Dual-Readout Calorimetry

for High-Quality Energy Measurements

*Status report of the RD52 (DREAM) Collaboration**

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CERN, April 9, 2013

* *DREAM (RD52) Collaboration:*
Cagliari, Cosenza, Lisbon, Pavia, Pisa, Roma, Iowa State, TTU

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

Outline:

- *Construction of the new fiber calorimeter*
- *Results of beam tests in 2012*
- *Future plans*

D U A L - R E A D O U T   C A L O R I M E T R Y

- *Dual-Readout Method (DREAM):*
  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

- DREAM offers a powerful technique to *improve* hadronic calorimeter performance:
  - Correct hadronic energy reconstruction, *in an instrument calibrated with electrons!*
  - Linearity for hadrons and jets
  - Gaussian response functions
  - Energy resolution scales with $1/\sqrt{E}$
  - $\sigma/E < 5\%$ for high-energy "jets", in a detector with a mass of only 1 ton!
    dominated by fluctuations in shower leakage

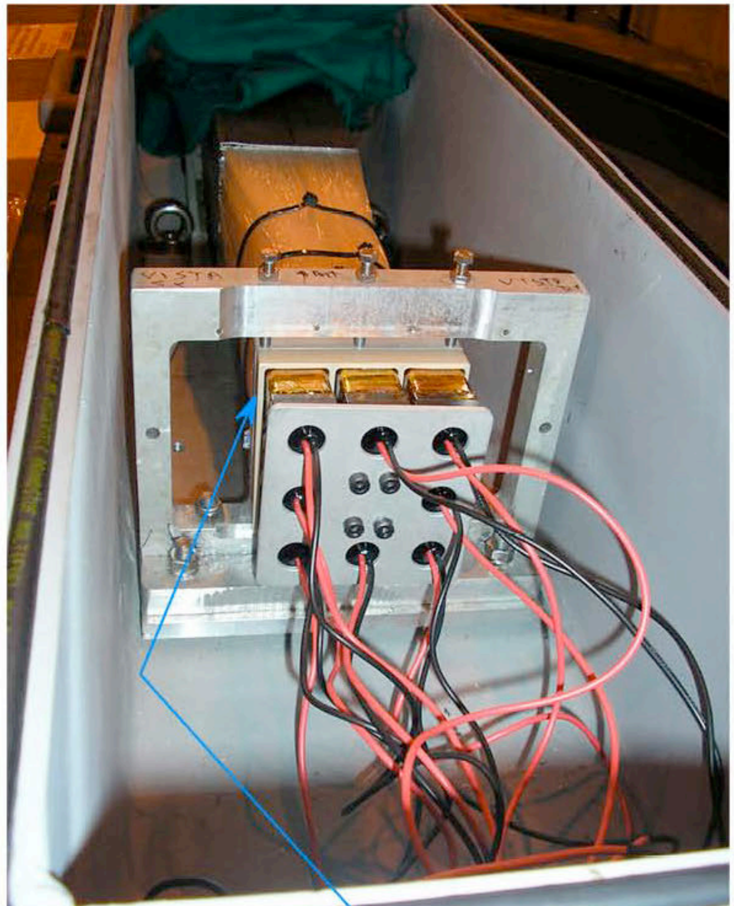
In other words:
The same advantages as intrinsically compensating calorimeters (e/h = 1)
WITHOUT the limitations (sampling fraction, integration volume, time)

- *RD52 goals:*
  Reduce the factors that limit the resolution of DR calorimeters as much as possible
  1) Shower leakage effects,
  2) Čerenkov light yield,
  3) Sampling fluctuations

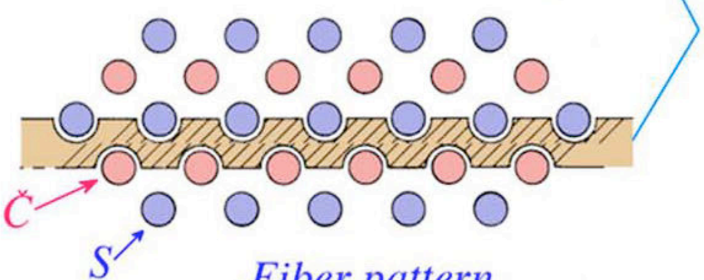
  → *Construct new, 5-ton fiber calorimeter*
  + study crystal options (BGO, $PbWO_4$, BSO)

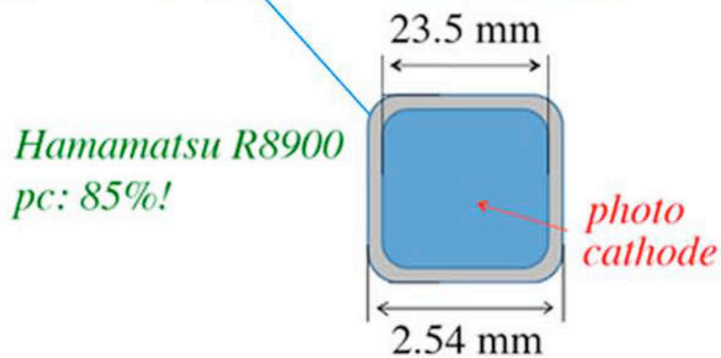
The new fiber calorimeter

The first SuperDREAM module tested at CERN

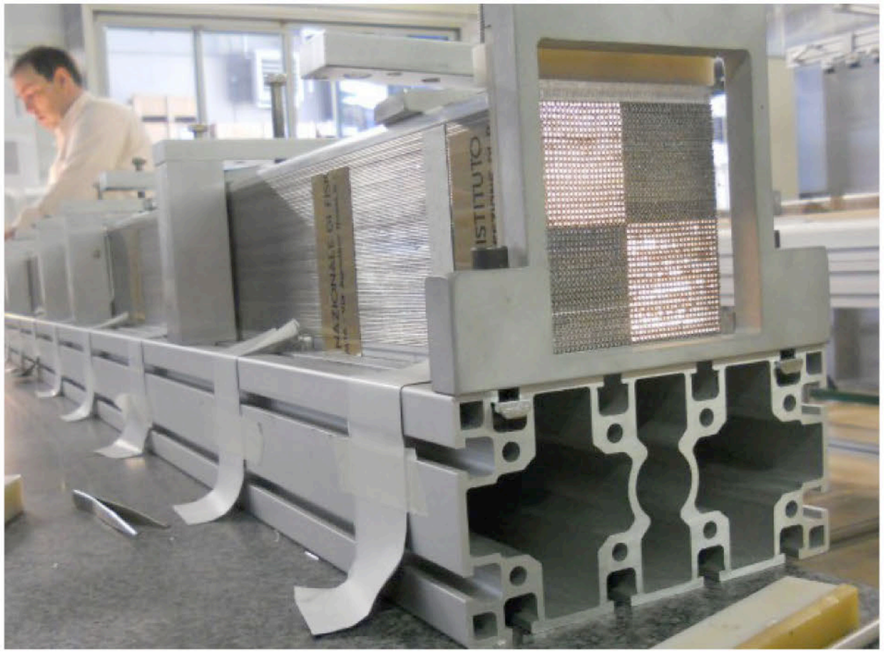


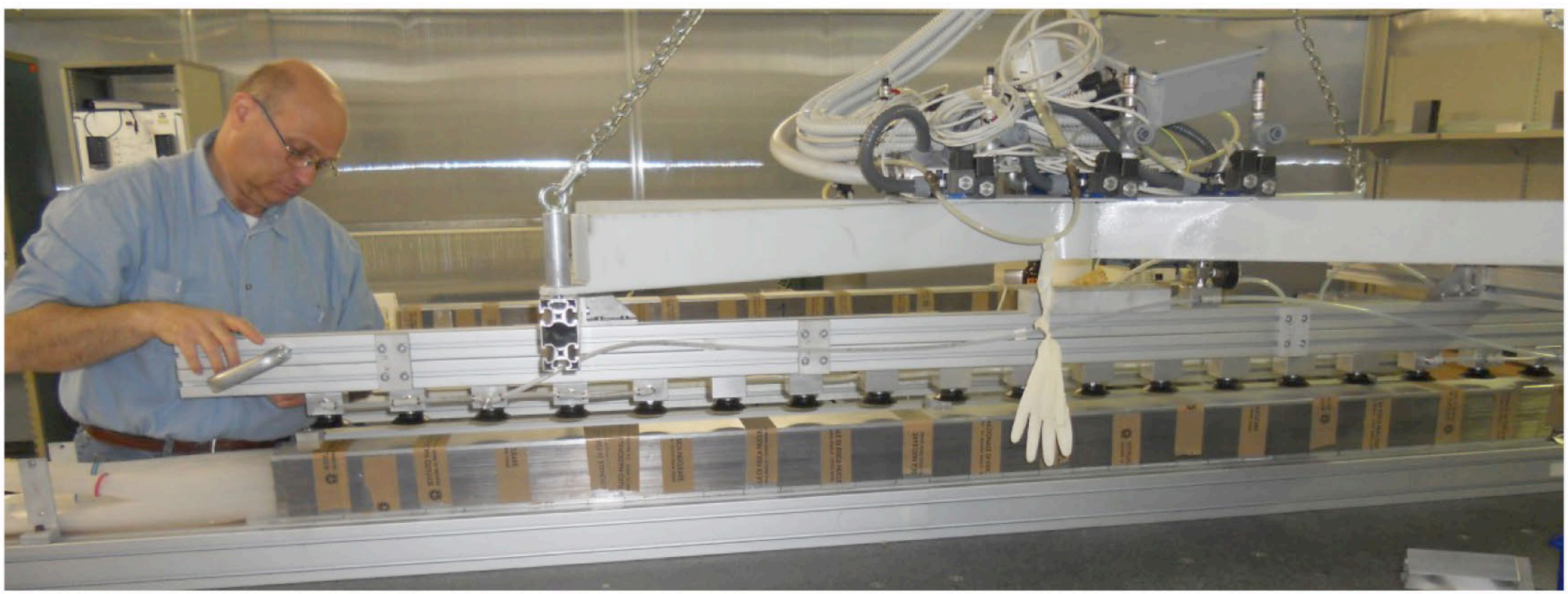
Pb absorber
9.3 x 9.3 x 250 cm
150 kg
4 towers, 8 PMTs
2 x 2048 fibers



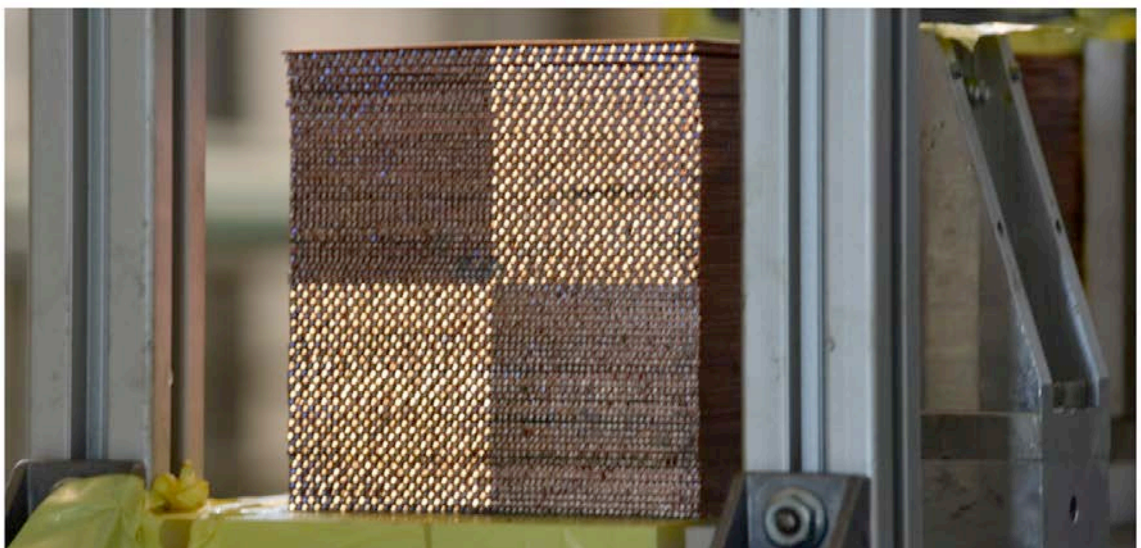


Production of Pb based SuperDREAM modules



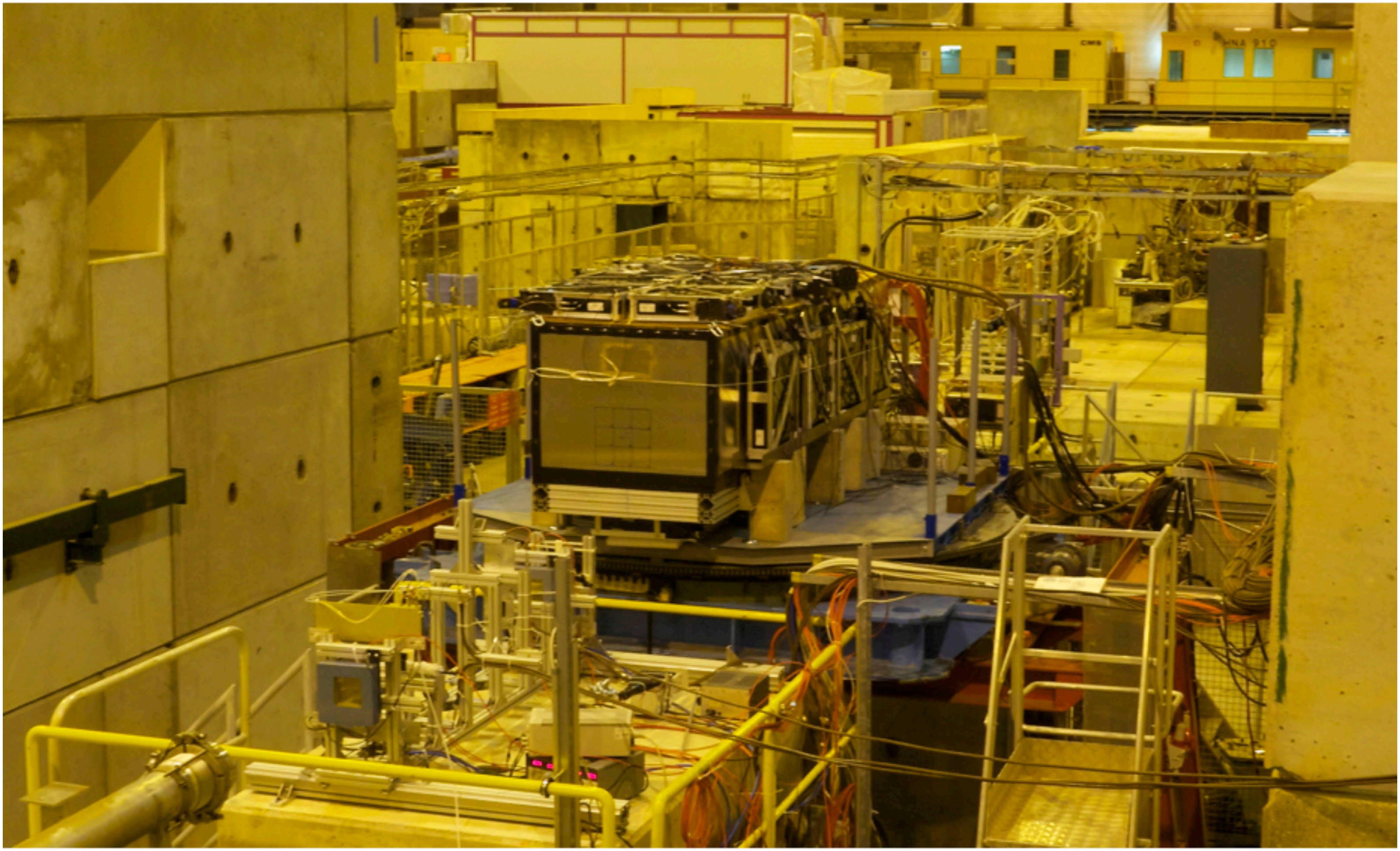


The first copper module



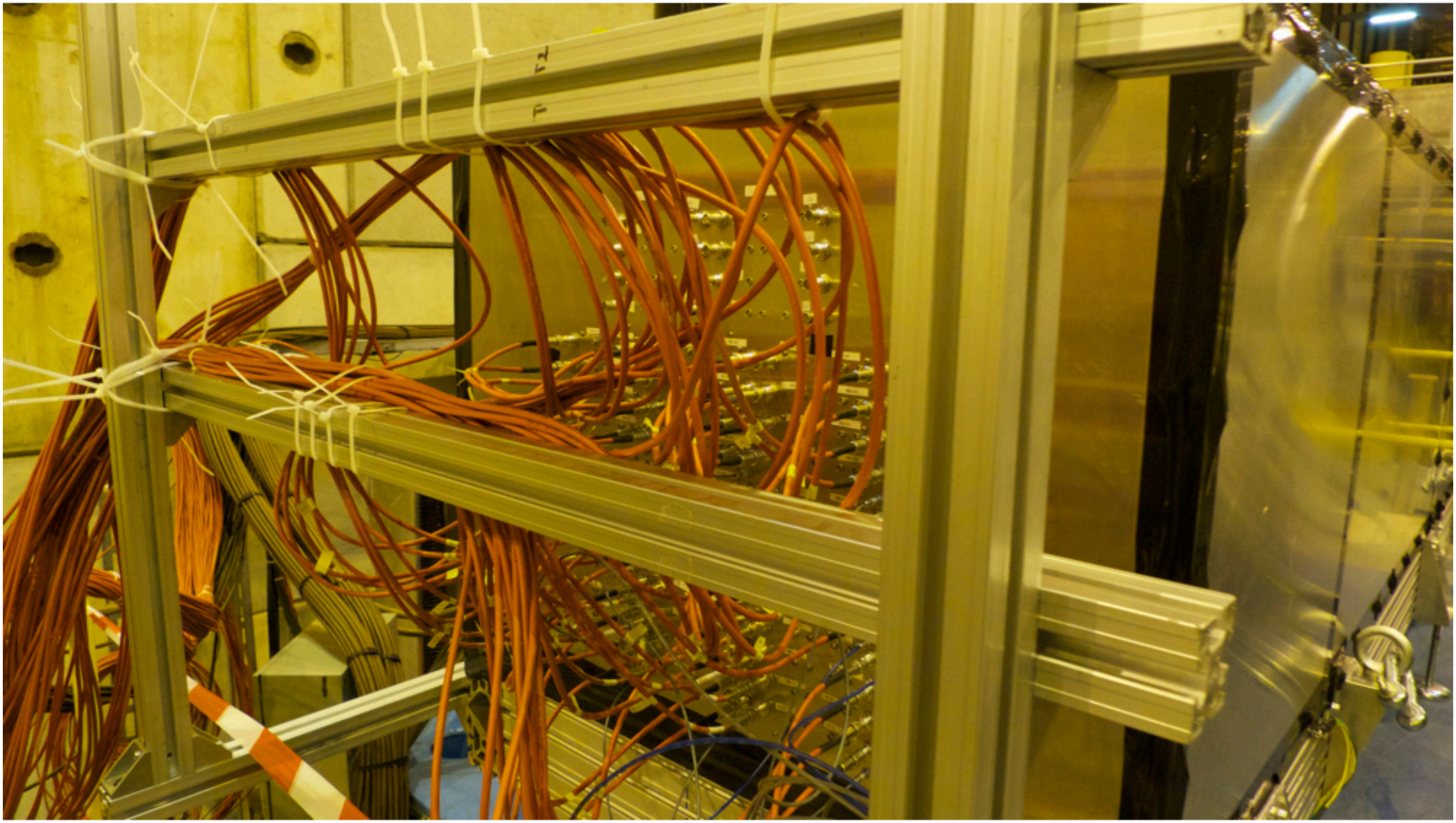
The new SuperDREAM fiber module tested at CERN

(December 2012)

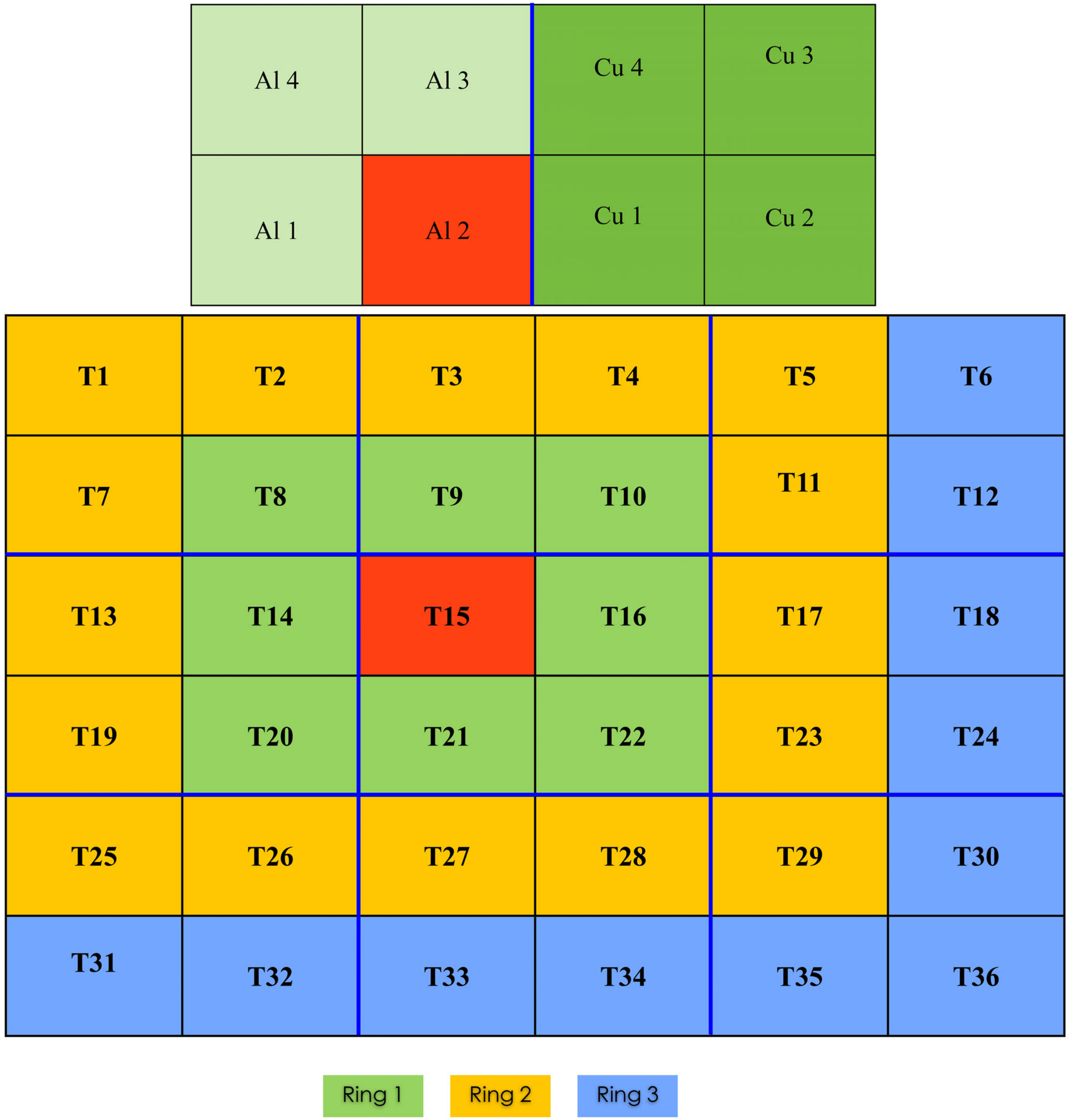


9 modules (36 towers, 72 signals), 1.4 tonnes Pb/fiber + 2 modules Cu/fiber
20 leakage modules (500 kg plastic scintillator)

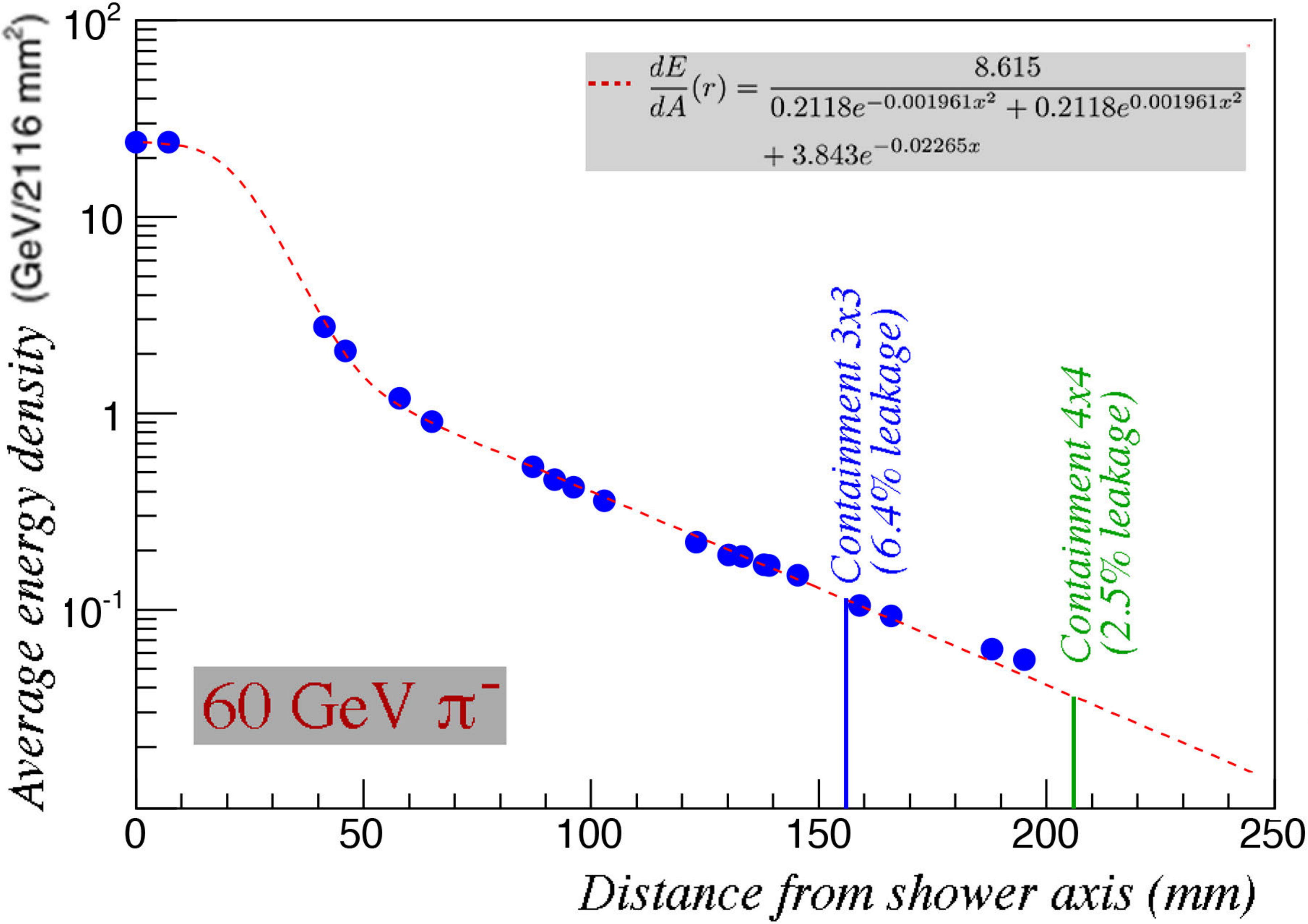
Rear side of the new SuperDREAM module



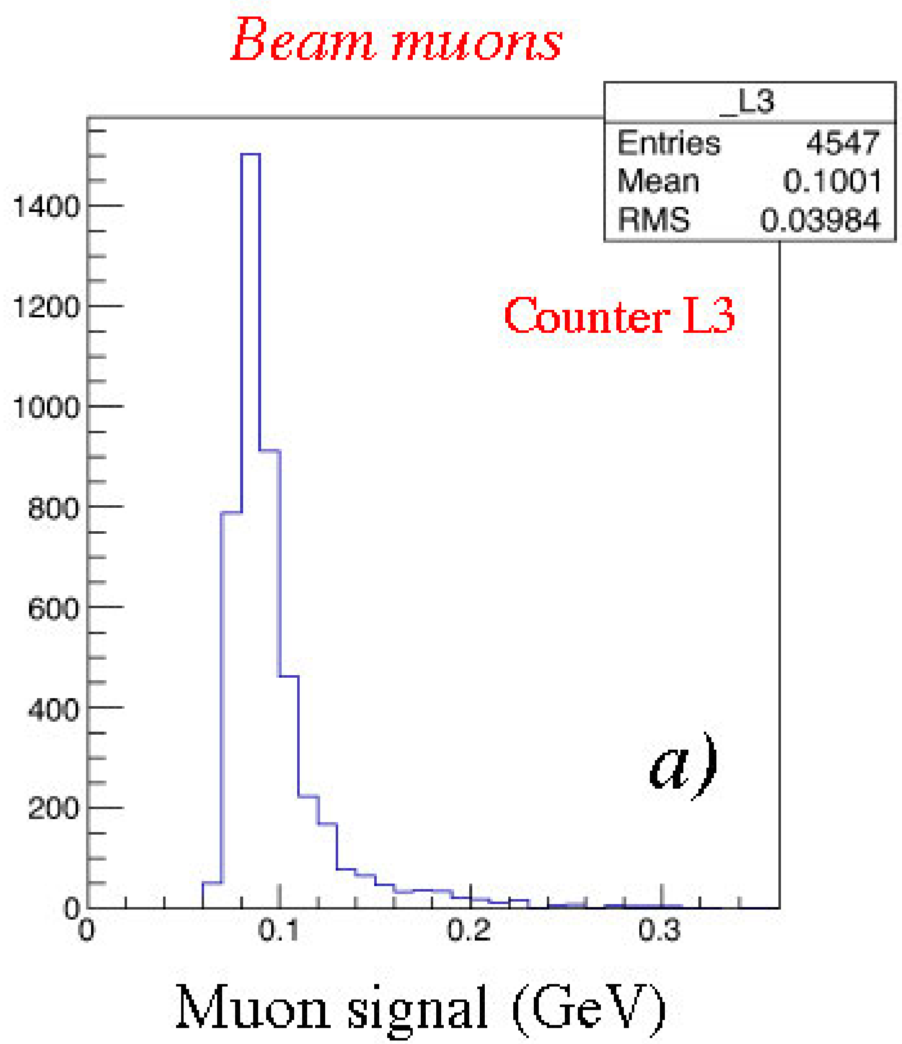
The RD52 fiber calorimeter tested in December 2012

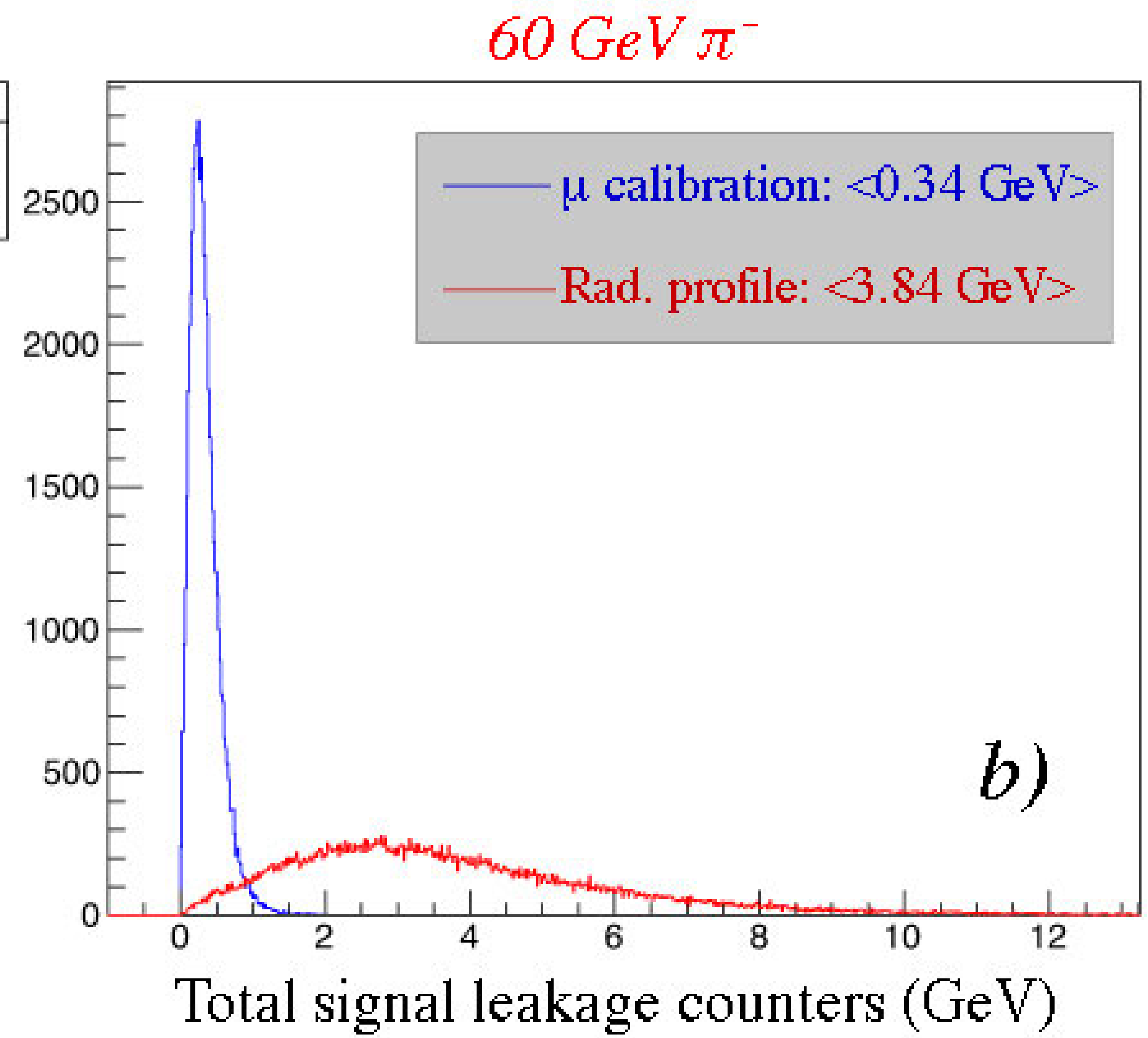


Radial profile and hadronic shower containment



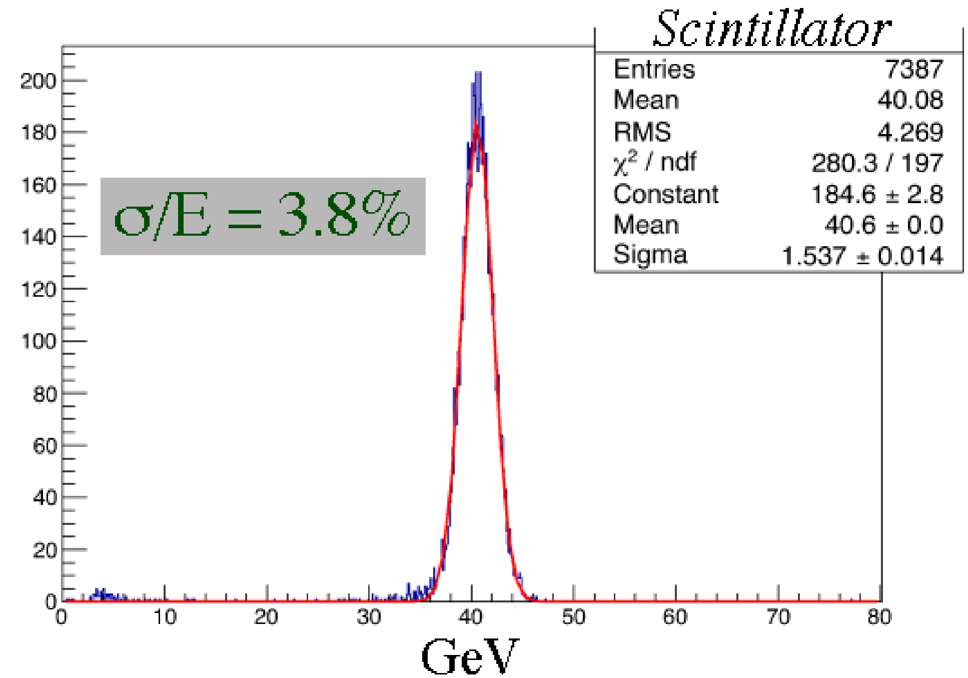
Calibration of the surrounding lateral leakage counters

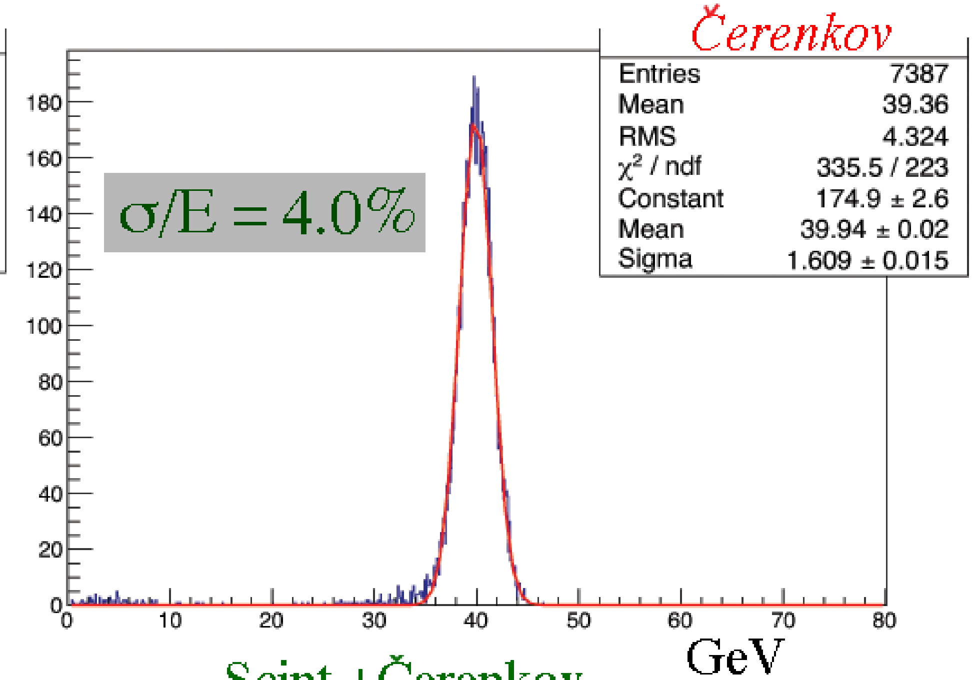




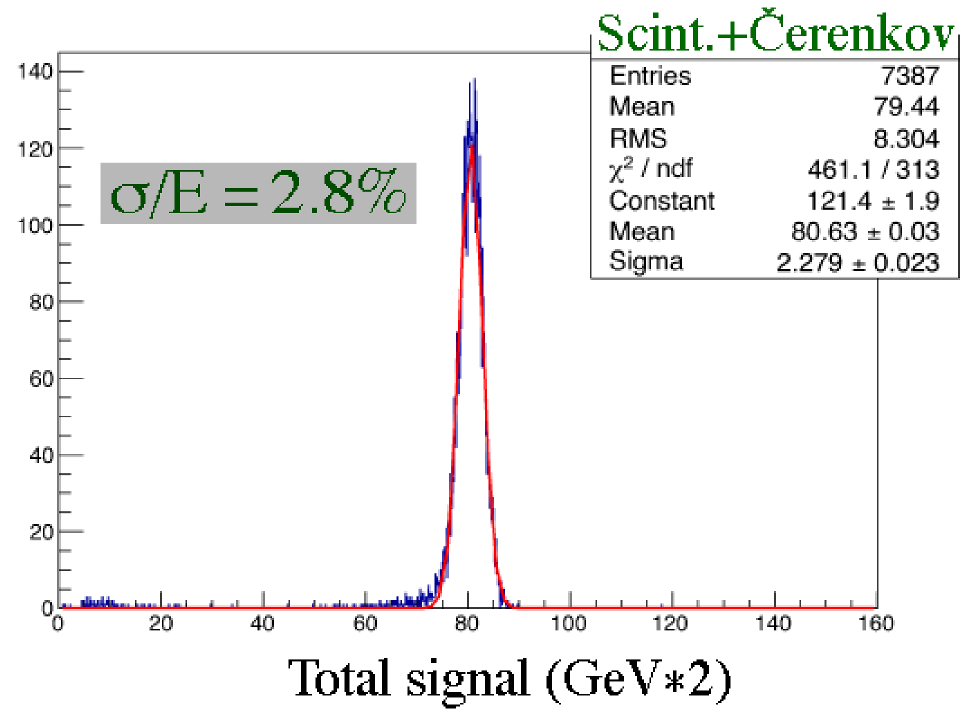
Electromagnetic performance

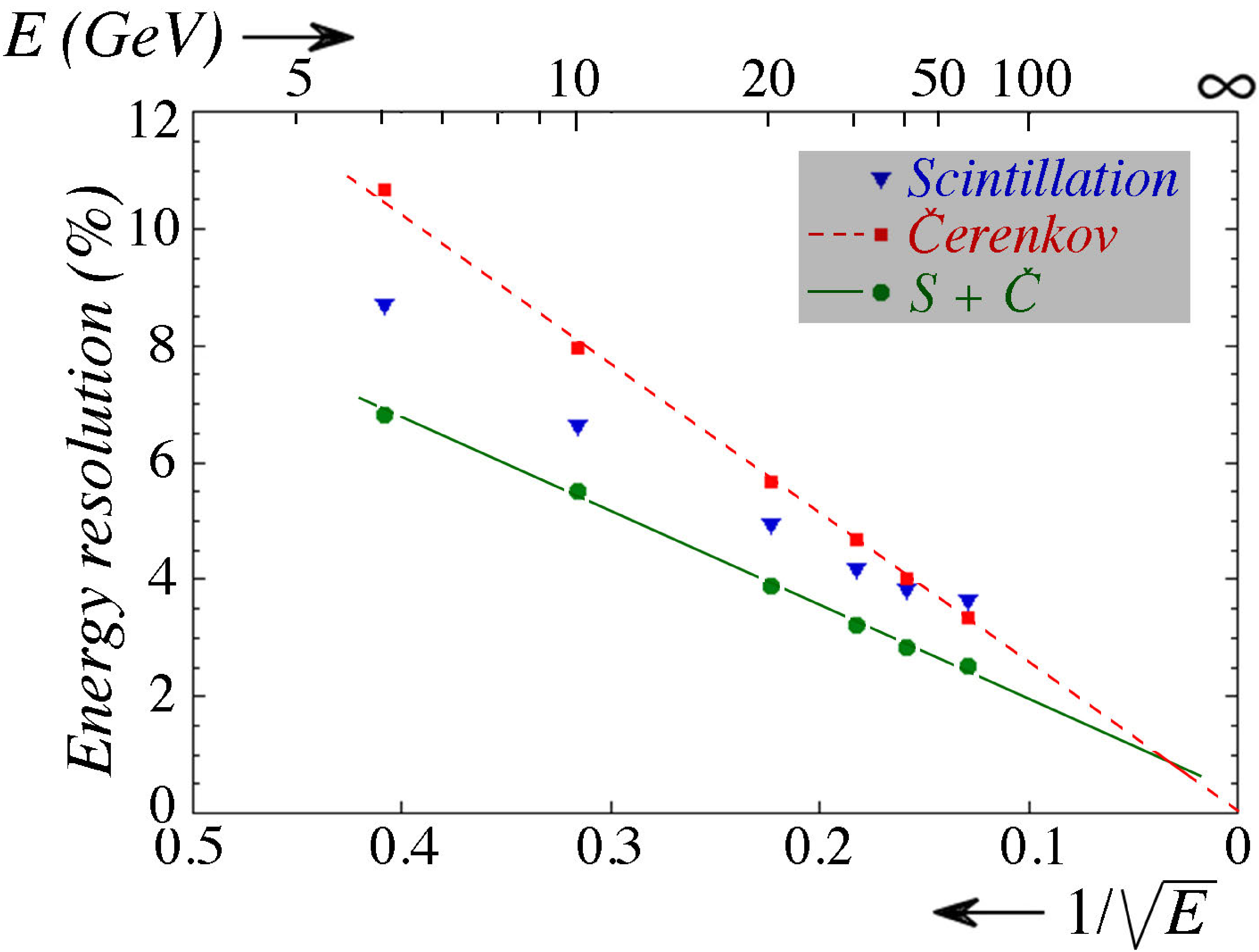
S and Č signals sample the showers independently
Resolution improves by combining



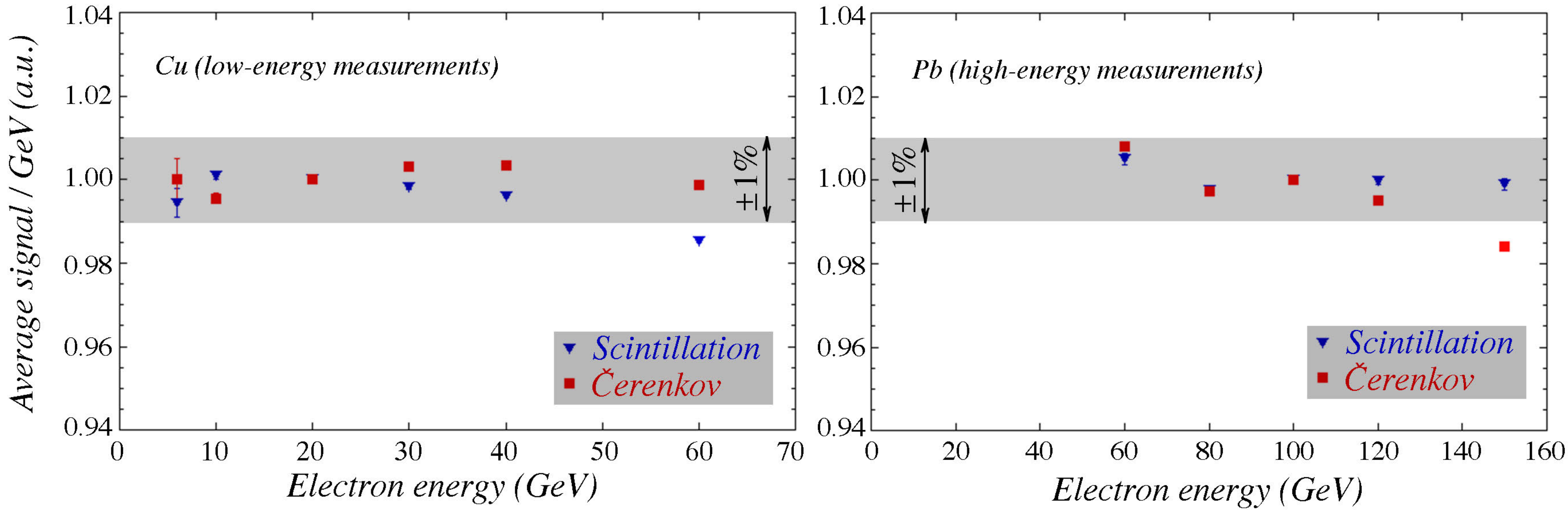


40 GeV electrons
Cu-fiber calorimeter




E (GeV)
5
10
20
50
100
∞
Scintillation
Čerenkov
S + Č
Energy resolution (%)
12
10
8
6
4
2
0
0.5
0.4
0.3
0.2
0.1
0
1/√E

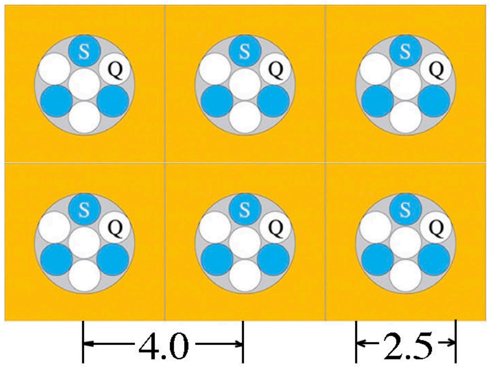
The signal linearity of the new dual-readout fiber calorimeters
(response = constant)



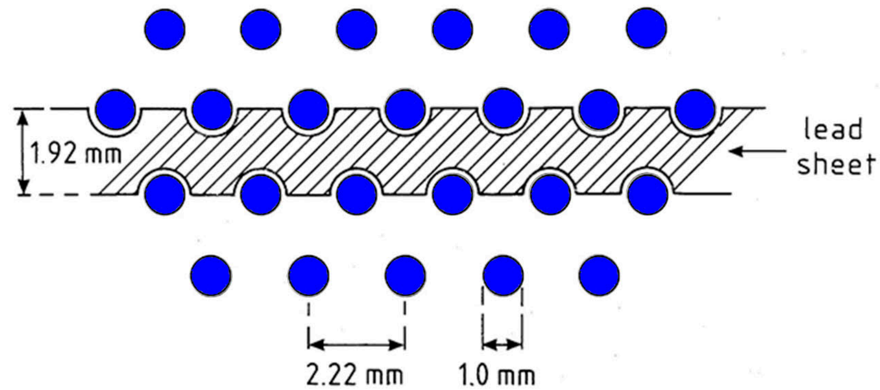
Comparison different longitudinally unsegmented fiber calorimeters

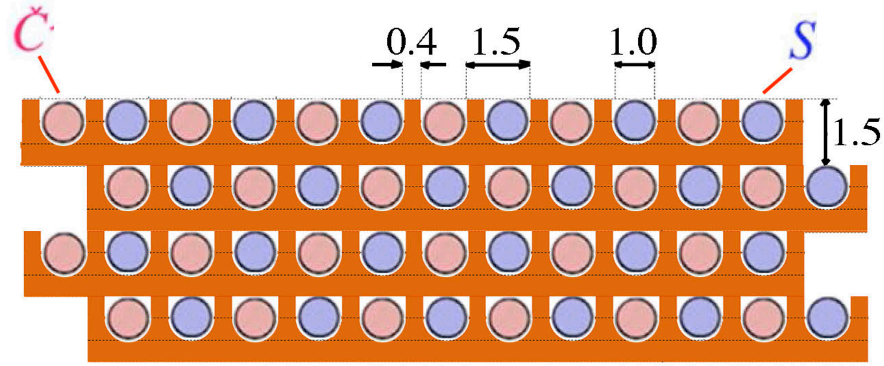
Sampling fraction & frequency

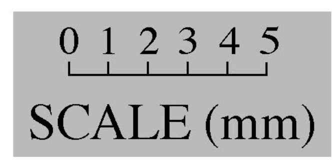
DREAM



SPACAL





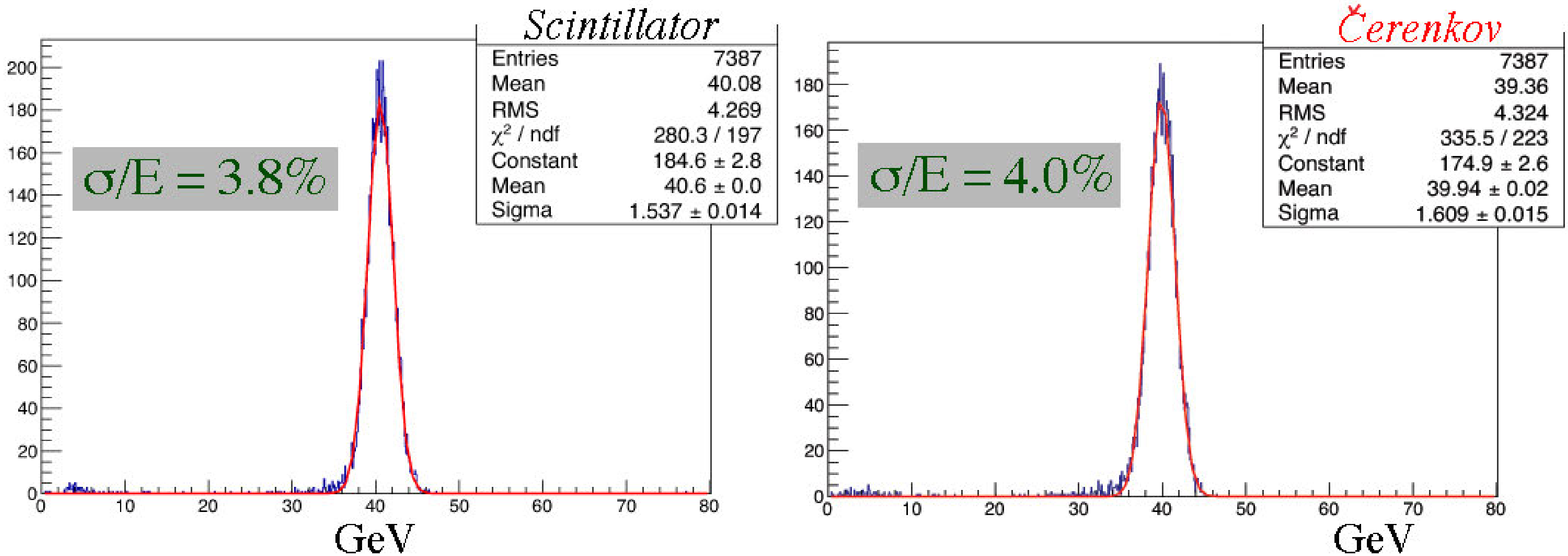


Fiber pattern RD52

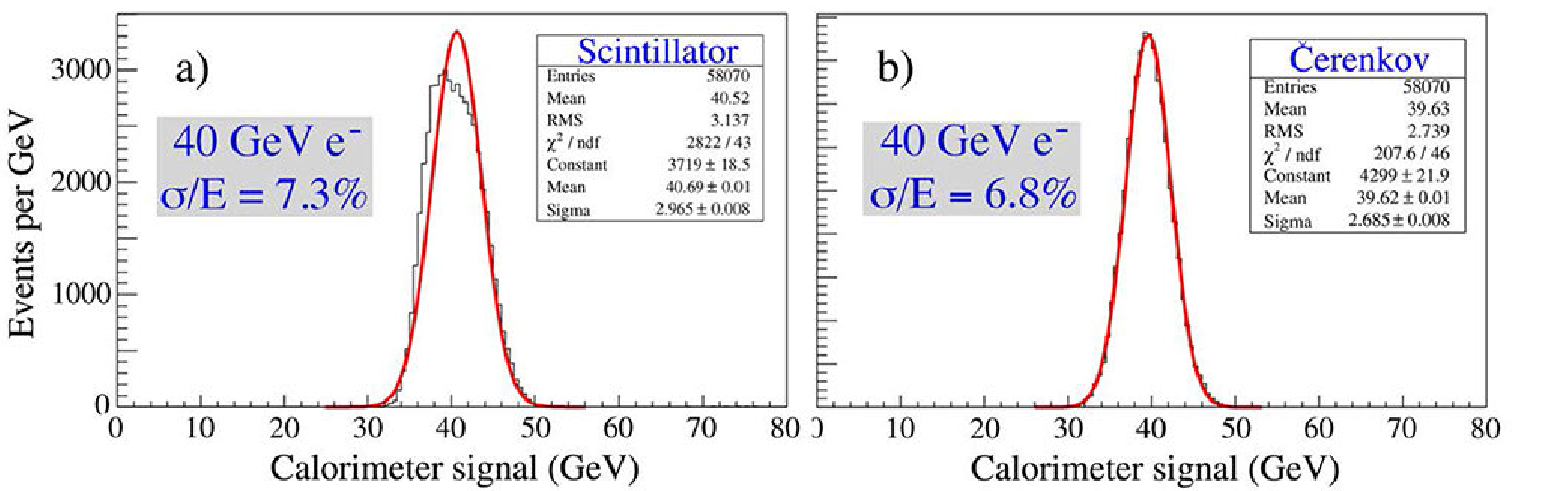
Absorber thickness between sampling layers (Moliere radii):

SPACAL 0.071 *DREAM 0.099* *RD52 0.027*

The new RD52 results on 40 GeV electrons ($\theta = 1.5^{o}$)

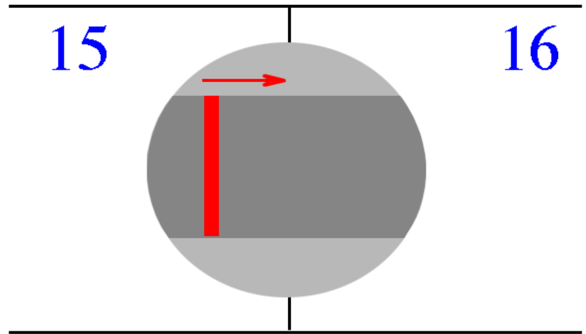


Compared with original DREAM results (NIM A536, 29) ($\theta = 2^{o}$)

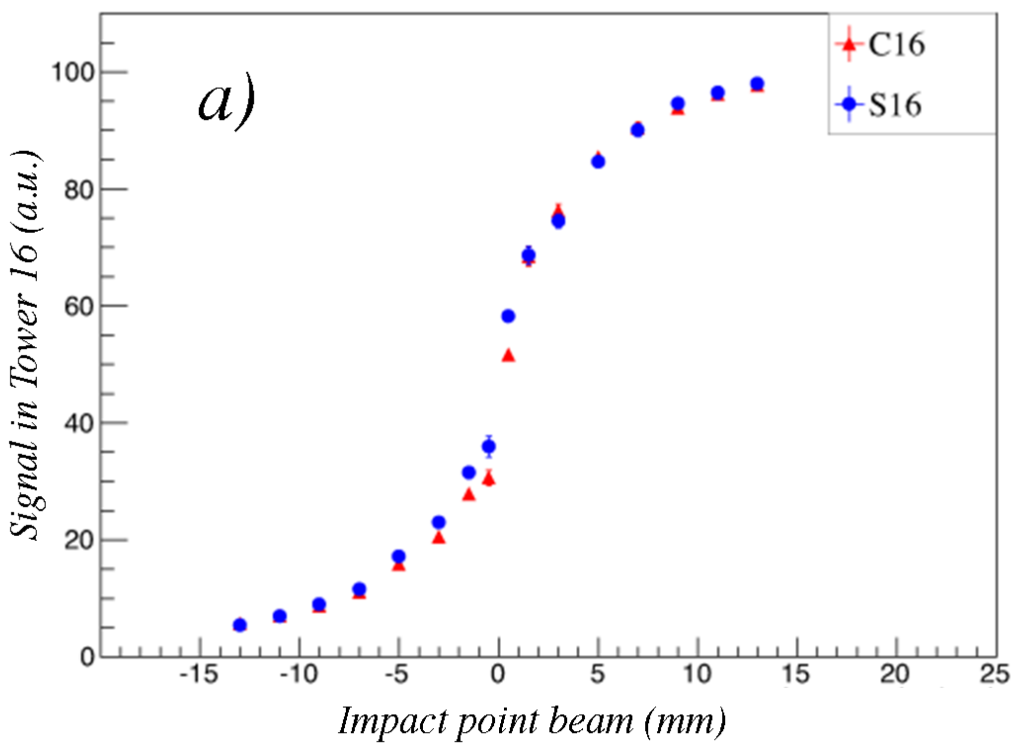


The extremely narrow electromagnetic shower profile

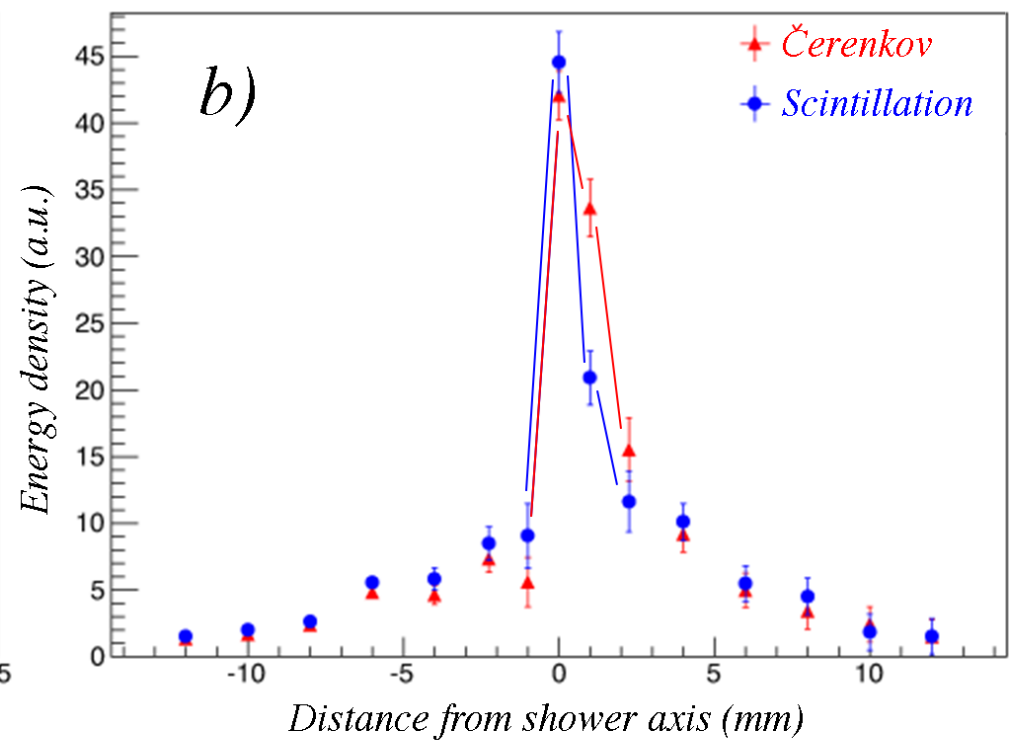
Move small beam spot across tower boundary



Horizontal scan with 1 mm wide beam

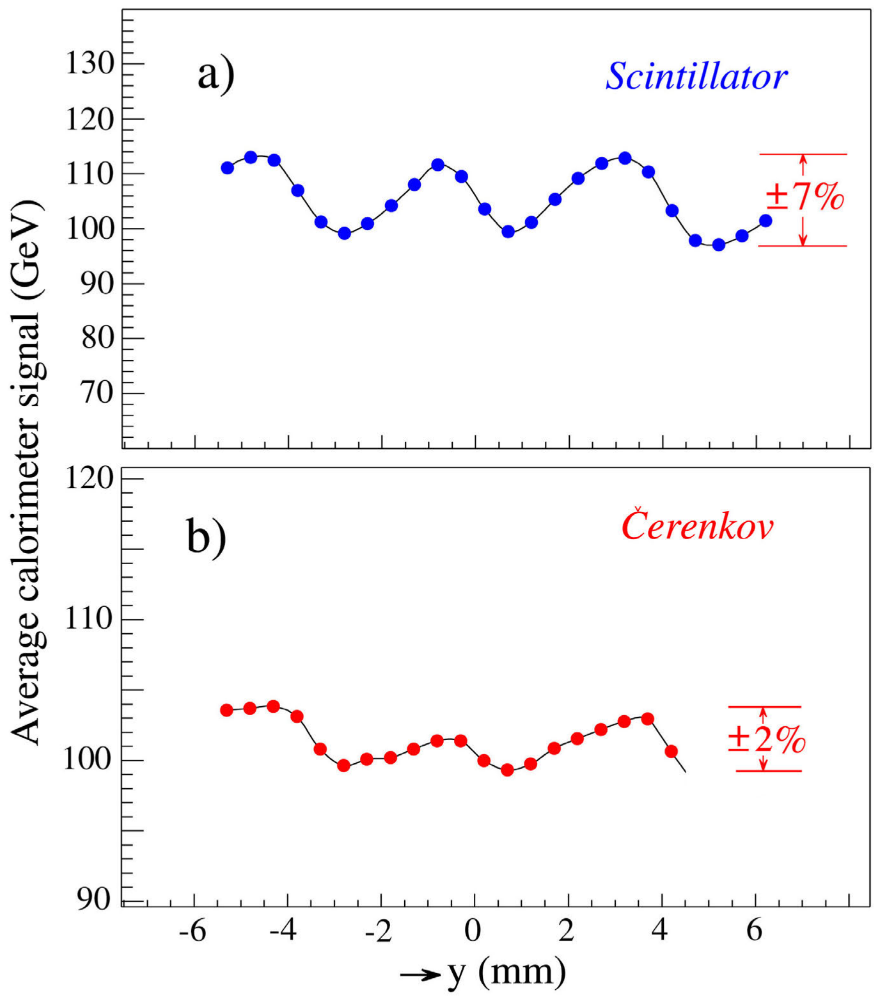


Lateral shower profile

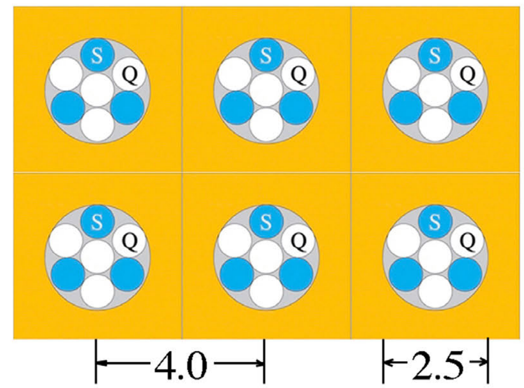


Channeling effects in fiber calorimeters

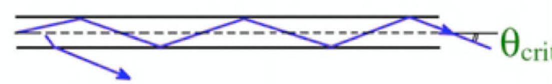
From NIM A536, 29



DREAM

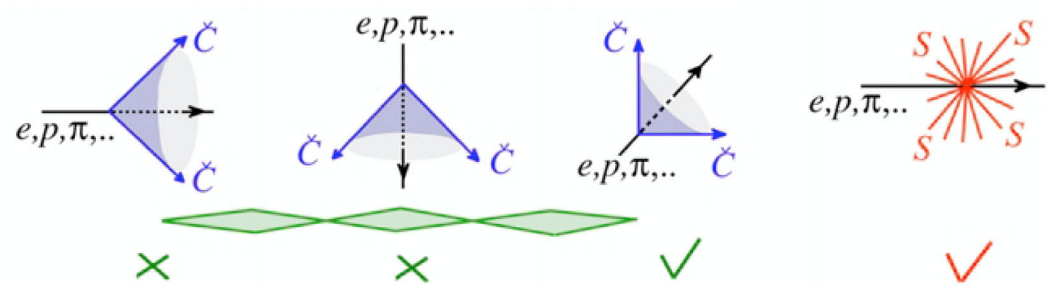


- *Optical fibers* only trap light emitted within the *numerical aperture*



$\theta_{crit} \sim 20^{o}$ for quartz fibers

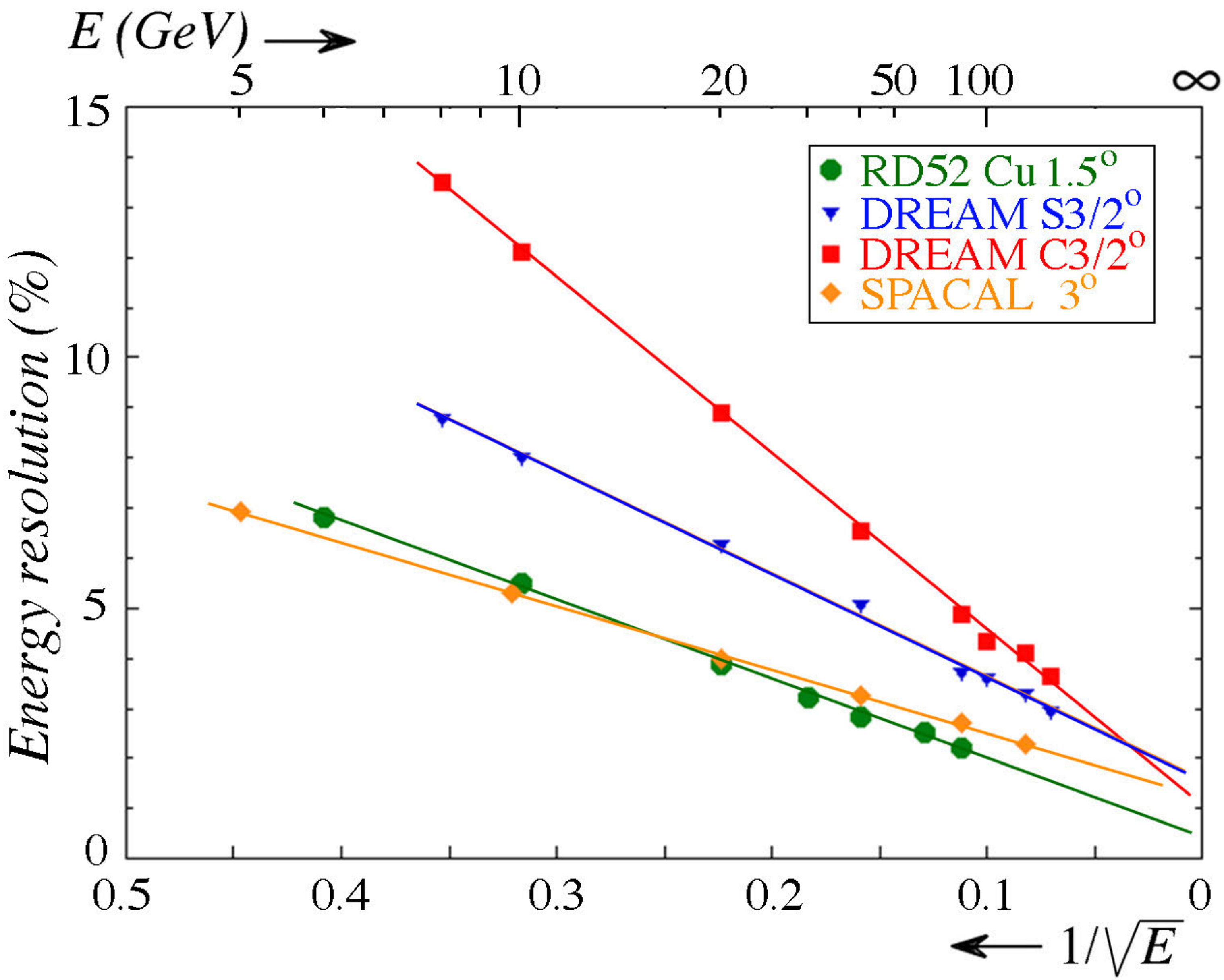
- Comparison of *Čerenkov* light (directional) and *scintillation* light (isotropic) produced in fiber calorimeters



The early, highly collimated em shower component leads to a position dependent response

This component does NOT contribute to the Čerenkov calorimeter signals!

Em resolution RD52 compared to other fiber calorimeters

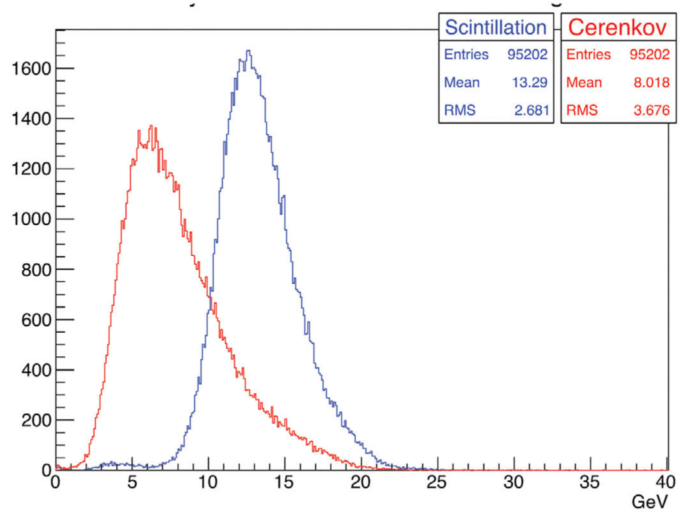


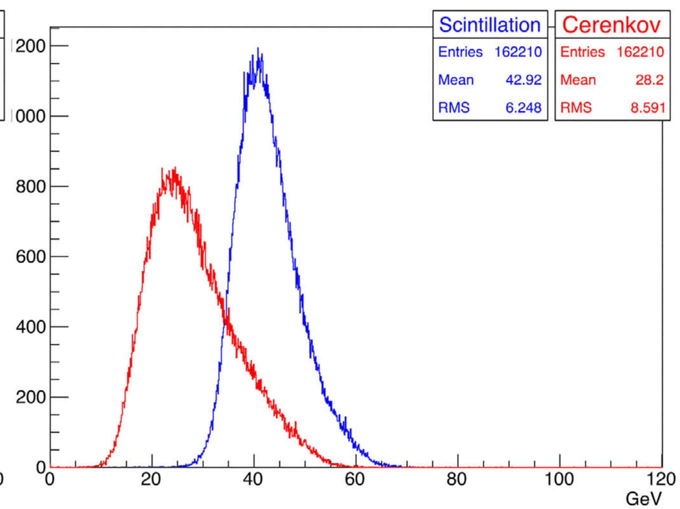
Pion detection in SuperDREAM

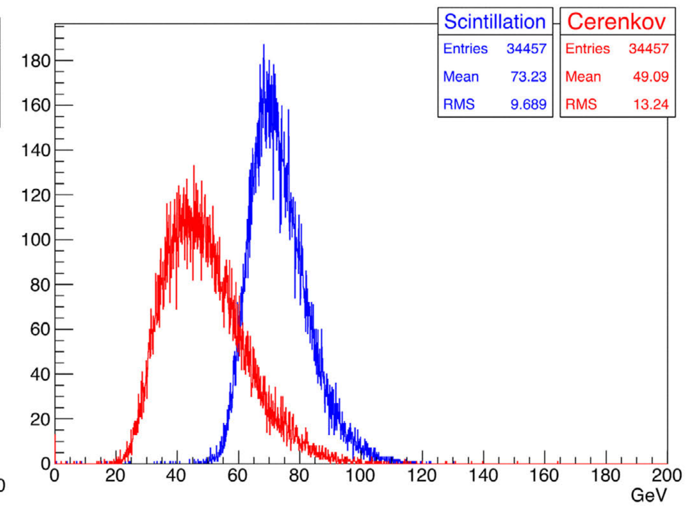
Hadron detection with a dual-readout calorimeter

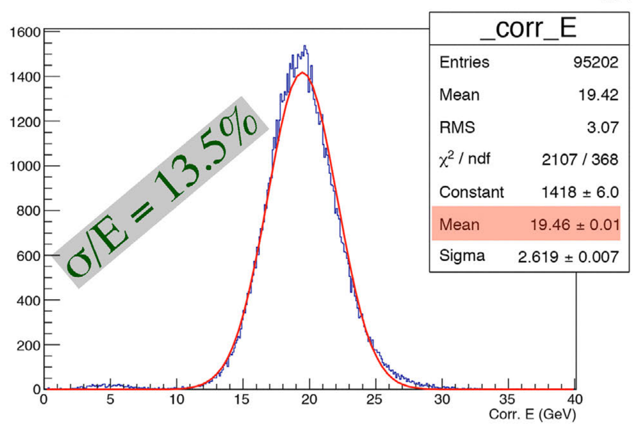
$$E = \frac{S - \chi C}{1 - \chi} \quad \textit{with} \quad \chi = \frac{1 - (h/e)_S}{1 - (h/e)_C} = 0.45$$

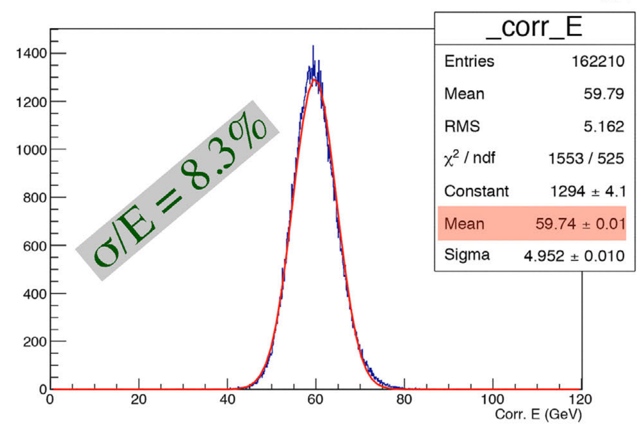
20 GeV π^- | 60 GeV π^- | 100 GeV π^-

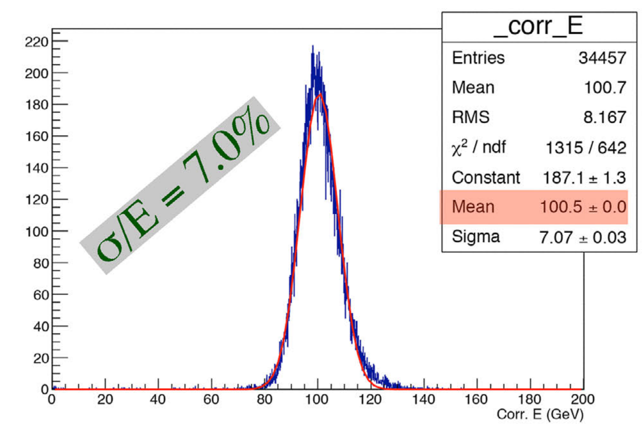






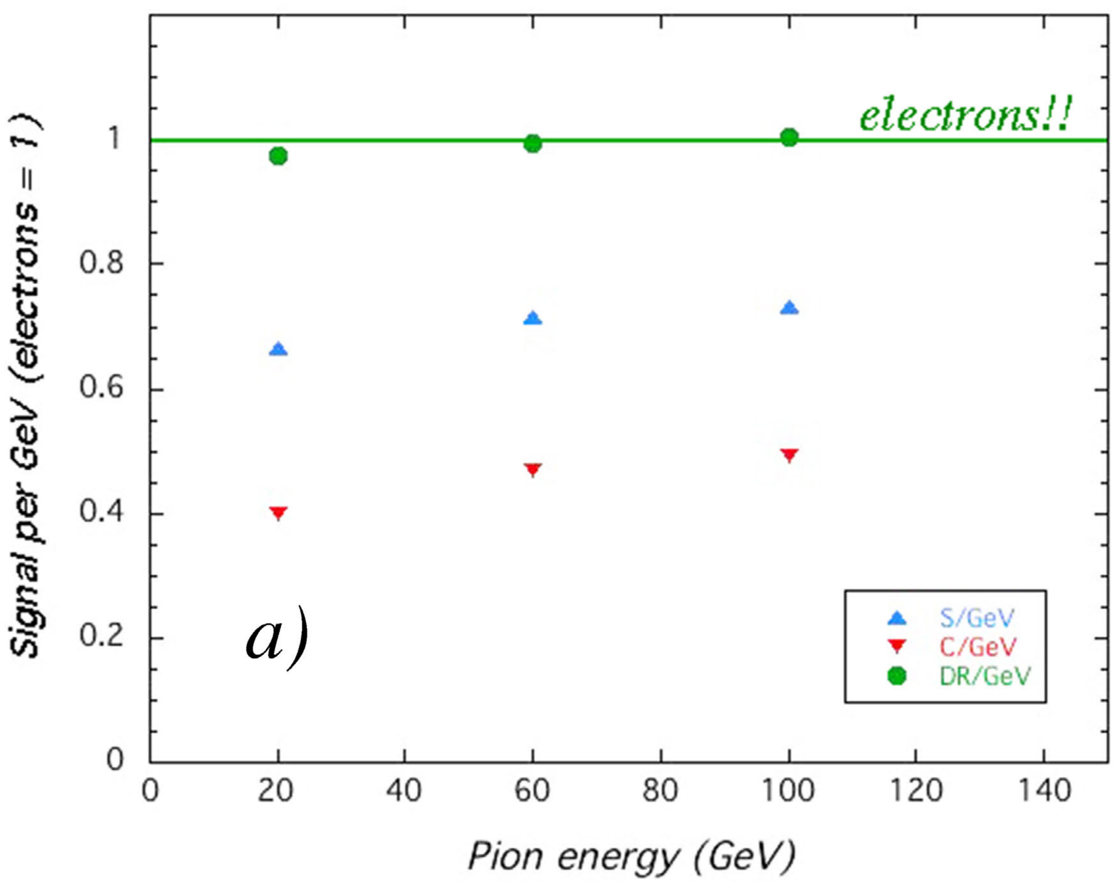


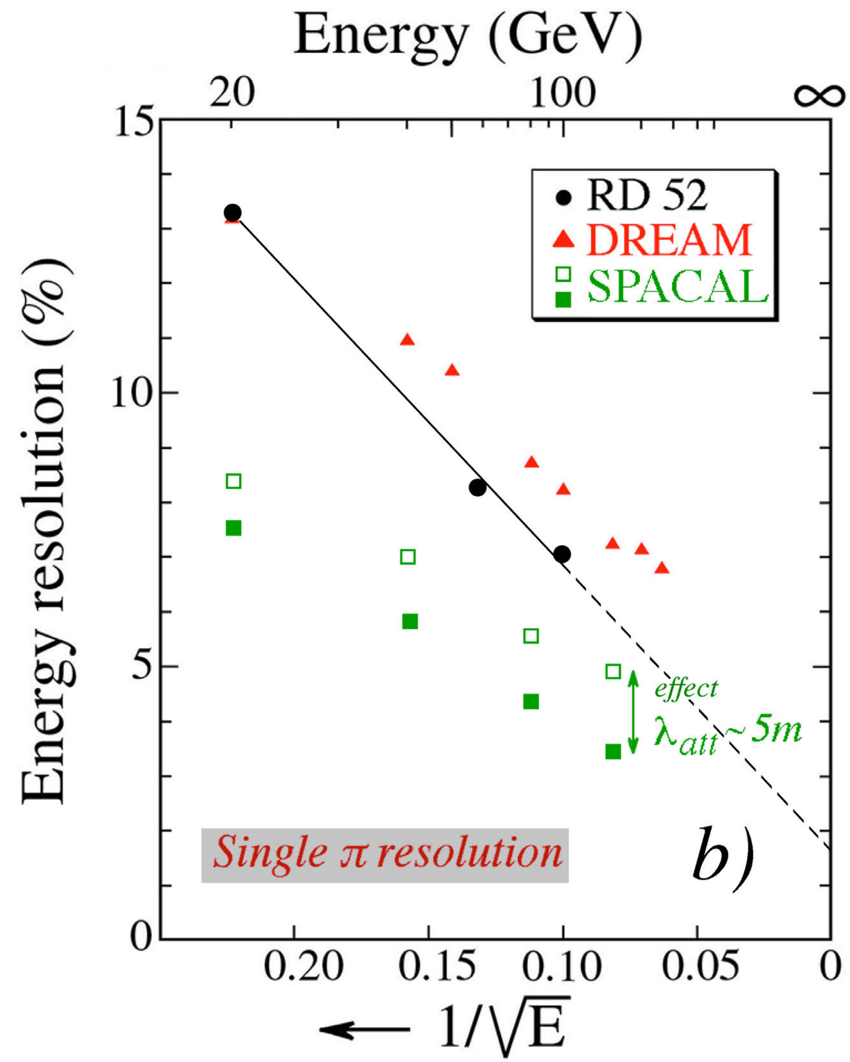




The calorimeter response and energy resolution for single pions

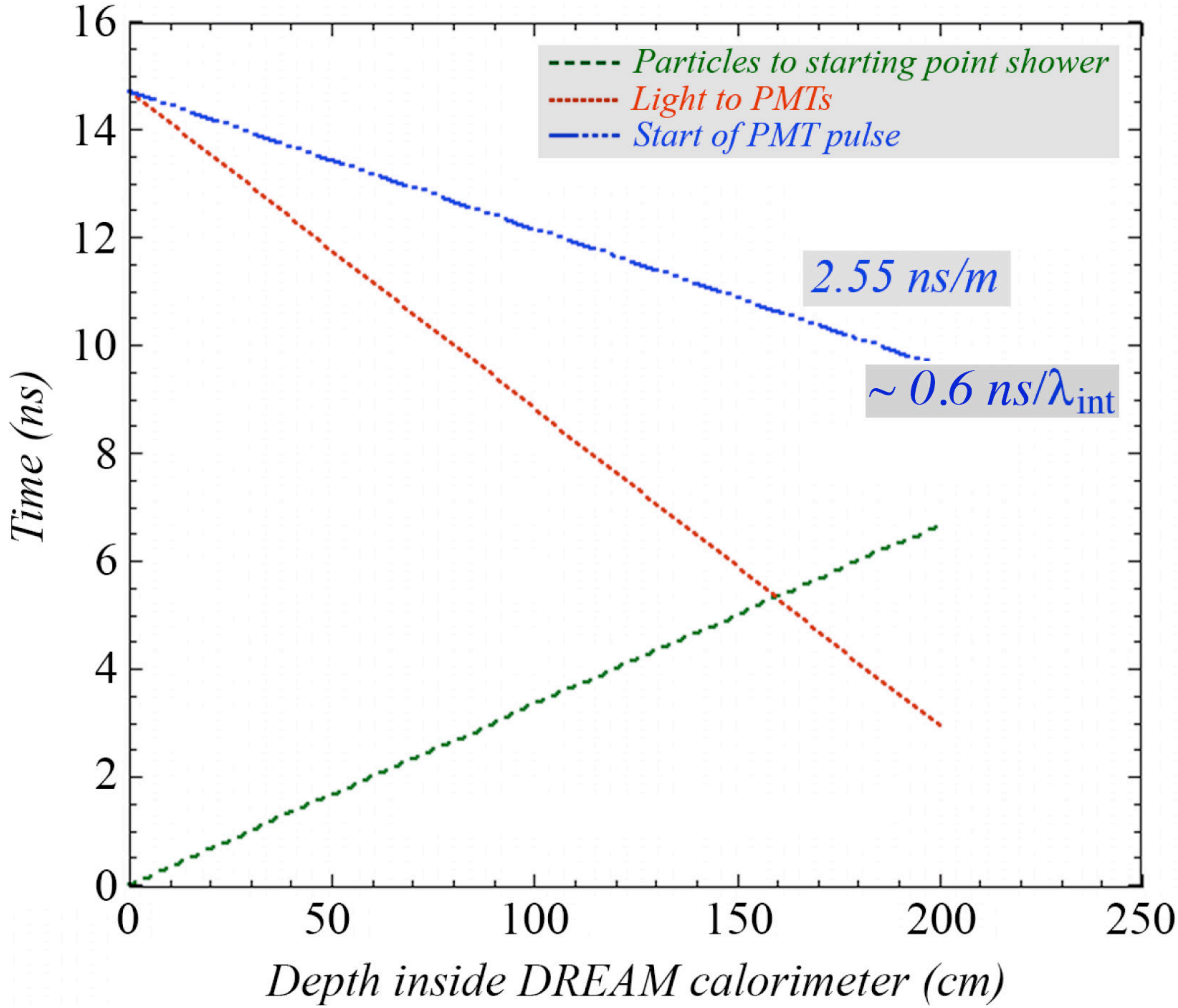
Electron energy scale well reproduced by DR!!



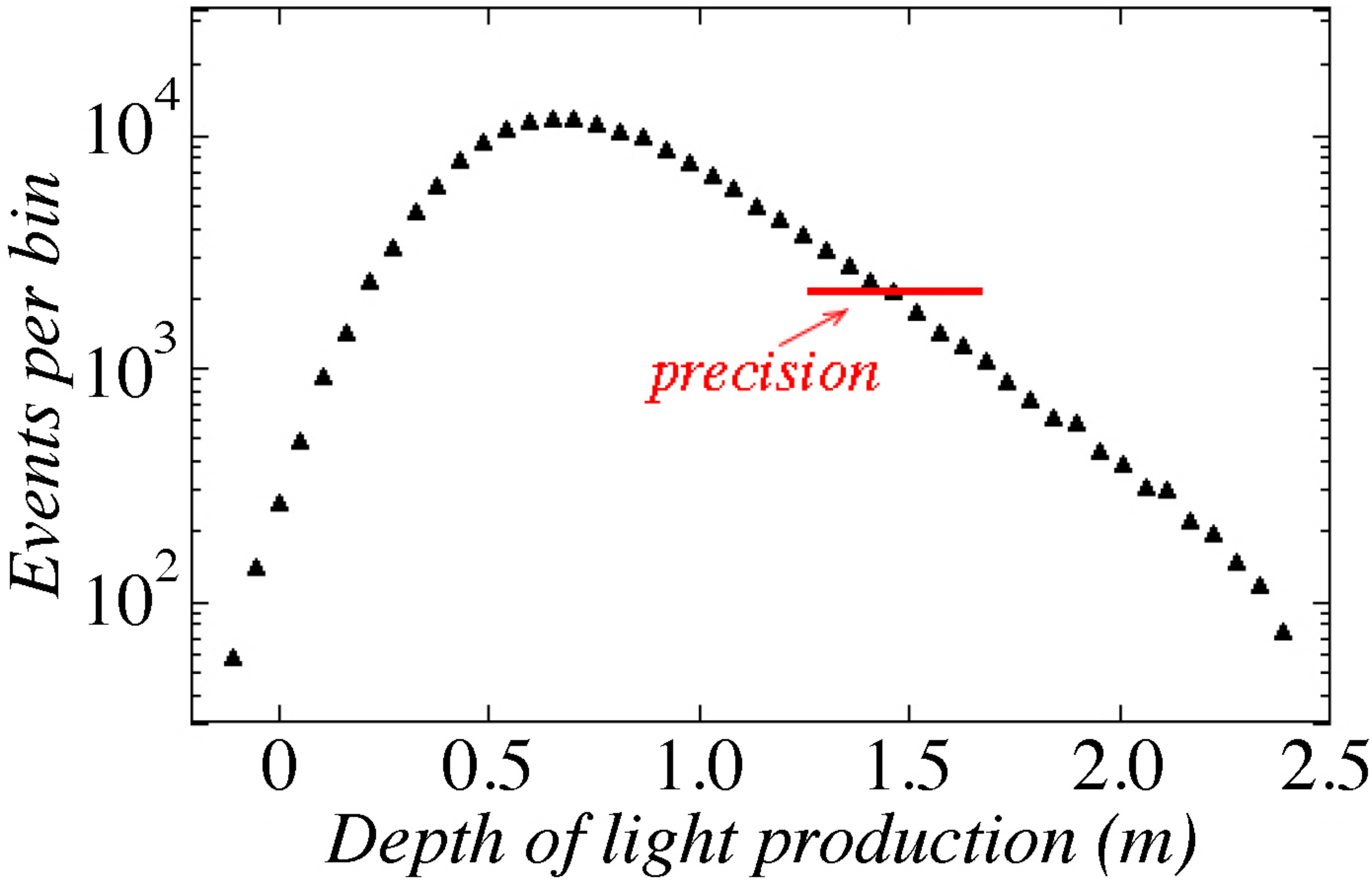


The power of time information

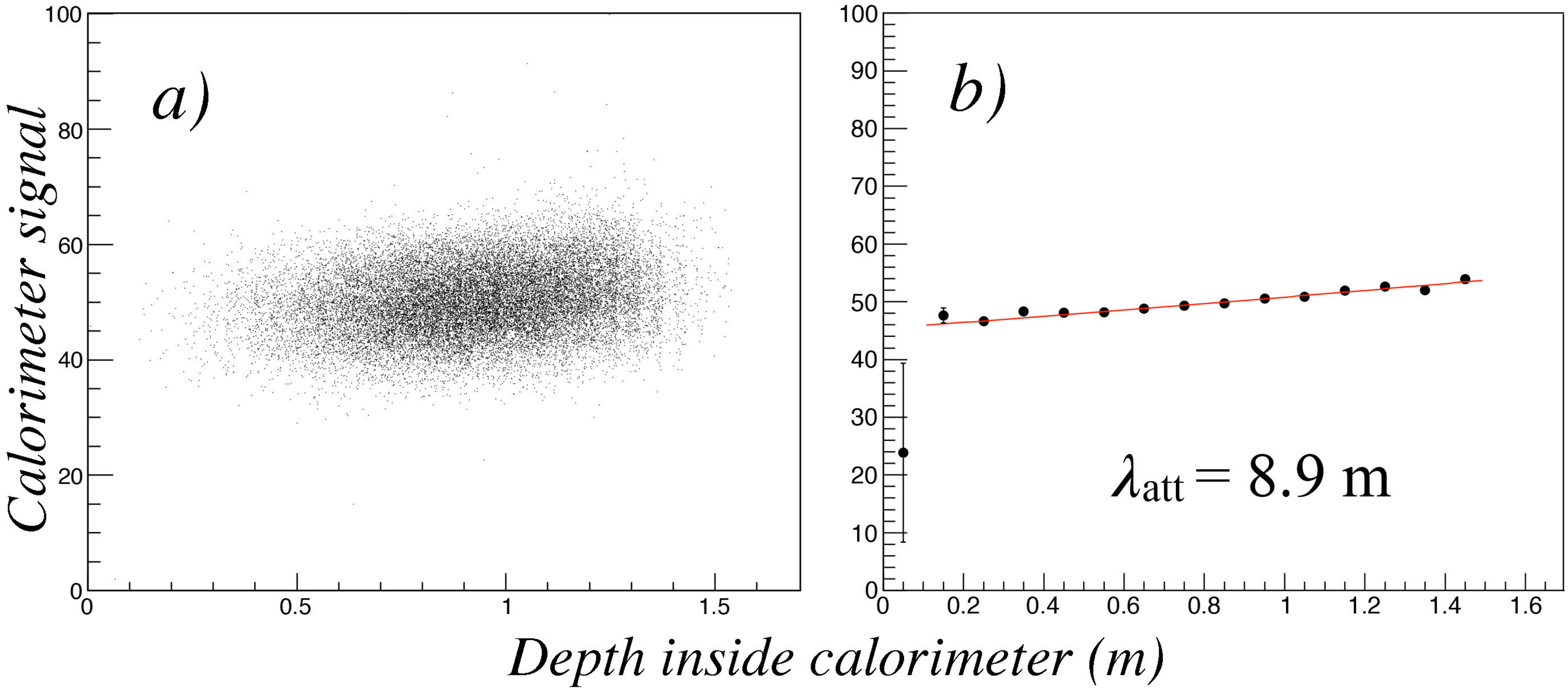
Depth of the light production and the starting point of the PMT signals



Measurement of the depth at which light is produced (longitudinal shower profile) based on the starting time of the calorimeter signals



Measurement of the light attenuation characteristics of the fibers from the starting time of the hadron showers



Future research plans

- *Increase the size of the SuperDREAM calorimeter as much as possible for next SPS tests*

With only 5 additional modules, average leakage will go from 6.4% → 2.5%
DRS readout on leakage counters → distinguish mip from neutron leakage

→ Expect significant improvement in hadronic energy resolution

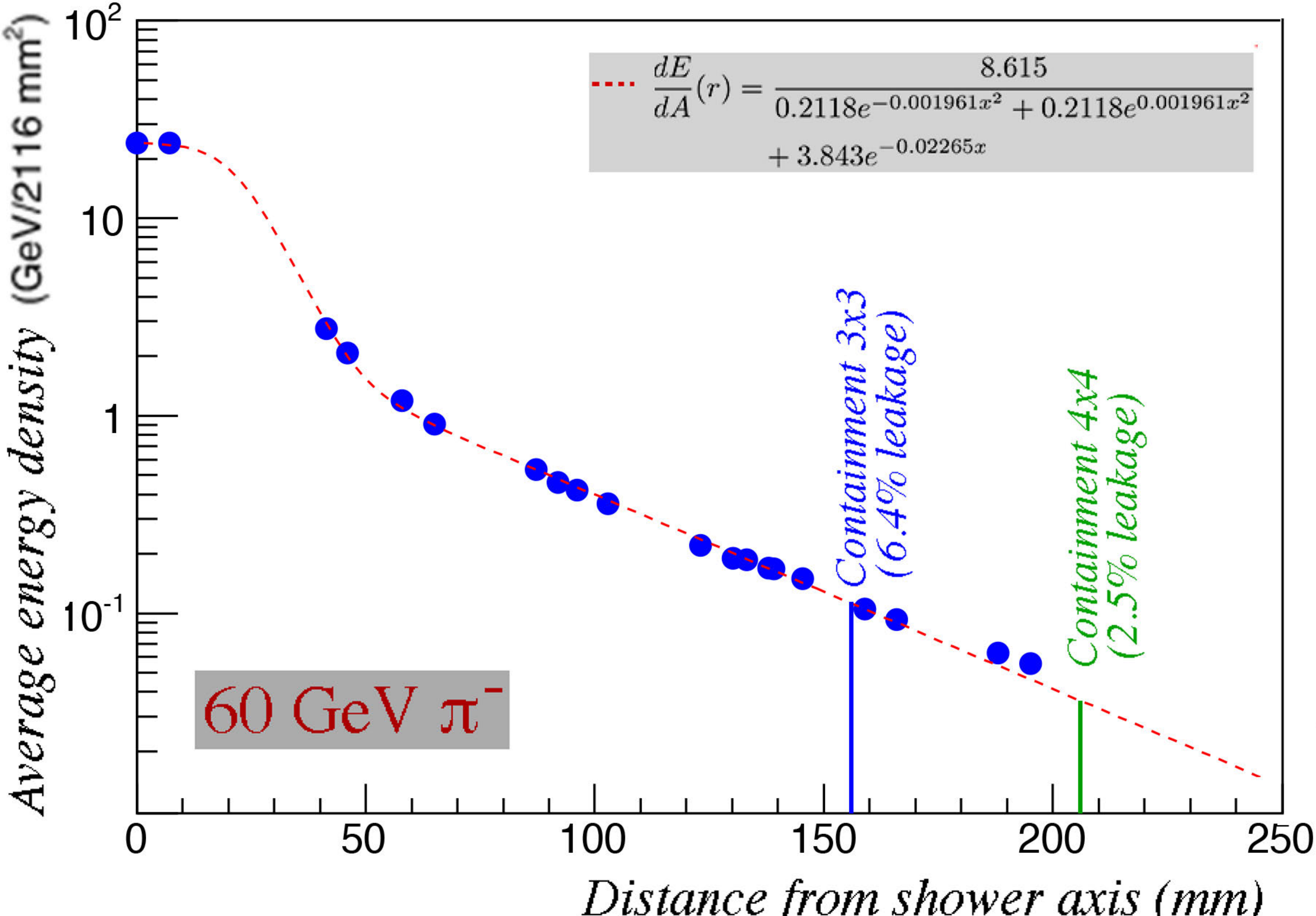
Study issues related to implementing DREAM calorimeters in practice

- *Readout: Get rid of rear fiber forests (SiPM)*

- *Shorter effective interaction length (W?)*

- *Projective geometry*

Radial profile and hadronic shower containment



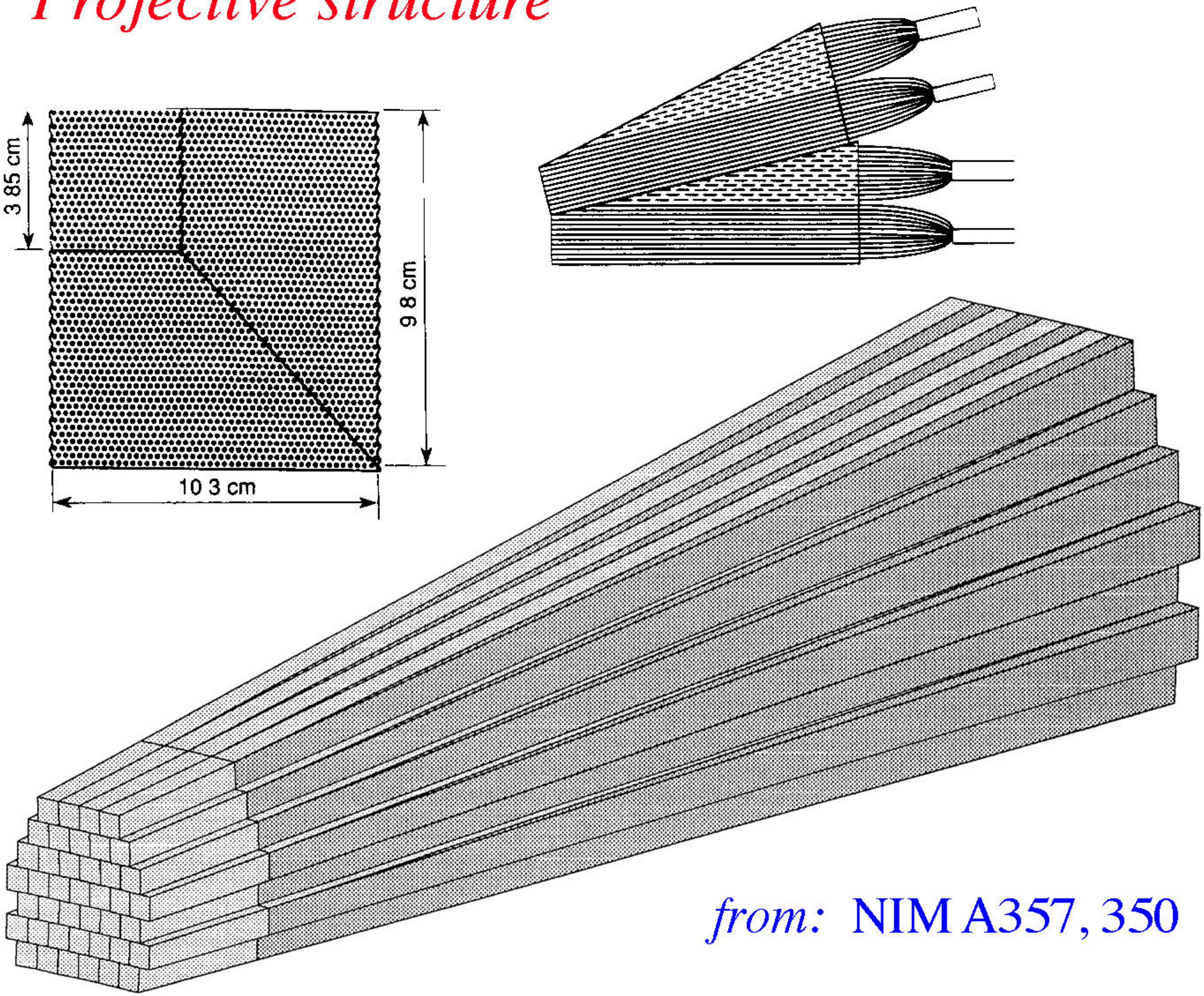
RD52 requests to the SPSC

- > 20 days of H8 beam in 2014
- Very important: Need to be primary user of T4 particles

  → Schedule H6 users that are insensitive to energy/sign of mips when RD52 is running

Backup slides

Projective structure



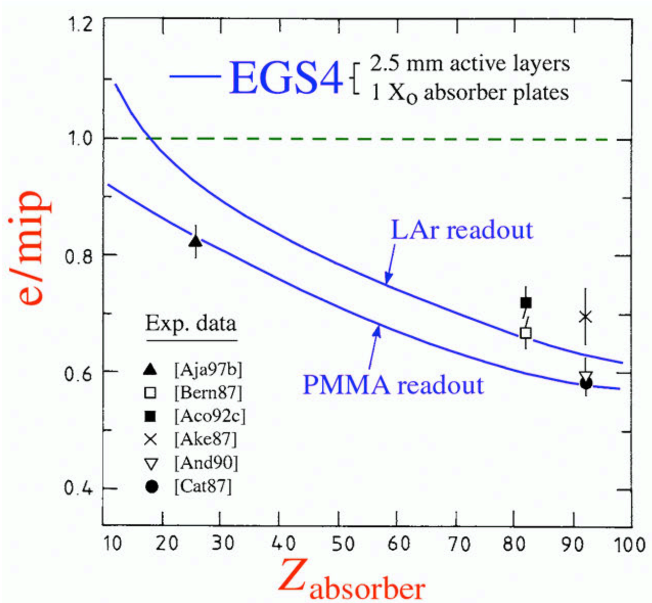
from: NIM A357, 350

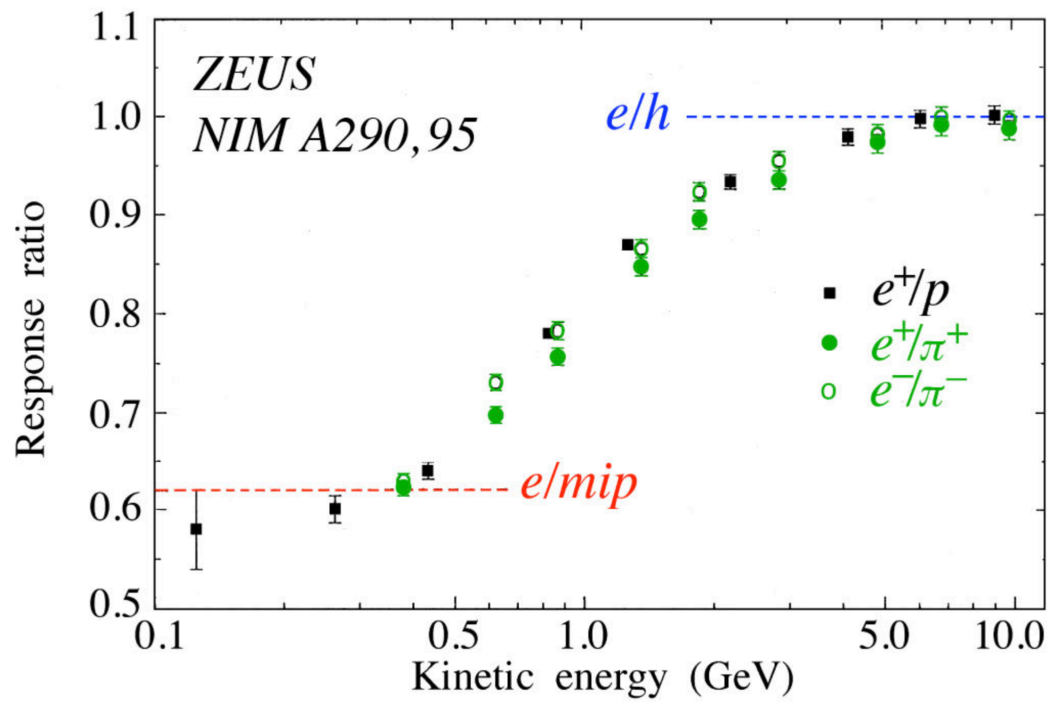
Absorber choice: Cu vs Pb

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

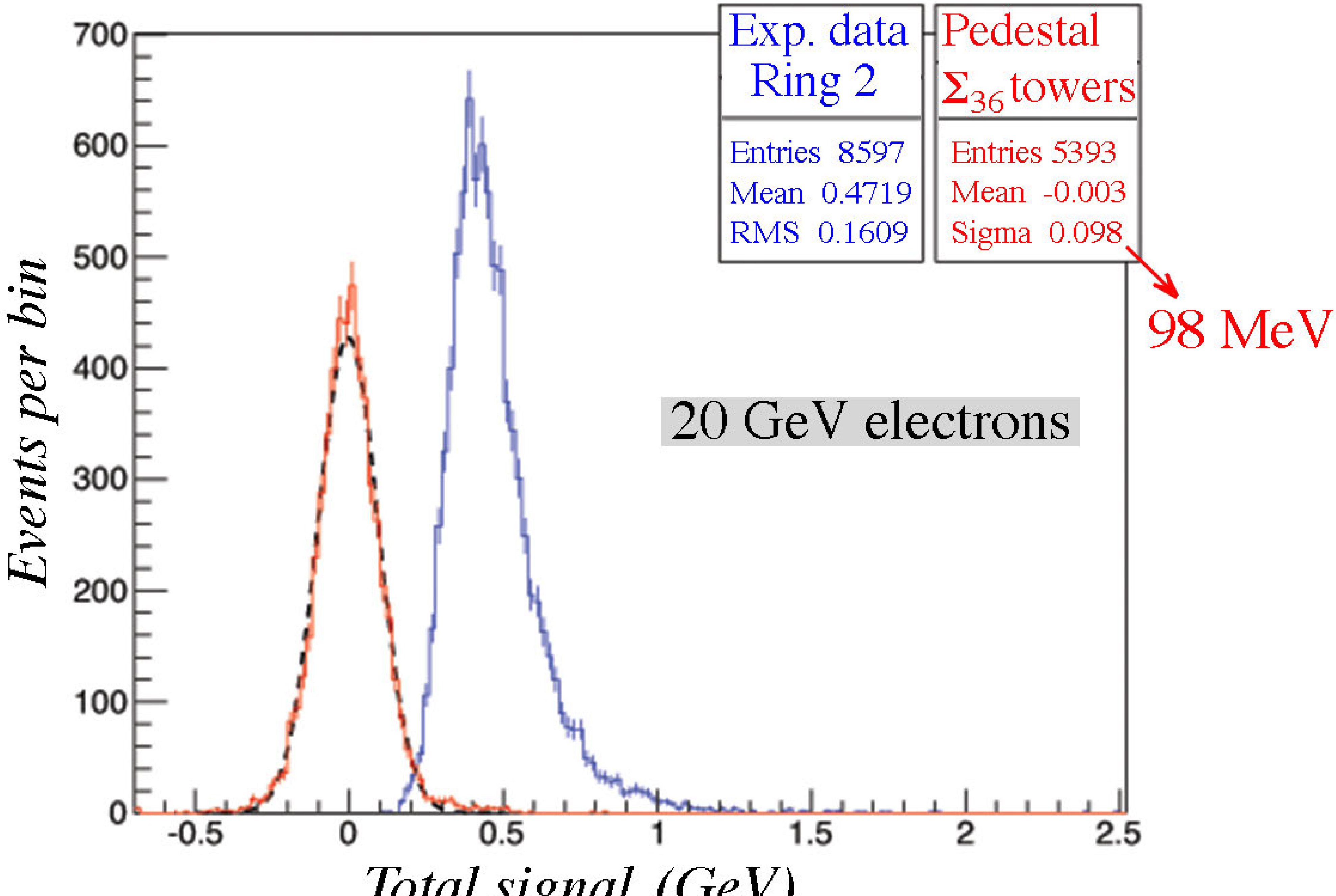
- *e/mip* ⟶ *Čerenkov light yield Cu/Pb ~ 1.4*
  (Showers inefficiently sampled in calorimeters with high-Z absorber)

- *Non-linearity at low energy in calorimeters with high-Z absorber*
  Important for jet detection

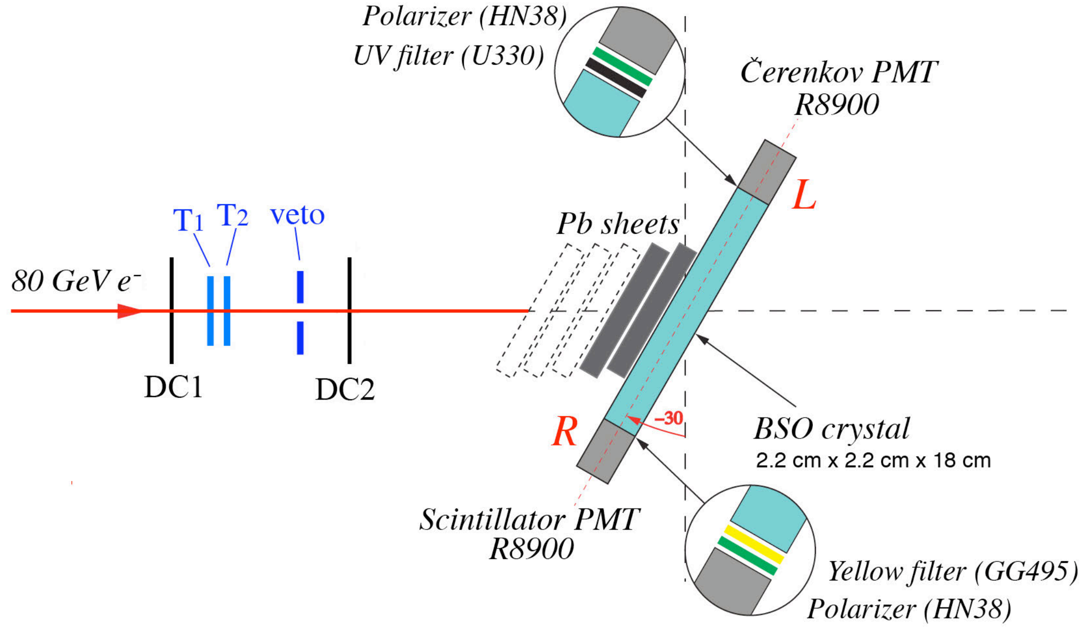


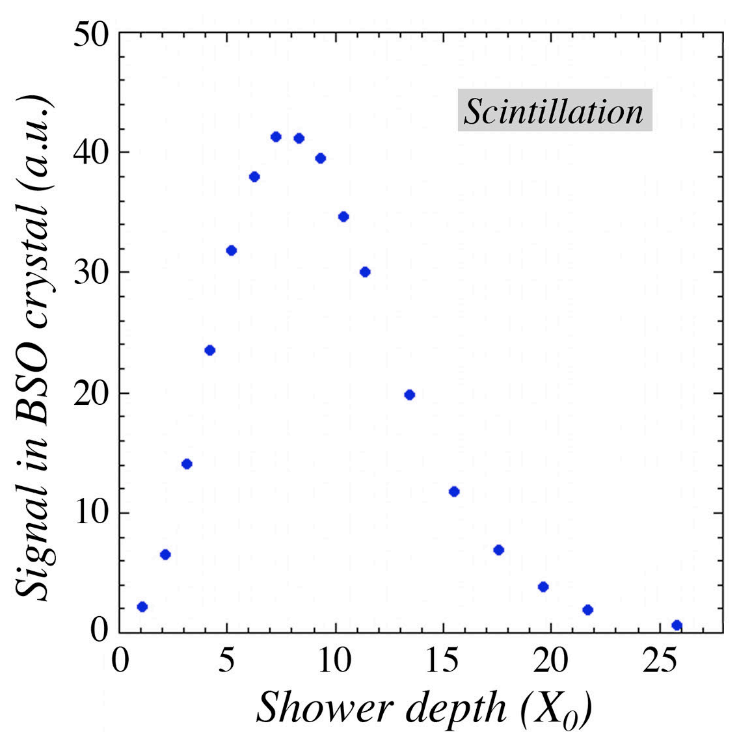


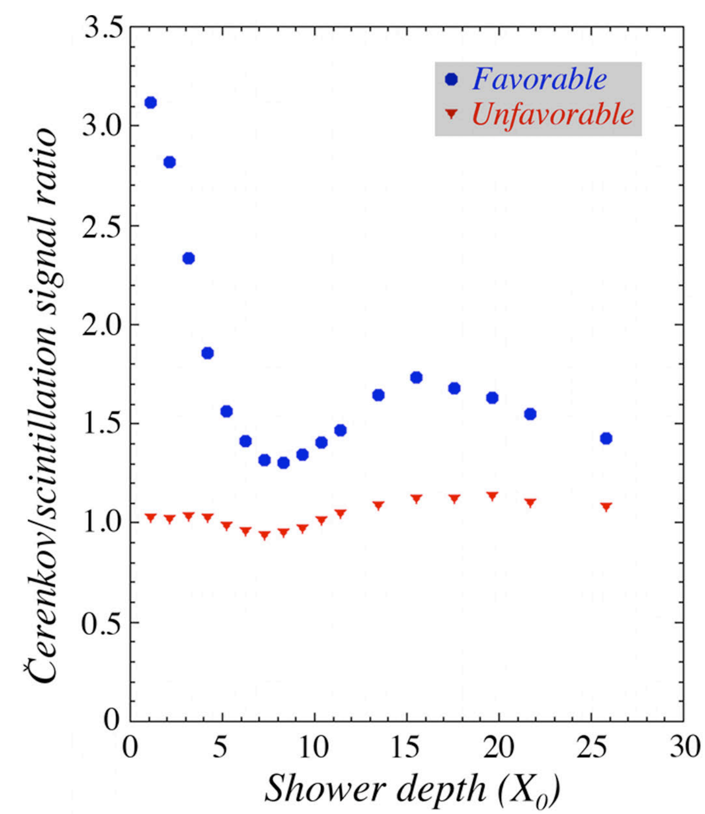
The electronic noise in this calorimeter is very small



Polarization measurements

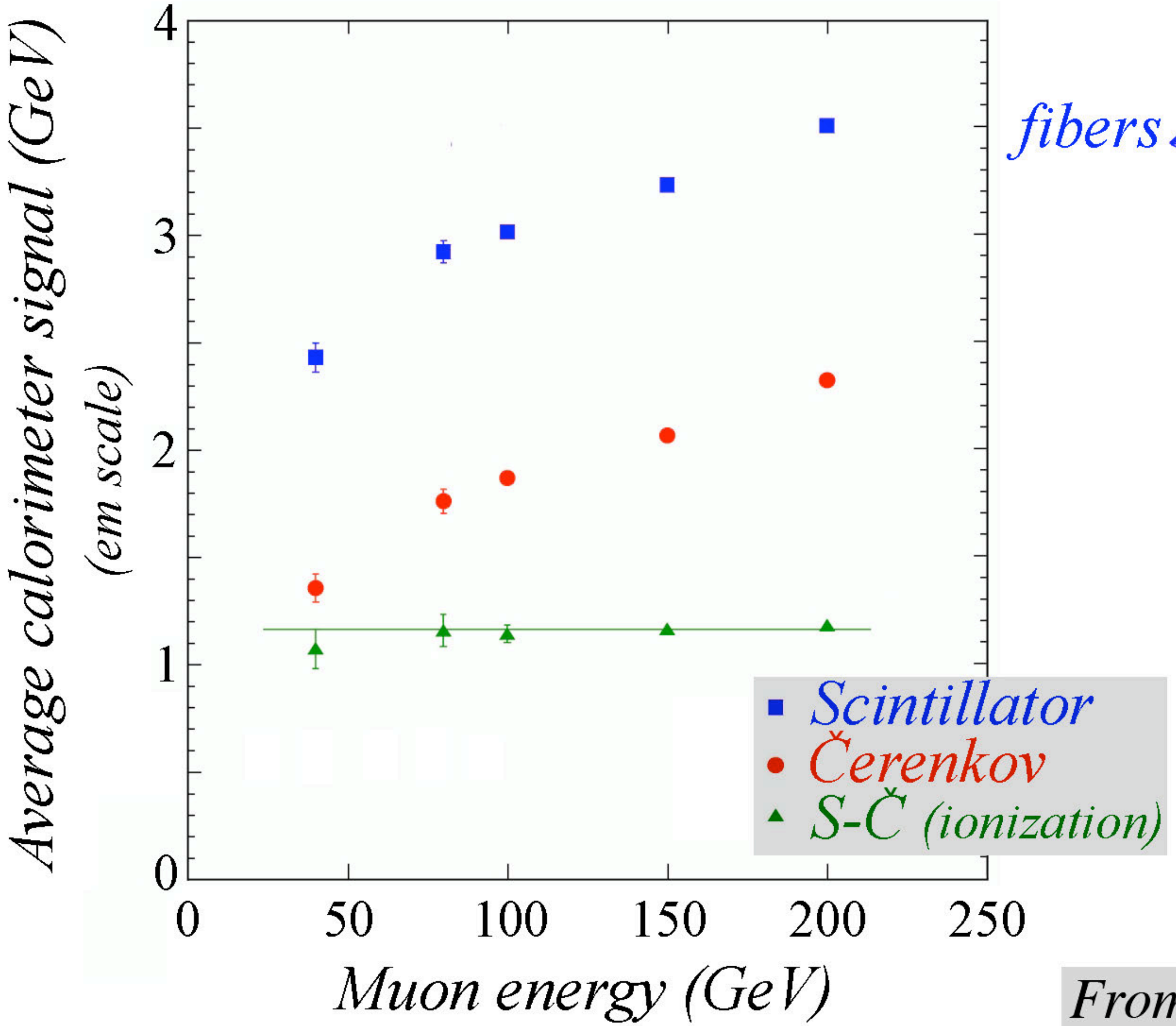


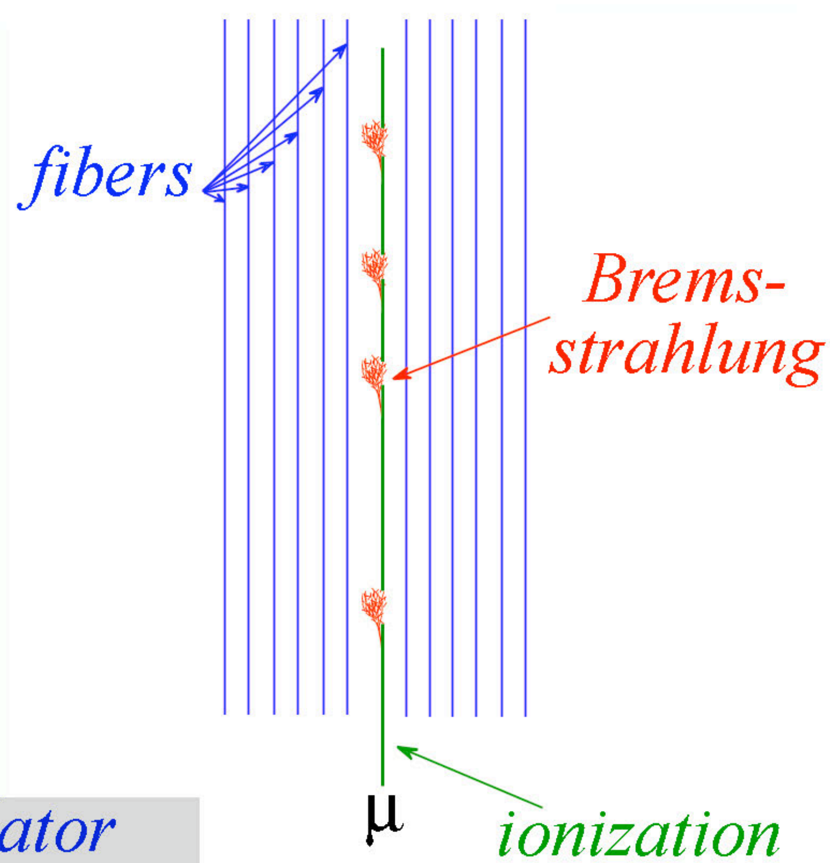




Calorimetric separation of ionization / radiation losses

Muon signals in the DREAM calorimeter

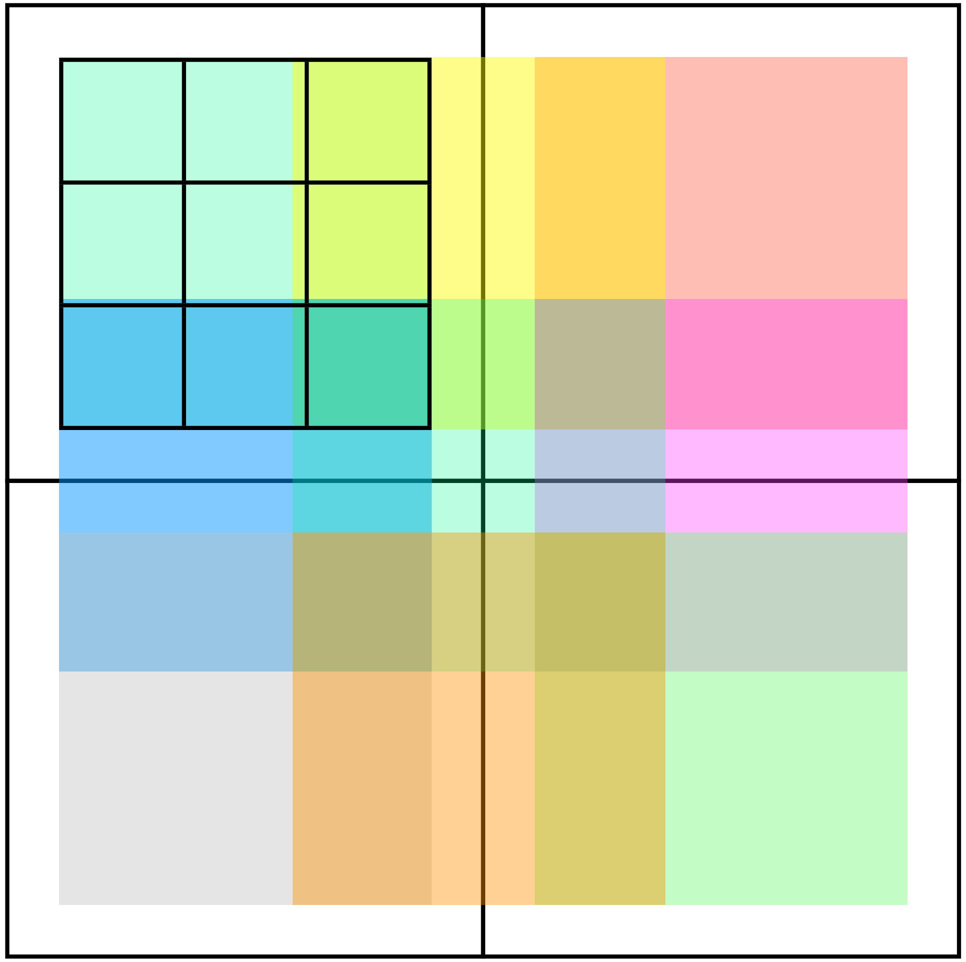




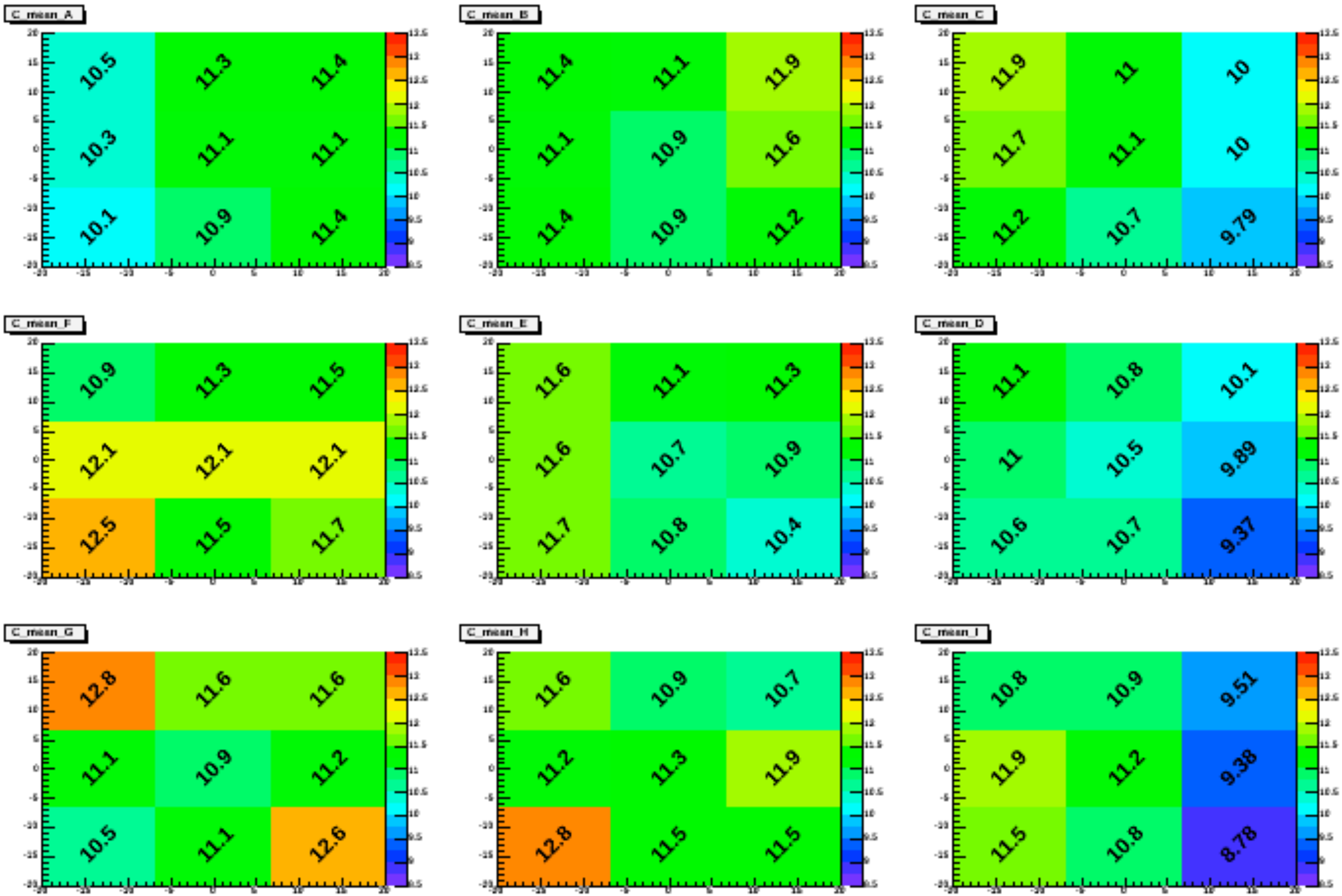
From: NIM A533 (2004)305

Mapping schema

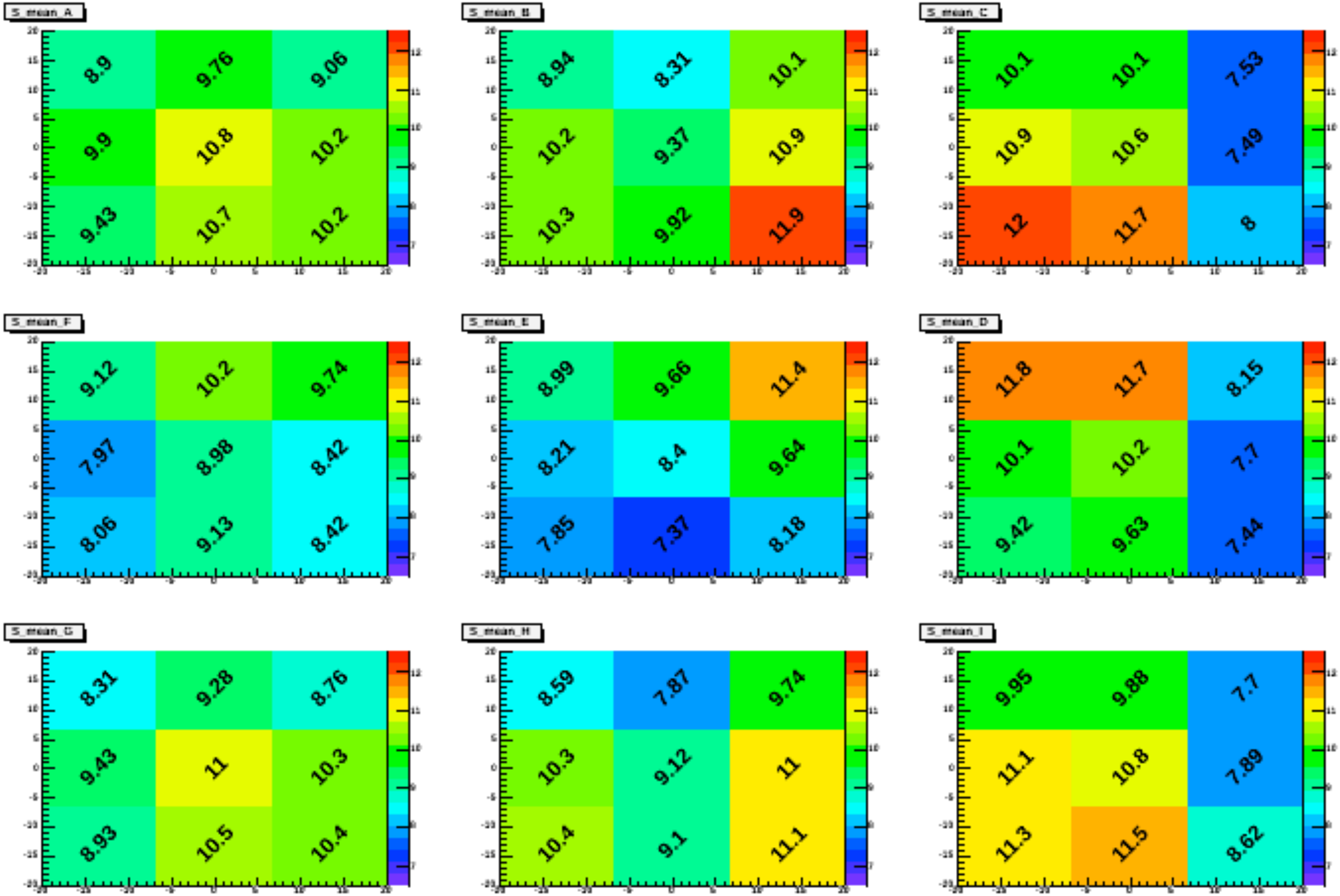
- Because of the dimensions of the beam spot, each map overlap partially with the one nearby
- Problem in reducing the beamspot because too low statistic ⇒ fit fails



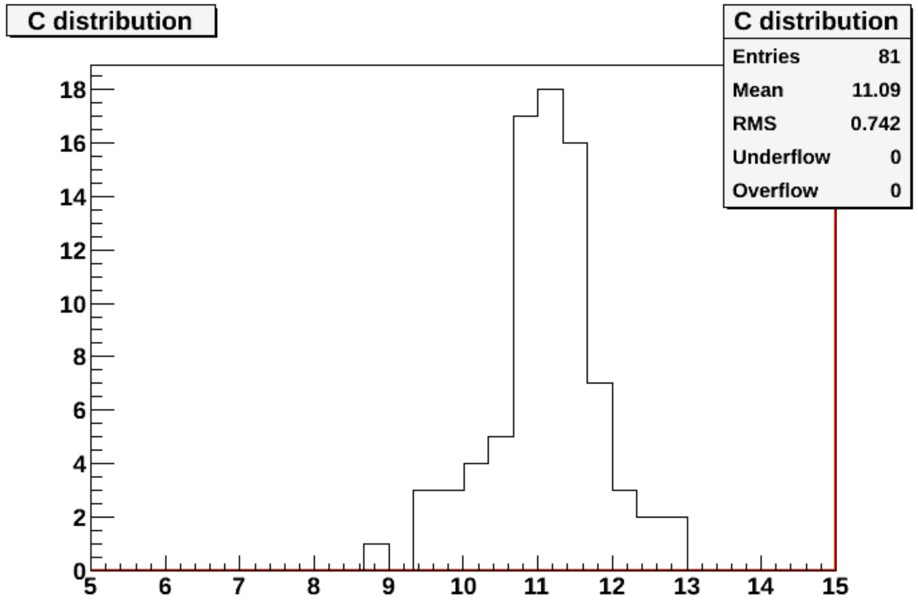
Uniformity Cherenkov

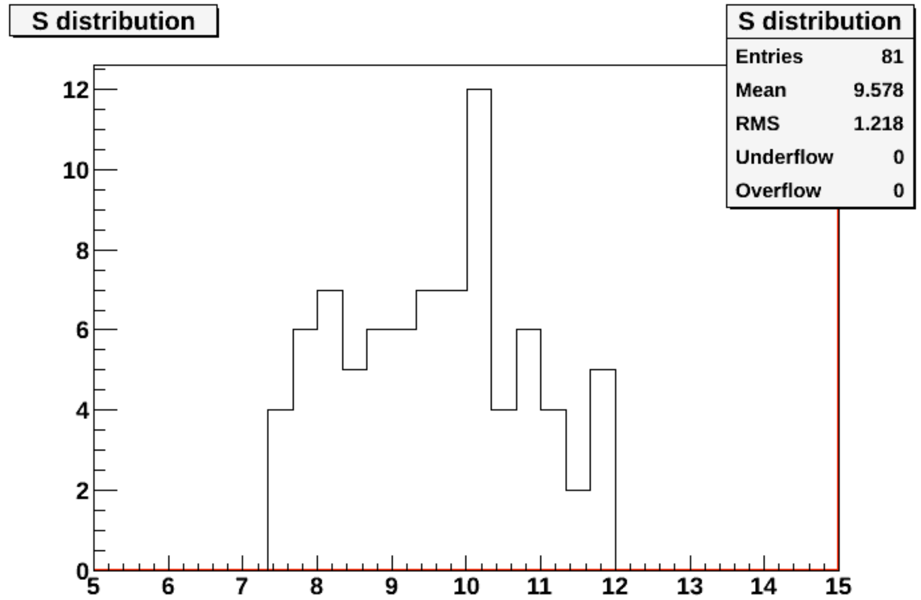


Uniformity Scintillation



Uniformity distributions





$\sigma/\mu = 7\%$

$\sigma/\mu = 13\%$