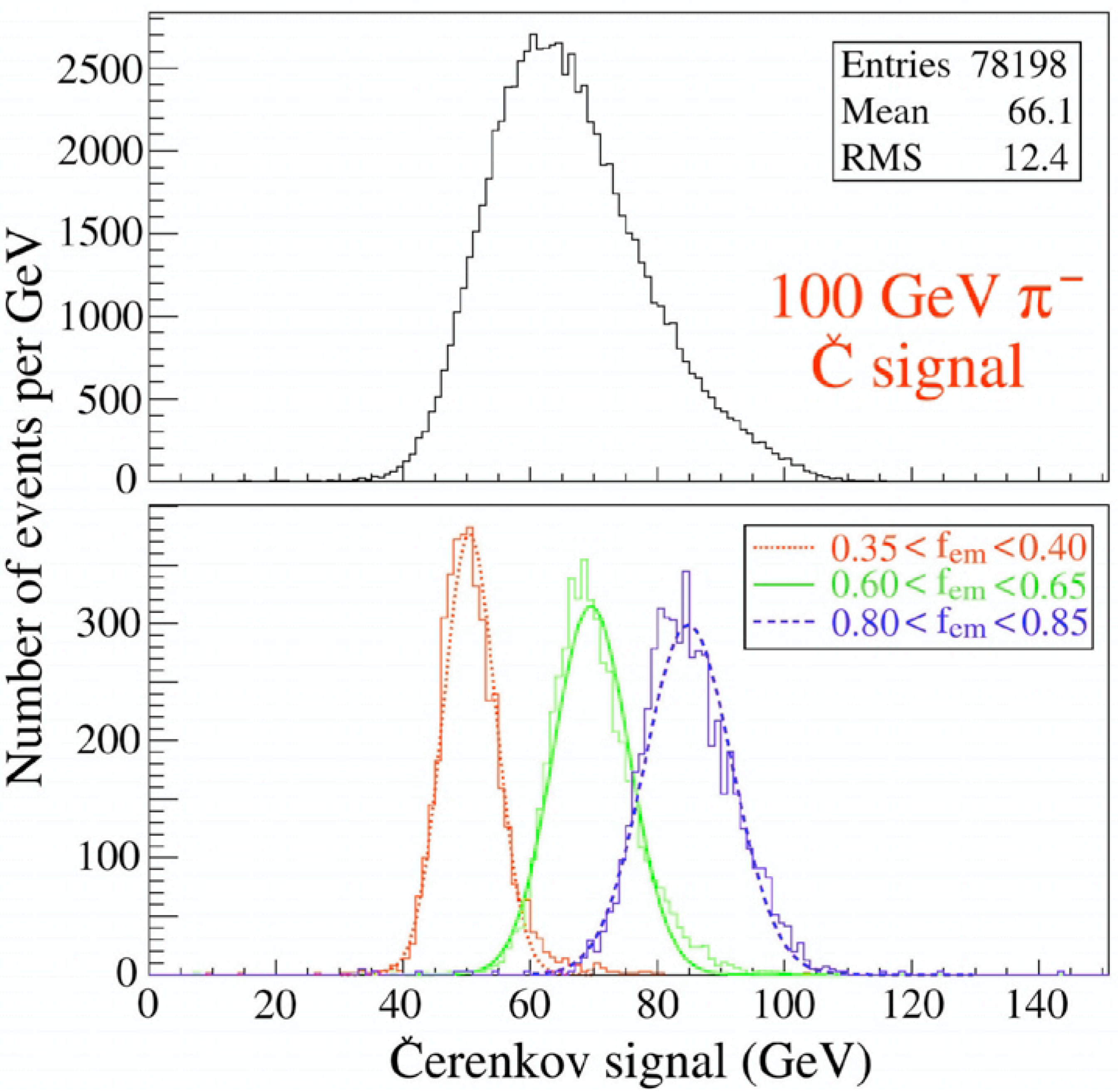
$$\boxed{E = \frac{S - \chi Q}{1-\chi}}$$

with $\chi = \dfrac{1-(h/e)_S}{1-(h/e)_Q} \sim 0.3$

DREAM: relationship between Q/S ratio and f_{em}

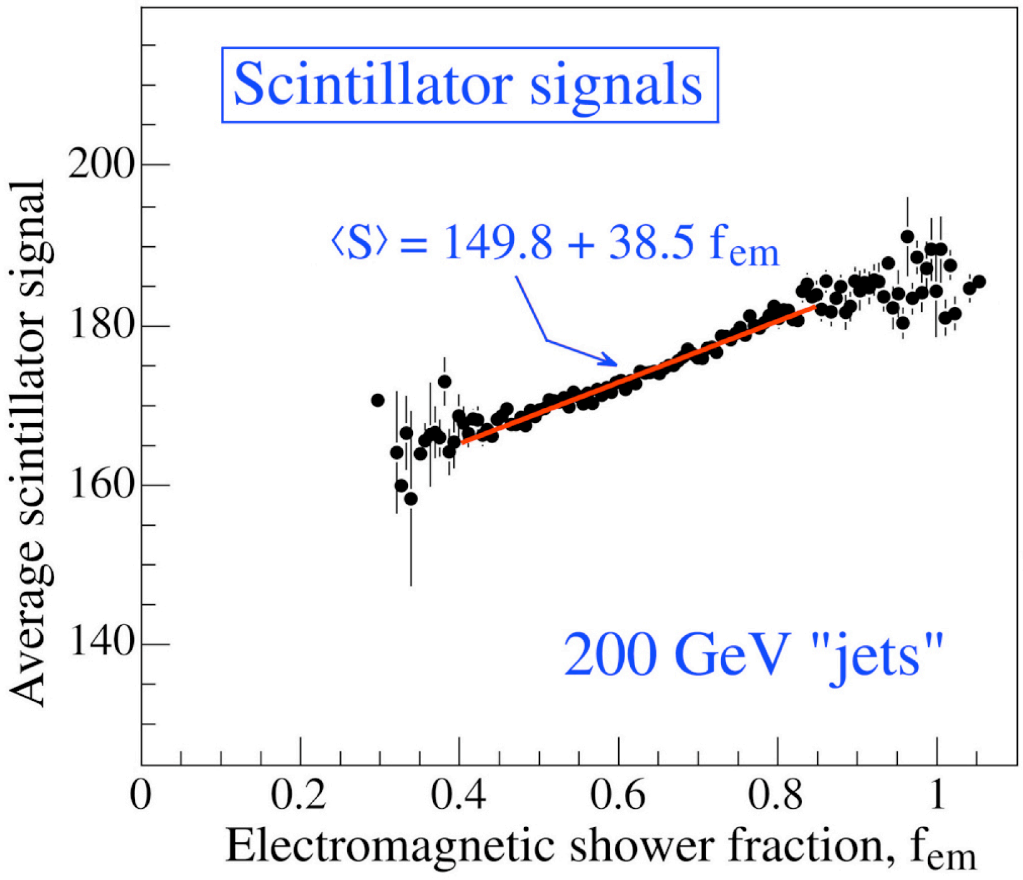


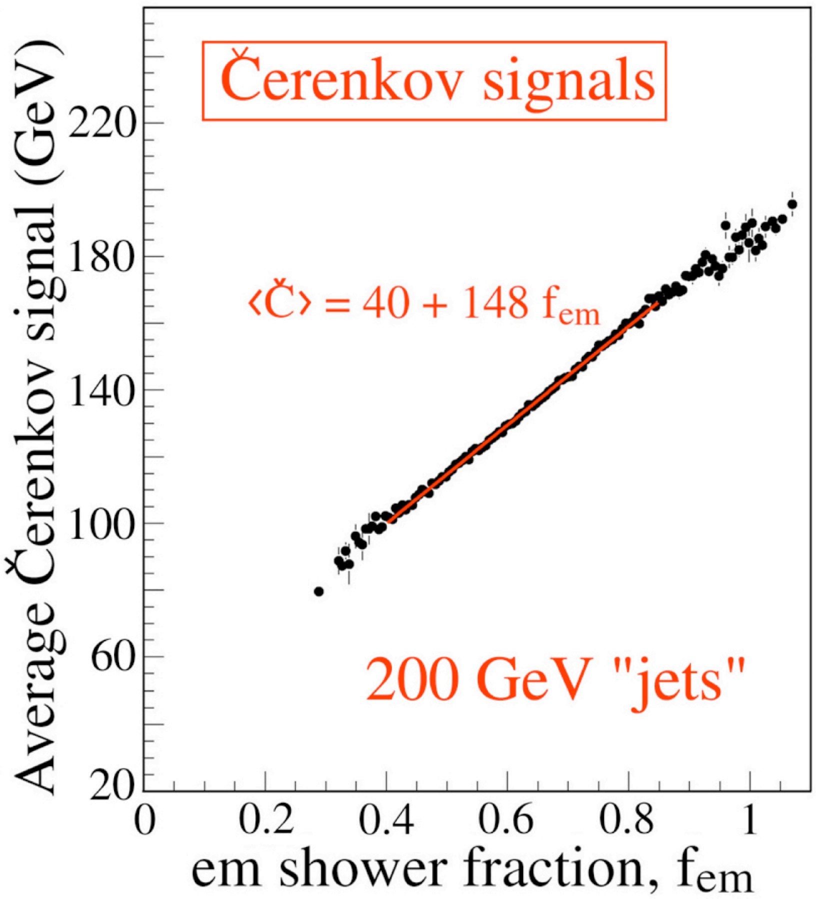
DREAM: Effect of event selection based on f_{em}



From:
NIM A537 (2005) 537

DREAM: Signal dependence on f_{em}





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

Cu/scintillator e/h = 1.3

Cu/quartz e/h = 4.7

From:
NIM A537 (2005) 537

DREAM: Effect of corrections (200 GeV "jets")