Dual-Readout Calorimetry
for High-Quality Energy Measurements

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

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CERN, April 3, 2012

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* *DREAM (RD52) Collaboration:*
Cagliari, Cosenza, 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:

- *Activities in 2011*
- *Results of beam tests in 2011*
- *Construction of the new fiber calorimeter*
- *Test beam program 2012*
- *Long term plans*

DUAL-READOUT CALORIMETRY

- *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

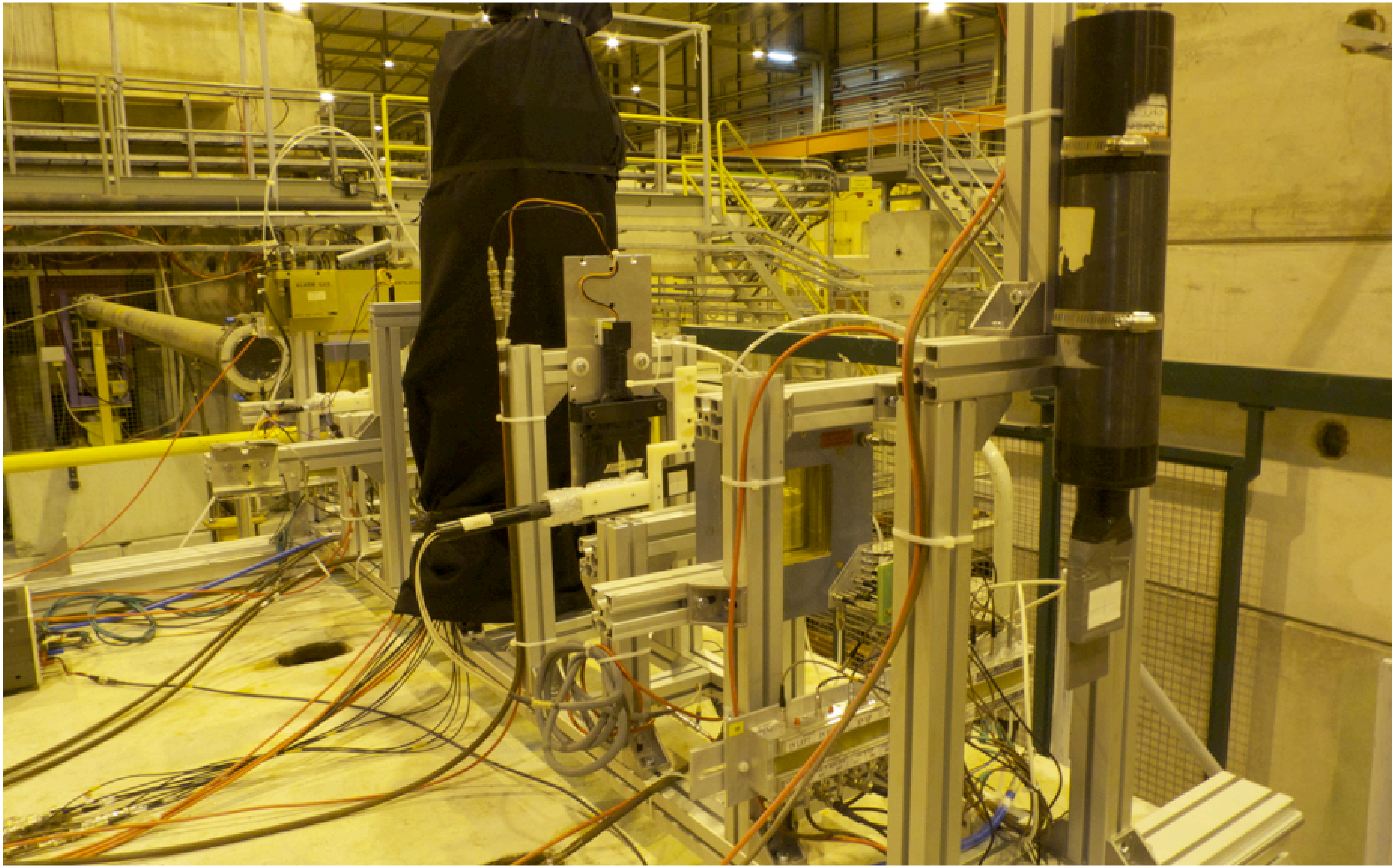
- DREAM offers a powerful technique to *improve* hadronic calorimeter performance:
  - Correct hadronic energy reconstruction, *in an instrument calibrated with electrons!*
  - Linearity for hadrons and jets
  - Gaussian response functions
  - Energy resolution scales with $1/\sqrt{E}$
  - $\sigma/E < 5\%$ 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)

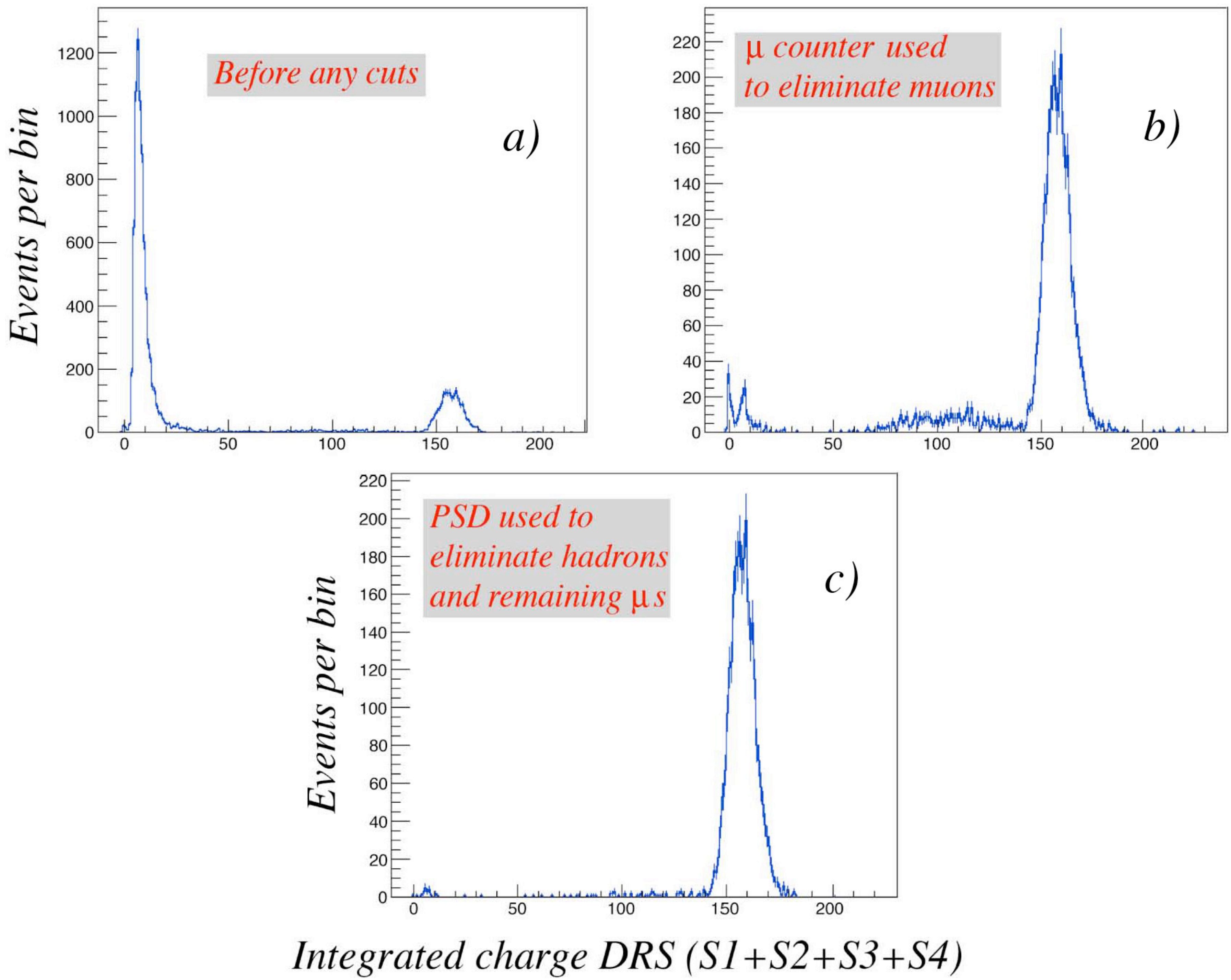
- *RD52 goals:*
  Reduce the factors that limit the resolution of DR calorimeters as much as possible
  1) Shower leakage effects,
  2) Čerenkov light yield,
  3) Sampling fluctuations
  → *Construct new, 5-ton fiber calorimeter + study crystal options (BGO, $PbWO_4$, BSO)*

H8 Infrastructure improvement

Moveable beam definition/trigger system for RD52



Cleaning up e^- event samples with auxiliary detector info



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

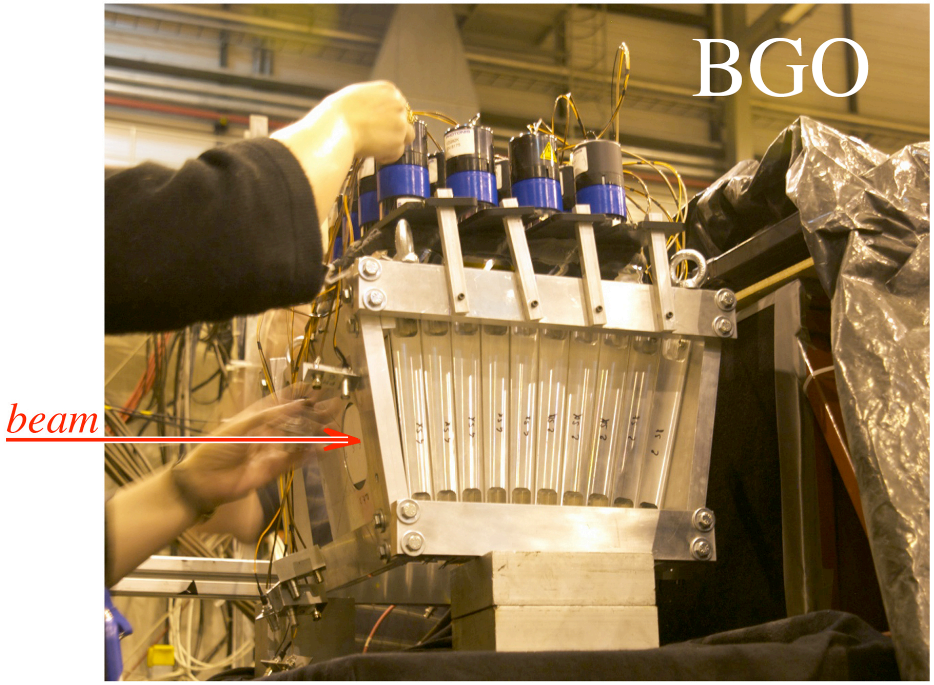
- *Minimization of contributions of fluctuations in visible energy*
  Efficient detection of "nuclear" shower component
  (e.g., energy resolution ZEUS much better than D0)

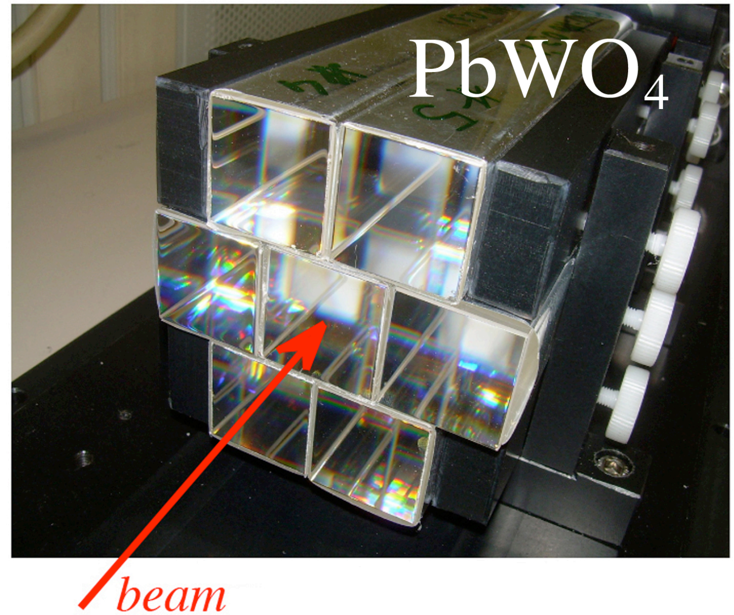
- *Limit contribution of stochastic fluctuations*
  These are THE limiting factor for em energy resolution

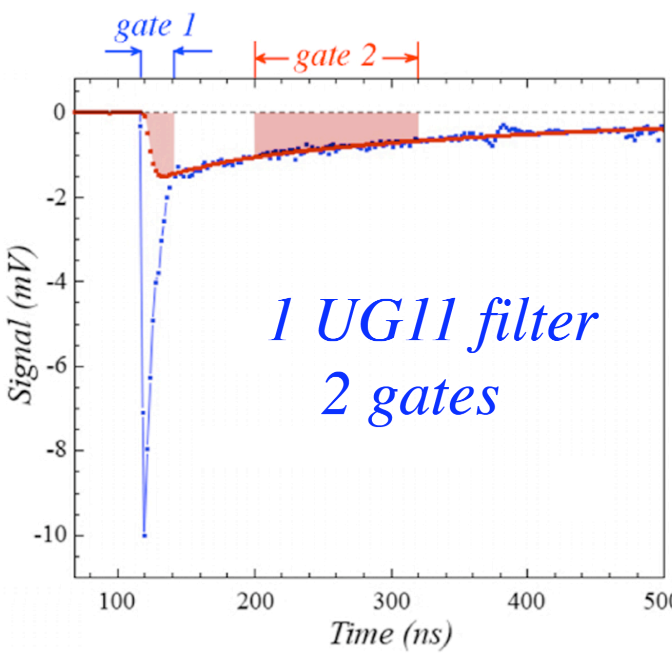
Measurements with crystals

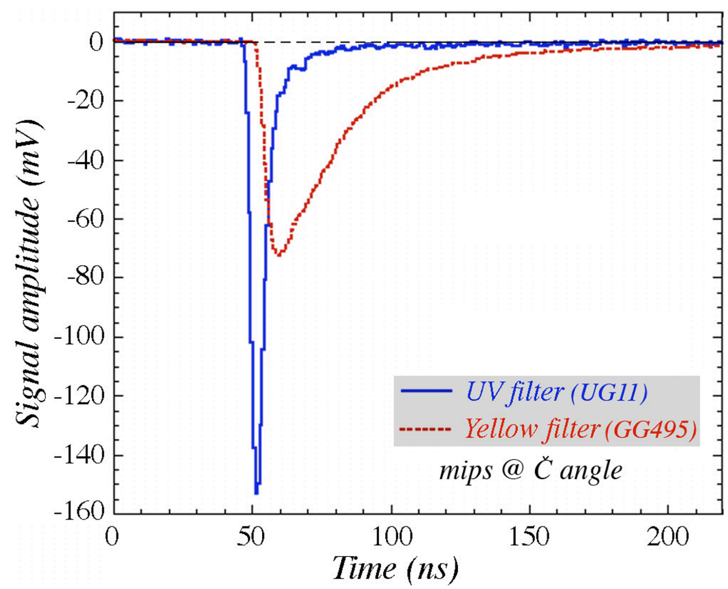
Tests of Dual-Readout crystal matrices with electron beams

Selection of Čerenkov, Scintillation signals



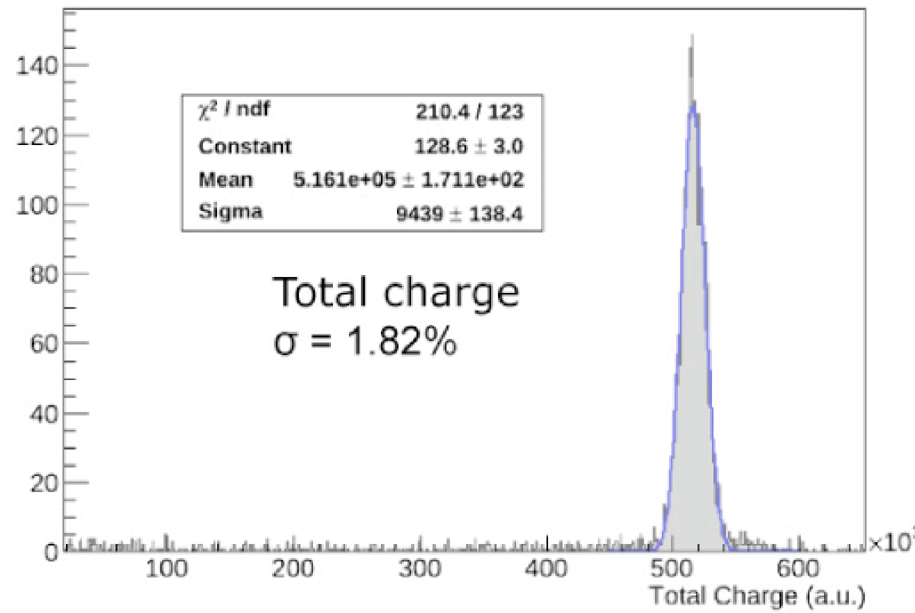


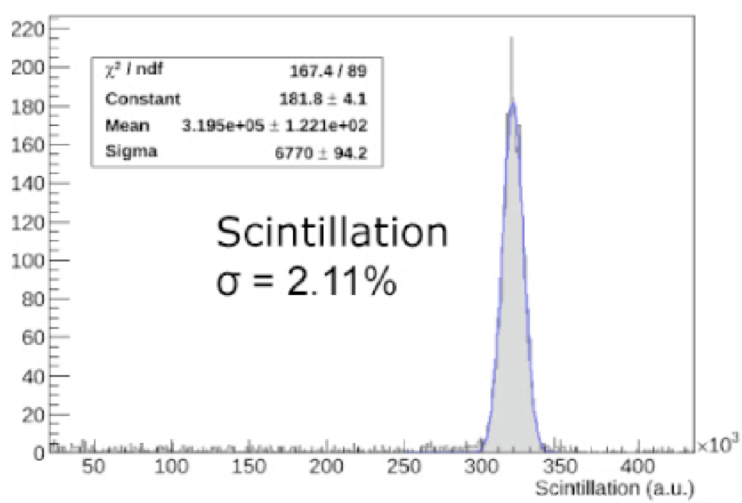


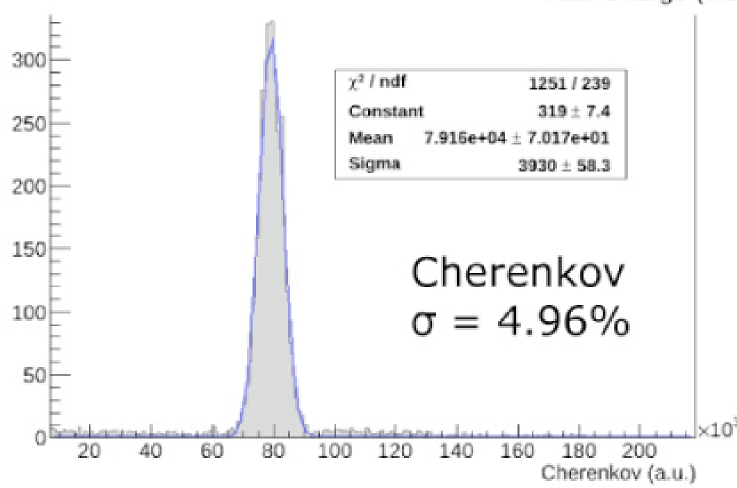


Dual-Readout BGO calorimeter: Resolution for 100 GeV electrons

Signals decomposed into Scintillating and Čerenkov components on the basis of their time structure



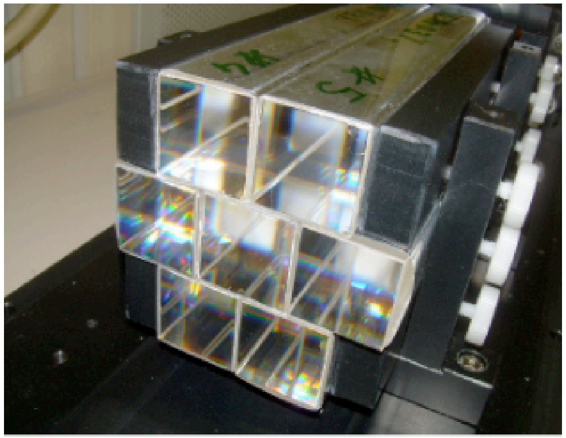




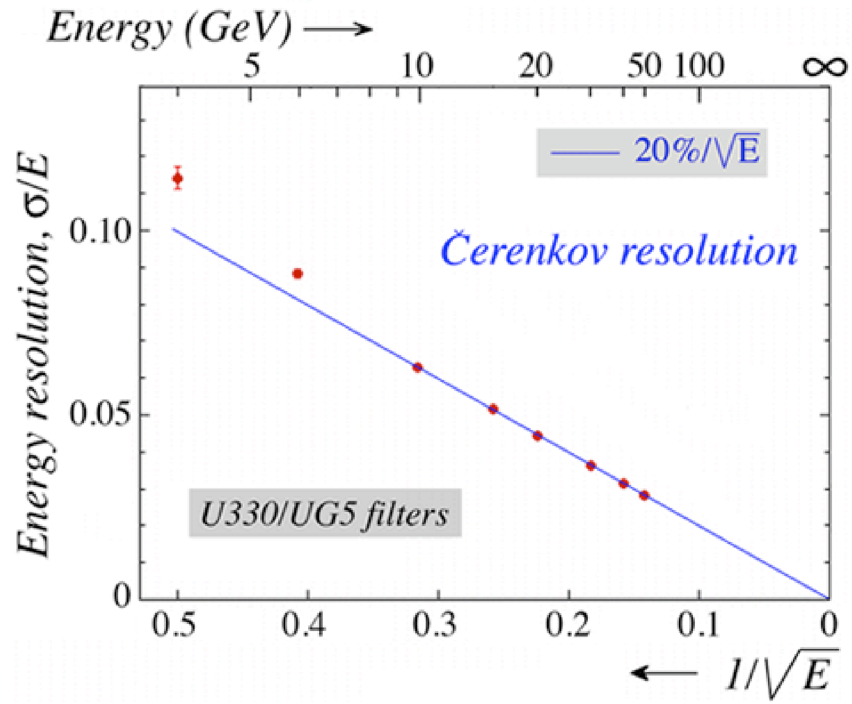
D. Pinci, IEEE, Valencia 2011

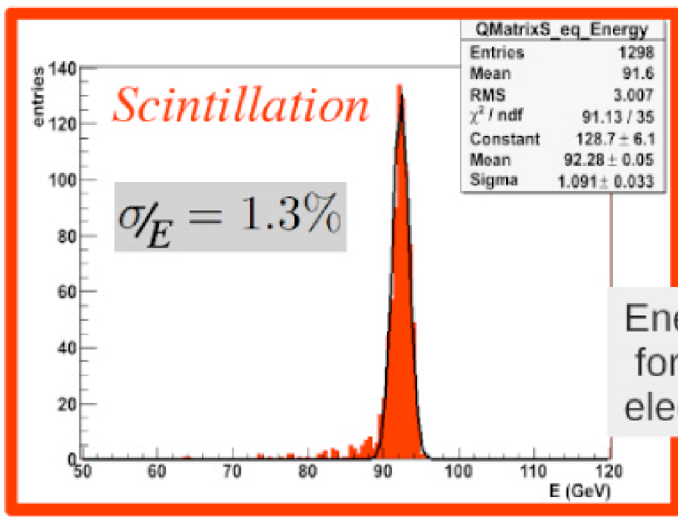
Dual-readout crystal calorimetry

S/C signal separation with filters

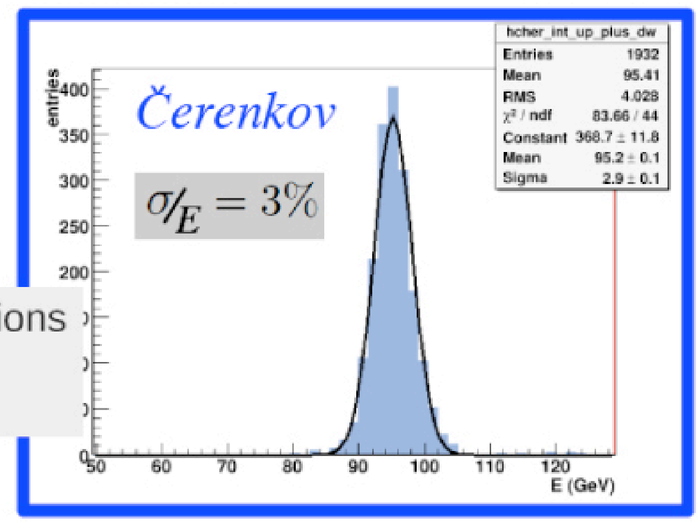


Mo-doped $PbWO_4$ crystal matrix
7 crystals, 3 x 3 x 20 cm^3



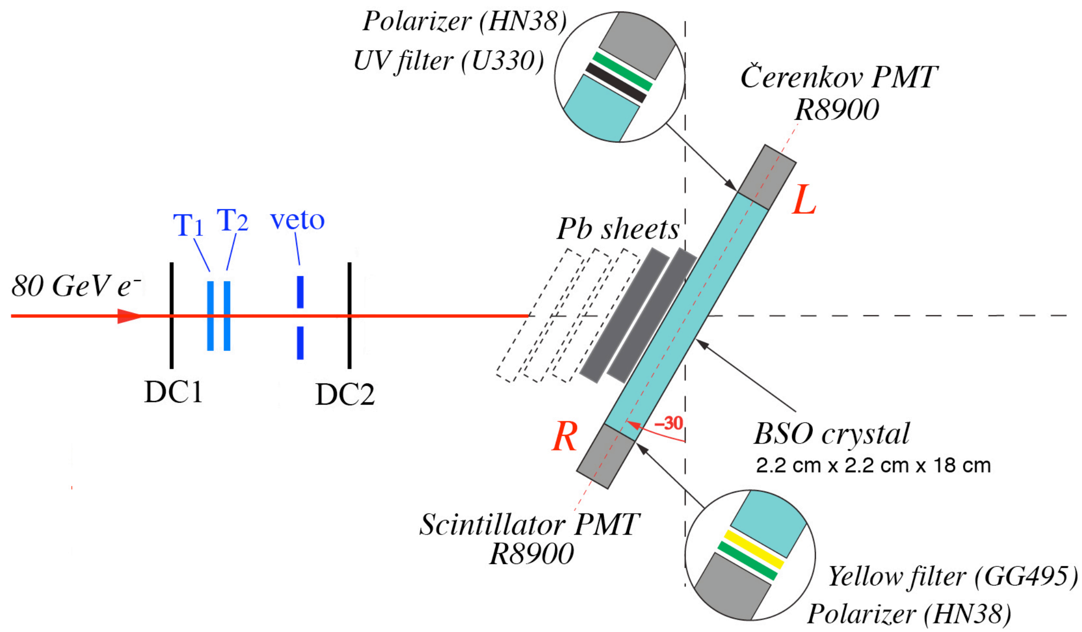


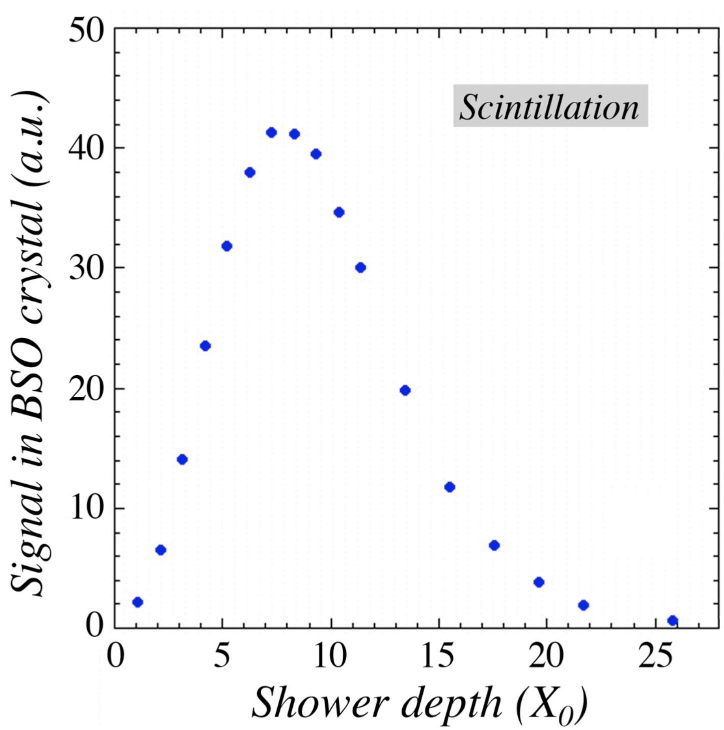
Energy distributions for 100 GeV electron beam

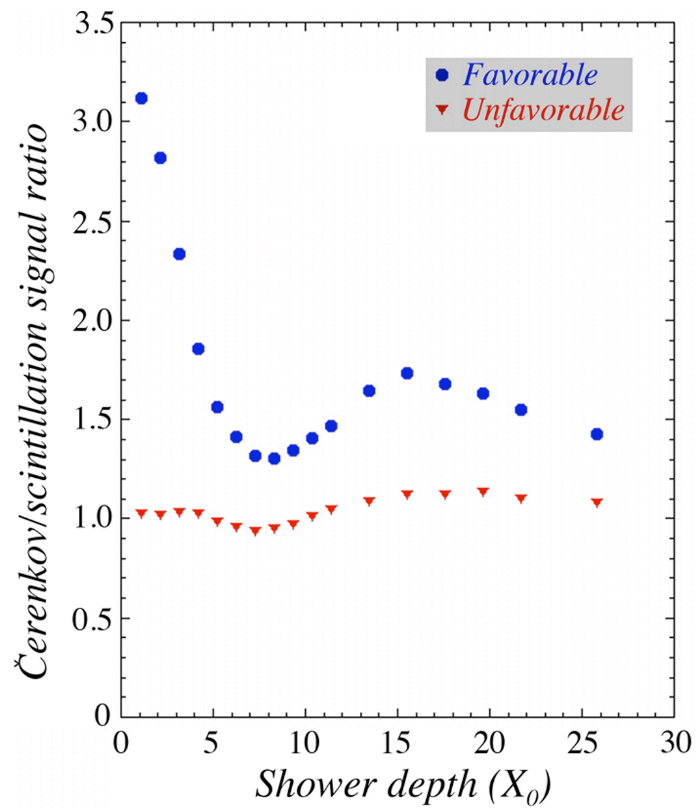


S. Franchino, IEEE, Valencia 2011

Polarization measurements

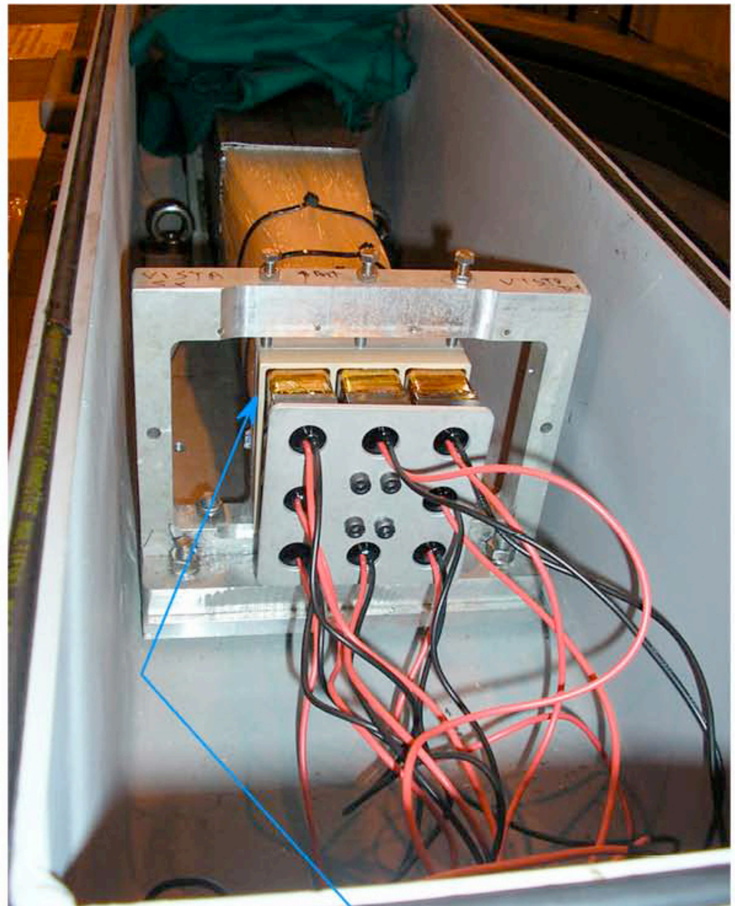




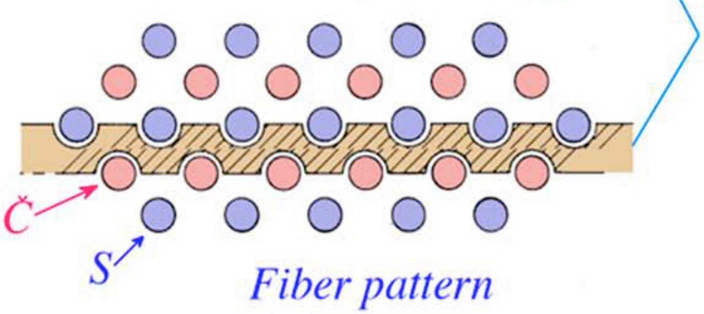


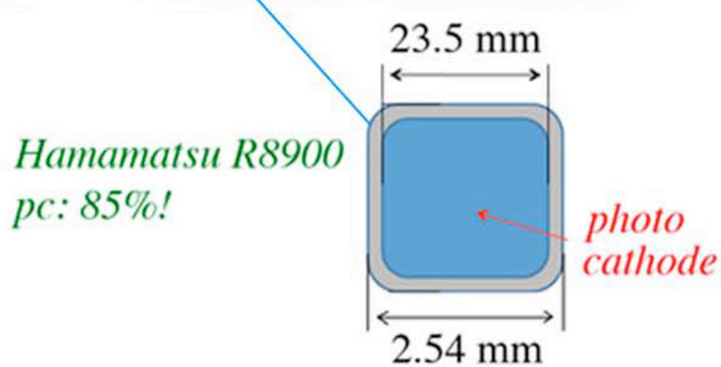
The new fiber calorimeter

The first SuperDREAM module tested at CERN

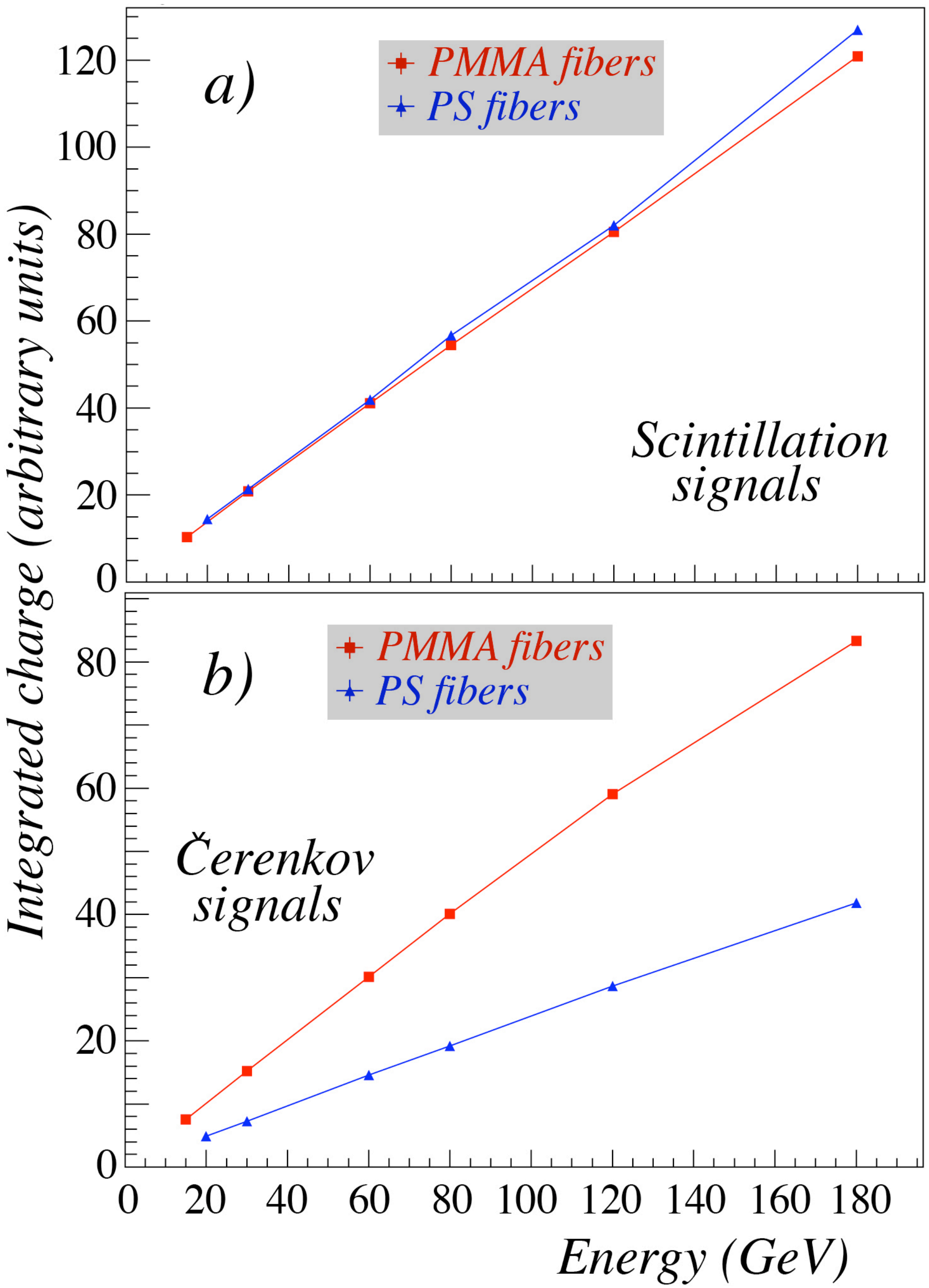


Pb absorber
9.3 x 9.3 x 250 cm
150 kg
4 towers, 8 PMTs
2 x 2048 fibers





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

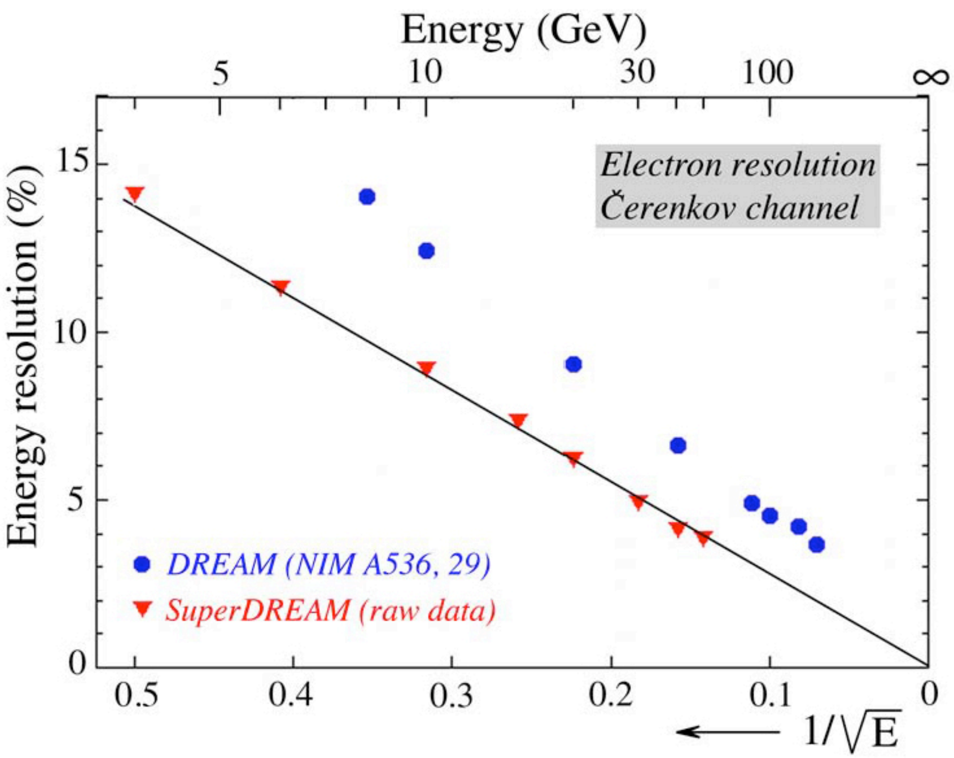
Scintillator: no change
Čerenkov: x 2!

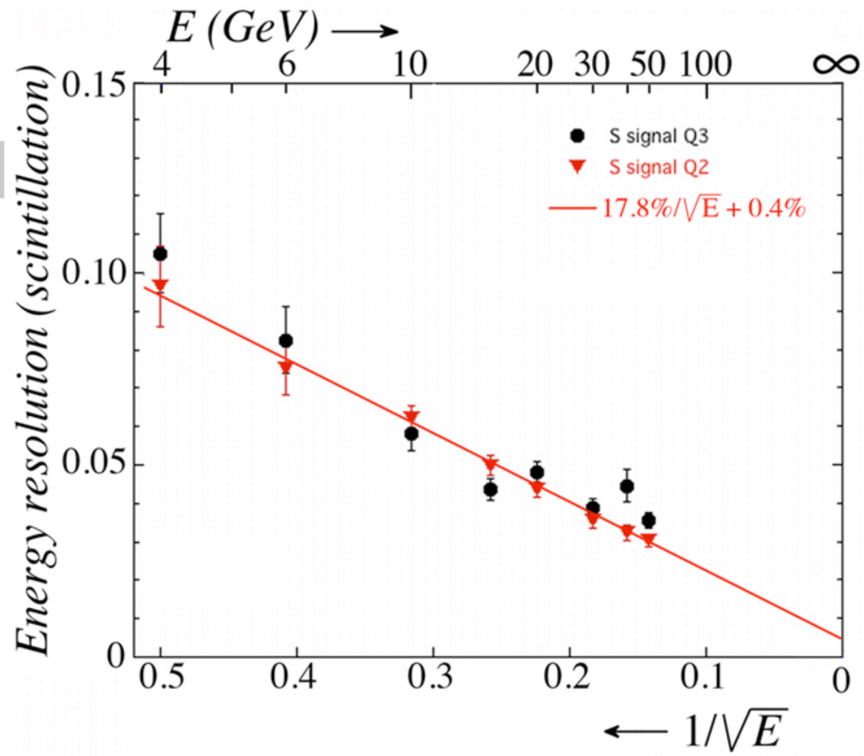
Č light yield was measured for PS module with LED: 32 p.e./GeV
→ twice as high for PMMA

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*
- *Alumizing upstream end of (C) fibers → more light*
- *Light mixers → eliminate position dependence of response*
- *Reduce noise contribution of readout electronics*

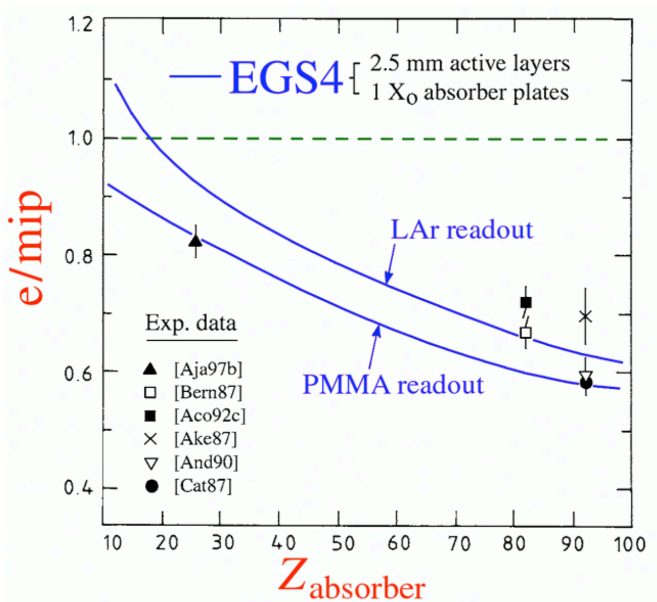
Expect $10\%/\sqrt{E}$ by combining signals from two types of fibers

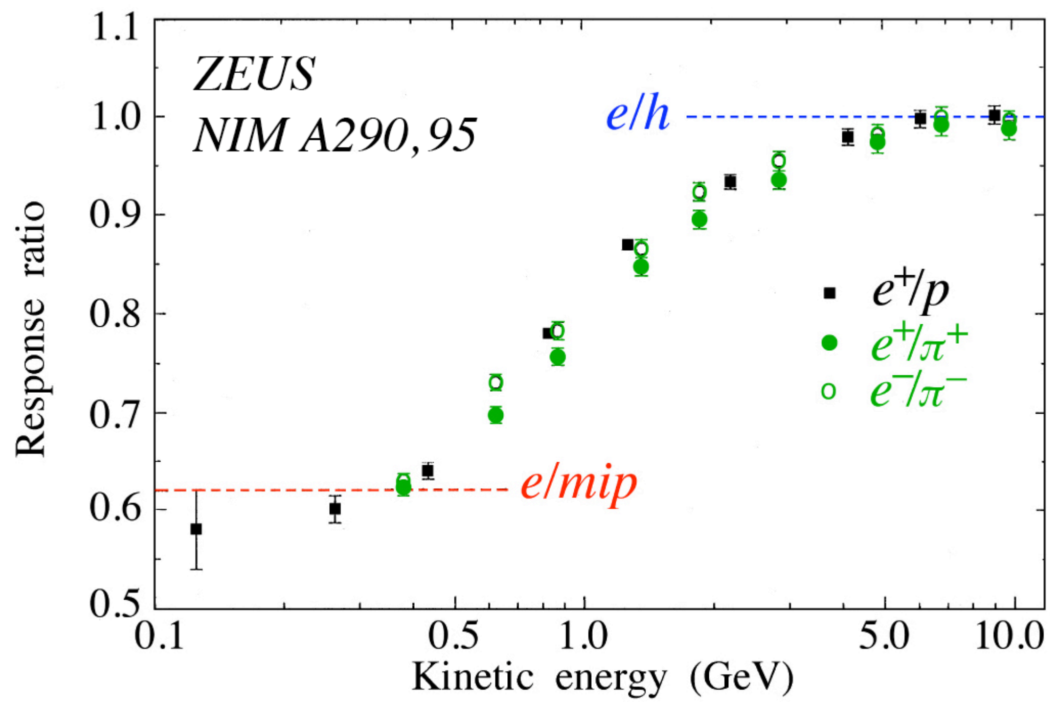
Absorber choice: Cu vs Pb

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

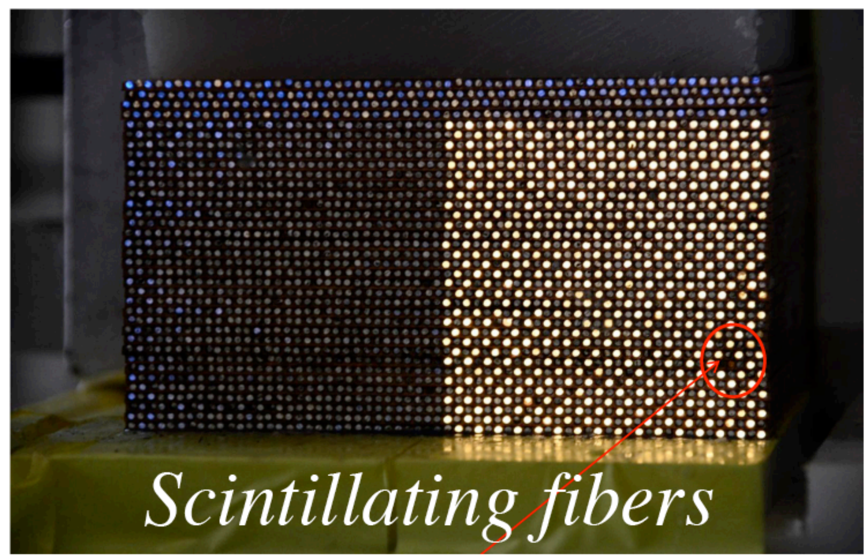
- *e/mip* ⟶ *Čerenkov light yield Cu/Pb ~ 1.4*
  (Showers inefficiently sampled in calorimeters with high-Z absorber)

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



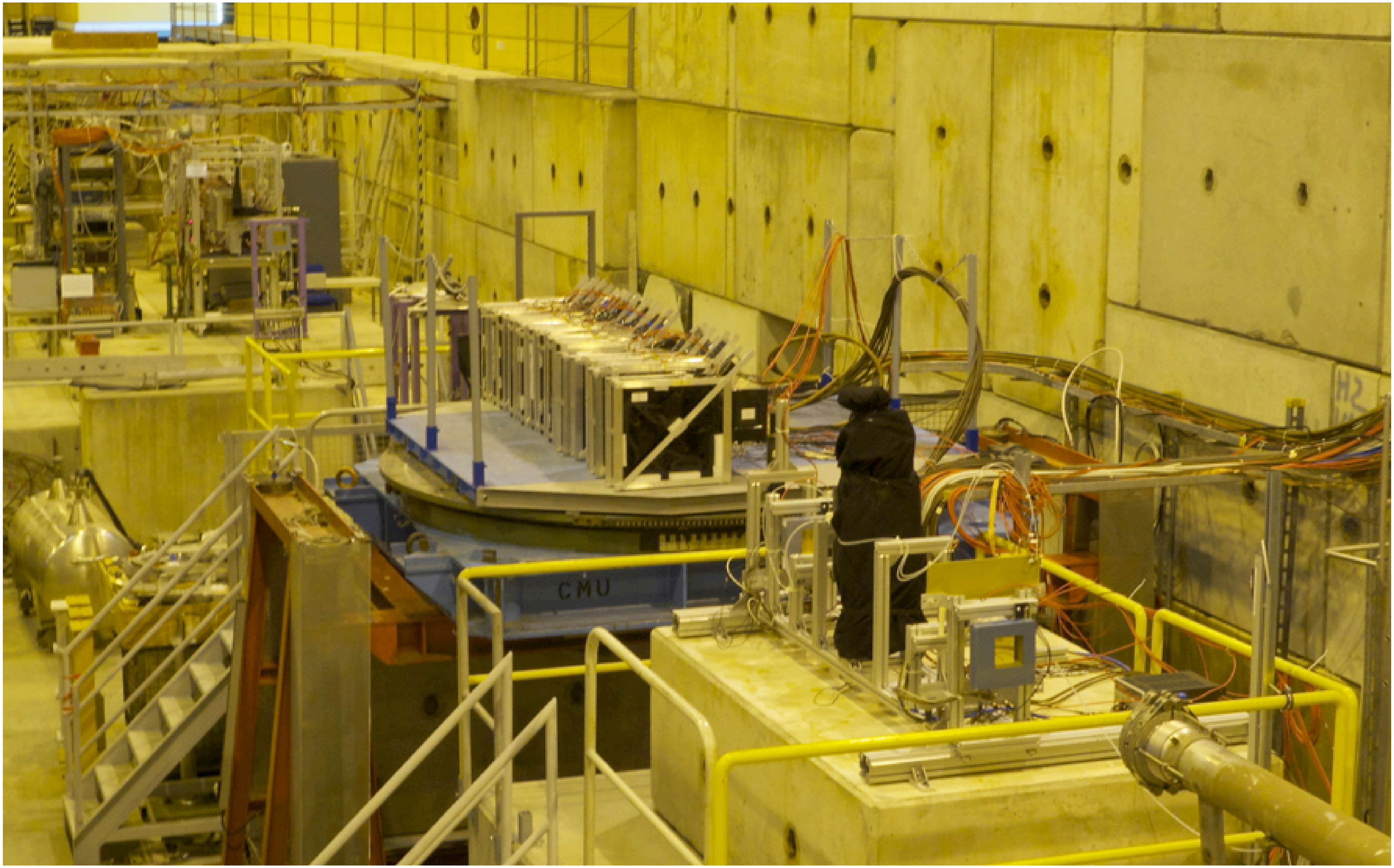


The first copper module



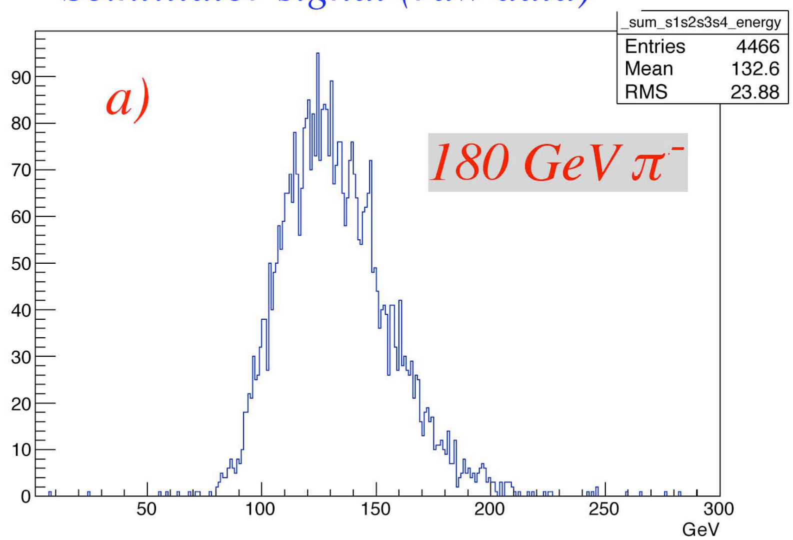
First hadrons in SuperDREAM (1 Pb module + n-shield)

Calibration of neutron shield (muon beam)

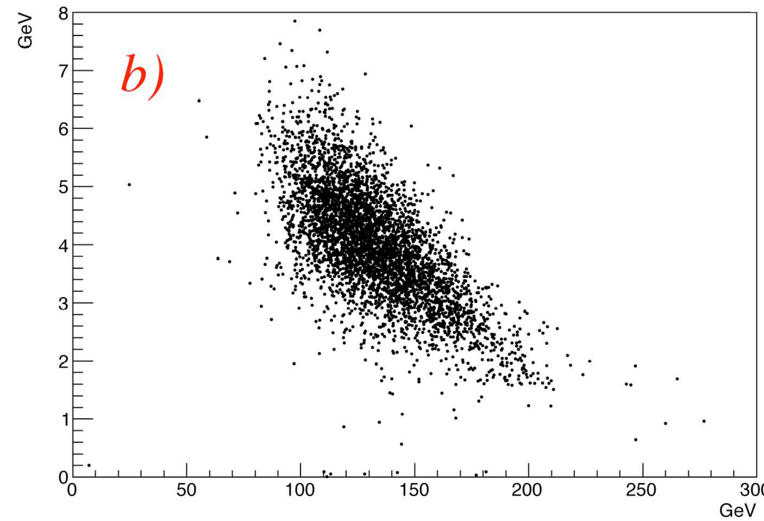


First results on pion detection in the new fiber calorimeter

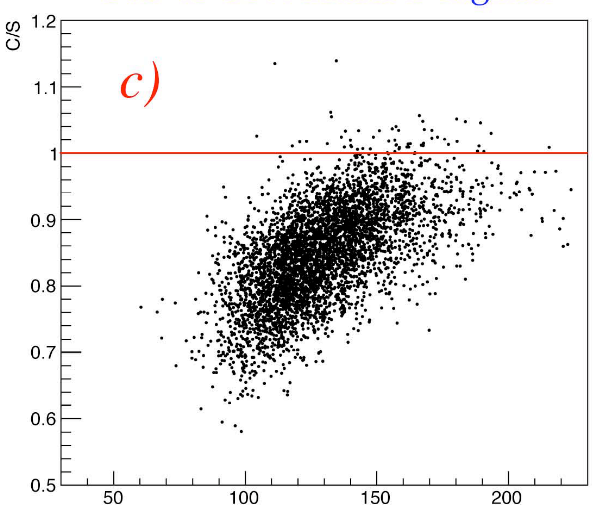
Scintillator signal (raw data)



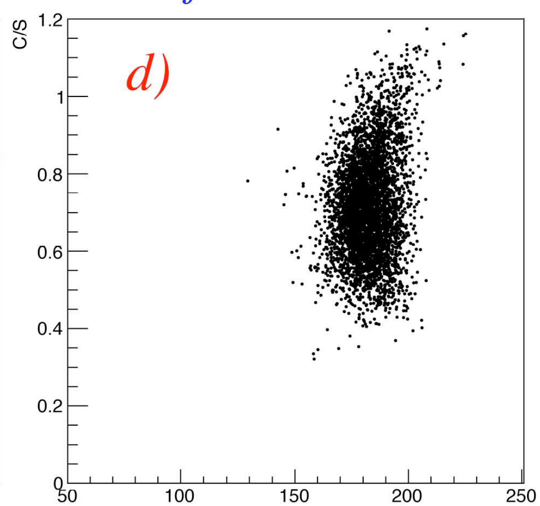
Leakage vs scintillator signals



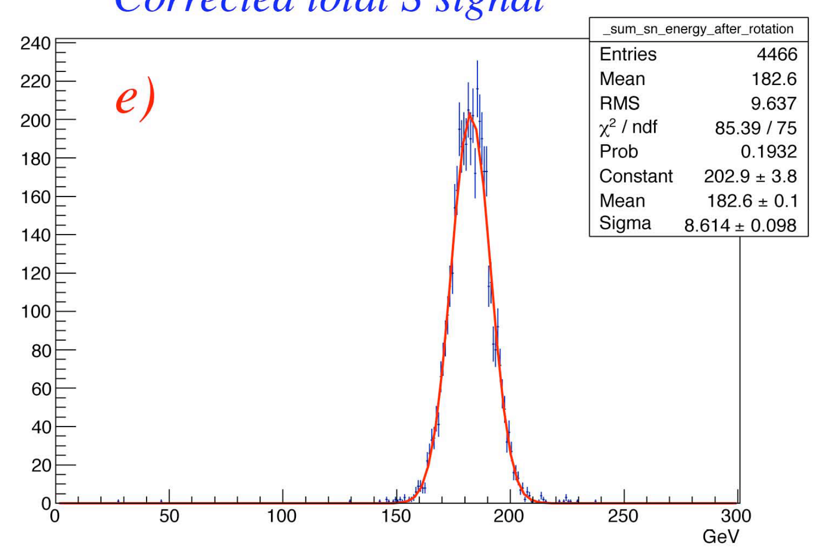
Č/S vs corrected S signal



After rotation



Corrected total S signal



Time structure signals

Fiber calorimeter: needed for

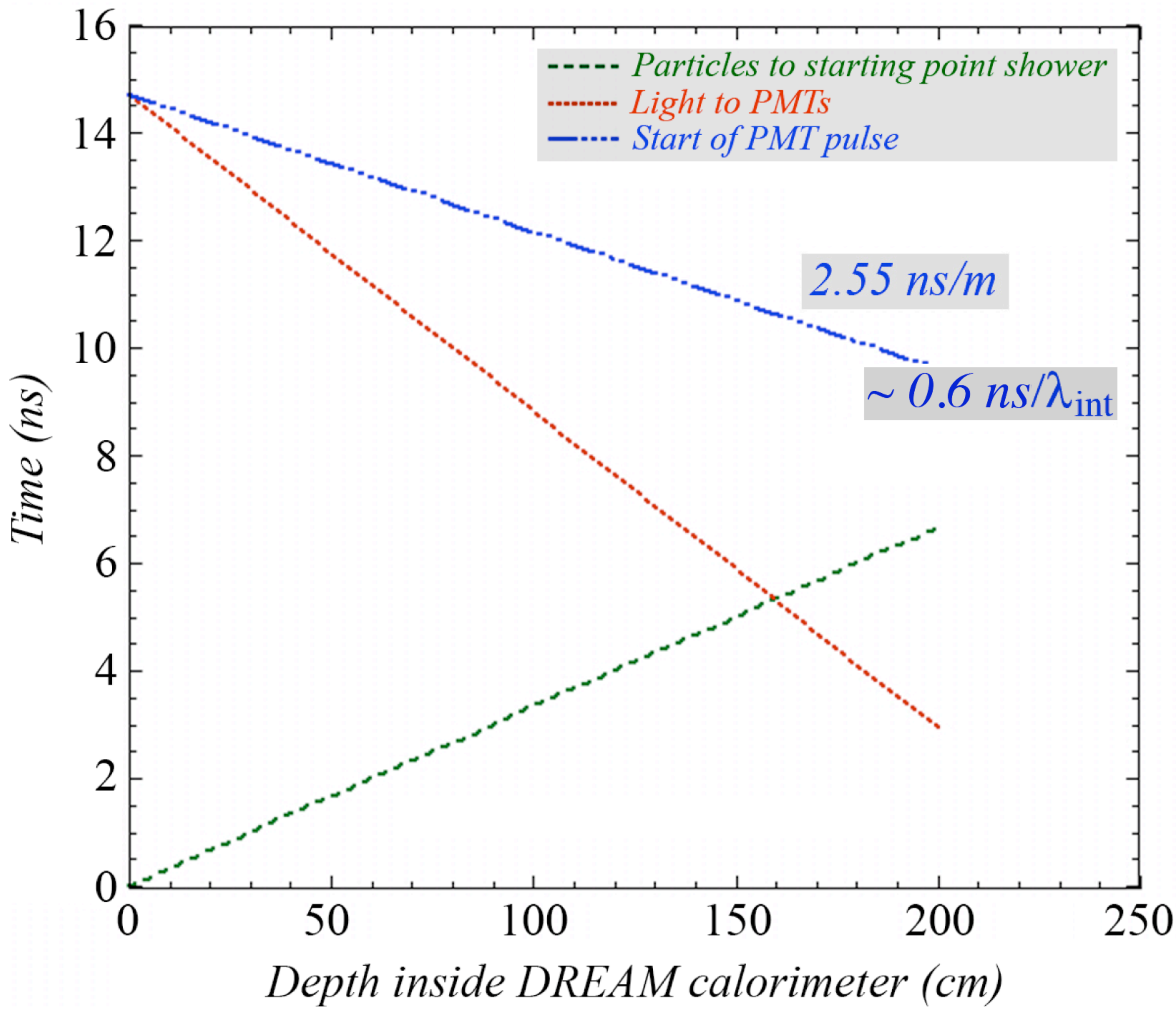
- *precision measurement of start time signals*
- *neutron tail of S signals*

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.

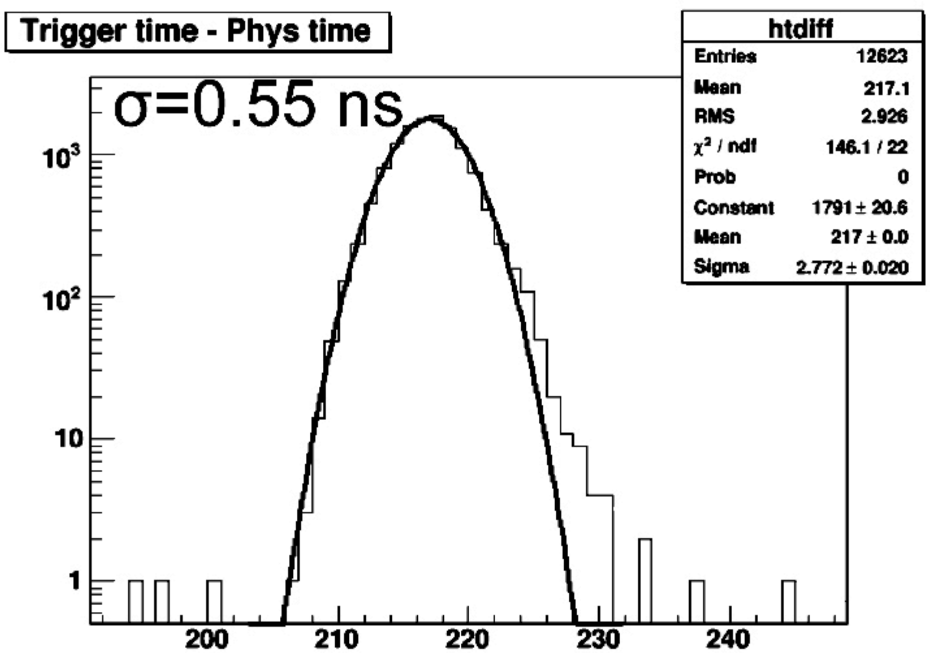
* *See* NIM A518 (2004) 407

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

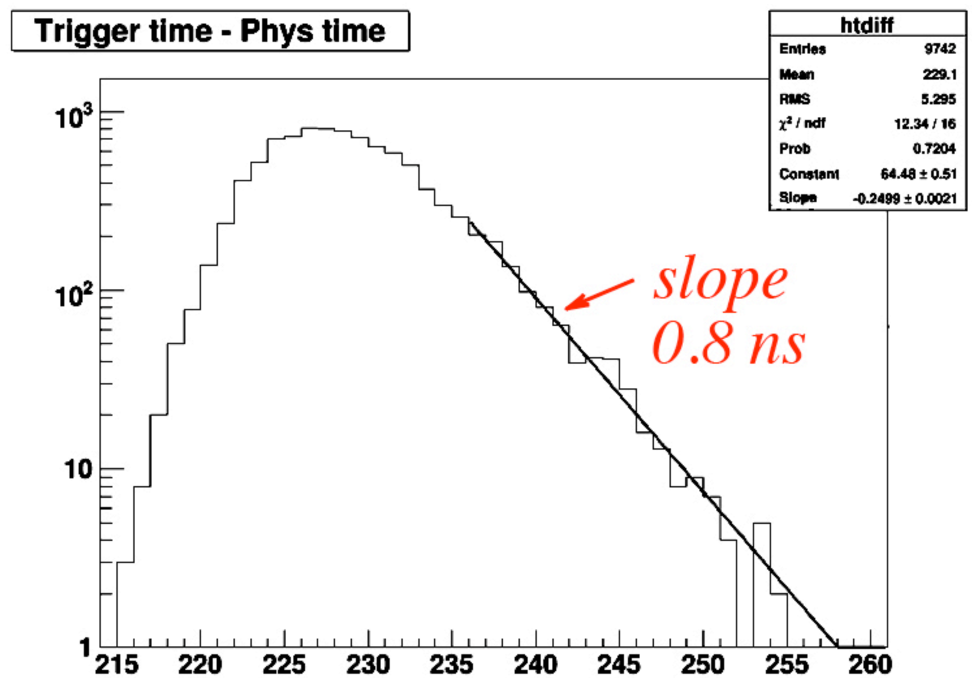


Measurement of the depth of the light production in module using the DRS timing

80 GeV electrons

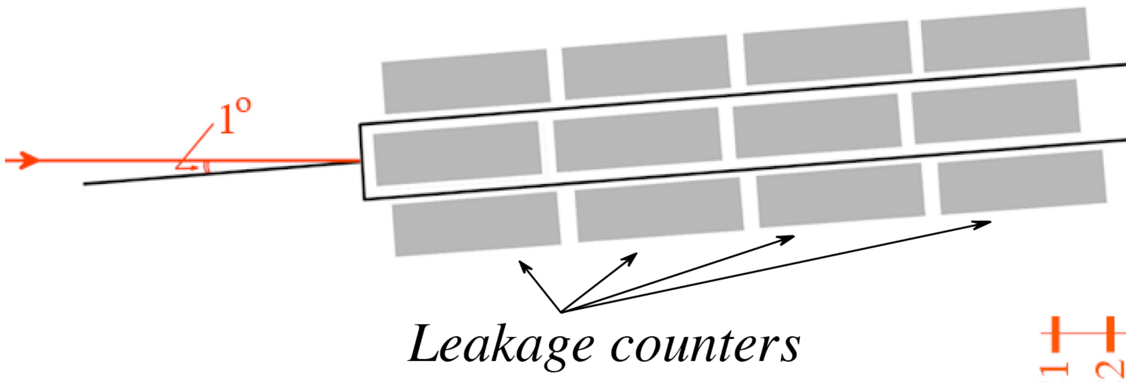


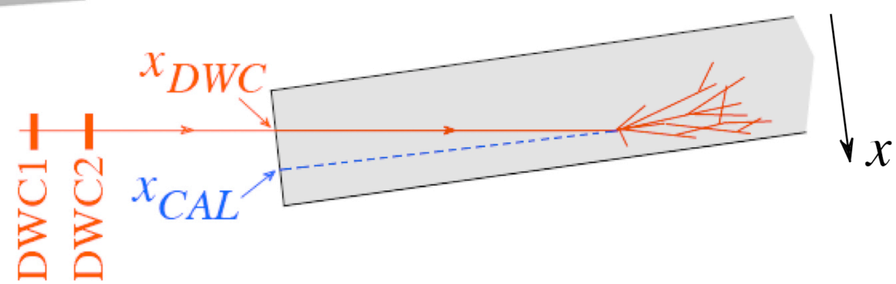
180 GeV pions

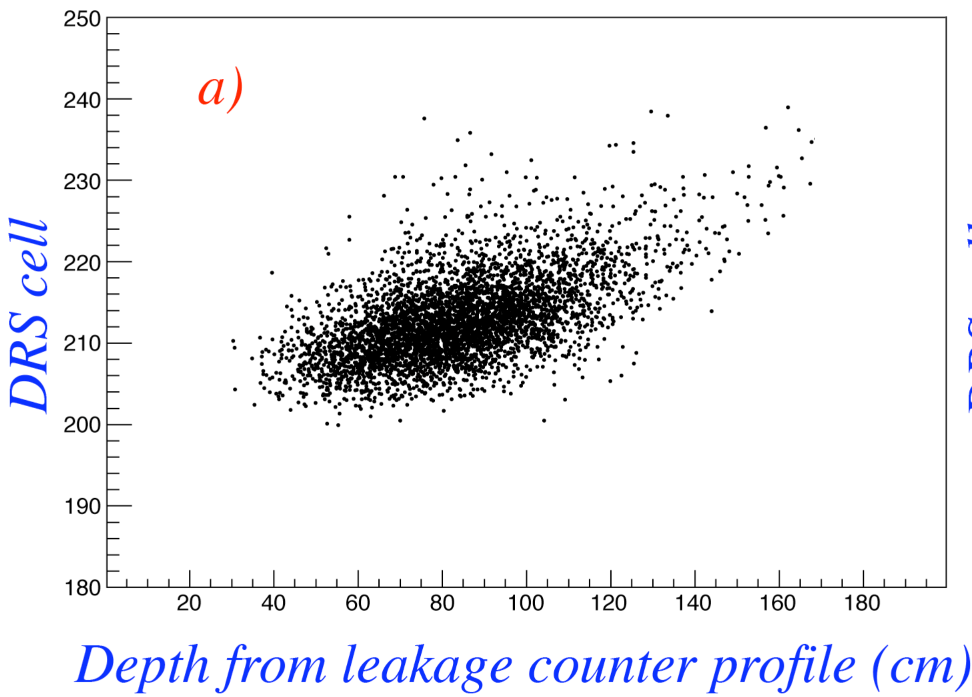


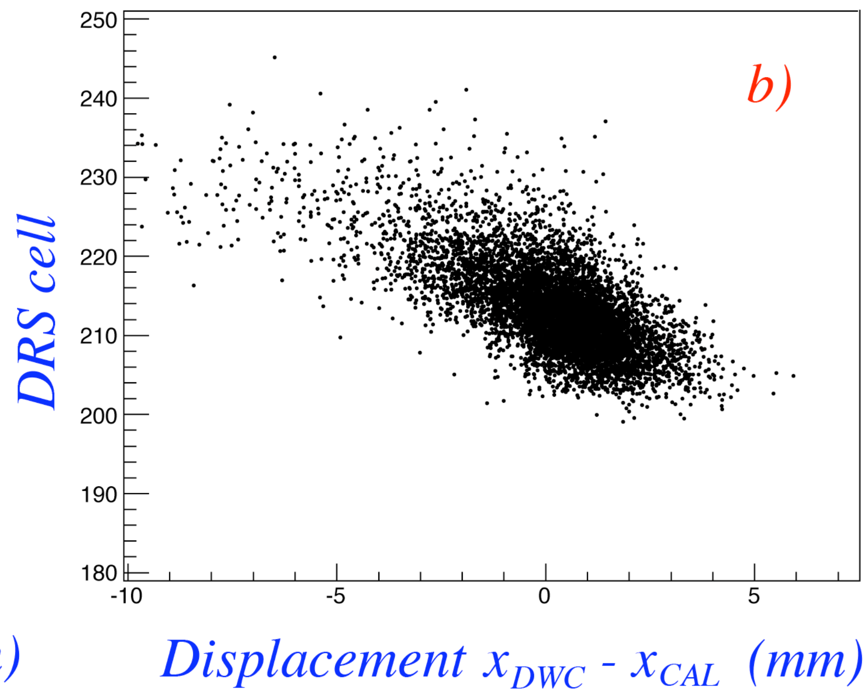
Start of calorimeter signal (in DRS cells = 0.2 ns)

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

Plans for $\geq$ 2013

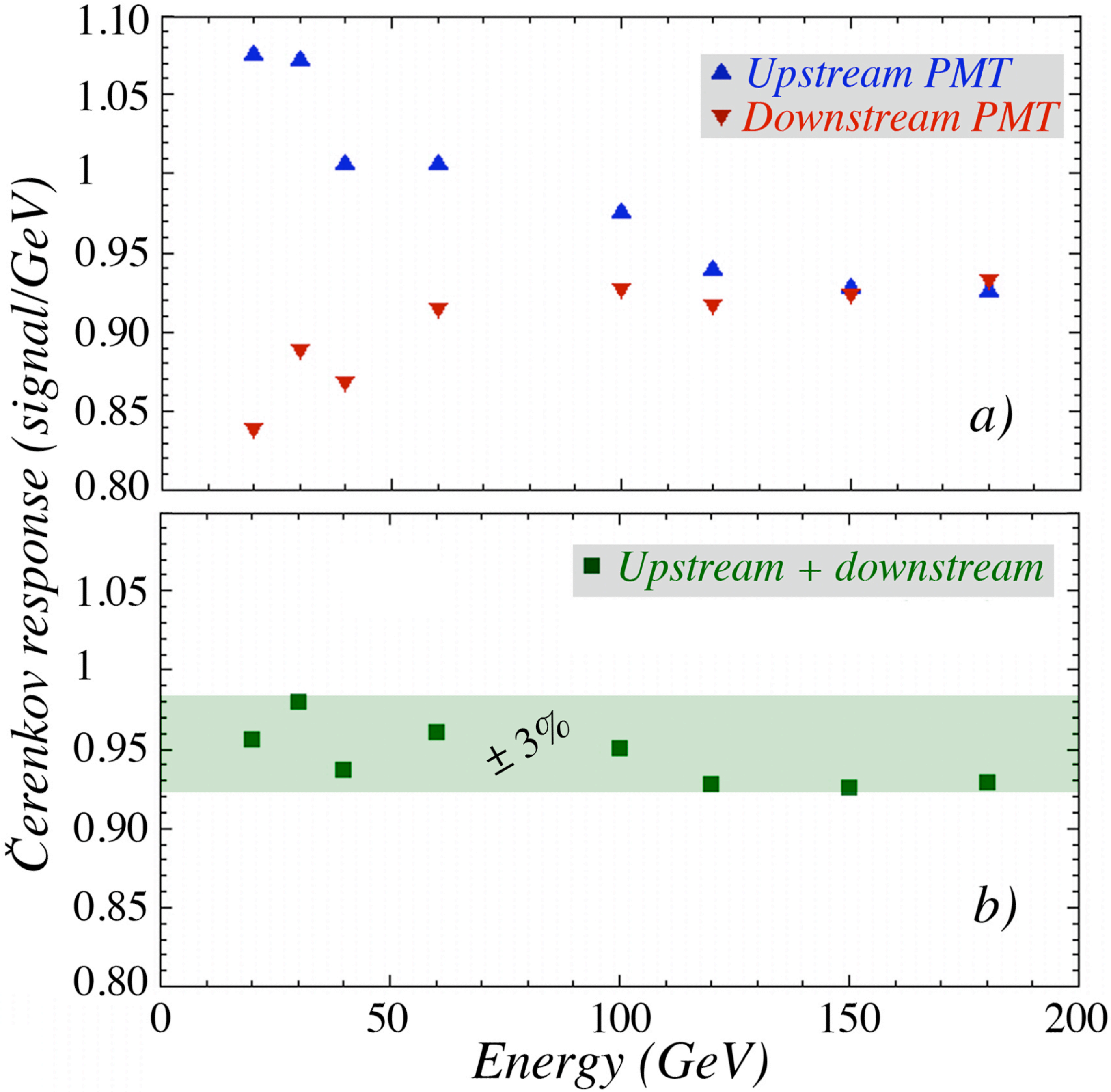
- *Finish construction of the 5-ton calorimeter*

- *Tests of full calorimeter with/without em Xtal matrix*

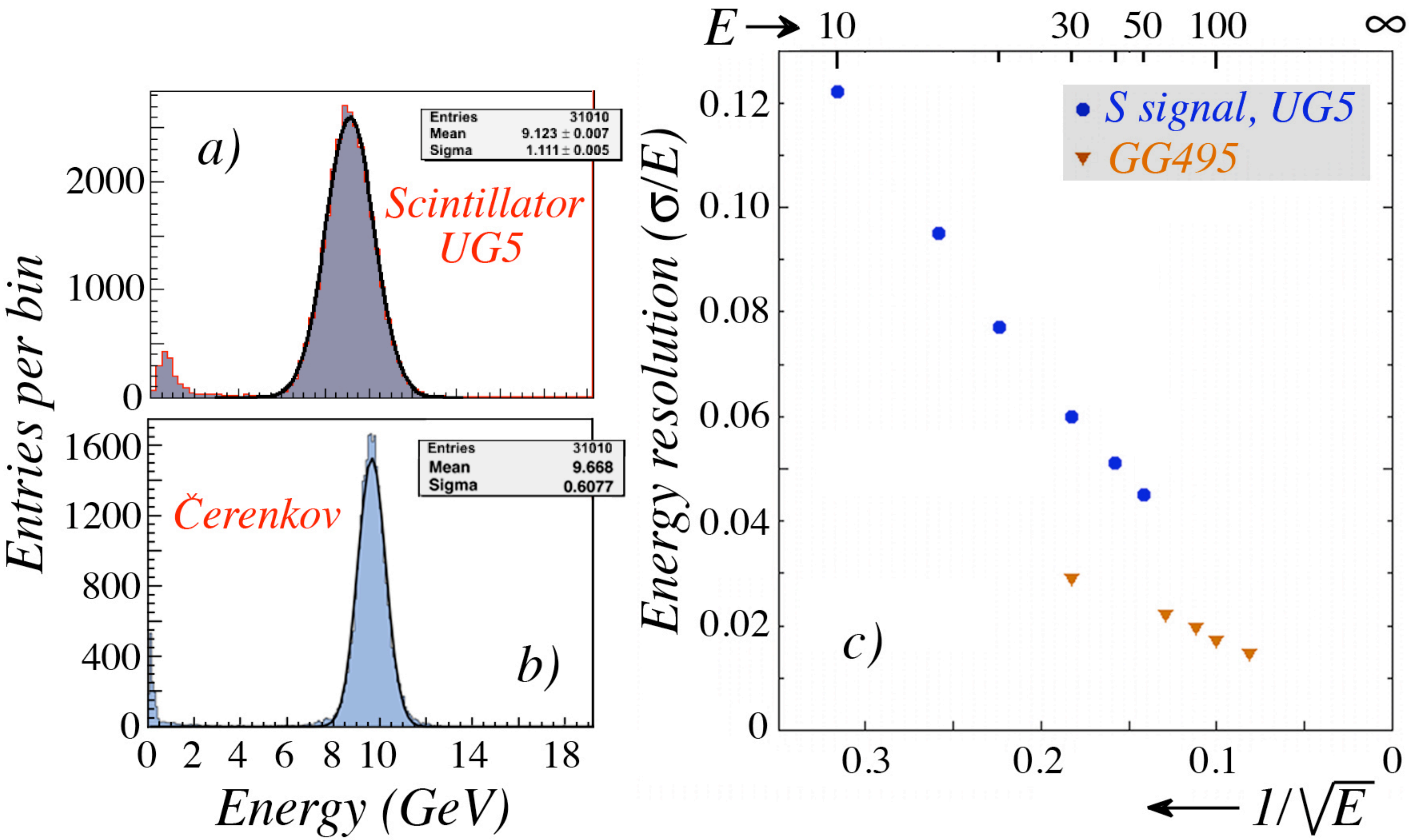
- *Address issues associated with implementation in experiment*
  - *Compactness: investigate W option*
  - *Readout: test SiPM readout of fiber module*
  - *Projectivity*

Backup slides

Čerenkov signals in crystals are strongly affected by light attenuation
Improve resolution by reading signals from bothe ends



Scintillation signals in $PbWO_4$ matrix optimized for detection of Čerenkov light



New Collaborators

Several institutes have expressed interest in joining RD52

- *LIP (Lisbon) has valuable expertise in fiber aluminization*
- *A group from DESY is interested in the W/SiPM options*
- *Fermilab would like to make this a FNAL project*