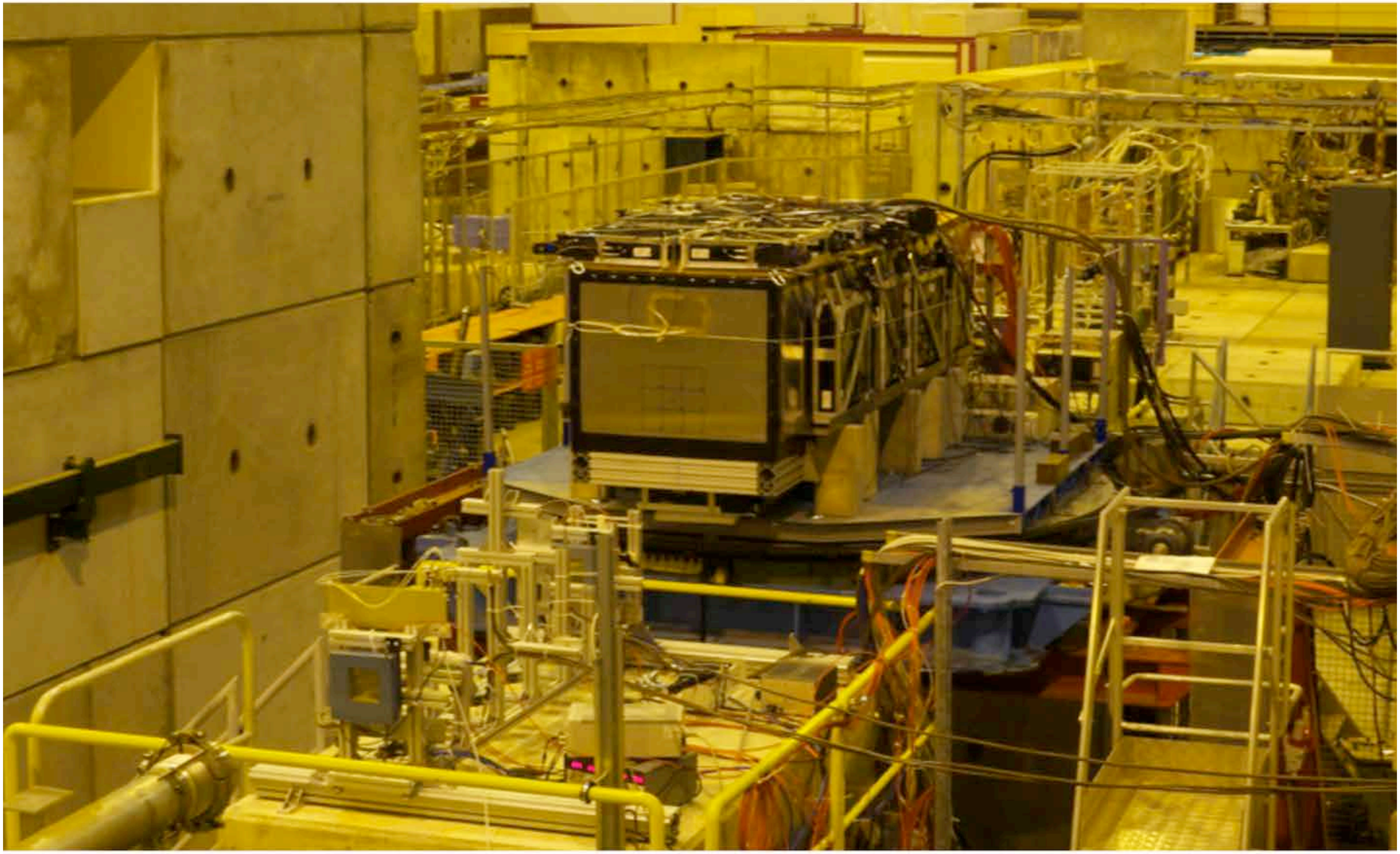
RD52 (DREAM)

Dual-Readout calorimetry for high-quality energy measurements

Richard Wigmans

LHCC meeting, CERN June 4, 2014



Mission statement

RD52 is a *generic* detector R&D project, carried out by the DREAM Collaboration. It is *not* linked to any particular experiment, but the results could be very important for a variety of experiments, especially at a high-energy Lepton Collider

Goal: Investigate + eliminate the factors that prevent us from measuring hadrons and jets with similar precision as electrons, photons

All (28) papers, talks etc. can be found at

highenergy.phys.ttu.edu/dream

The RD52 Collaboration

Lessons from Monte Carlo simulations of the performance of a dual-readout fiber calorimeter

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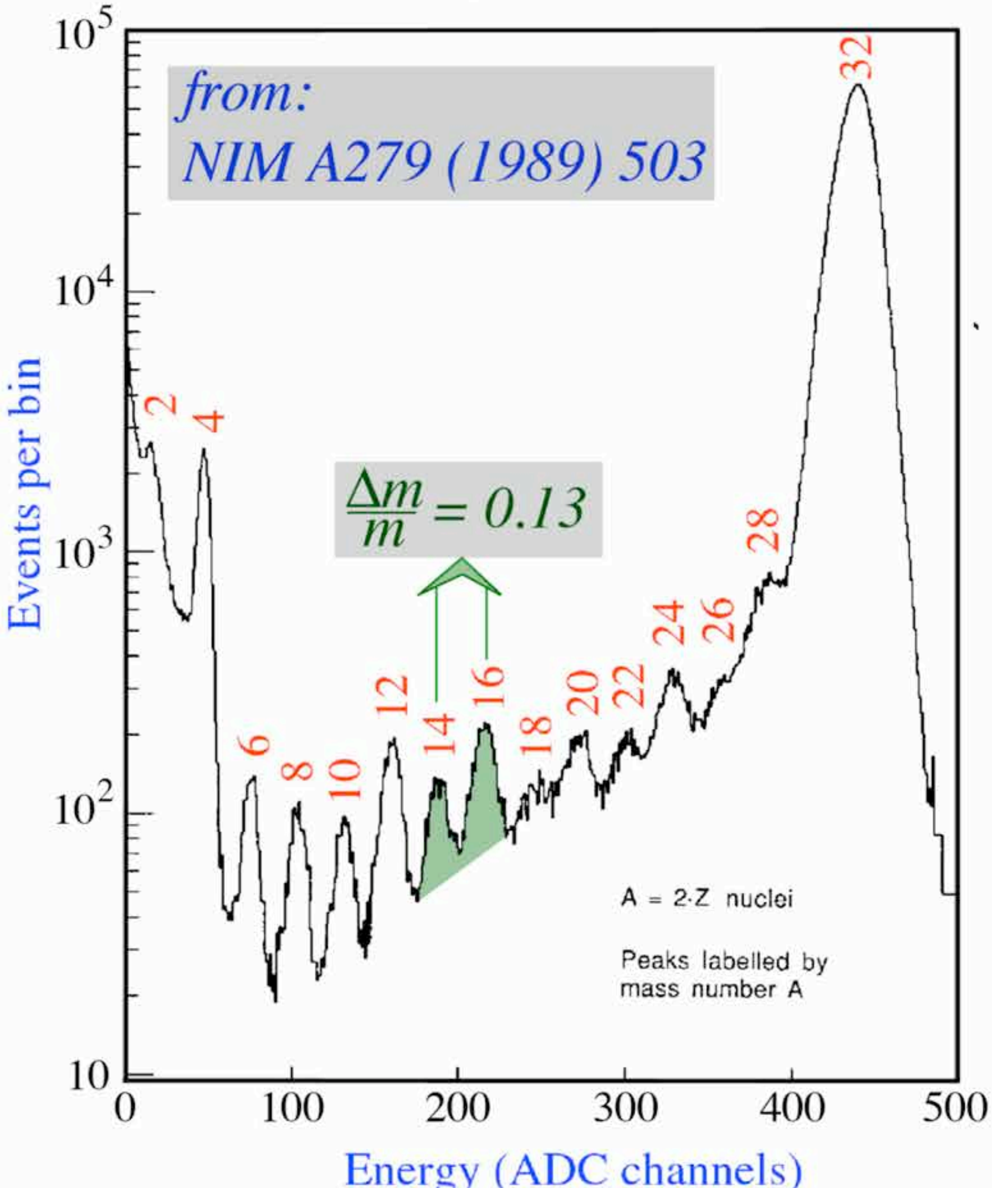
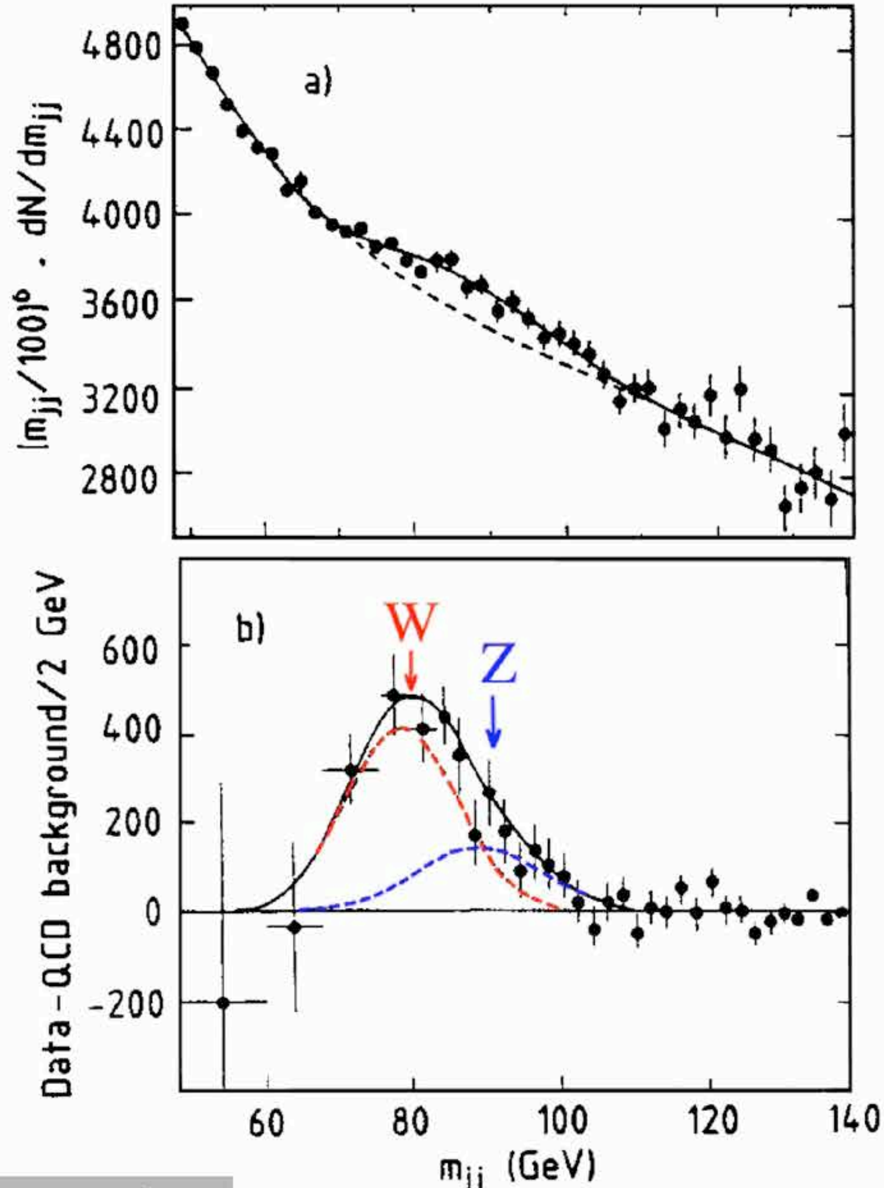
The importance of high-quality hadron calorimetry

Compensating calorimeter (WA80)



UA2: Non-compensating



W/Z separation:
$\frac{\Delta m}{m} \sim 0.11$

An attractive option for improving the quality of hadron calorimetry:

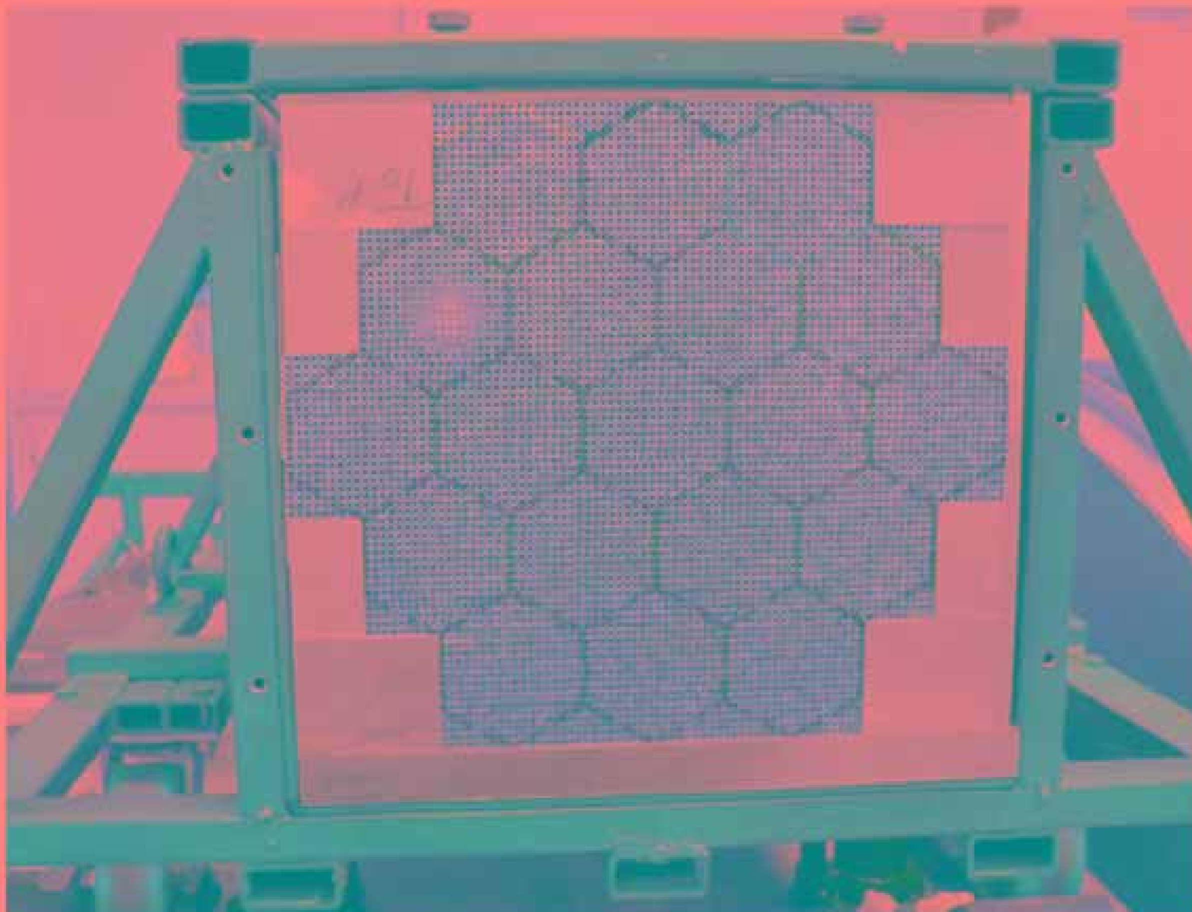
Use Čerenkov light!! *Why?*

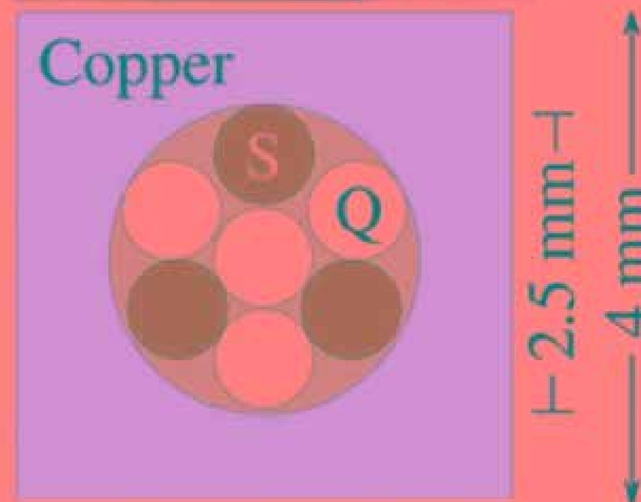
- Hadron showers < *em* component (π^o) / *non-em* component (mainly soft p)
- Calorimeter response to these components not the same *(e/h ≠ 1)*
- Large, non-Gaussian event-to-event fluctuations in f_{em}

Čerenkov light almost exclusively produced by em component
(~80% of non-em energy deposited by non-relativistic particles)

➡ DREAM (Dual REAdout Method) principle:
Measure f_{em} event by event by comparing Č and dE/dx signals

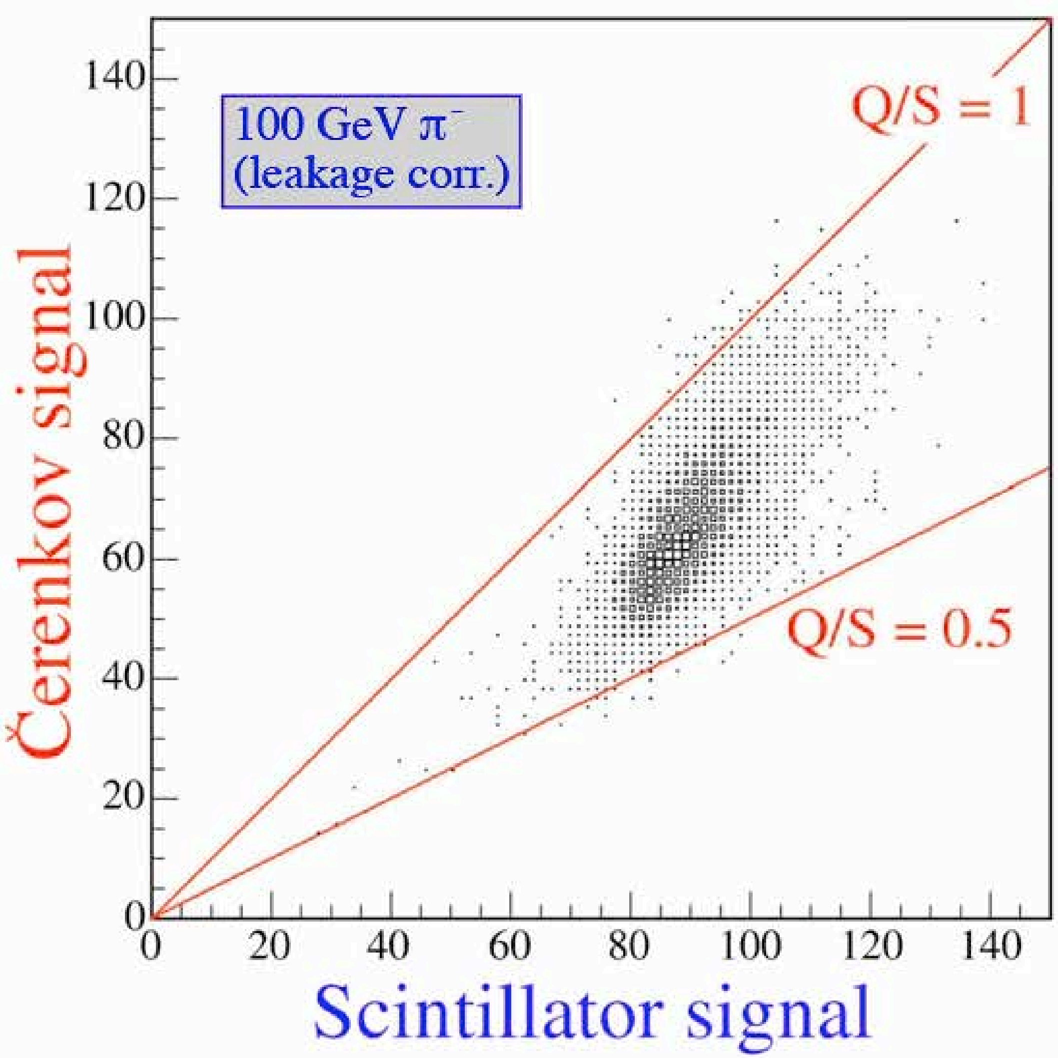
The original DREAM calorimeter





- *Some characteristics of the DREAM detector*
  - Depth 200 cm (10.0 $\lambda_{\rm int}$)
  - Effective radius 16.2 cm (0.81 $\lambda_{\rm int}$, 8.0 ρ_M)
  - Mass instrumented volume 1030 kg
  - Number of fibers 35910, diameter 0.8 mm, total length $\approx$ 90 km
  - Hexagonal towers (19), each read out by 2 PMTs

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



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

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

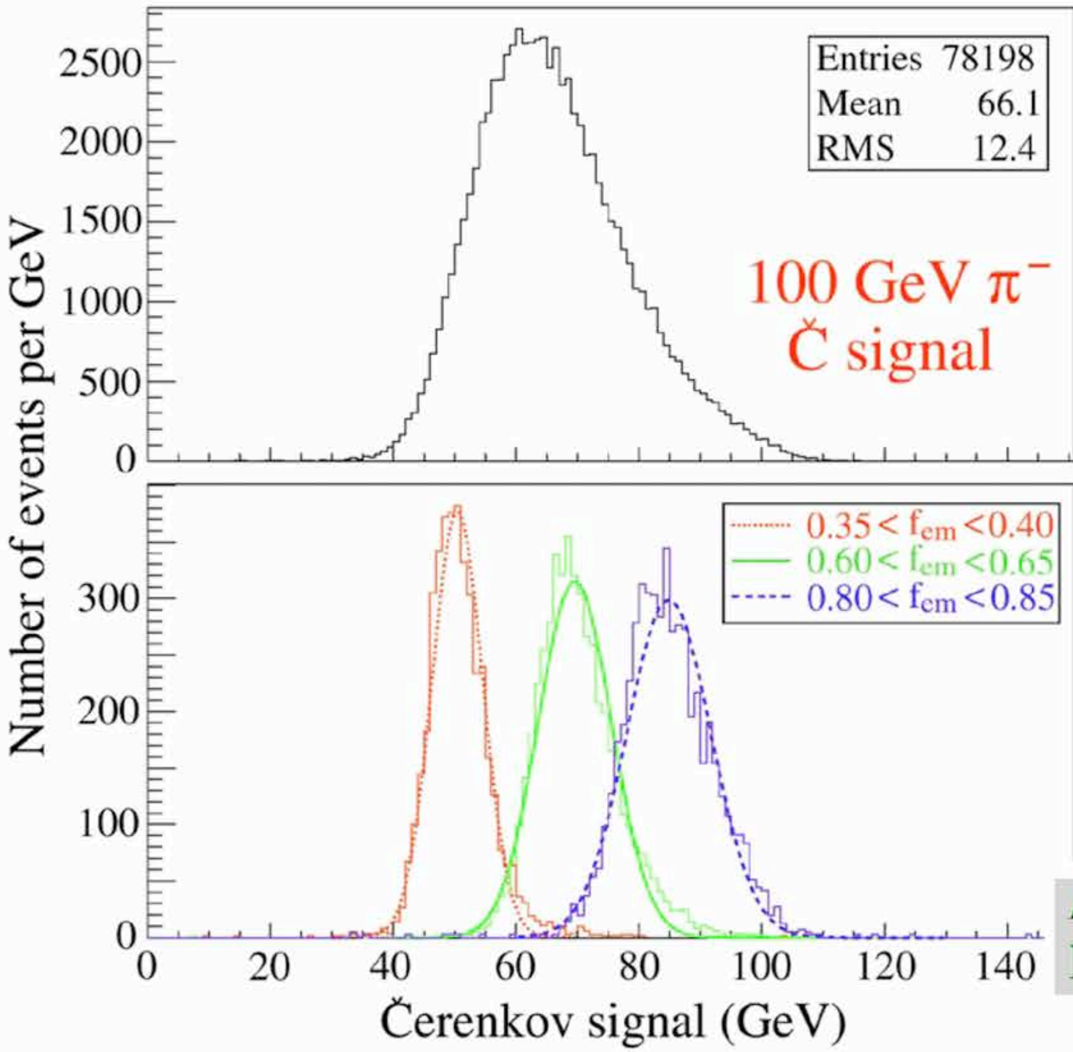
e.g. If $e/h = 1.3$ (S), 4.7 (Q)

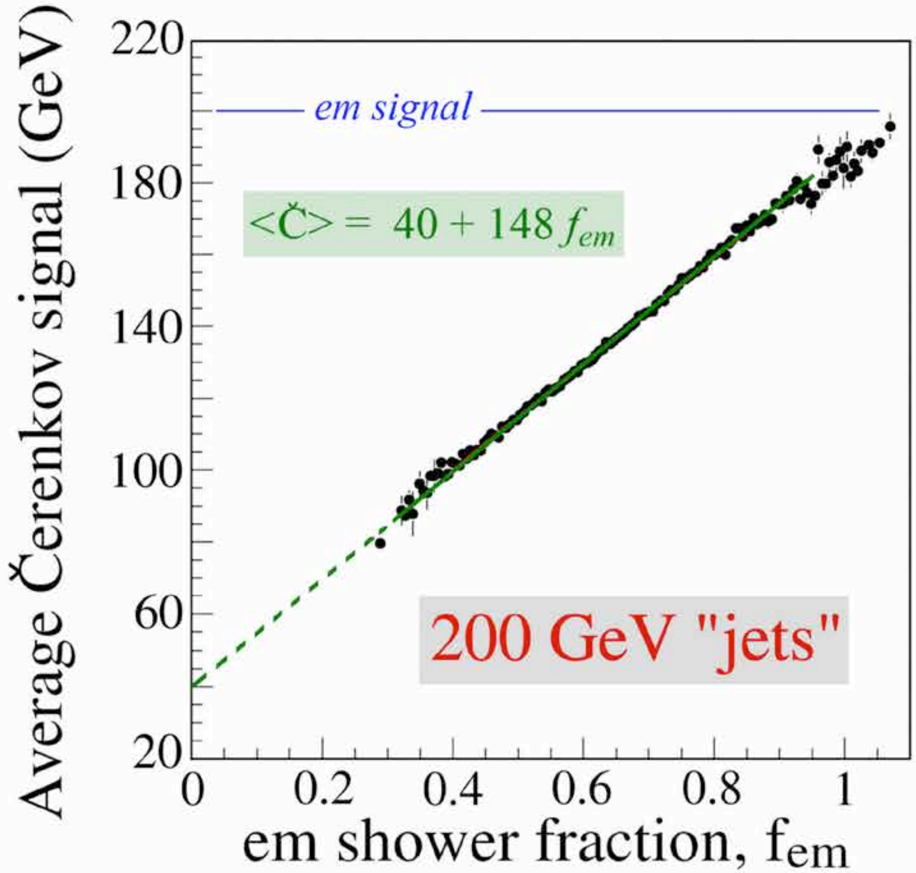
$$\frac{Q}{S} = \frac{f_{\mathrm{em}} + 0.21\,(1 - f_{\mathrm{em}})}{f_{\mathrm{em}} + 0.77\,(1 - f_{\mathrm{em}})}$$

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

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

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





From:
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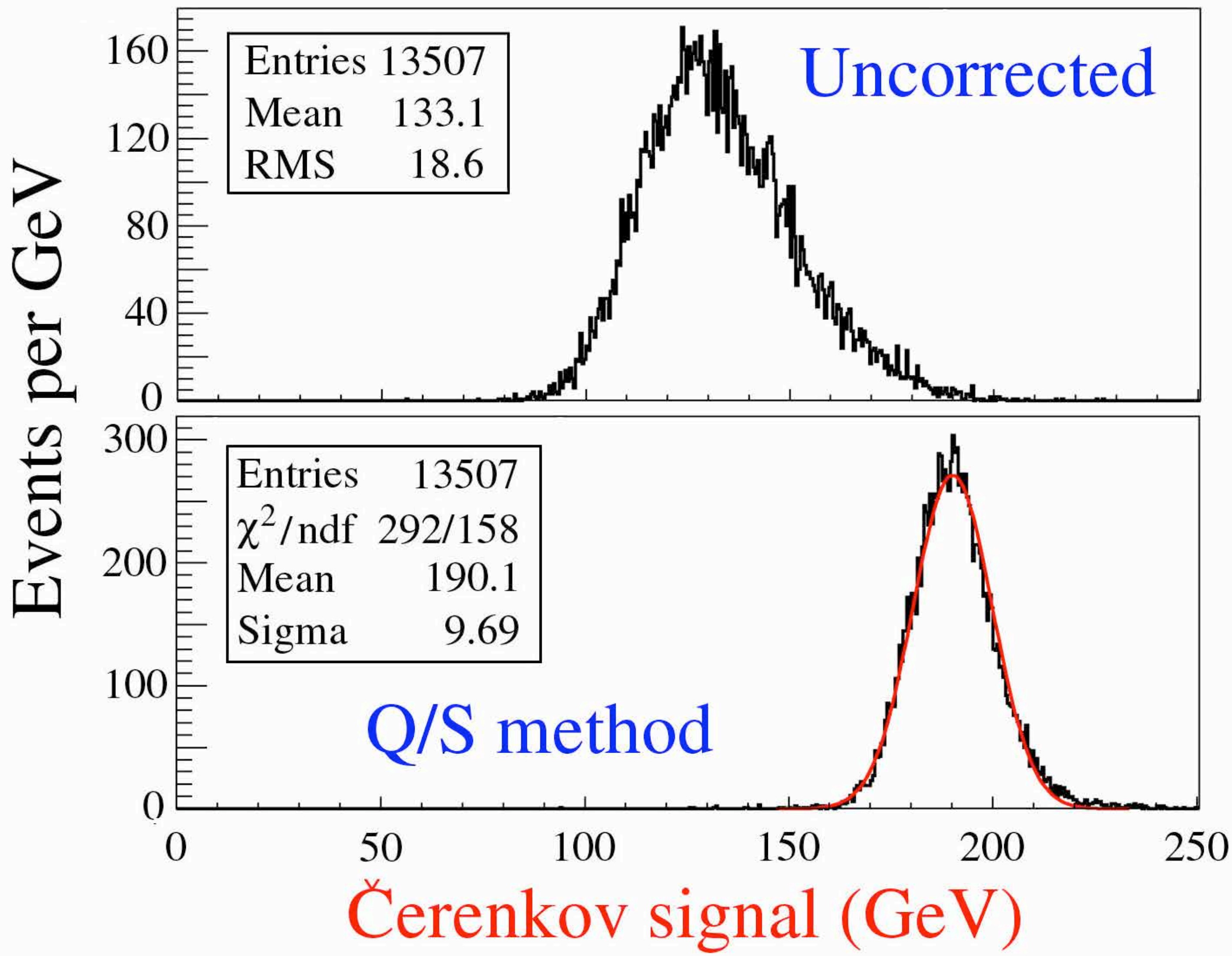
Experimentally, one measures f_{em} event by event
Scale signal up to f_{em} =1 , i.e. the em scale

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



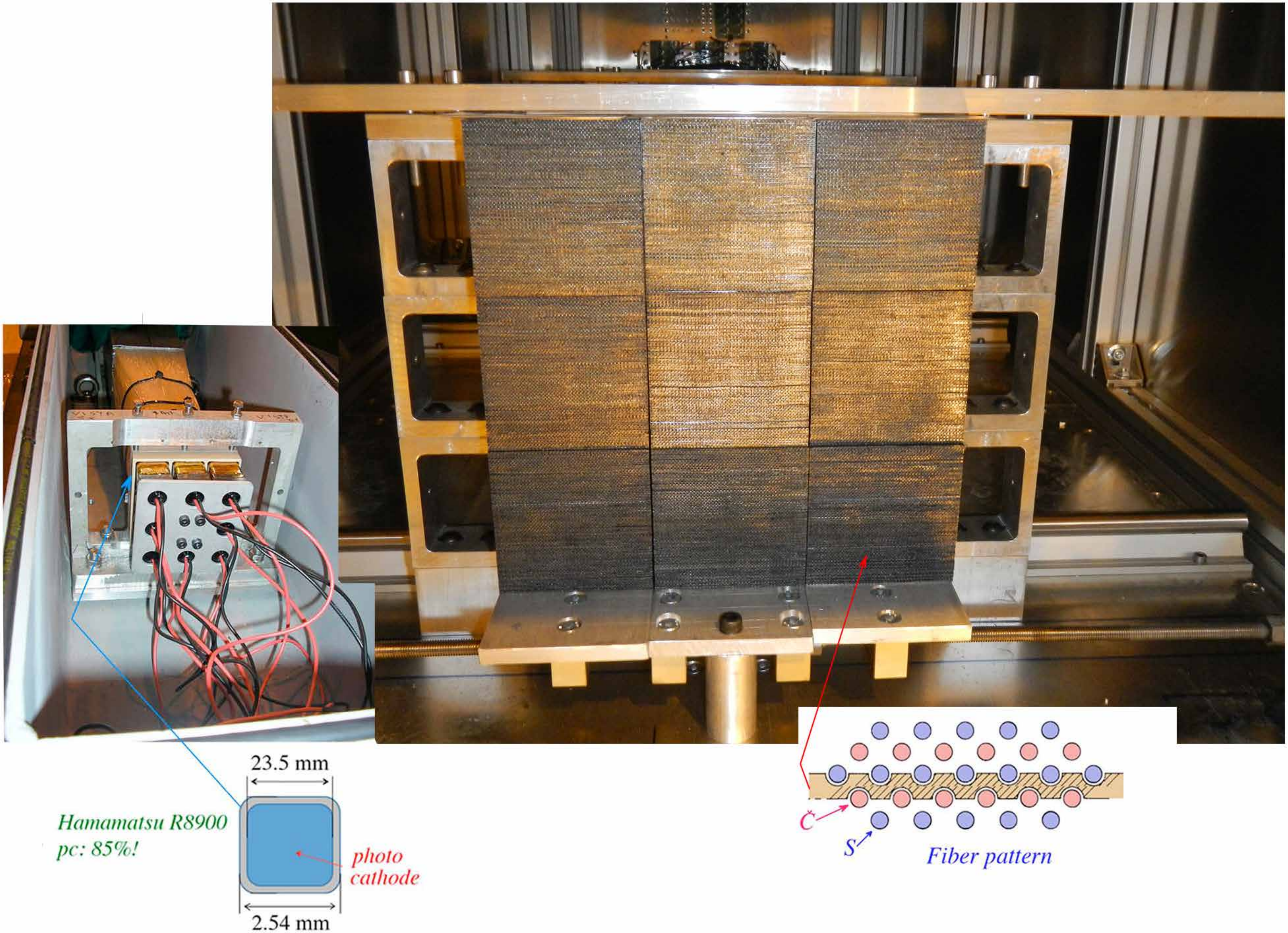
CONCLUSIONS
from tests of fiber prototype

- 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

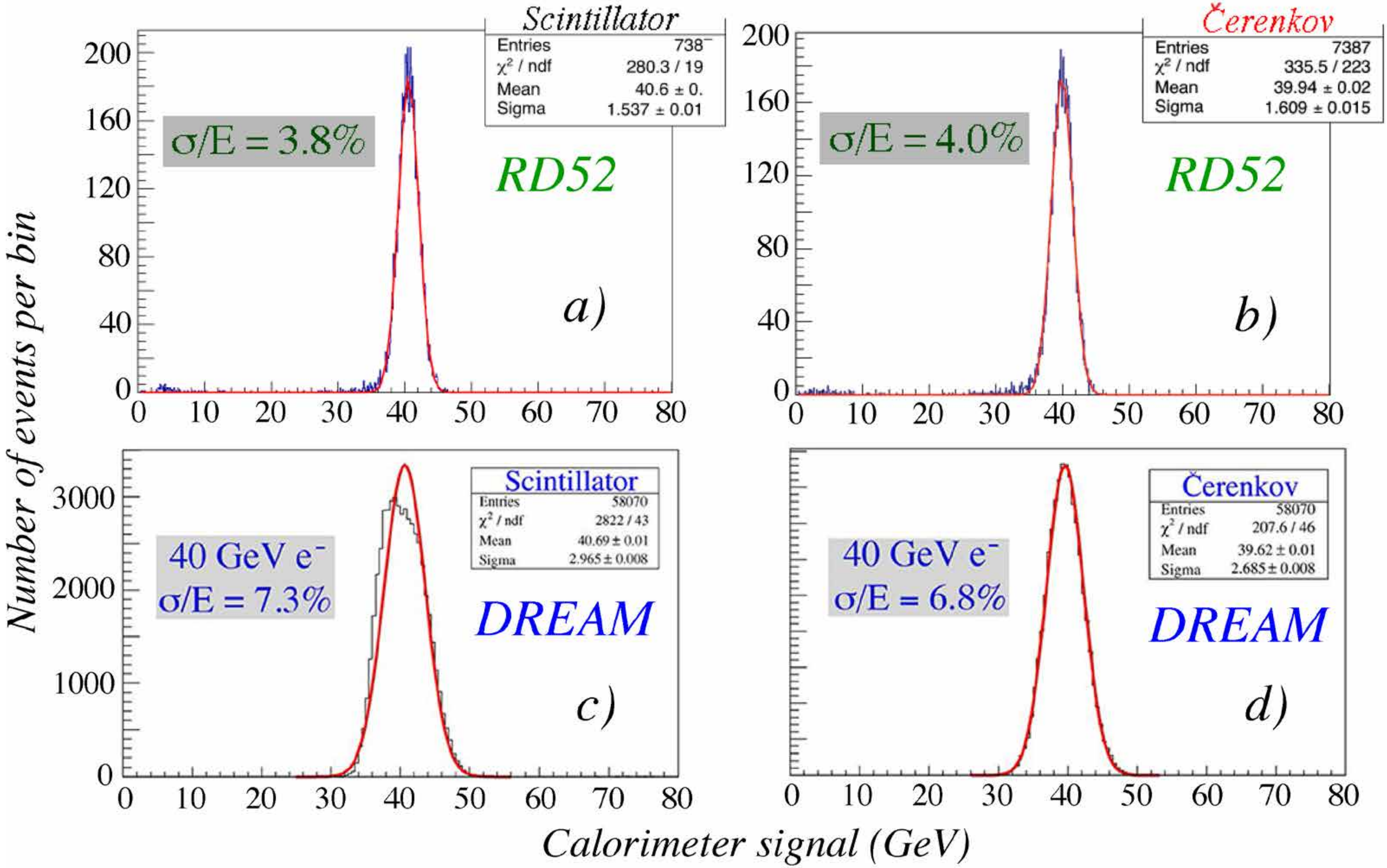
In other words:
The same advantages as intrinsically compensating calorimeters (e/h = 1)
WITHOUT the limitations (sampling fraction, integration volume, time)

And this performance can be achieved with a calorimeter consisting of low-Z absorber material!

The new RD52 fiber calorimeter



Electromagnetic performance strongly improved in RD52



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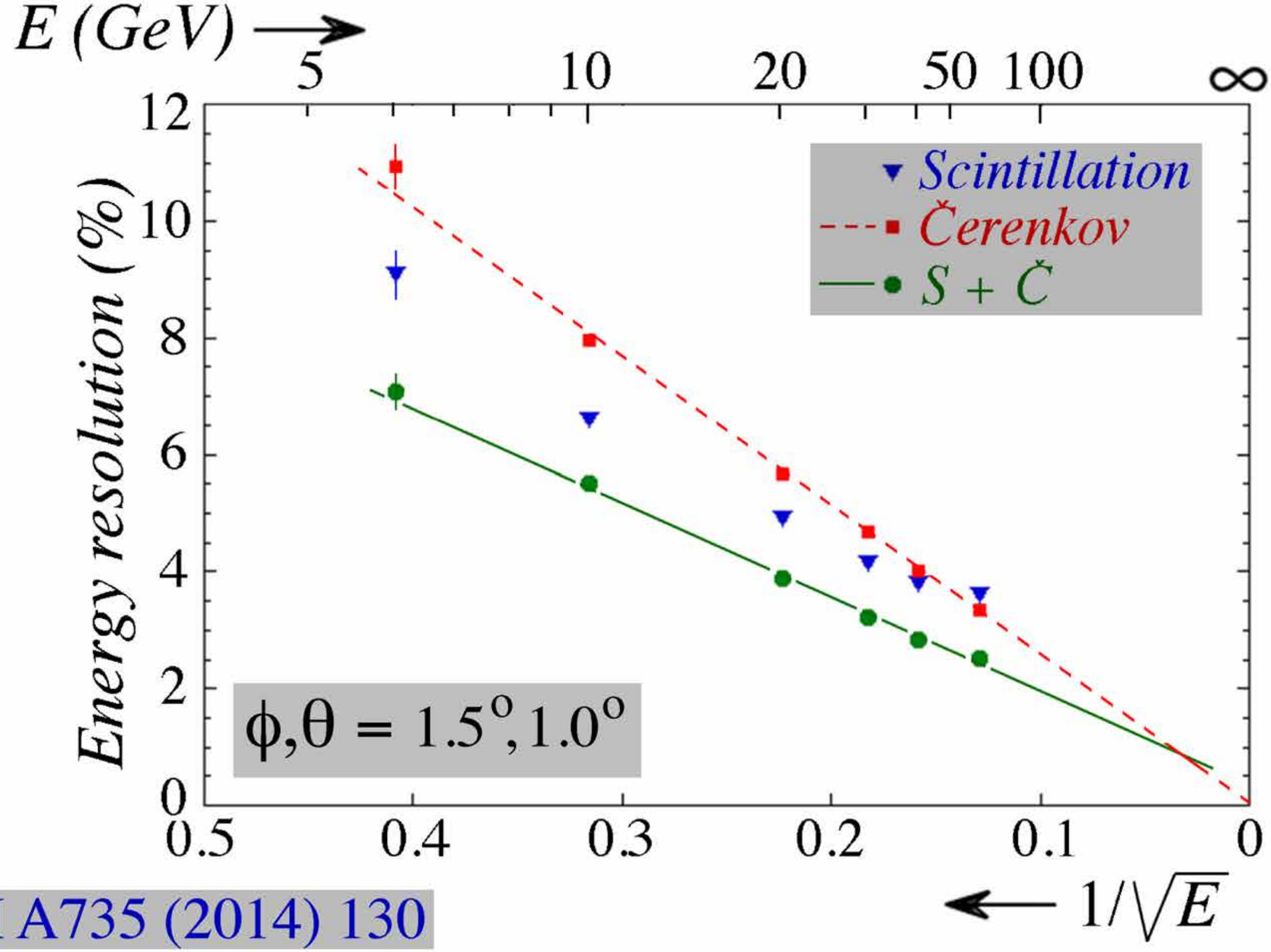
Electromagnetic performance RD52 calorimeter

Moreover, combining S and C signals further improves resolution



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Electromagnetic performance RD52 calorimeter

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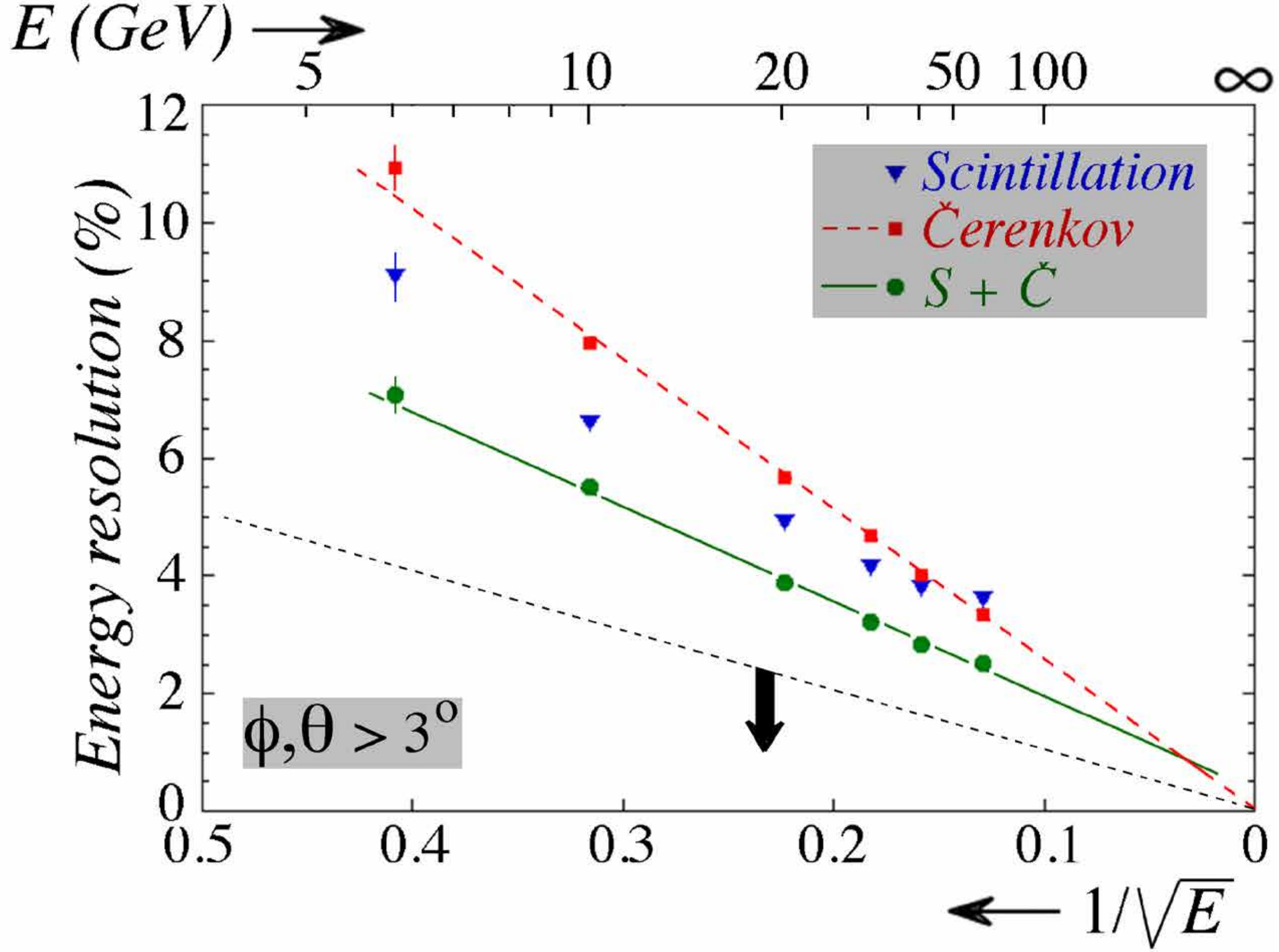
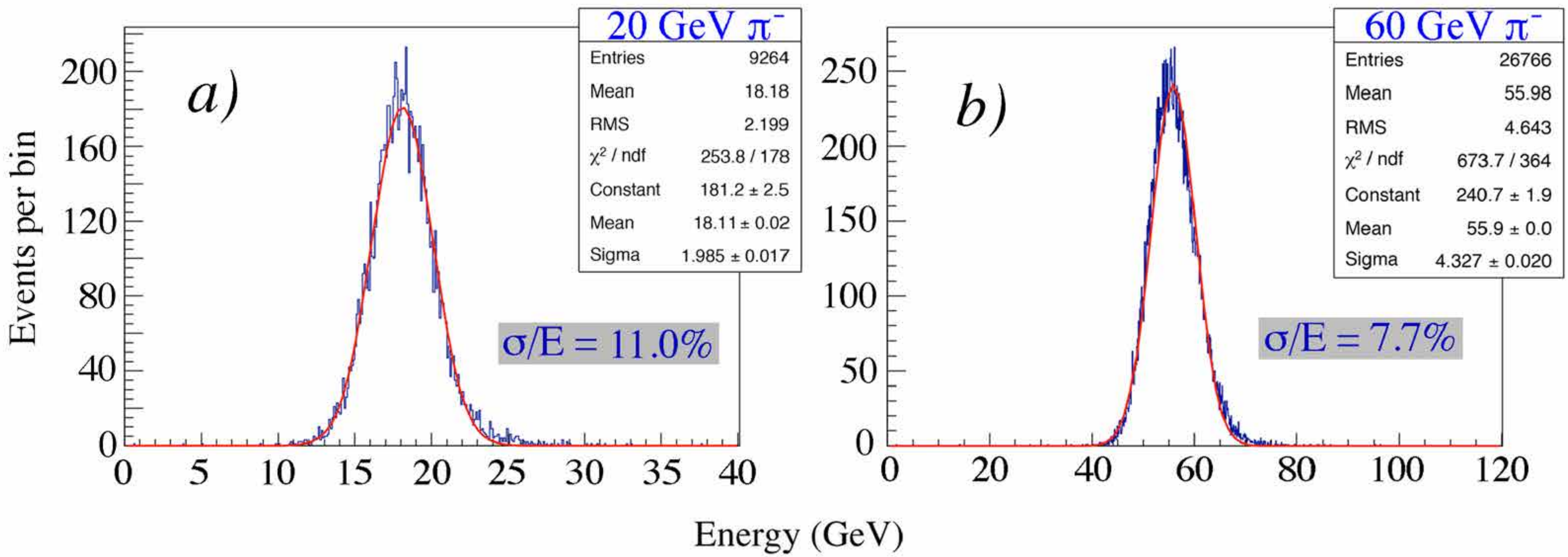


GEANT4: If angle of incidence > 3°, resolution < 10%/$\sqrt{E}$

Hadronic performance
(1.2 ton RD52 Pb based calorimeter)



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Energy resolution dominated by lateral leakage fluctuations
Average shower containment 93.6% @ 60 GeV

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*

However, a fine lateral granularity can do wonders

In addition:

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

Methods to distinguish e/π in longitudinally unsegmented calorimeter

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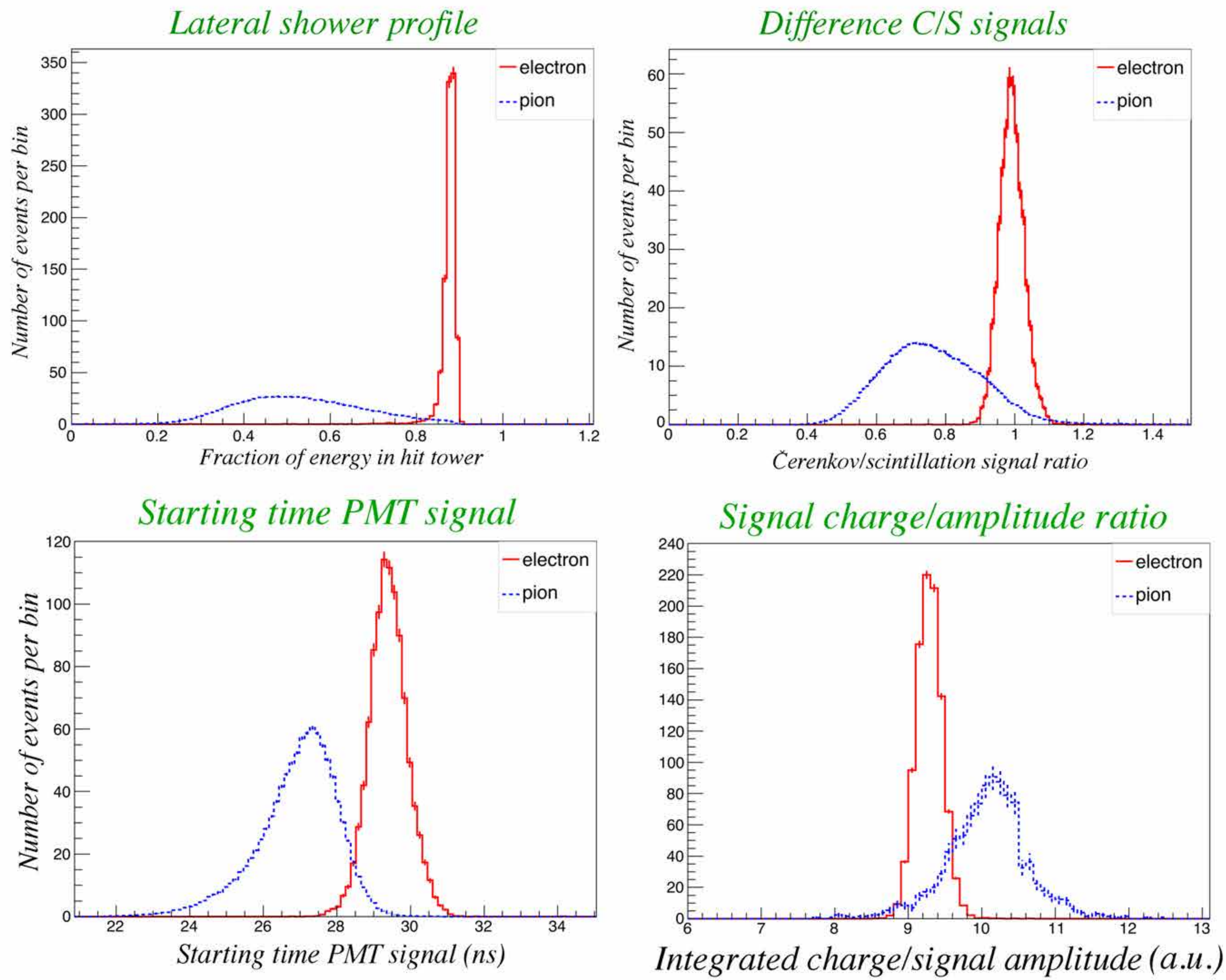


Combination of cuts: >99% electron efficiency, <0.2% pion mis-ID

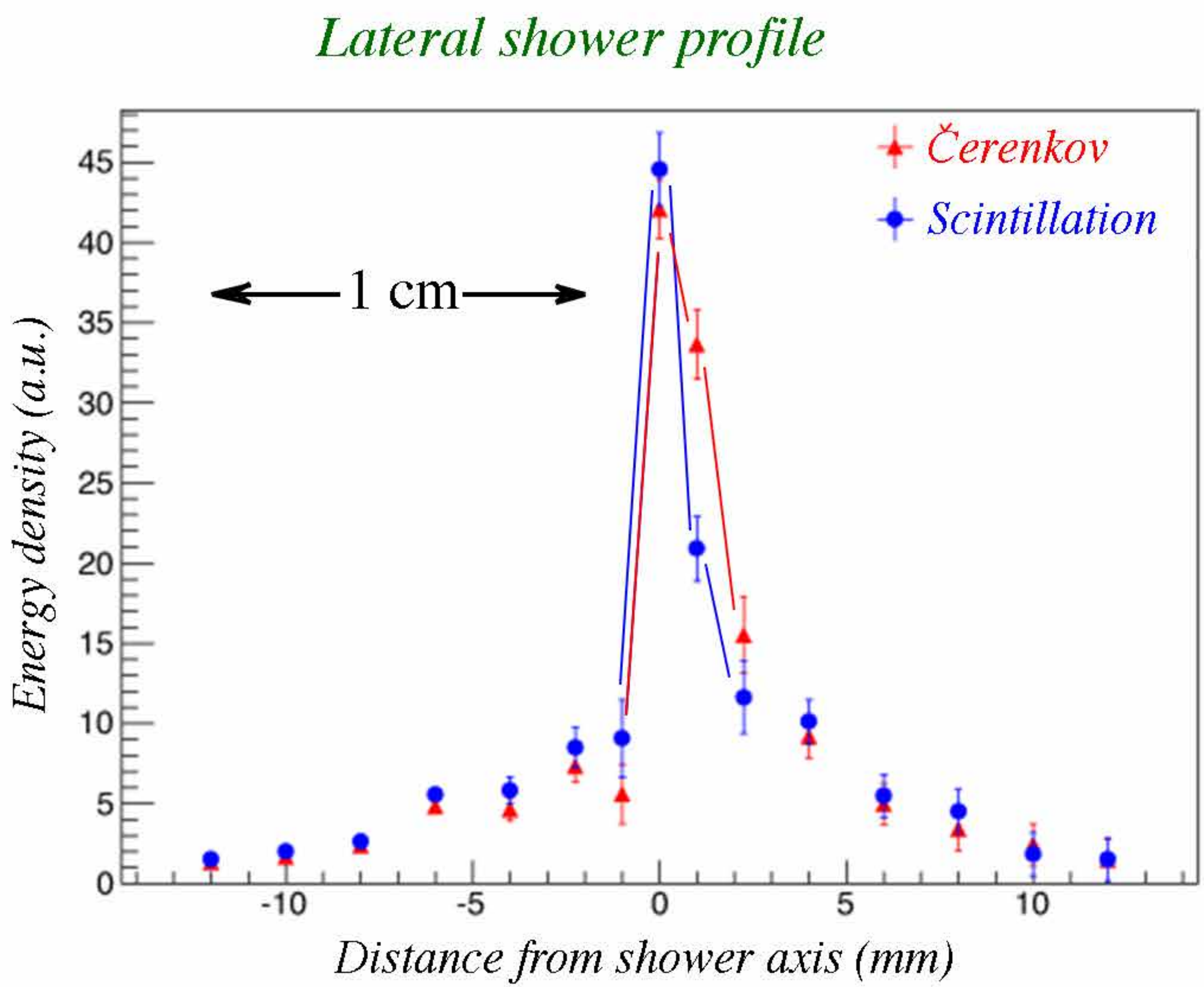
Attractive features of dual-readout fiber calorimeters

- *No intercalibration problems of longitudinal segments!*
  Calibrate with electrons and you are done
- *Uniform structure throughout detector, crucial for avoiding calibration problems*
- *Excellent resolution, for all particles*
  provided resolution is limited by sampling fluctuations
- *Possibility to make very fine LATERAL granularity*
  → *electron ID no problem*
  → *recognize electron in vicinity of other showering particles*
  → *separate closely spaced particles*

The RD52 calorimeter offers almost unlimited possibilities in that respect

- *In addition, the excellent time resolution achievable with Cherenkov light allows excellent position resolution (in depth), which may turn out to be very valuable for dealing with pile-up in high-rate experiments*

The extremely narrow electromagnetic shower profile



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Future research plans

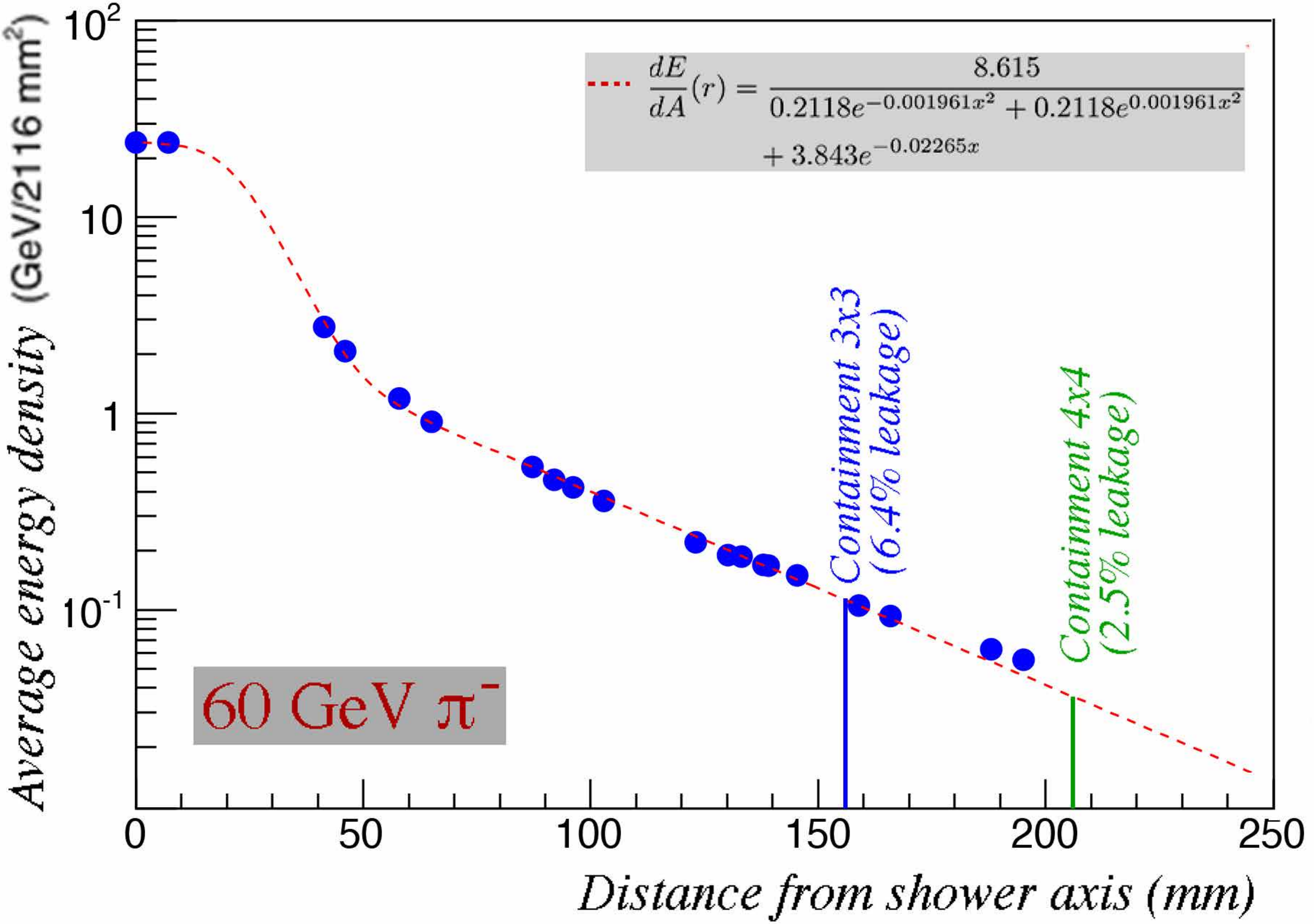
- *Increase the size of the SuperDREAM calorimeter as much as possible for next SPS tests*

  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



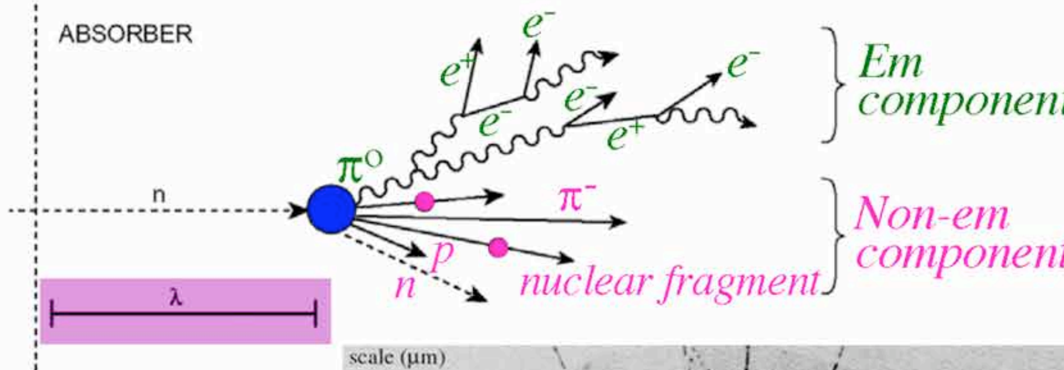
Summary

- The DREAM approach combines the advantages of compensating calorimetry with a reasonable amount of design flexibility
- The dominating factors that limited the hadronic resolution of compensating calorimeters (ZEUS, SPACAL) to 30 - 35%/$\sqrt{E}$ can be eliminated
- The theoretical resolution limit for hadron calorimeters (15%/$\sqrt{E}$) seems within reach
- The DREAM project holds the promise of high-quality calorimetry for *all* types of particles, with an instrument that can be calibrated with electrons

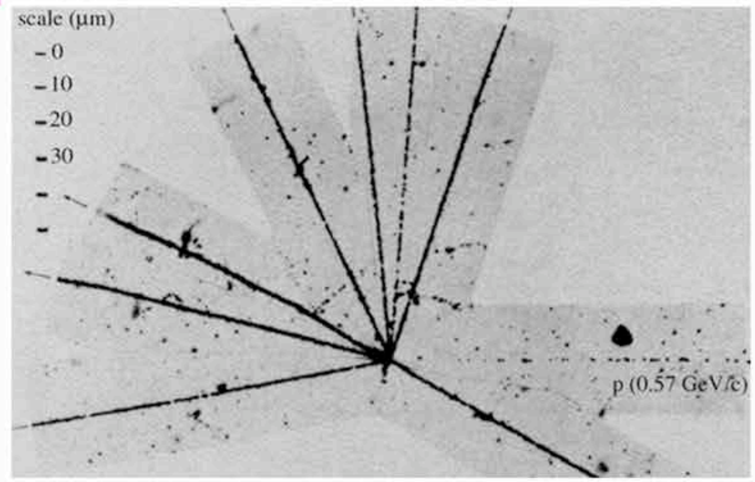
Backup slides

Hadronic Shower Development

- *A hadronic shower consists of two components*



  - *Electromagnetic component*
    - electrons, photons
    - neutral pions → 2 γ
  - *Hadronic (non-em) component*
    - charged hadrons $\pi^{\pm}$,$K^{\pm}$ (20%)
    - nuclear fragments, p (25%)
    - neutrons, neutrino's, soft γ's (15%)
    - break-up of nuclei *("invisible")* (40%)



- *Important characteristics for hadron calorimetry:*
  - *Large, non-Gaussian fluctuations in energy sharing em/non-em*
  - *Large, non-Gaussian fluctuations in "invisible" energy losses*
  - *Calorimeter response (average signal/GeV) different for em/non-em shower components (e/h ≠ 1)*
  - *Average em shower fraction increases with energy*