The new RD52 (DREAM)[*] fiber calorimeter

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(TTU)

Calorimetry in High Energy Physics
(CALOR 2012)

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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

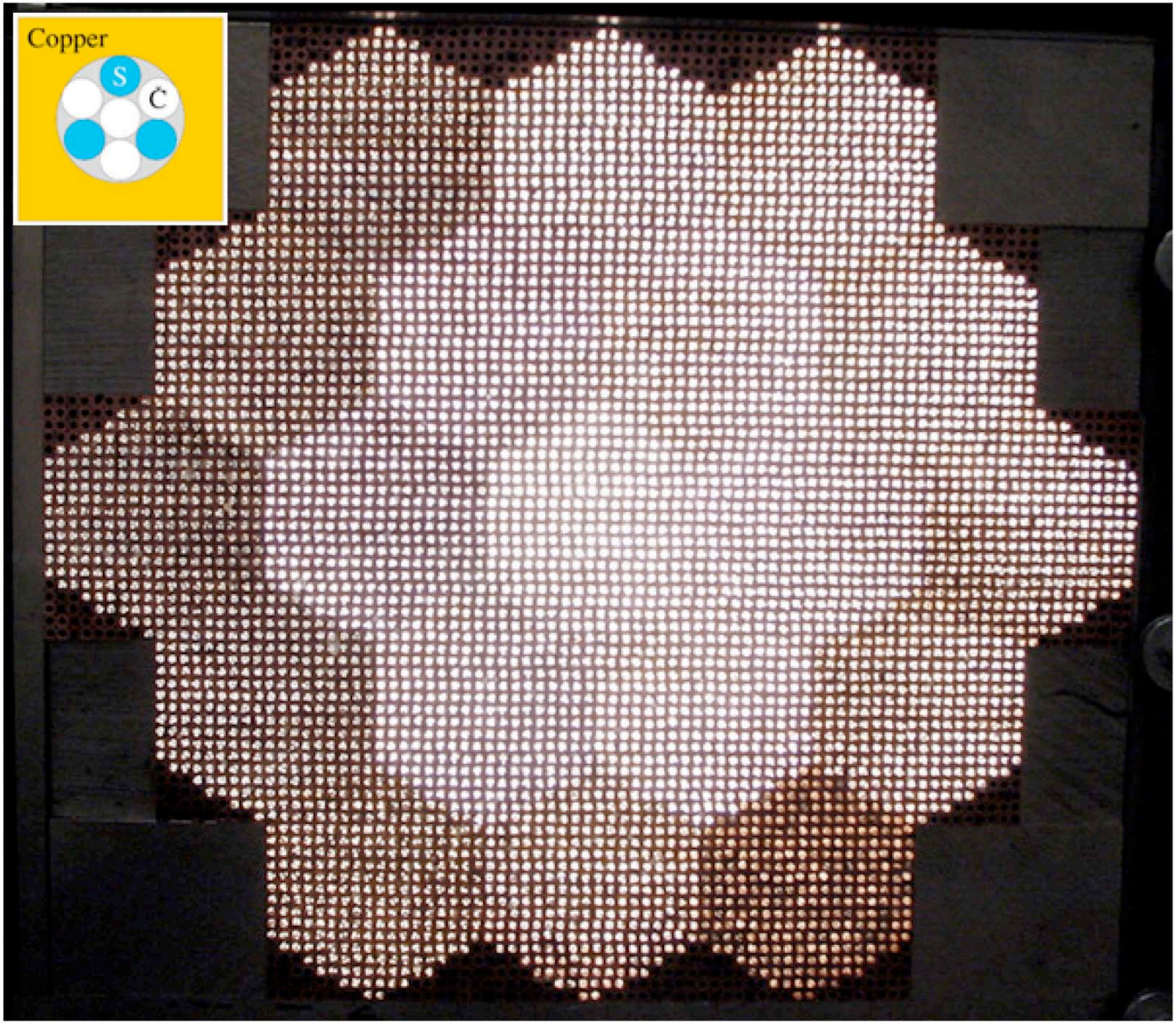
Method:

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)

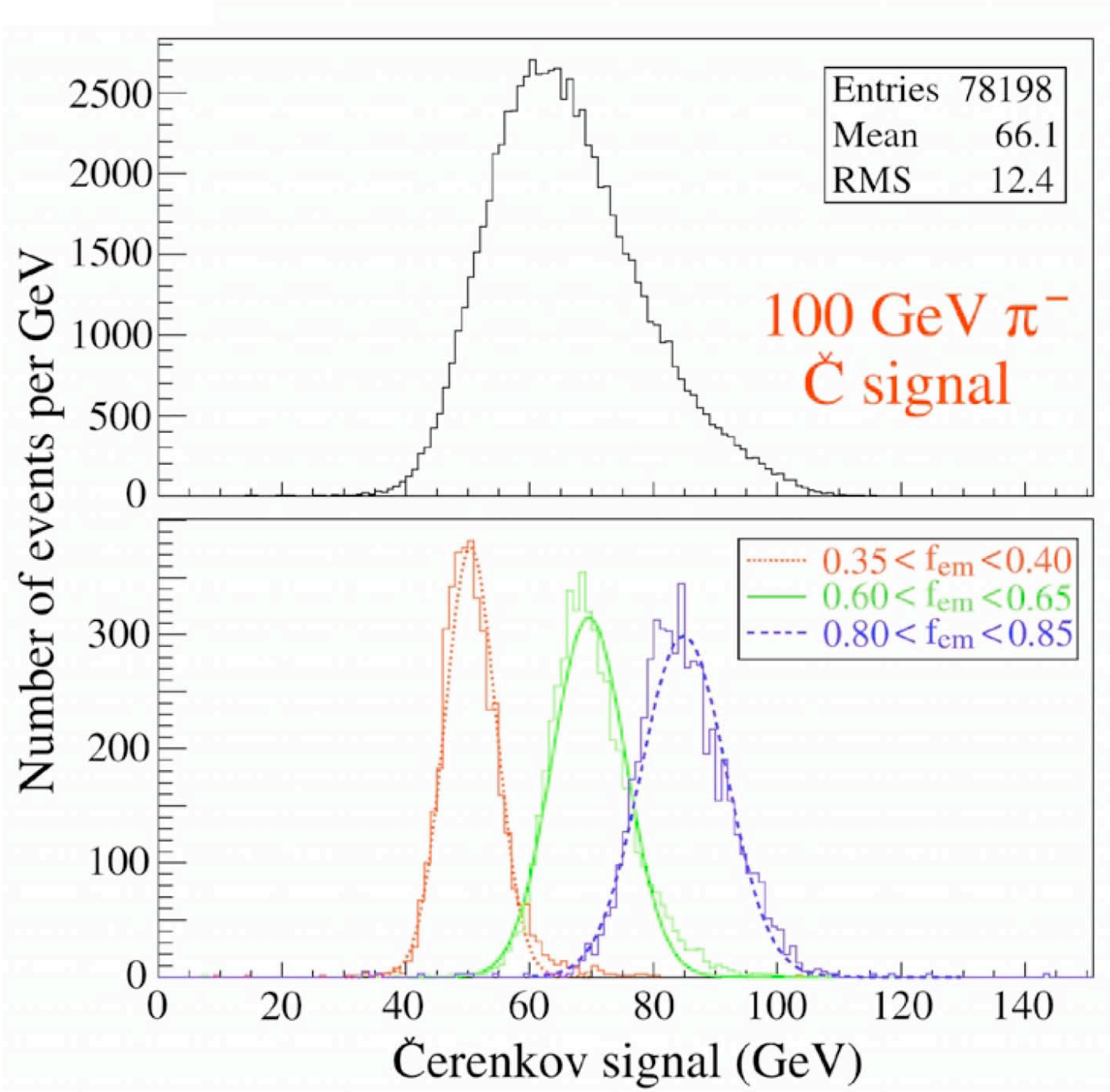
Relevance:

This method provides the same advantages as intrinsically compensating calorimeters (e/h =1) WITHOUT the limitations (sampling fraction, integration time, volume)

The original DREAM calorimeter



Experimental proof of dual-readout principle

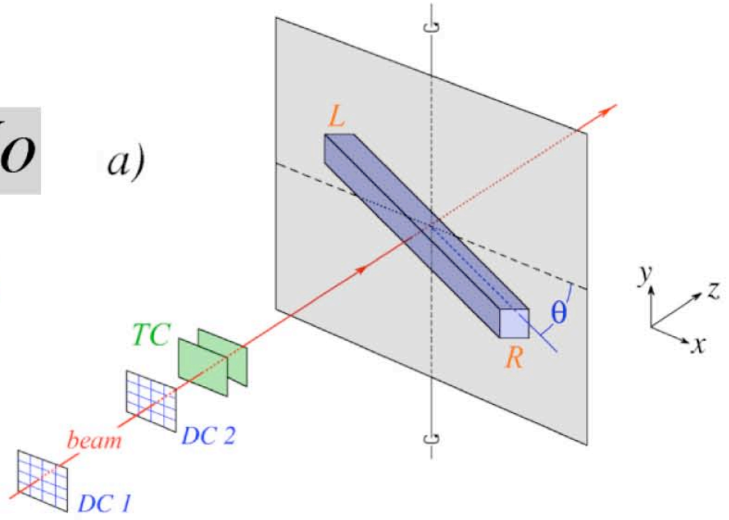


Č/S signal ratio measures f_{em} event by event!

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

Dual-readout method can also be used in crystal calorimeters

$PbWO_4$:1%Mo



Separate Č and S components through:

- *spectral characteristics*
- *time structure*

See talk G. Gaudio

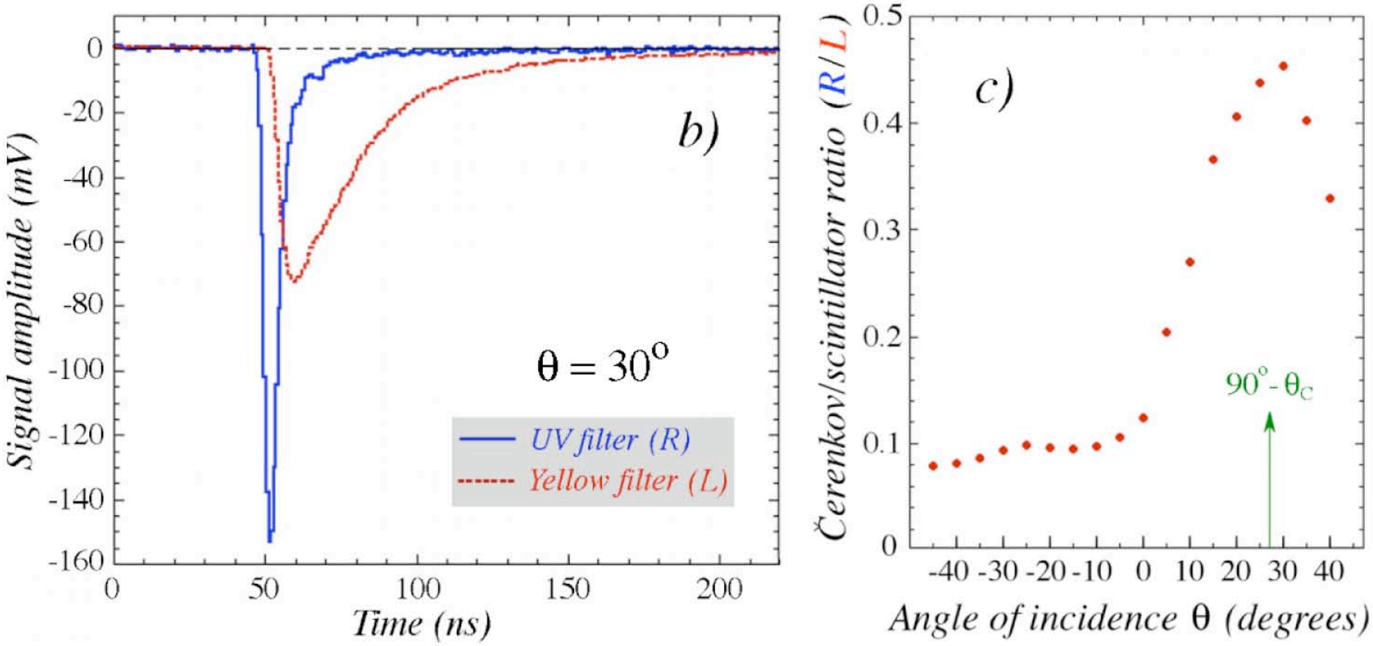
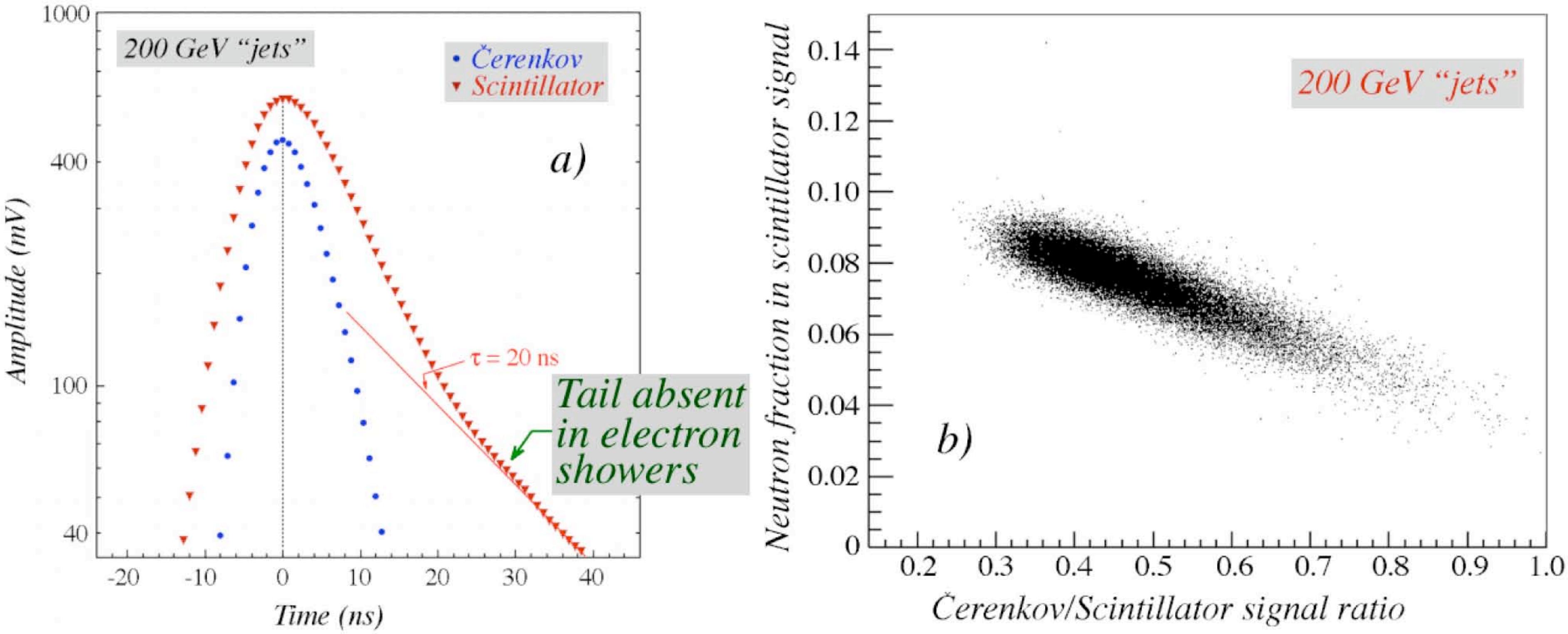


Figure 3: Unraveling of the signals from a Mo-doped $PbWO_4$ crystal into Čerenkov and scintillation components. The experimental setup is shown in diagram *a*. The two sides of the crystal were equipped with a UV filter (side *R*) and a yellow filter (side *L*), respectively. The signals from 50 GeV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

High-resolution hadron calorimetry also requires efficient detection of the "nuclear" shower component

Time structure of the DREAM signals: the neutron tail (anti-correlated with f_{em})



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:

- *How to achieve excellent hadronic energy resolution?*
- *The new dual-readout fiber calorimeter (SuperDREAM)*
  - *beam tests of prototype modules*
  - *final design choices*
- *Plans for 2012 and beyond*

How to achieve excellent hadronic energy resolution?

- *Energy resolution is determined by FLUCTUATIONS*
  - The fact that 65% of jet energy is carried by charged particles (PFA) is *IRRELEVANT*.
- *In most hadron calorimeters, fluctuations in* f_{em} *dominate*
  - Eliminate by: Compensation ($e/h = 1$)
    Measuring f_{em} event by event (DREAM)
- *Fluctuations in VISIBLE ENERGY (nuclear binding energy loss,* ΔB*)*
  - Non-em signal is dominated by "nuclear" component: *p*,*n*
  - Correlation between "nuclear signal" and ΔB determines ultimate limit on hadronic energy resolution (ZEUS *vs* D0)
  - Crystals disfavored in this respect (*see D. Groom's talk*)
- *STOCHASTIC fluctuations (sampling, light yield ...)*
  - Limiting factor for electromagnetic energy resolution

The new dual-readout fiber calorimeter

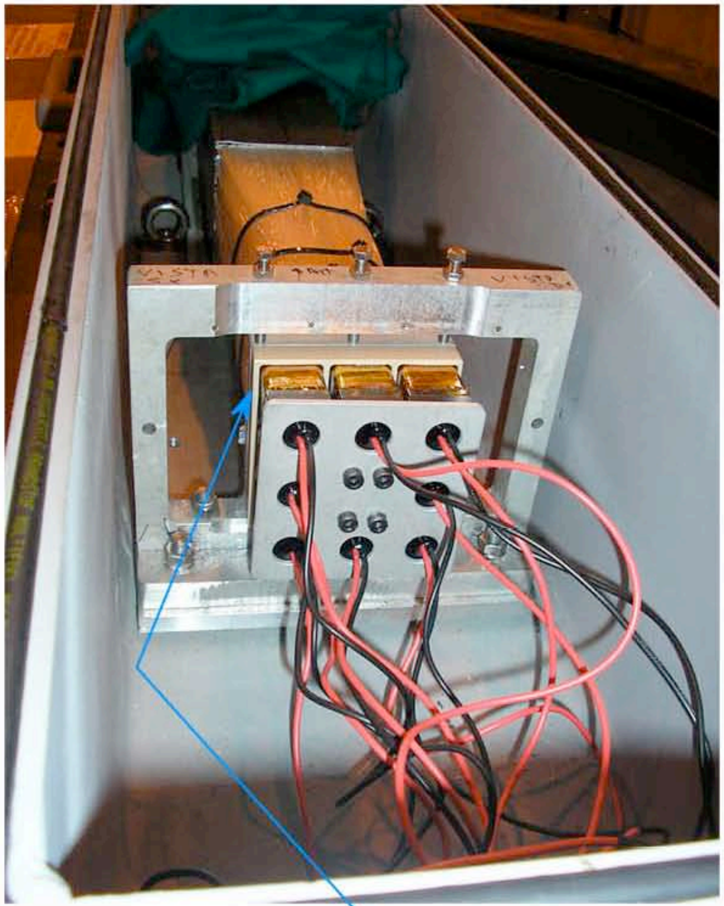
- *Fluctuations in f_{em} eliminated*
  Fluctuations in effects of ΔB minimized (estimate $15\%/\sqrt{E}$)

- *Improve on stochastic fluctuations*
  - *Sampling fluctuations*
  - *Čerenkov light yield*

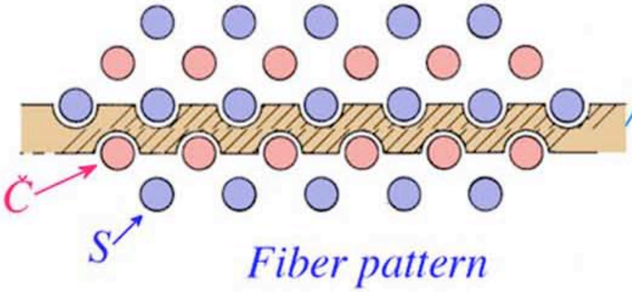
  Both contributed ~$35\%/\sqrt{E}$ to DREAM results

- *Test effect of improvements with electron showers,*
  since the em resolution is limited by stochastic fluctuations

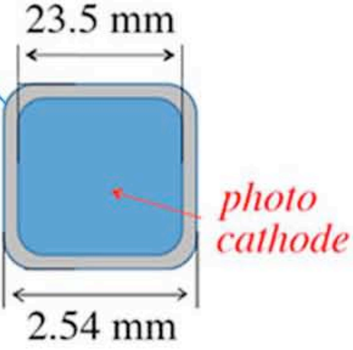
The first SuperDREAM module tested at CERN



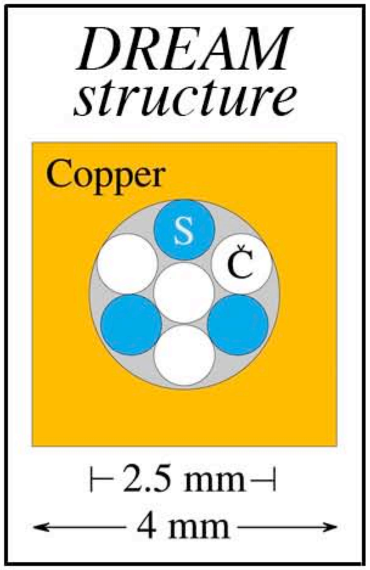
Pb absorber
9.3 x 9.3 x 250 cm
150 kg
4 towers, 8 PMTs
2 x 2048 fibers



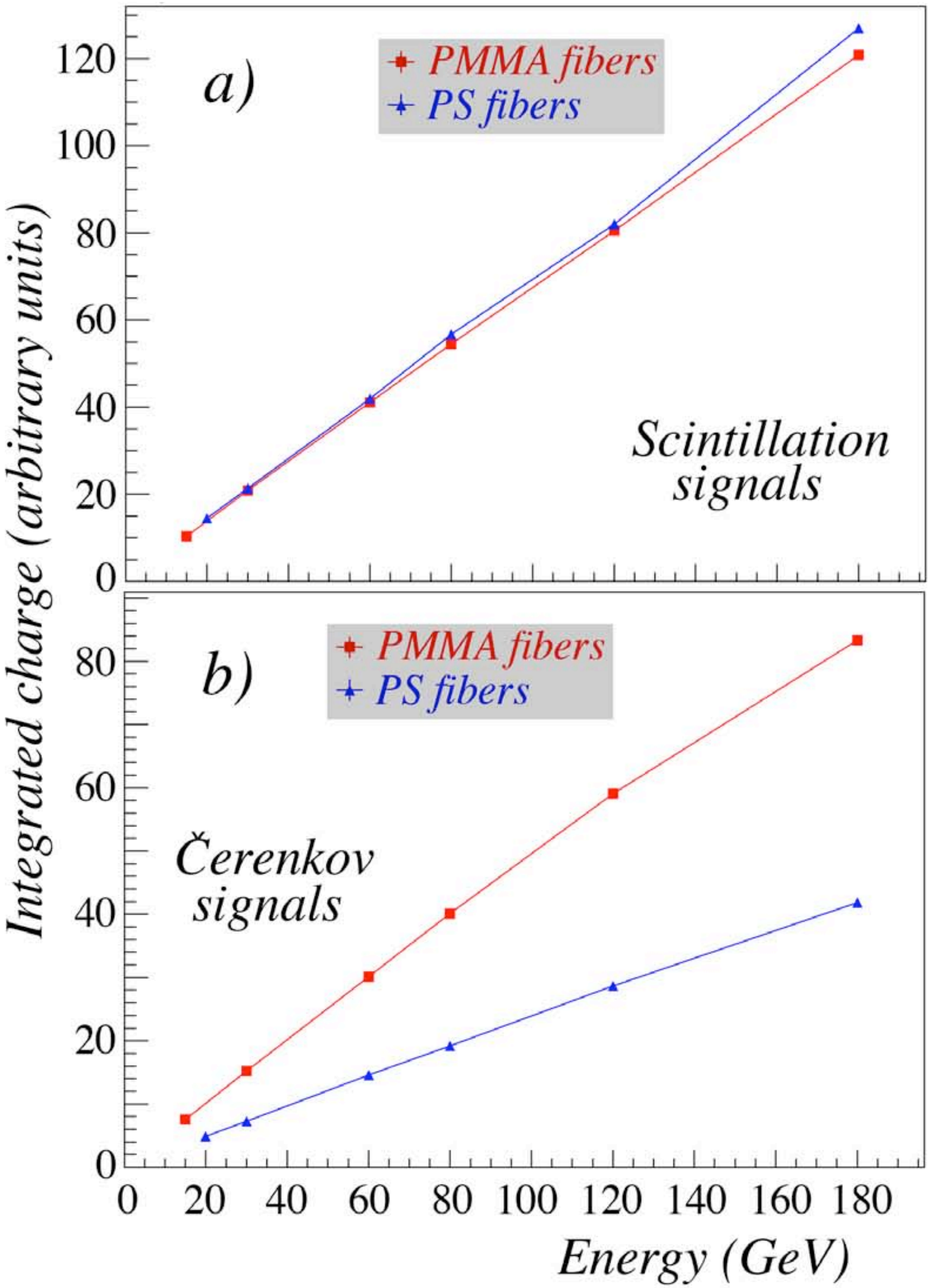
Fiber pattern



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), $\lambda_{\text{att}} \sim 3$ *m*

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

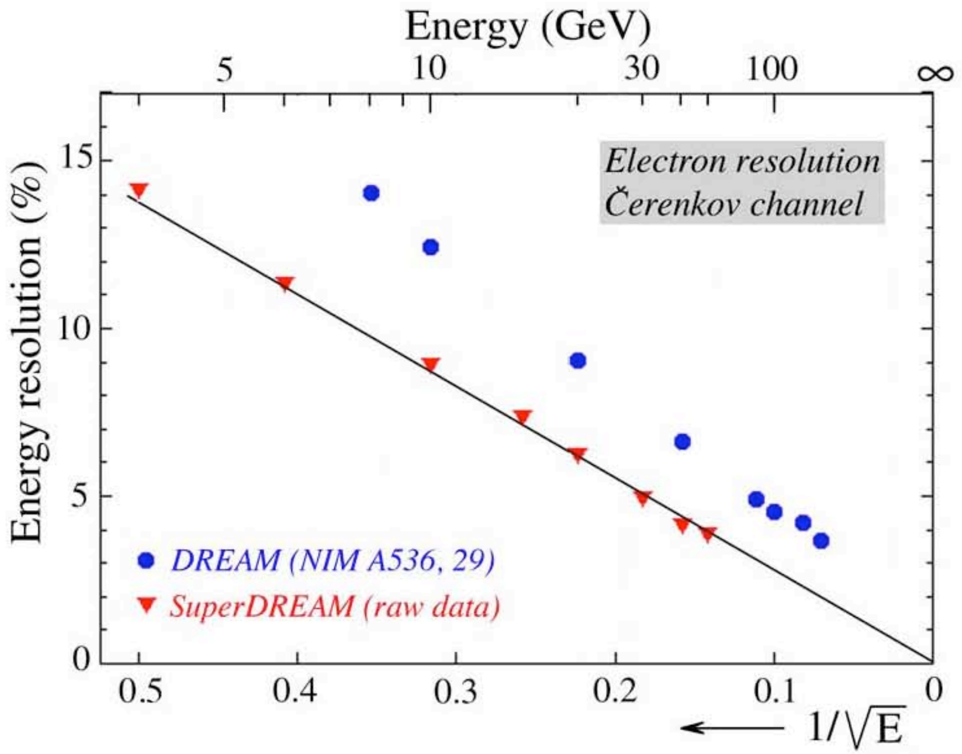
Scintillator: no change
Čerenkov: x 2!

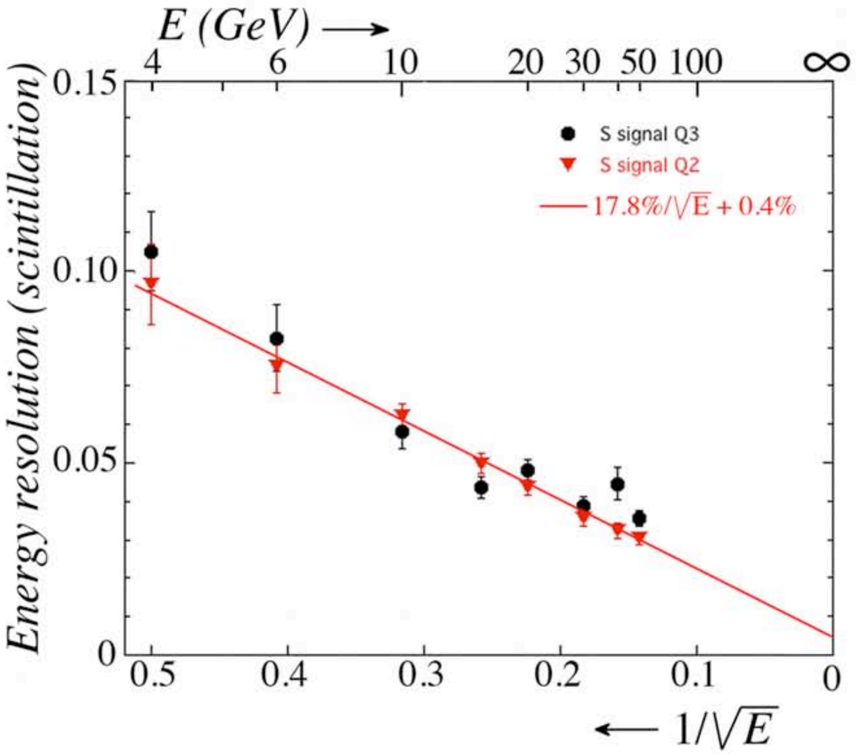
Č light yield was measured for PS module with LED: 32 p.e./GeV
→ *twice as high for PMMA*

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

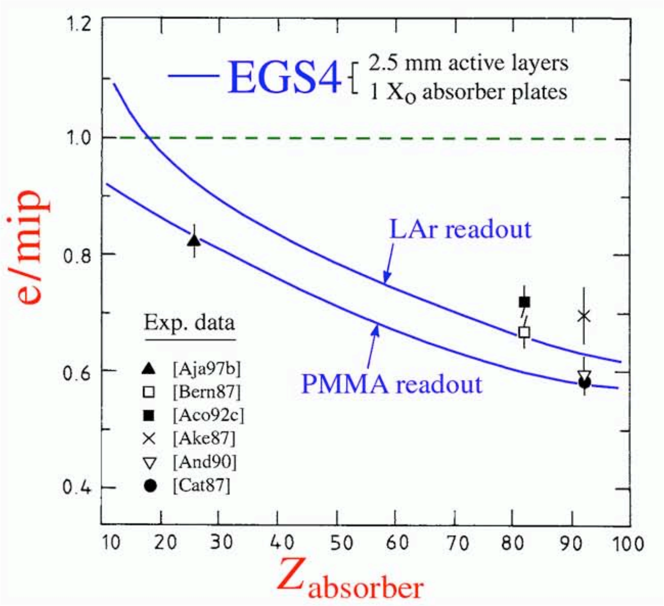
Further improvements:

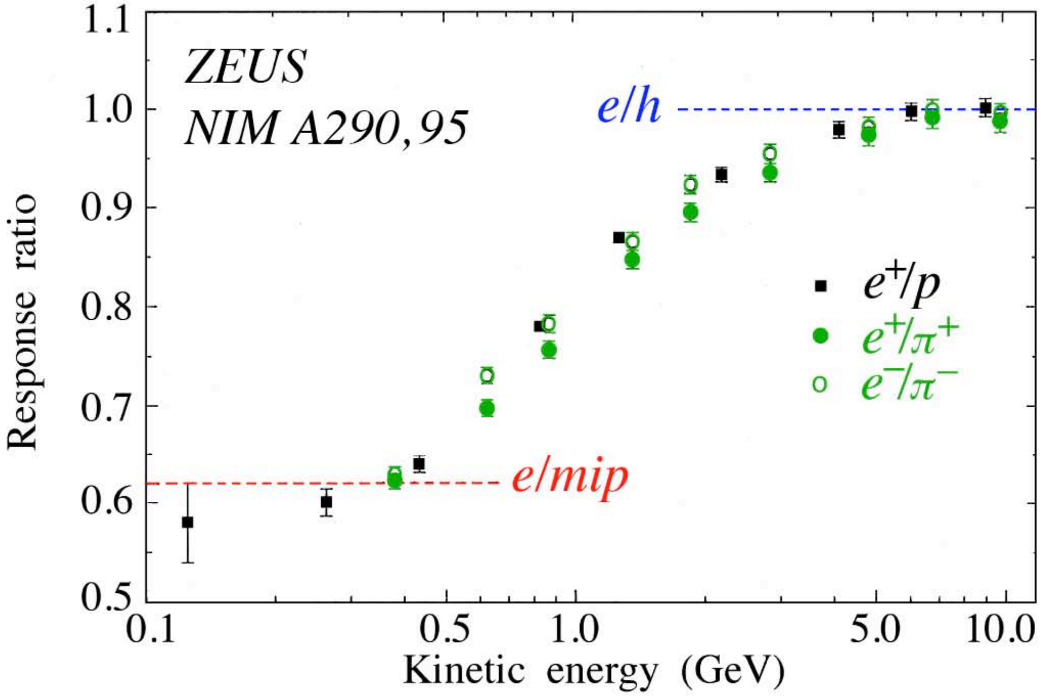
- *Combine different modules → better containment for beam in tower centers*
- *Aluminizing upstream end of (Č) fibers → more light*
- *Light mixers → eliminate position dependence of response*
- *Reduce noise contribution of readout electronics*

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

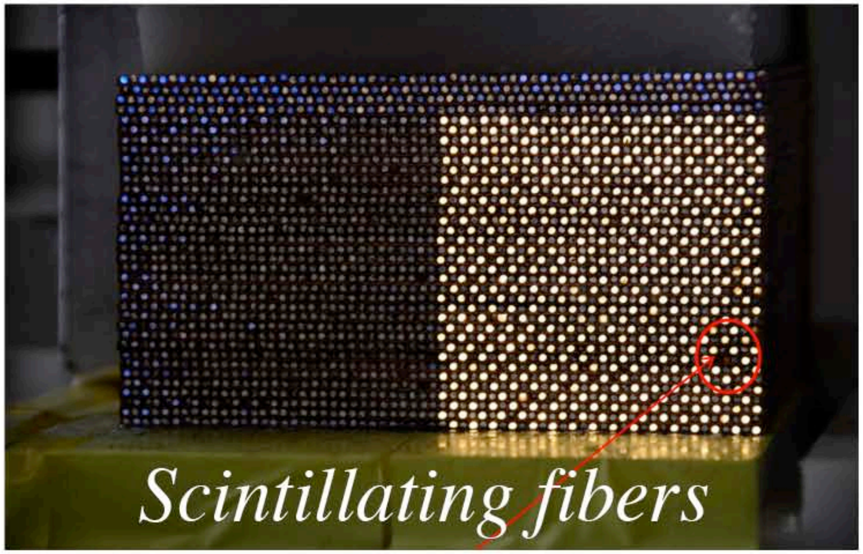
Absorber choice: Cu vs Pb

- *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

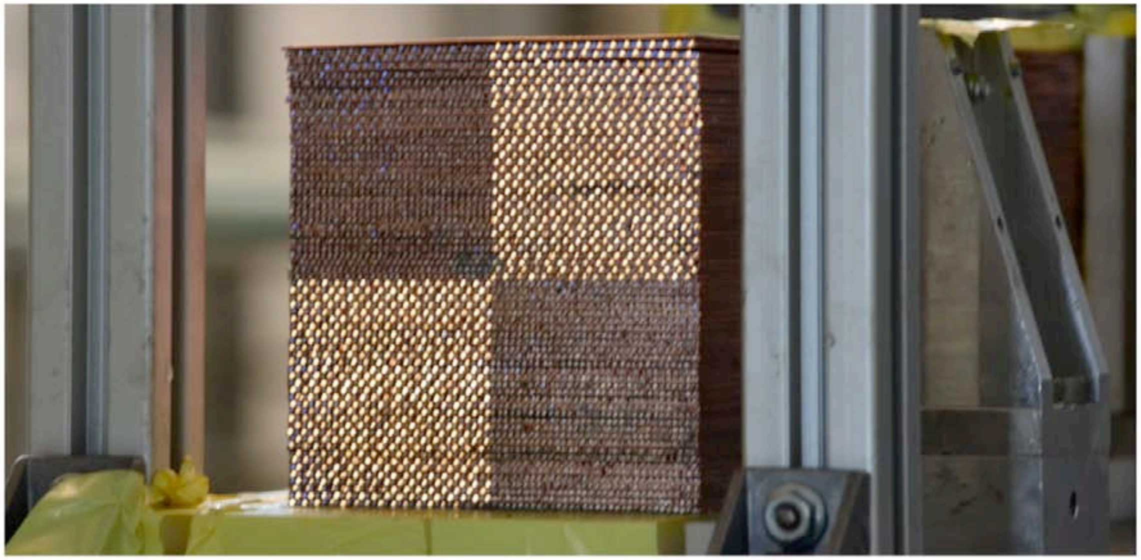




The first copper module

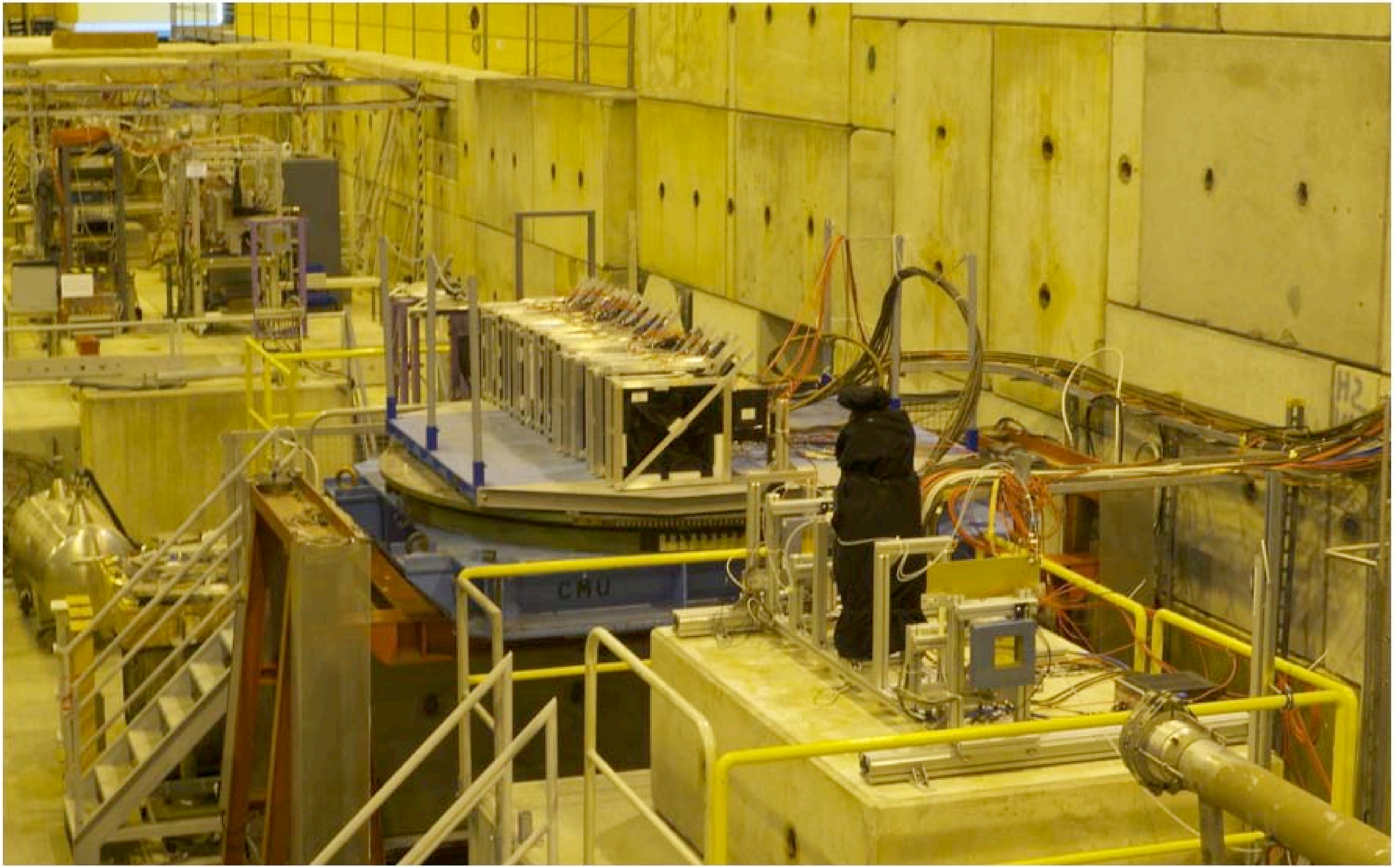


The first copper module



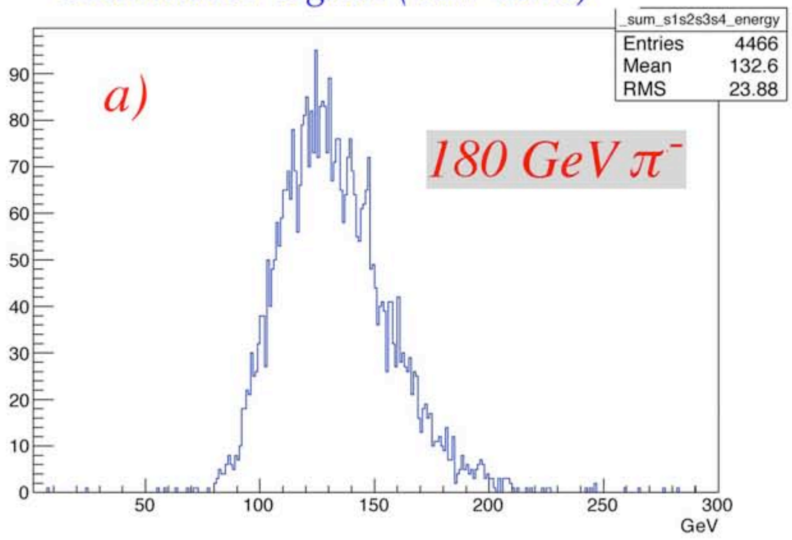
First hadrons in SuperDREAM (1 Pb module + n-shield)

Calibration of neutron shield (muon beam)

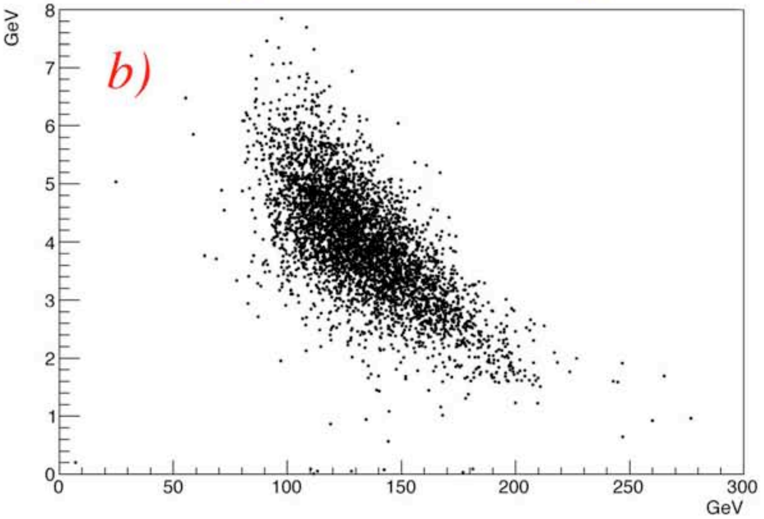


First results on pion detection in the new fiber calorimeter

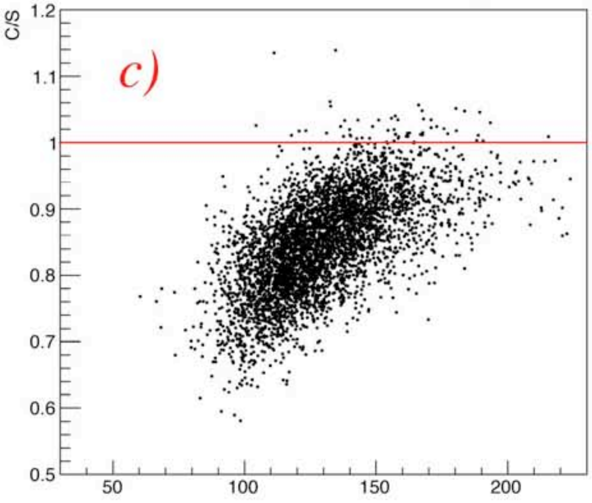
Scintillator signal (raw data)



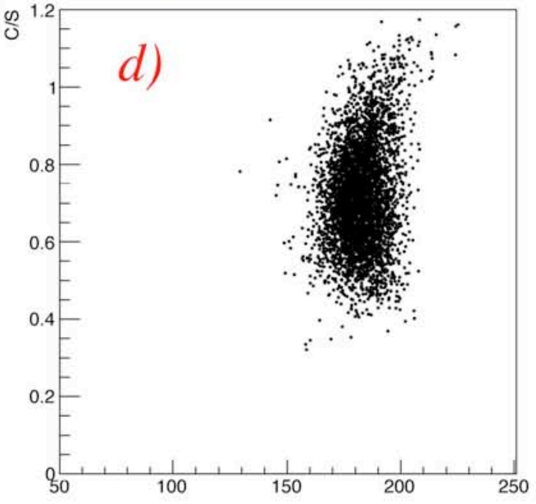
Leakage vs scintillator signals



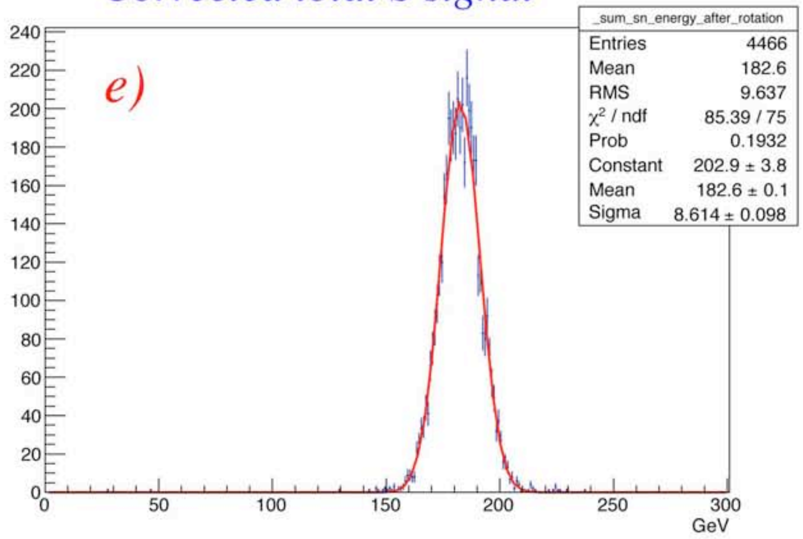
Č/S vs corrected S signal



After rotation



Corrected total S signal



A crucial feature: No longitudinal segmentation

- *Advantages:*
    - *Compact construction*
    - *No intercalibration of sections needed*
    - *Calibrate with electrons and you are done*

- *Possible disadvantages:*
    - *Pointing for neutral particles*
    - *Electron ID*
    - *Dealing with pile-up*

However, a fine lateral granularity can do wonders

In addition:

- *Time structure of the signals can provide crucial depth information*

Time structure signals

Fiber calorimeter: Can be used for
- *precision measurement of start time signals (effects* λ_{att}*)*
- *neutron tail of S signals*
- *electron/gamma ID (starting time + width of the 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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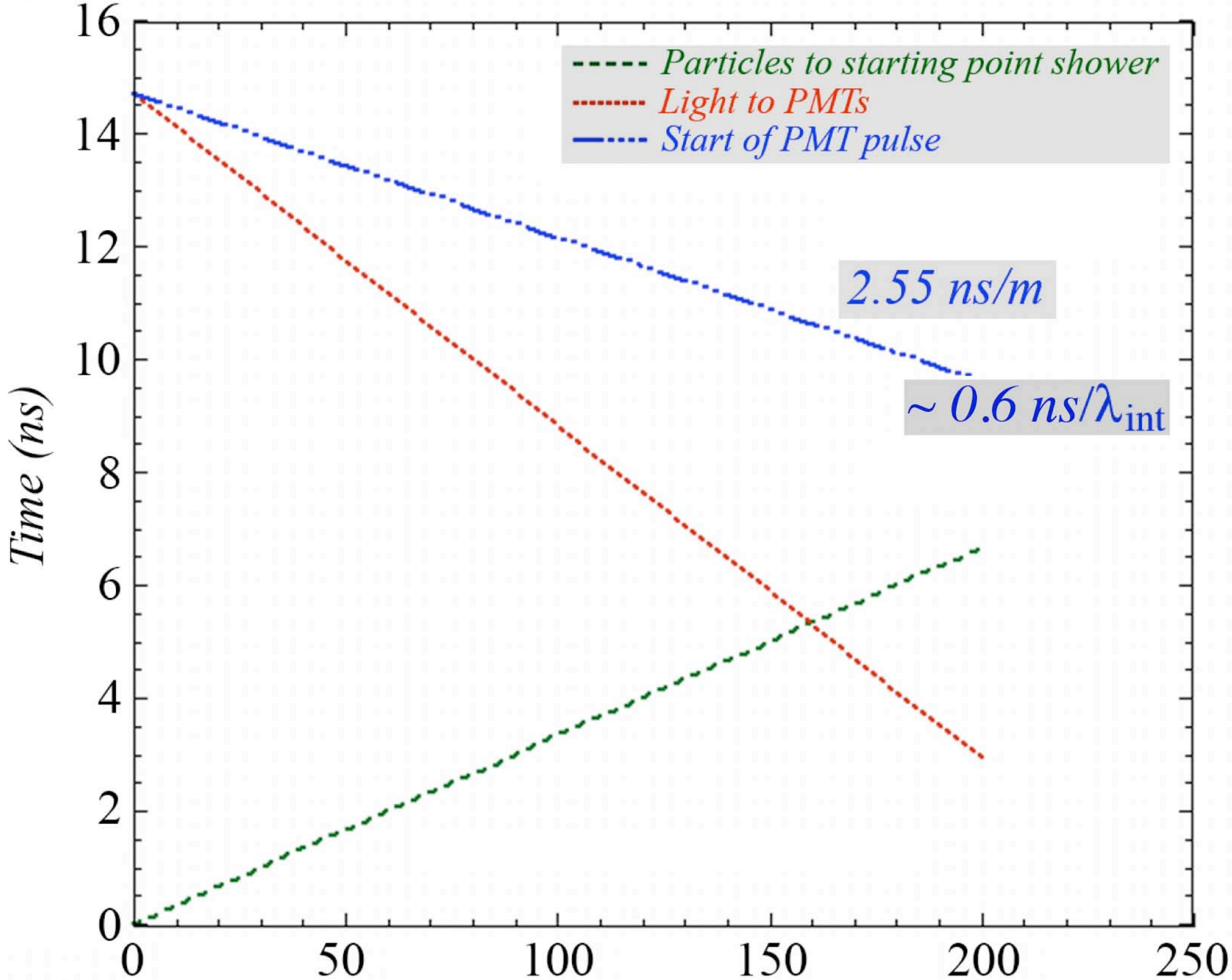
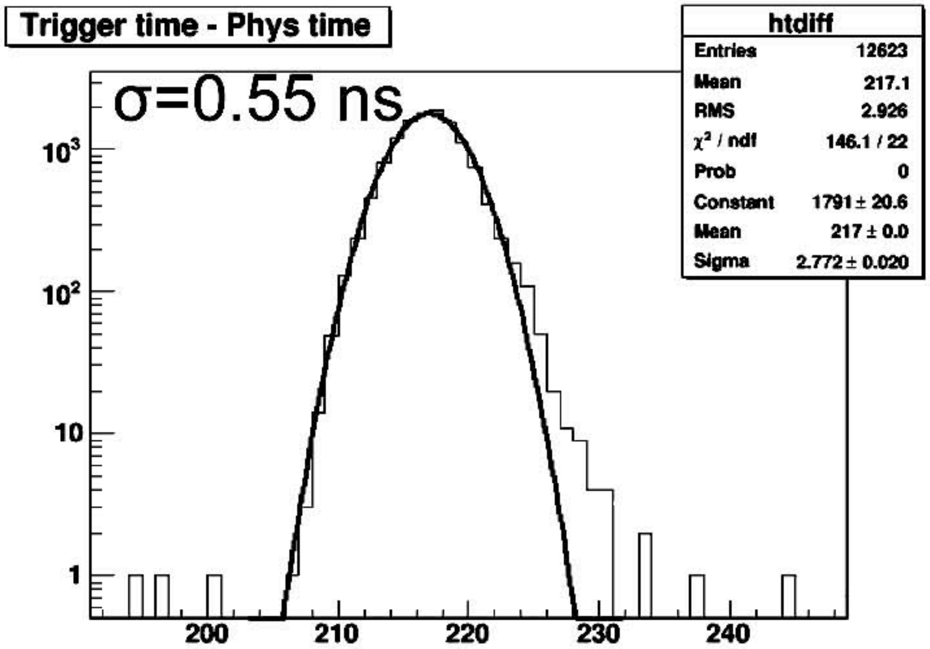
[*] *See* NIM A518 (2004) 407

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

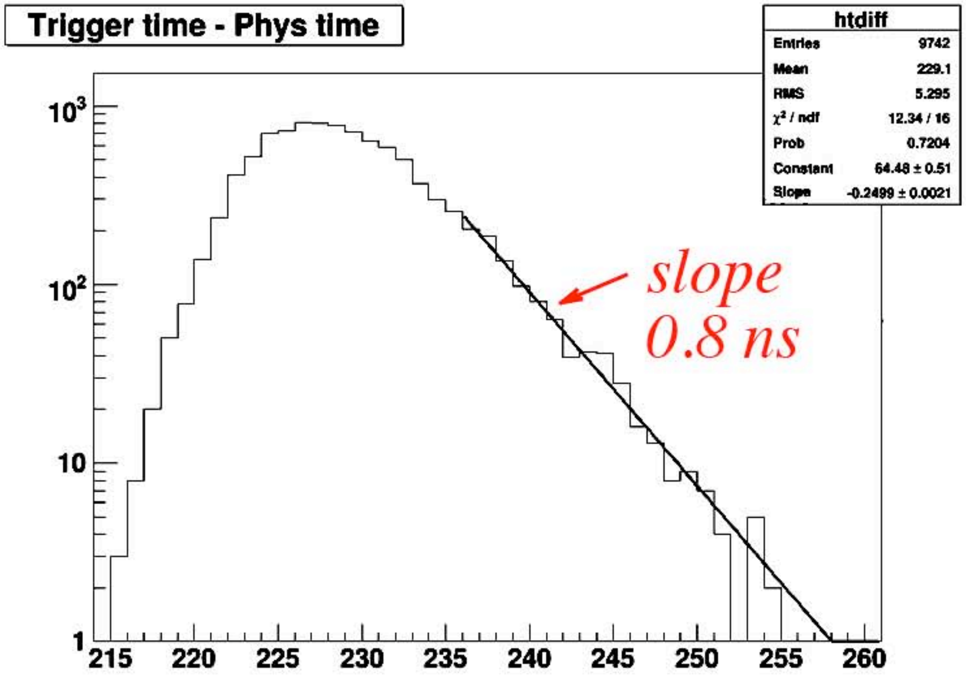


Measurement of the depth of the light production in module using the DRS timing

80 GeV electrons

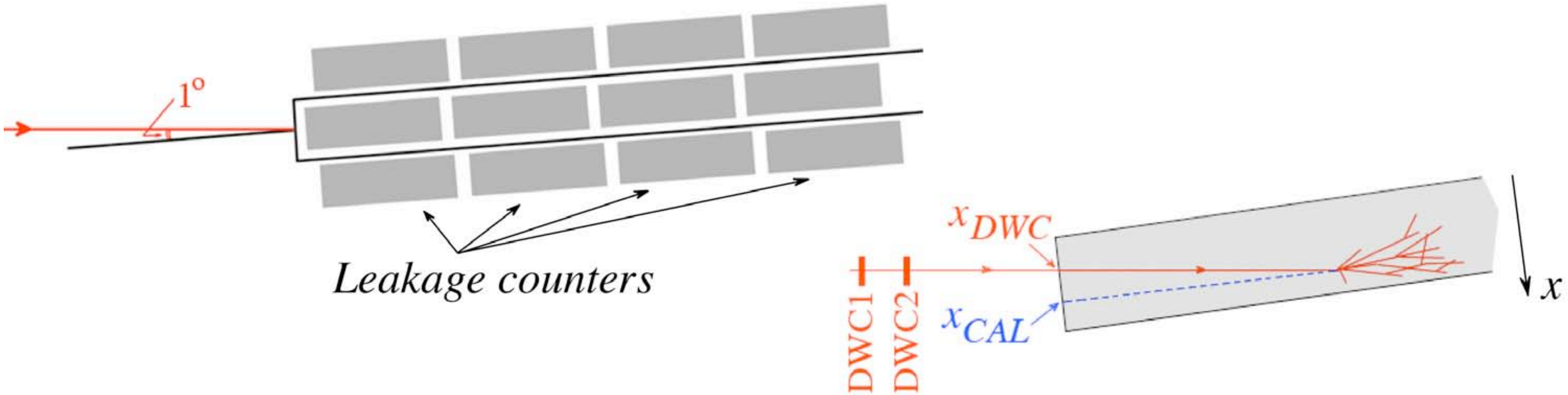


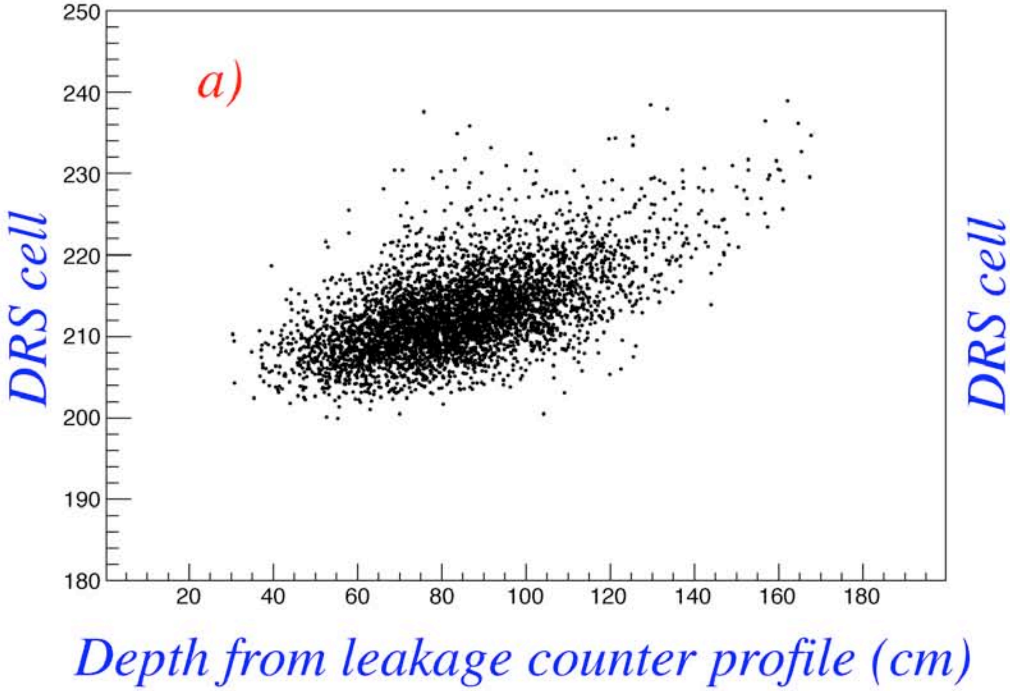
180 GeV pions

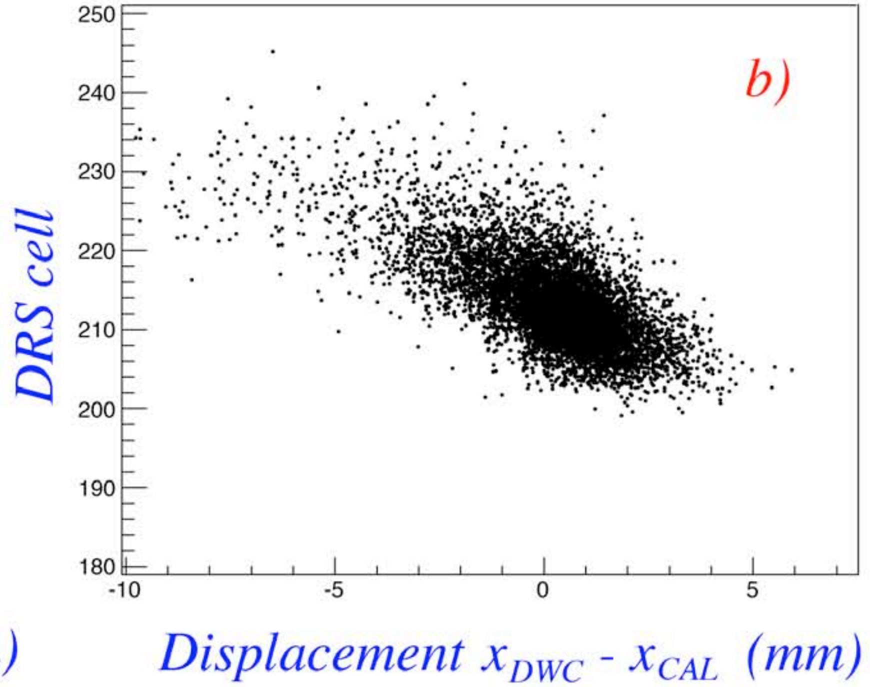


Start of calorimeter signal (in DRS cells = 0.2 ns)

Check that DRS time measures shower depth



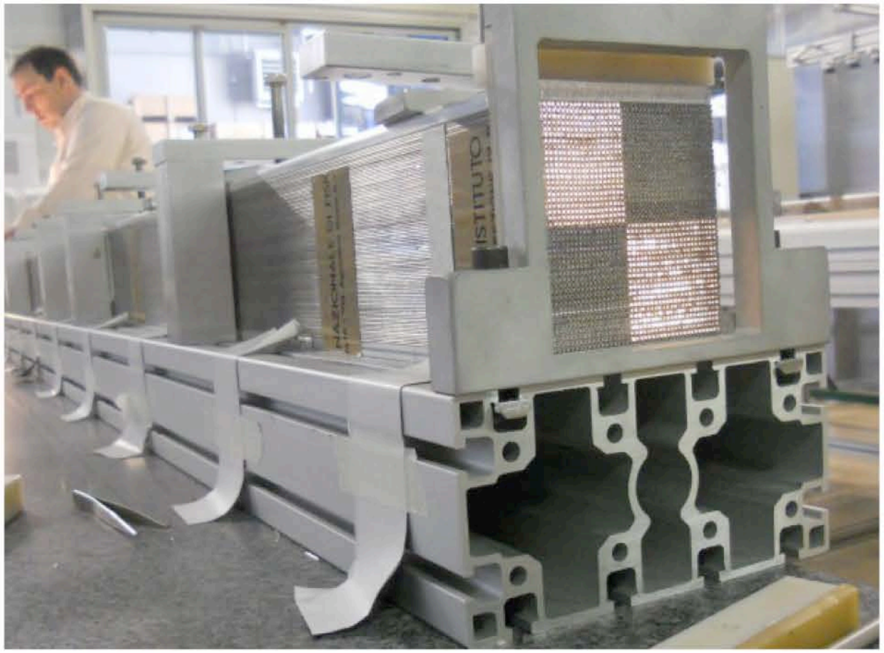


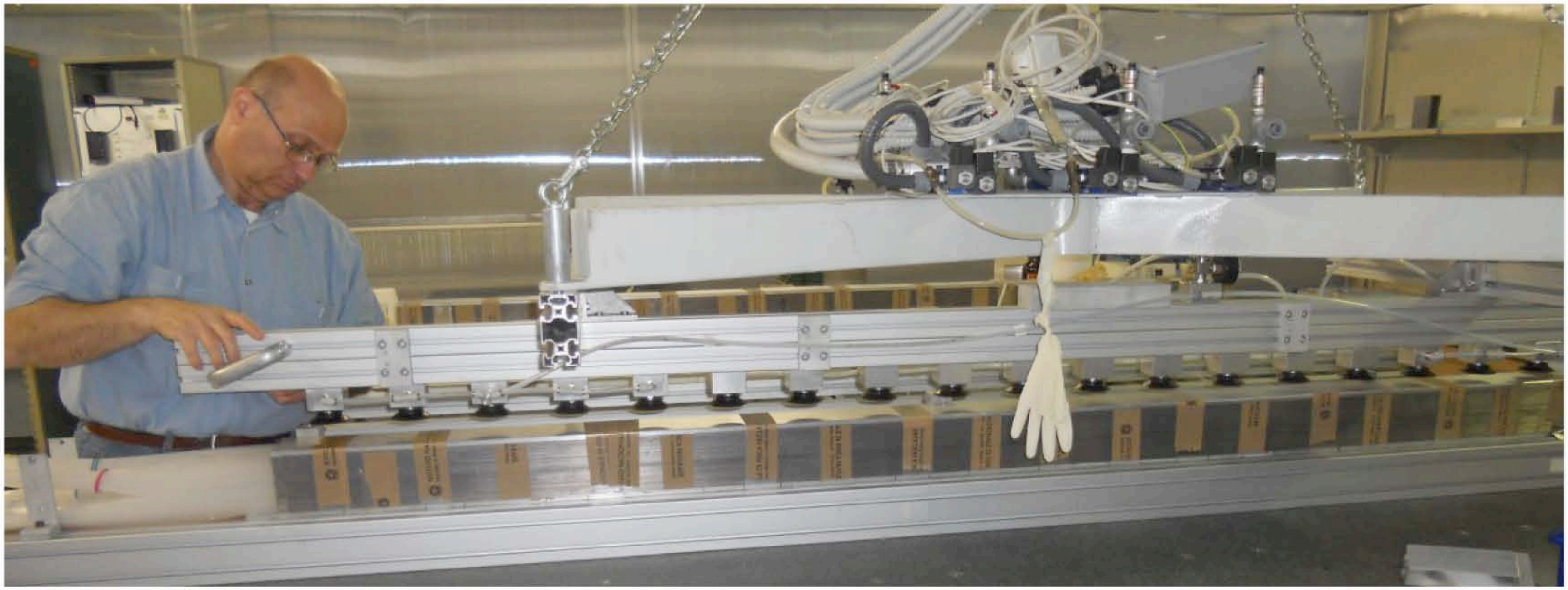


Plans for 2012

- *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*
- *Strongly dependent on available funds and manpower*

Conclusions

- *A fine-sampling Cu-fiber dual-readout calorimeter offers the best and, in my opinion the only, possibility to measure jets with energy resolutions at the 1% level*

- *The RD52 Collaboration hopes to prove this statement experimentally, which is the only way to prove anything concerning hadron calorimetry*

- *Come and join us, if you are interested in contributing to quantum leaps in detector performance*

Backup slides

Particle ID does NOT require segmentation!

e/π separation using time structure signals

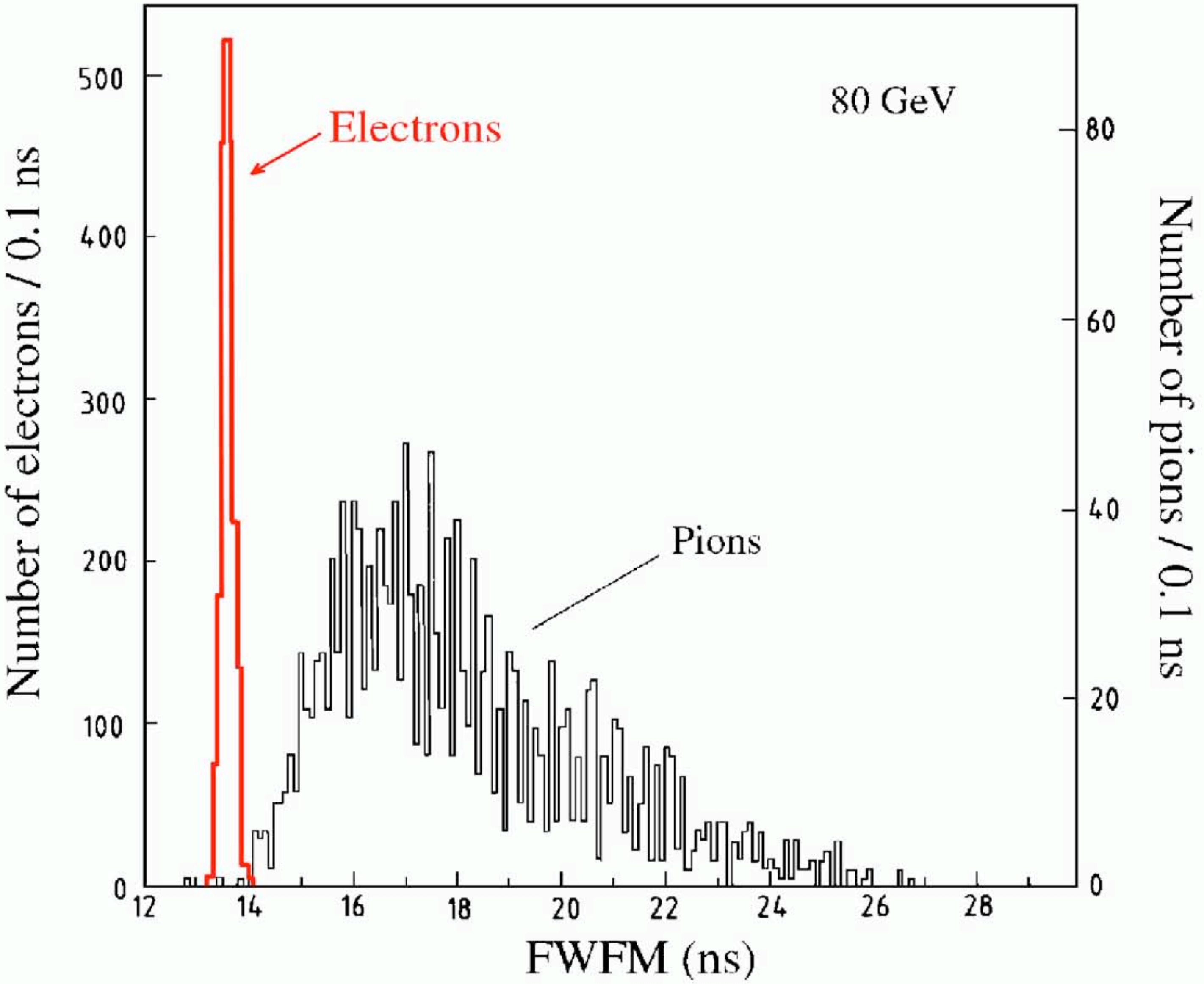
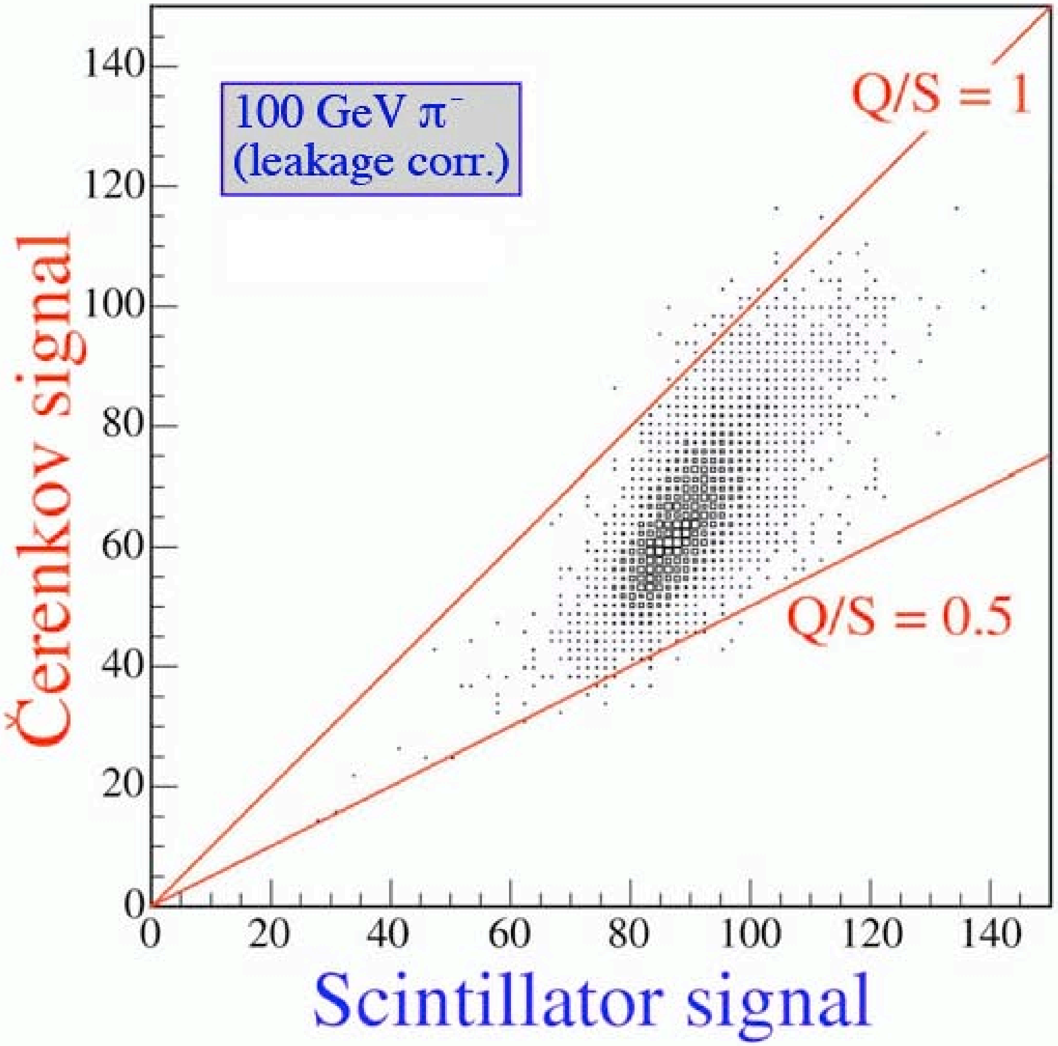


FIG. 7.33. The distribution of the full width at one-fifth maximum (FWFM) for 80 GeV electron and pion signals in SPACAL [Aco 91a].

DREAM: How to determine f_{em} and E ?



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

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

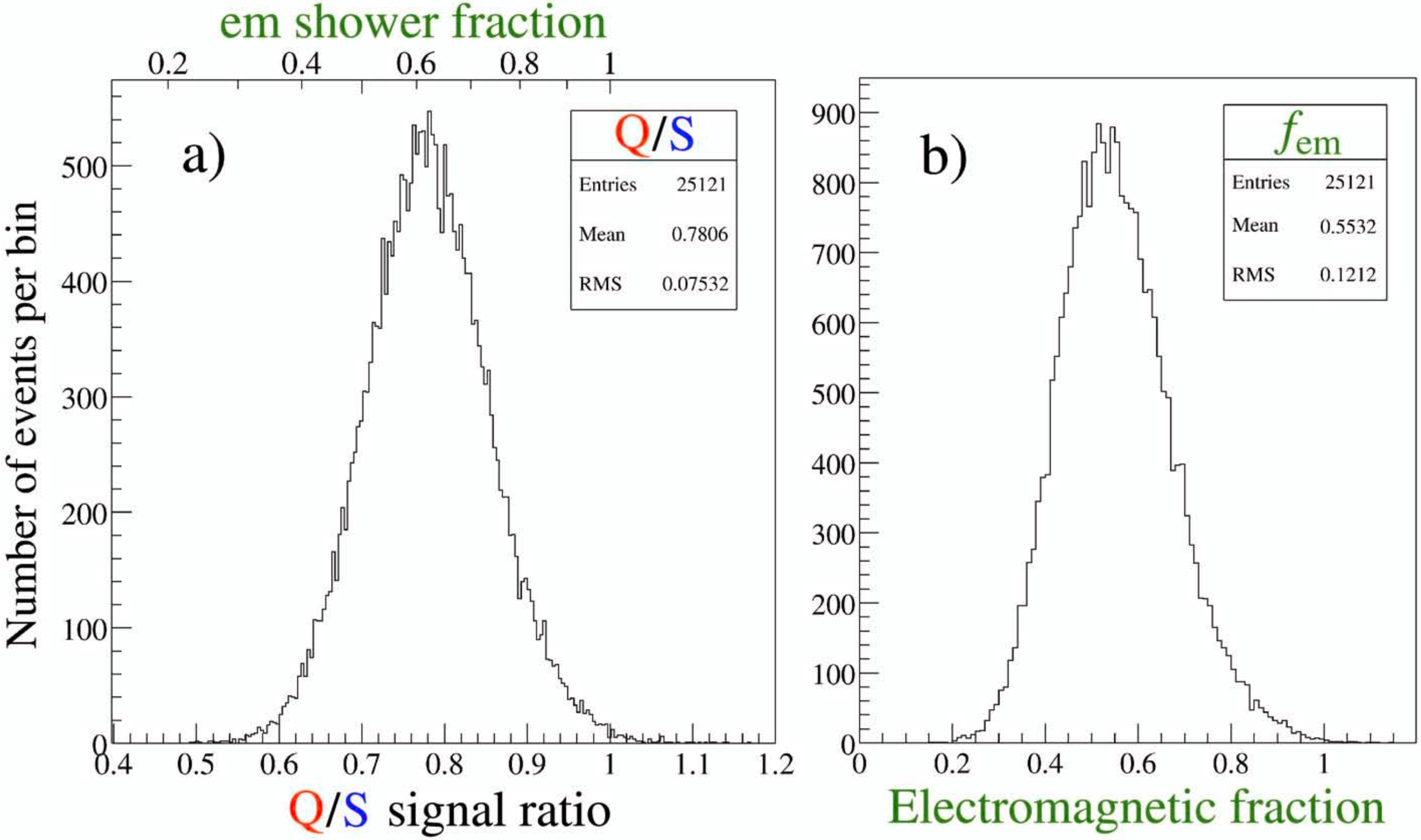
e.g. If $e/h = 1.3$ (S), 4.7 (Q)

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

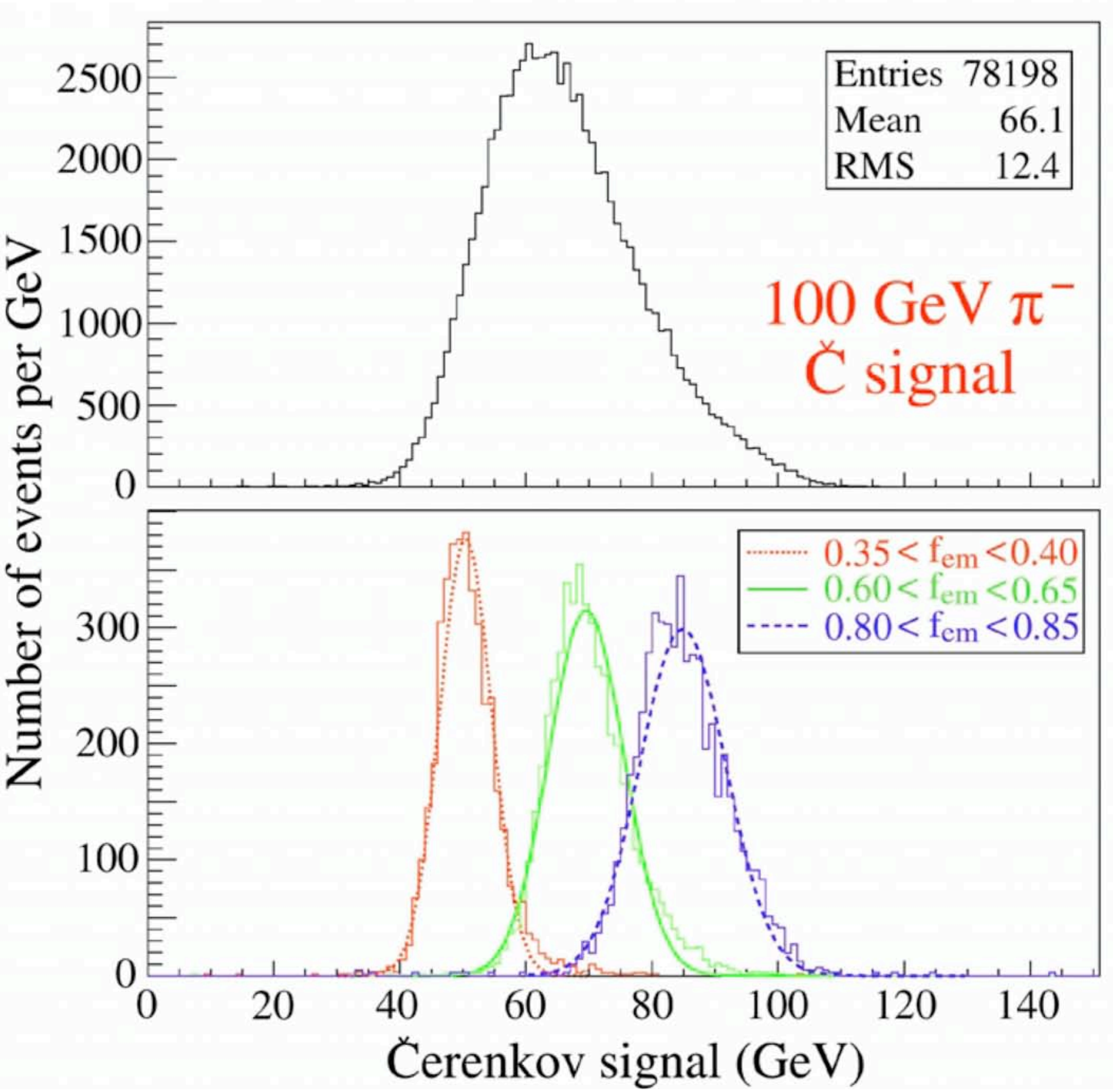
$$\boxed{E = \frac{S - \chi Q}{1 - \chi}}$$

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

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

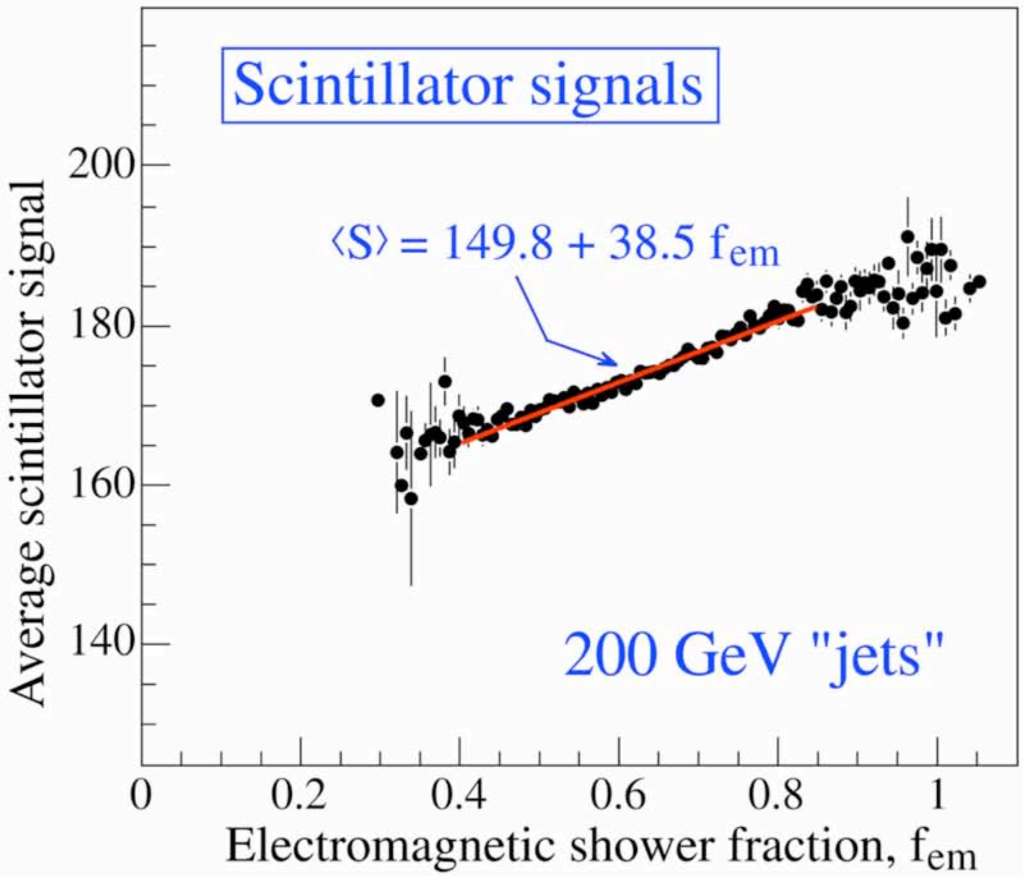


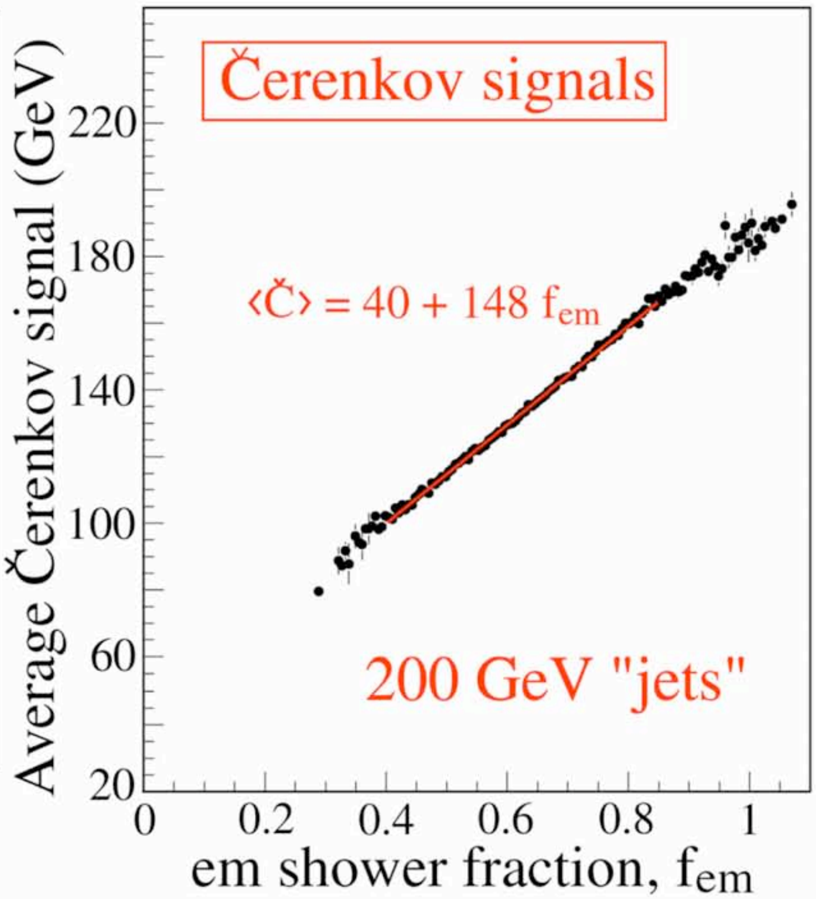
DREAM: Effect of event selection based on f_{em}



From:
NIM A537 (2005) 537

DREAM: Signal dependence on f_{em}





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

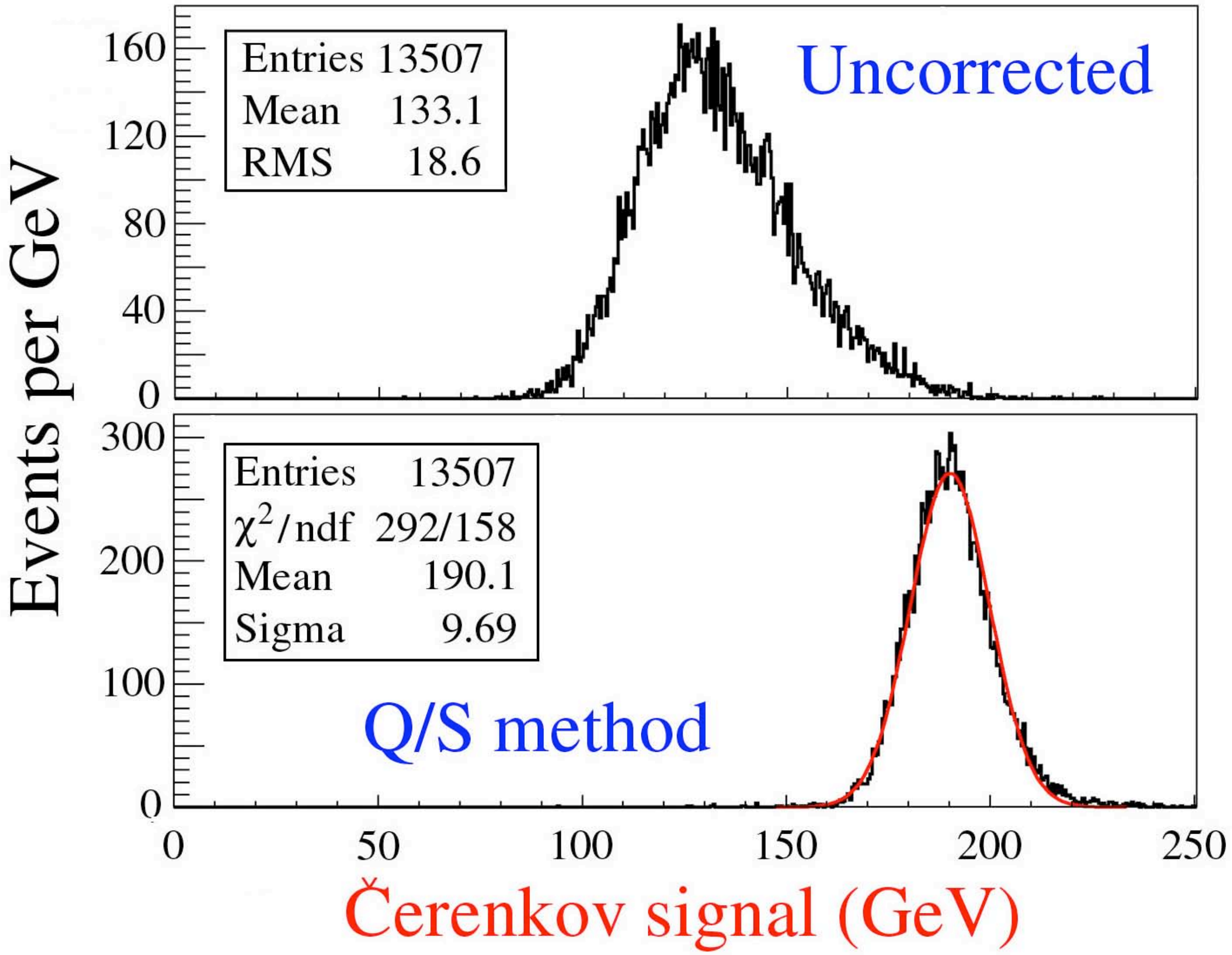
Cu/scintillator e/h = 1.3

Cu/quartz e/h = 4.7

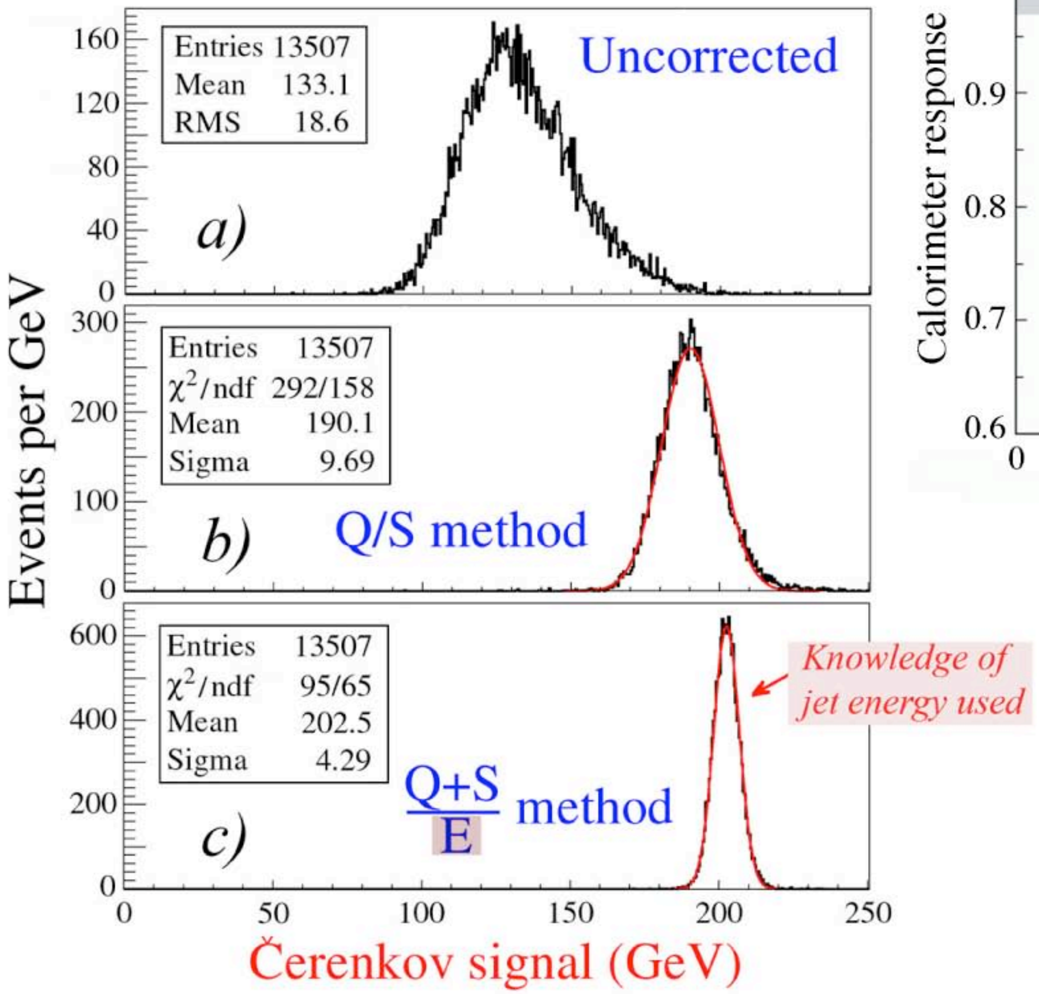
From:

NIM A537 (2005) 537

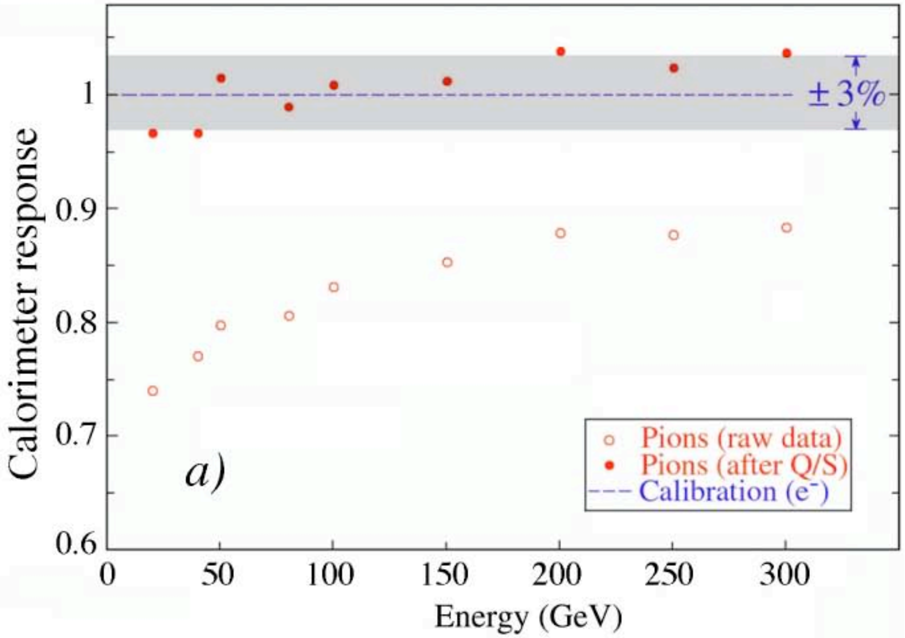
DREAM: Effect of corrections (200 GeV "jets")

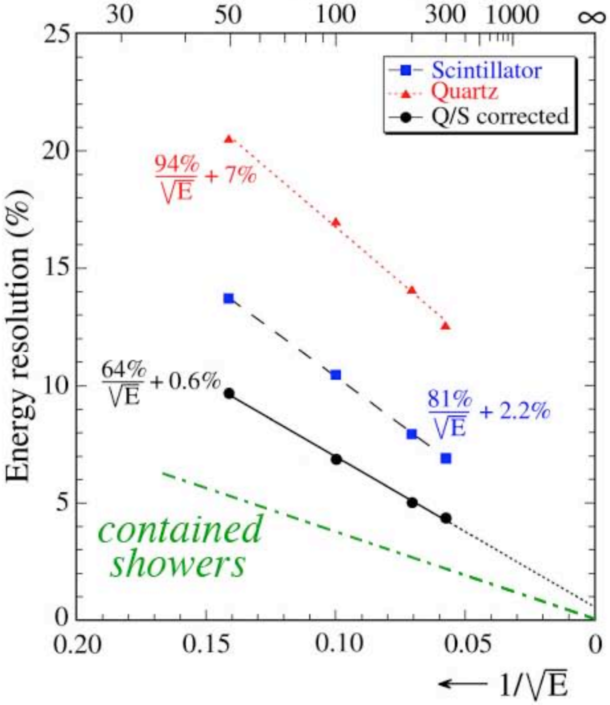


Effects of Q/S corrections on
hadronic signal linearity *and* *jet resolution*

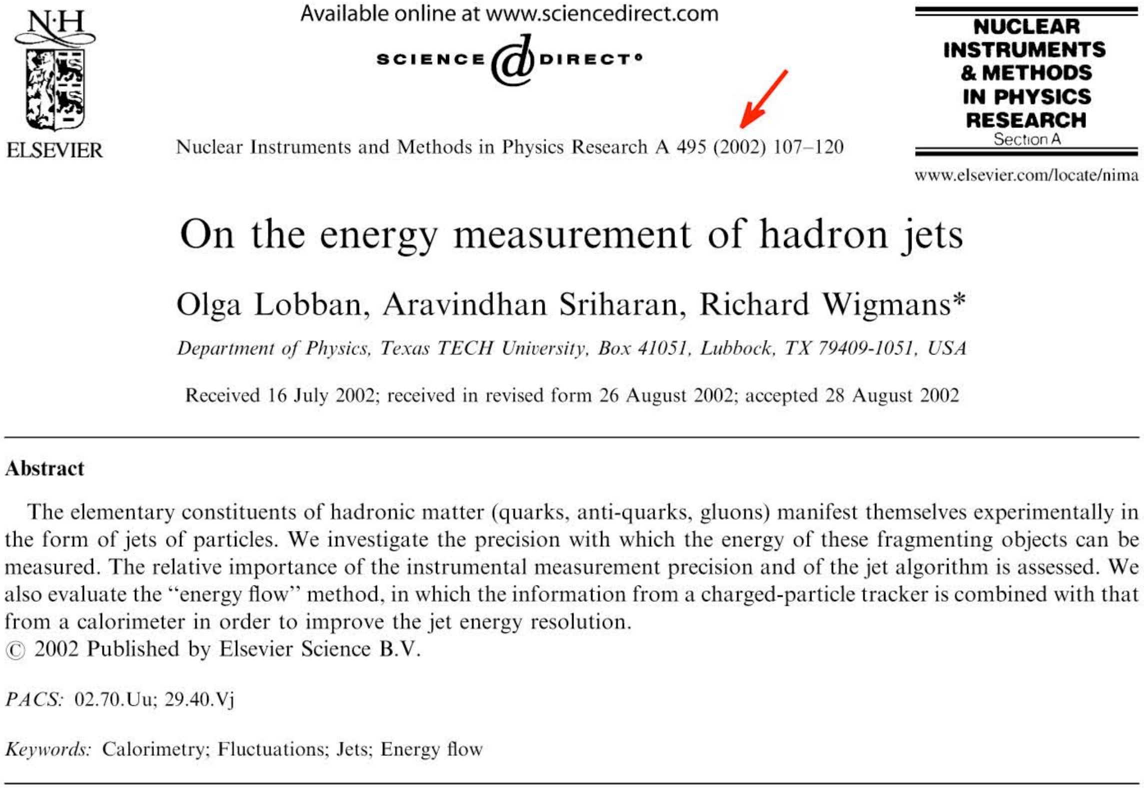


Knowledge of jet energy used





On high-resolution hadron calorimetry



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On the energy measurement of hadron jets

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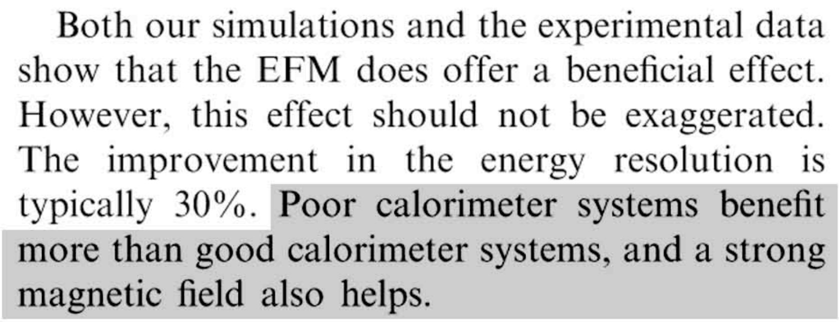
Abstract

The elementary constituents of hadronic matter (quarks, anti-quarks, gluons) manifest themselves experimentally in the form of jets of particles. We investigate the precision with which the energy of these fragmenting objects can be measured. The relative importance of the instrumental measurement precision and of the jet algorithm is assessed. We also evaluate the "energy flow" method, in which the information from a charged-particle tracker is combined with that from a calorimeter in order to improve the jet energy resolution.

PACS: 02.70.Uu; 29.40.Vj

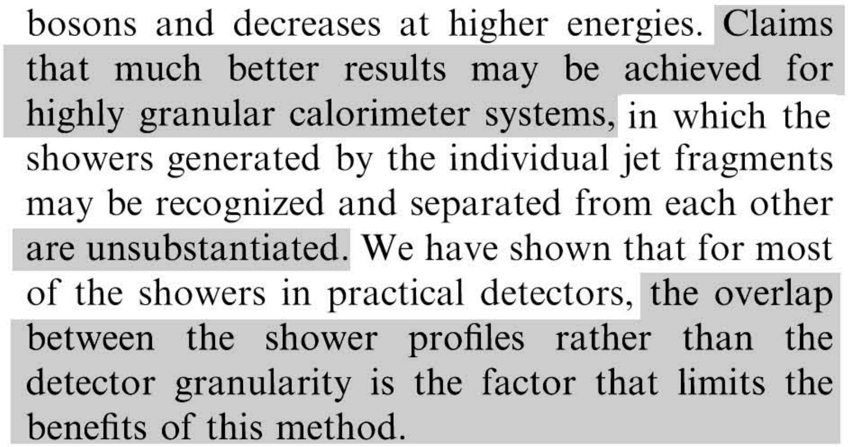
Keywords: Calorimetry; Fluctuations; Jets; Energy flow

From Conclusions:



Both our simulations and the experimental data show that the EFM does offer a beneficial effect. However, this effect should not be exaggerated. The improvement in the energy resolution is typically 30%. Poor calorimeter systems benefit more than good calorimeter systems, and a strong magnetic field also helps.

cf CMS vs ATLAS !!



bosons and decreases at higher energies. Claims that much better results may be achieved for highly granular calorimeter systems, in which the showers generated by the individual jet fragments may be recognized and separated from each other are unsubstantiated. We have shown that for most of the showers in practical detectors, the overlap between the shower profiles rather than the detector granularity is the factor that limits the benefits of this method.

No experimental evidence to the contrary!!