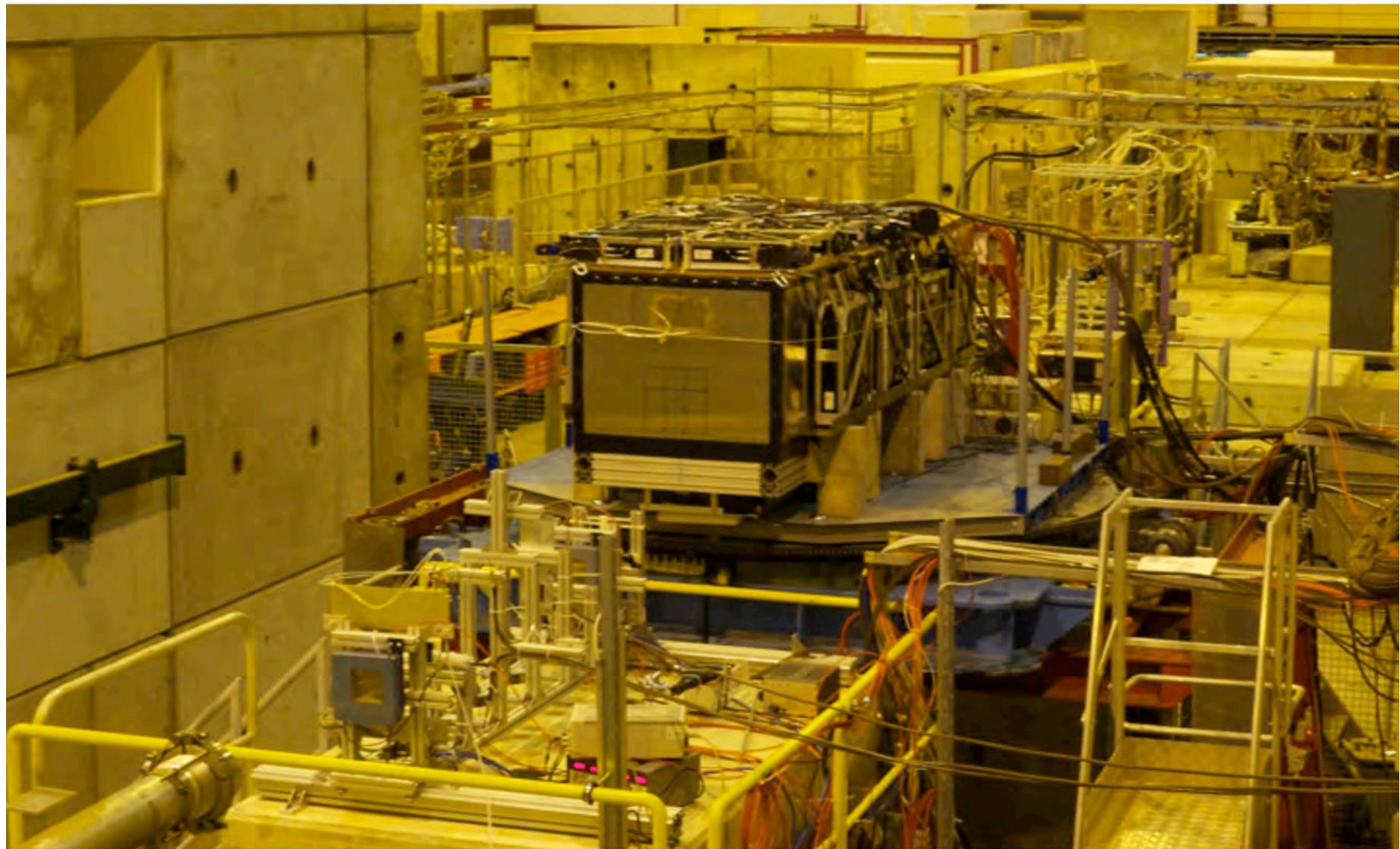


RD52 (DREAM)

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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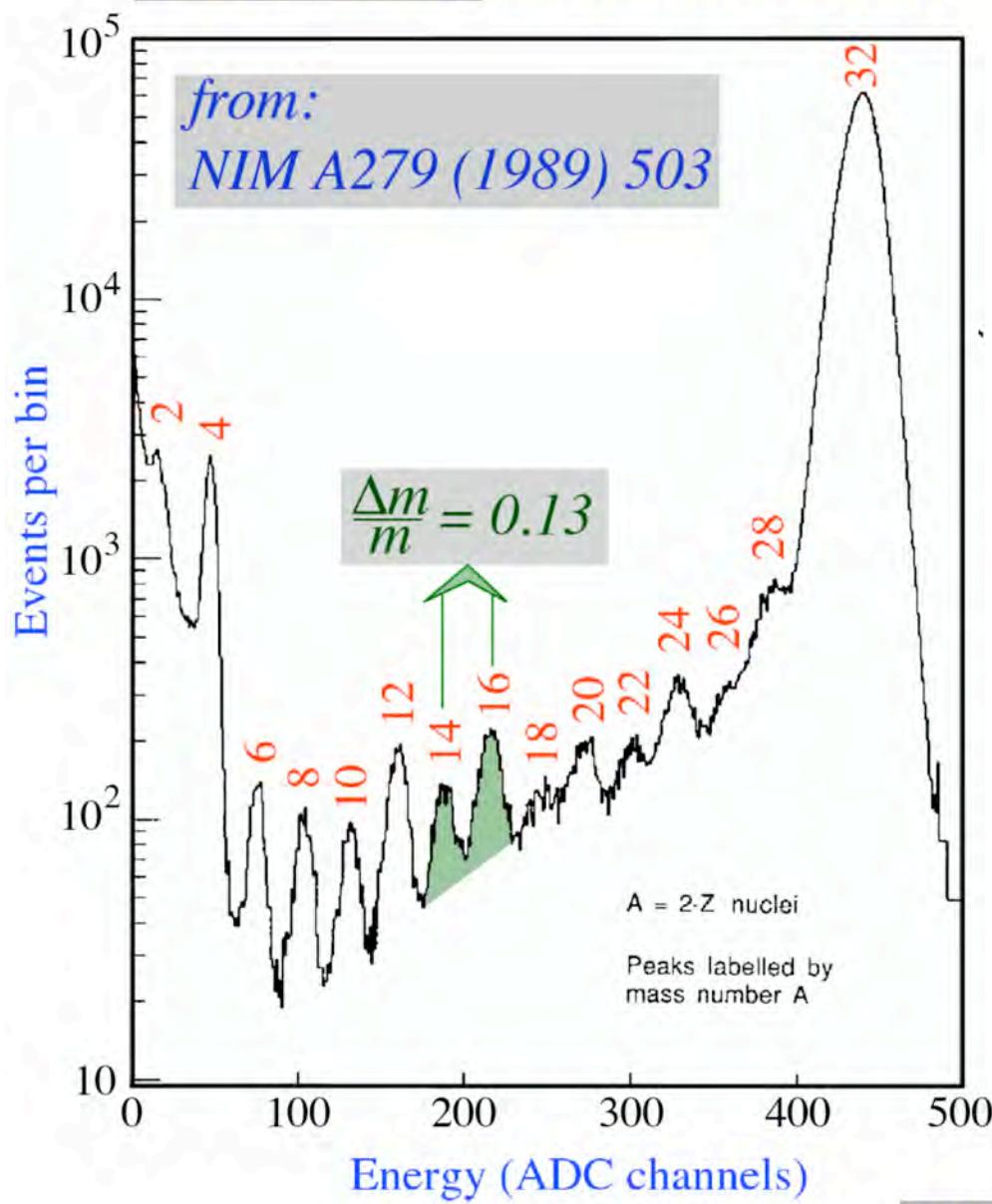
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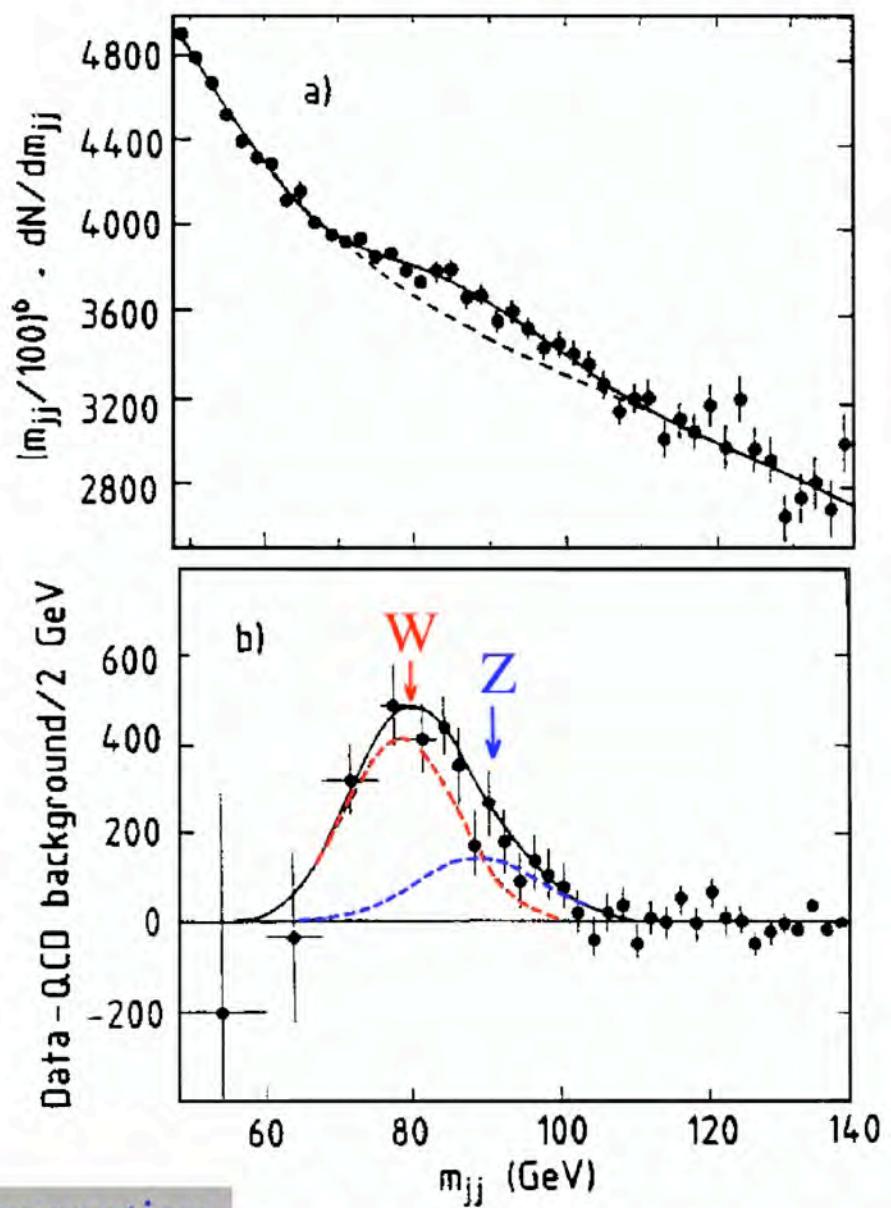
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The importance of high-quality hadron calorimetry

Compensating calorimeter (WA80)



UA2: Non-compensating



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

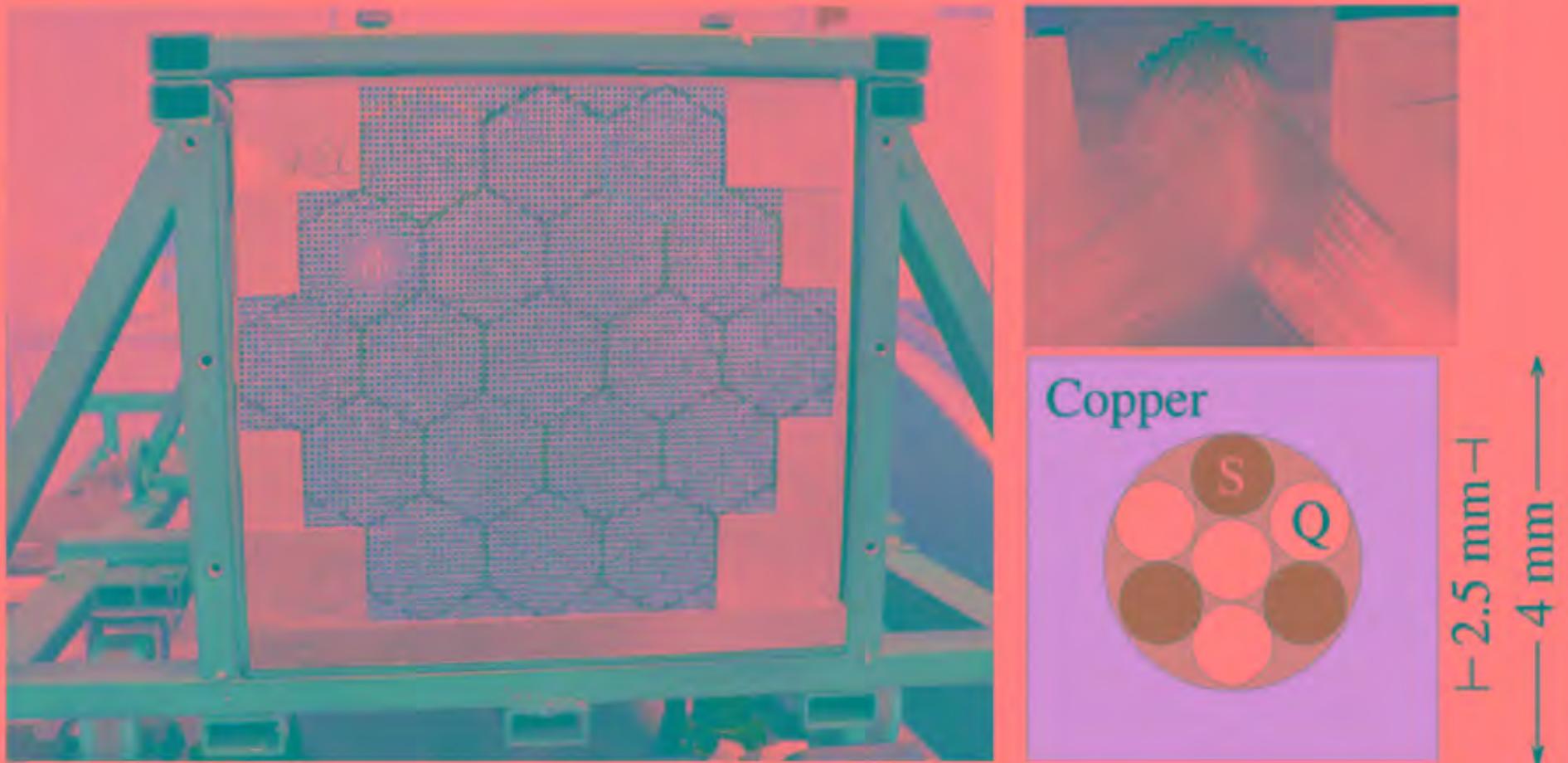
*An attractive option for improving the quality of hadron calorimetry:
Use Čerenkov light!! Why?*

- Hadron showers < em component (π^0)
 non-em component (mainly soft p)
- Calorimeter response to these components not the same ($e/h \neq 1$)
- 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)

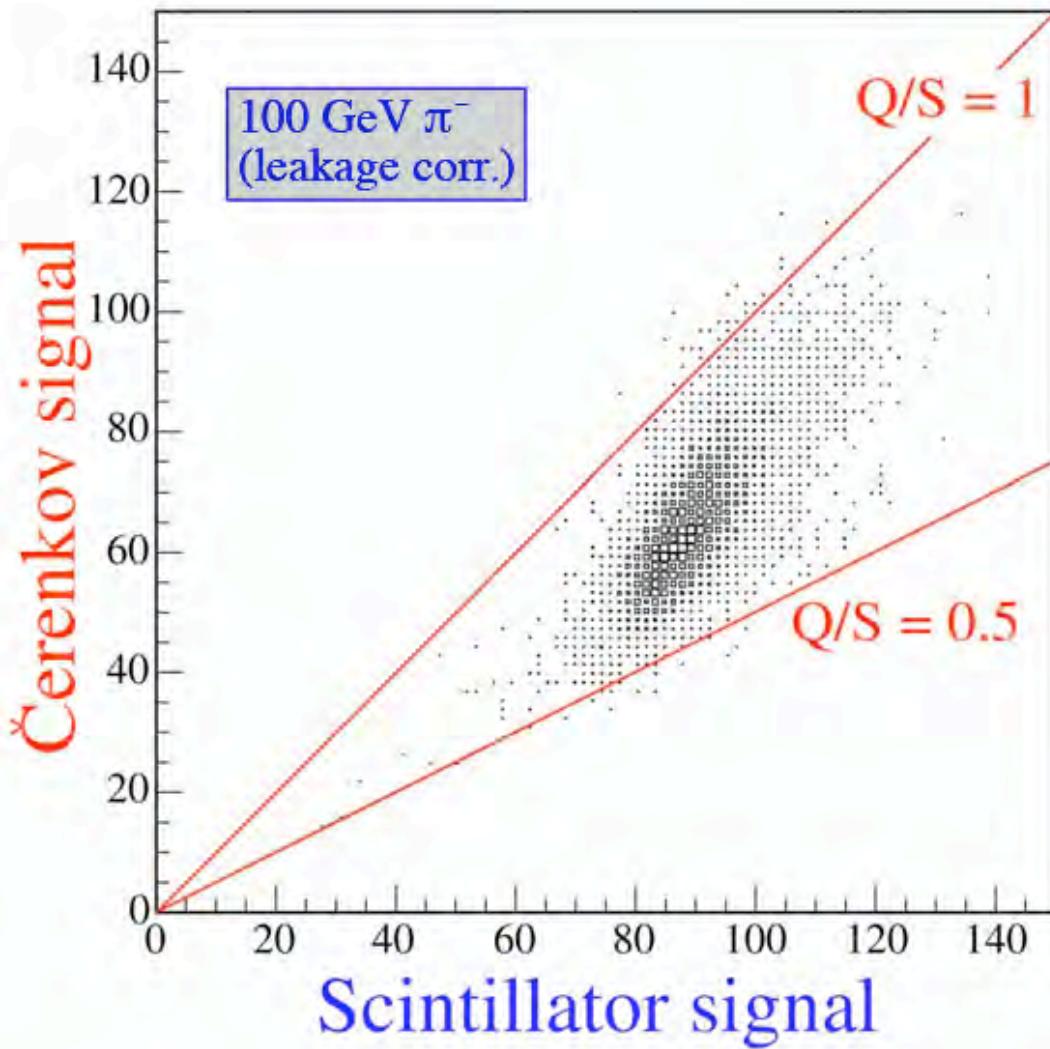
→ DREAM (Dual REAdout Method) principle:
Measure f_{em} event by event by comparing Č and dE/dx signals

The original DREAM calorimeter



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

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



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

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

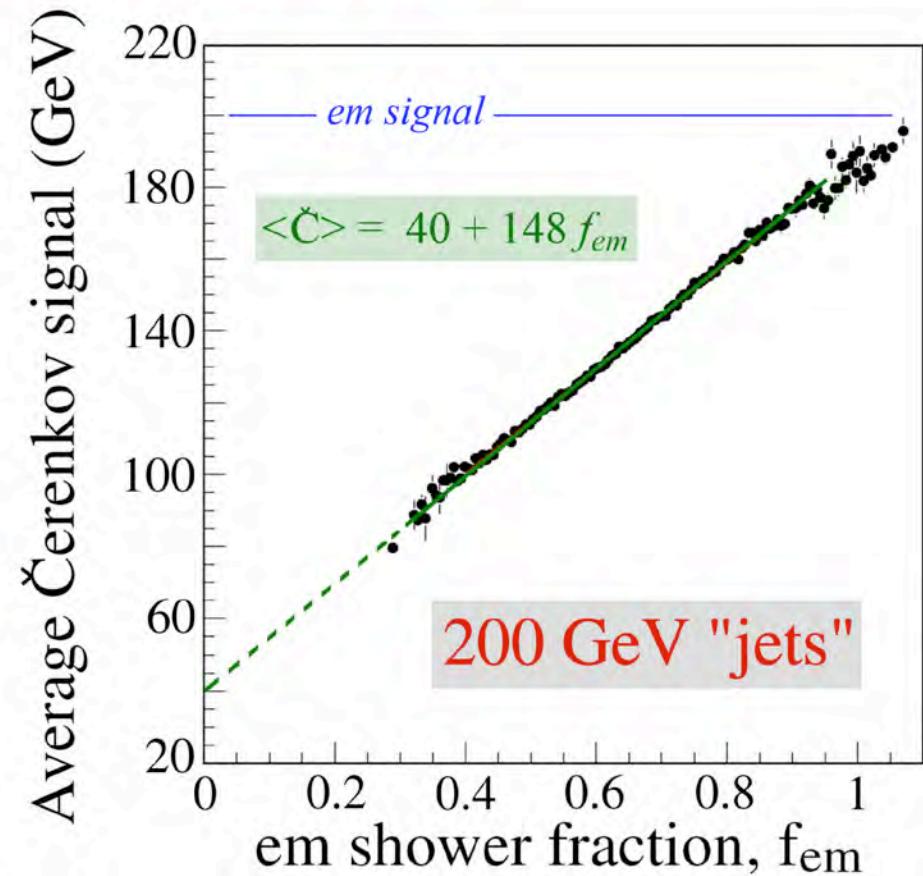
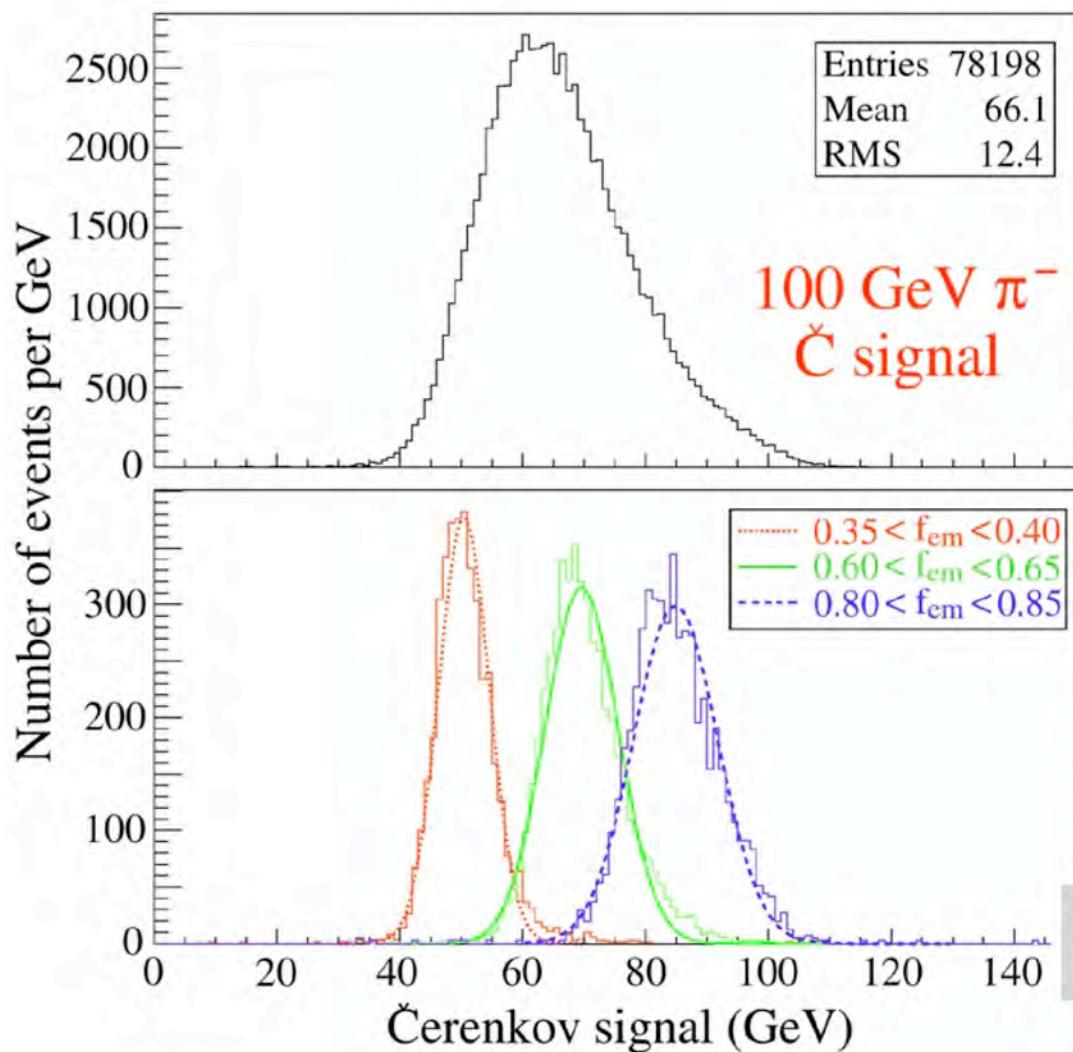
e.g. If $e/h = 1.3$ (S), 4.7 (Q)

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

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

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

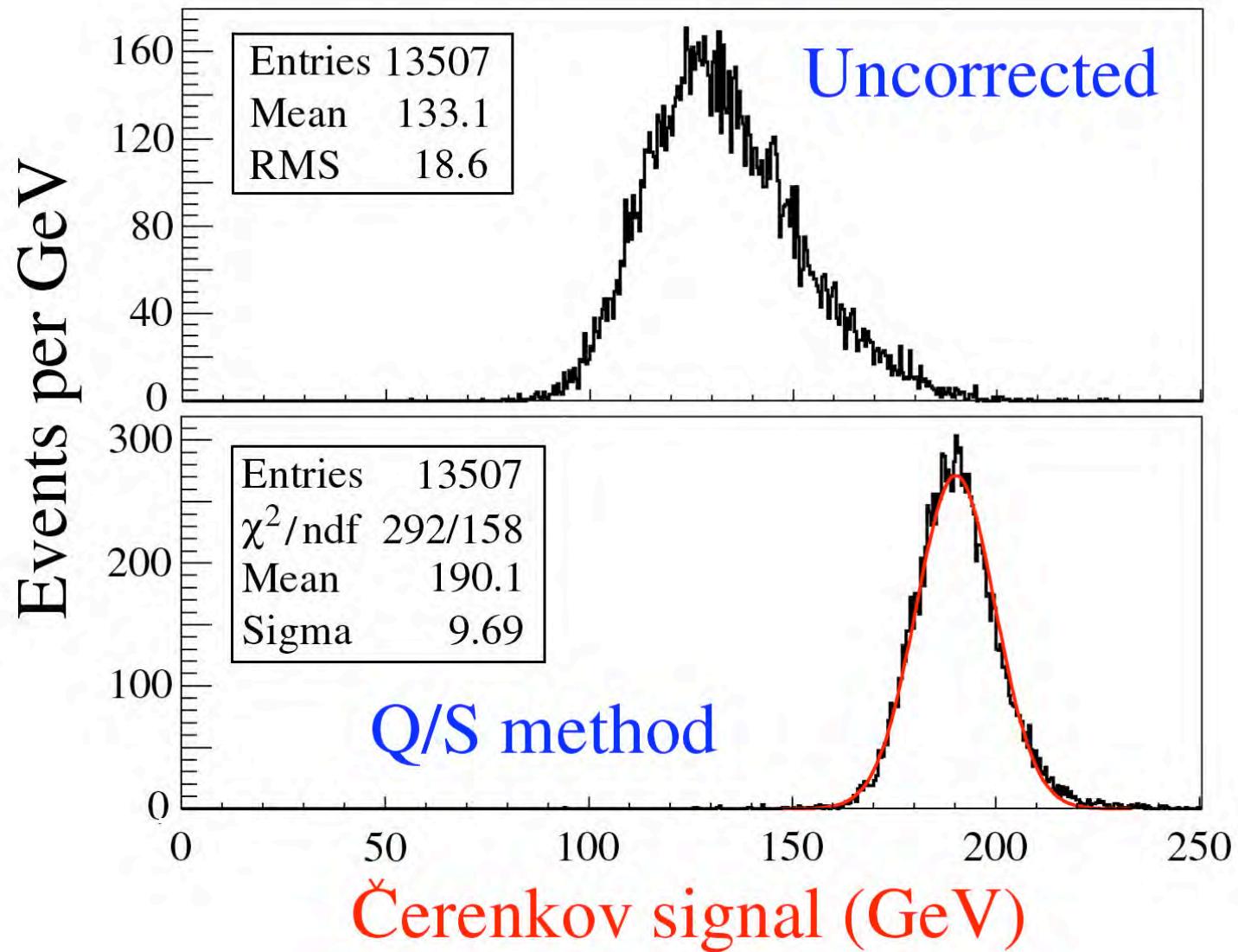
DREAM: Effect of event selection based on f_{em}



From:
NIM A537 (2005) 537

*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

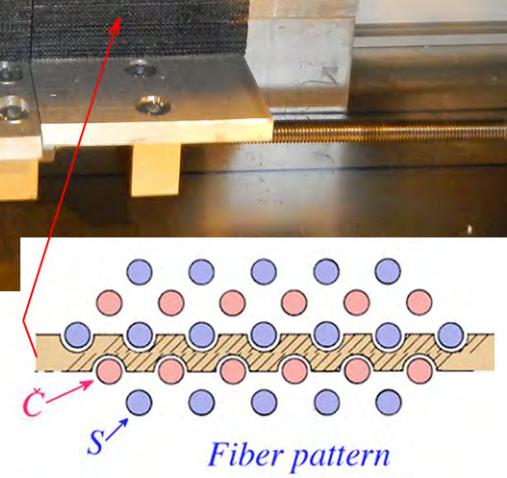
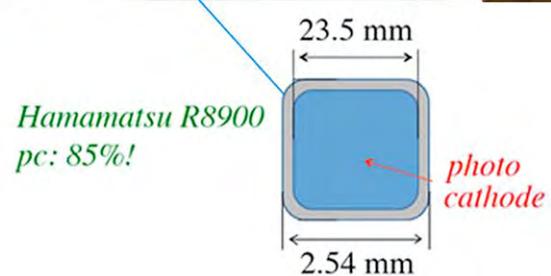
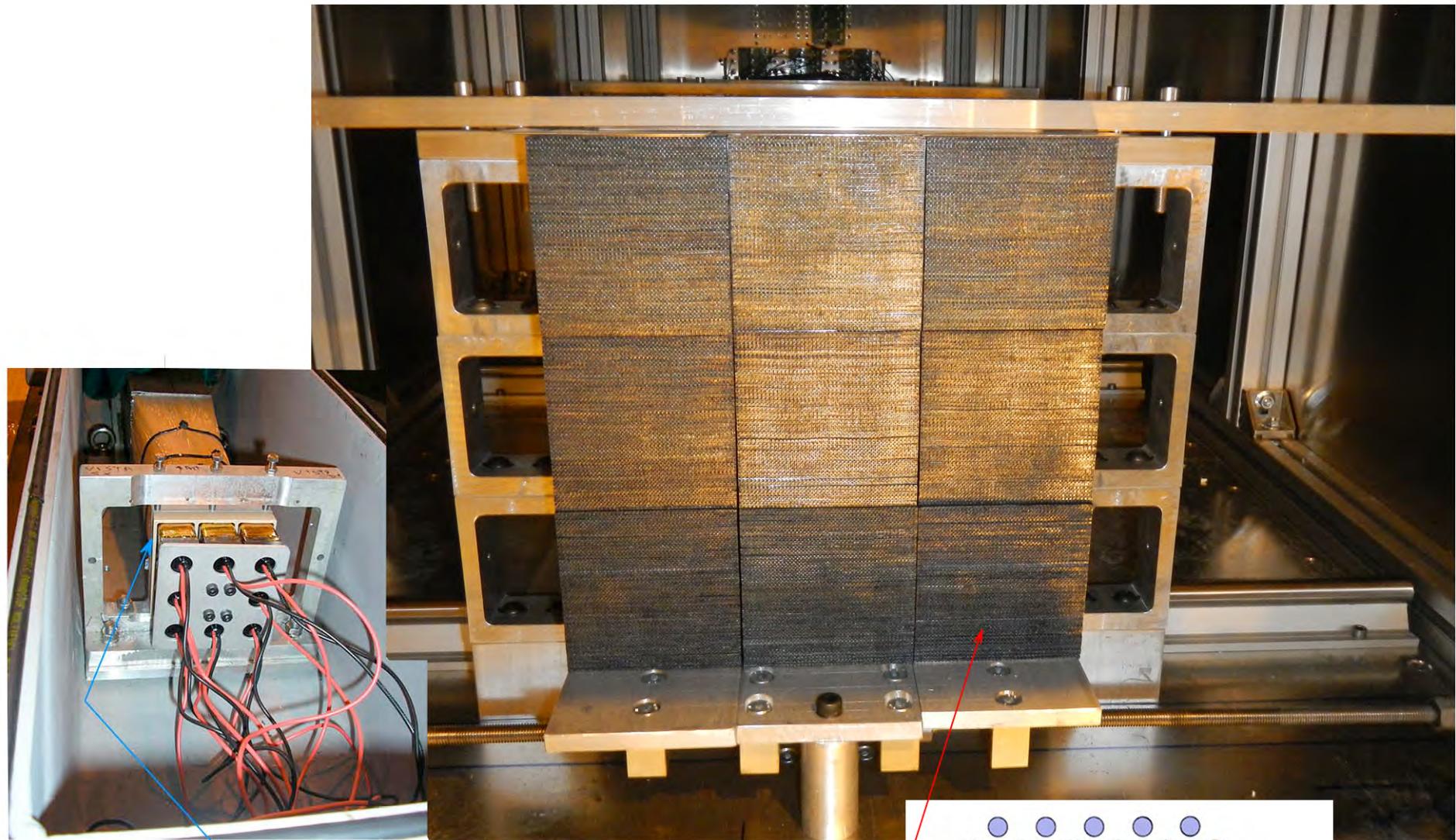
- DREAM offers a powerful technique to *improve* hadronic calorimeter performance:
 - Correct hadronic energy reconstruction, *in an instrument calibrated with electrons!*
 - Linearity for hadrons and jets
 - Gaussian response functions
 - Energy resolution scales with $1/\sqrt{E}$
 - $\sigma/E < 5\%$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

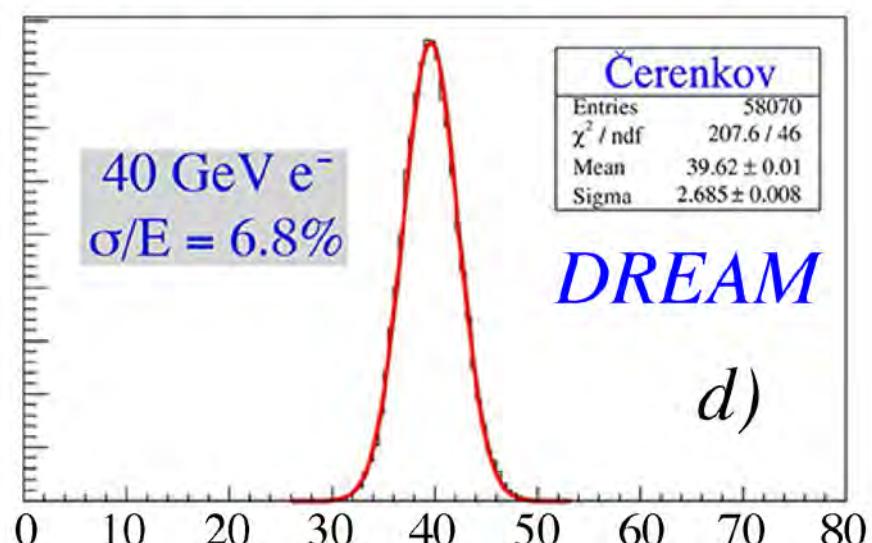
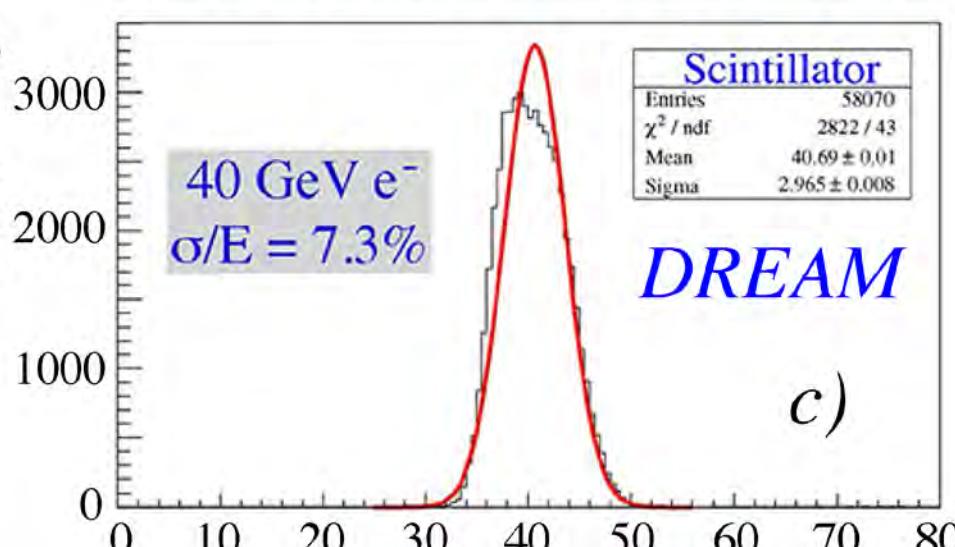
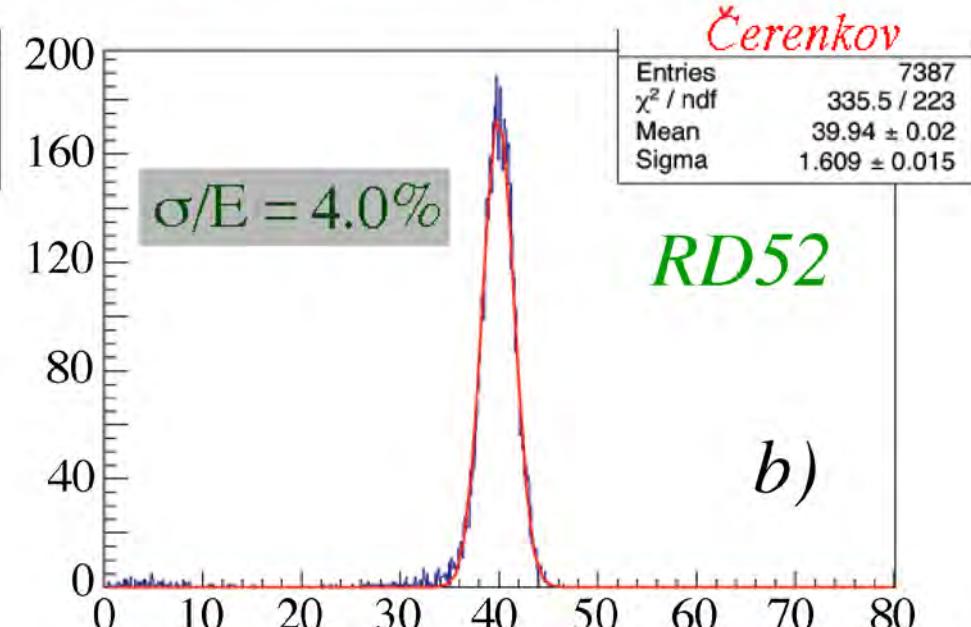
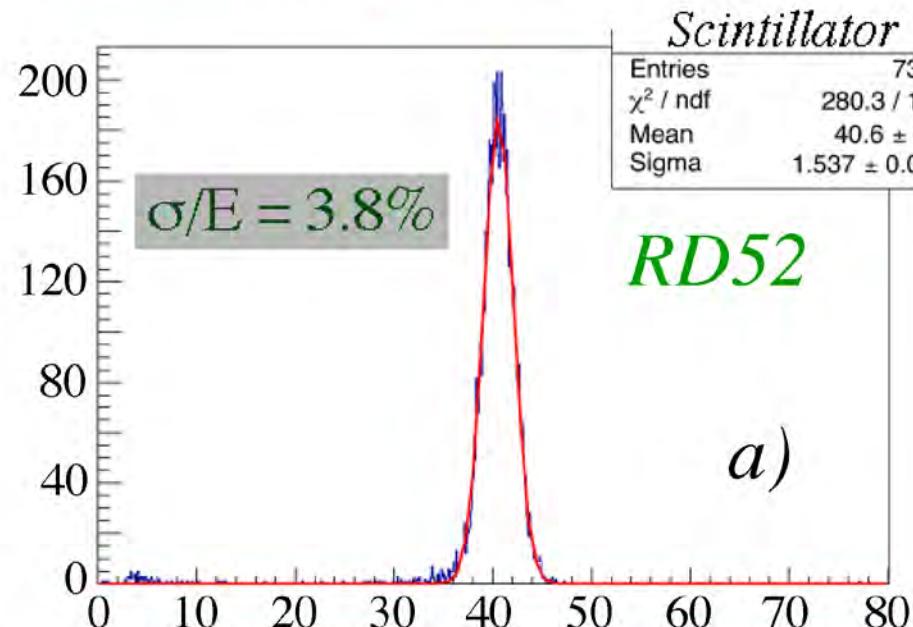
*And this performance can be achieved with a calorimeter consisting of
low-Z absorber material!*

The new RD52 fiber calorimeter



Electromagnetic performance strongly improved in RD52

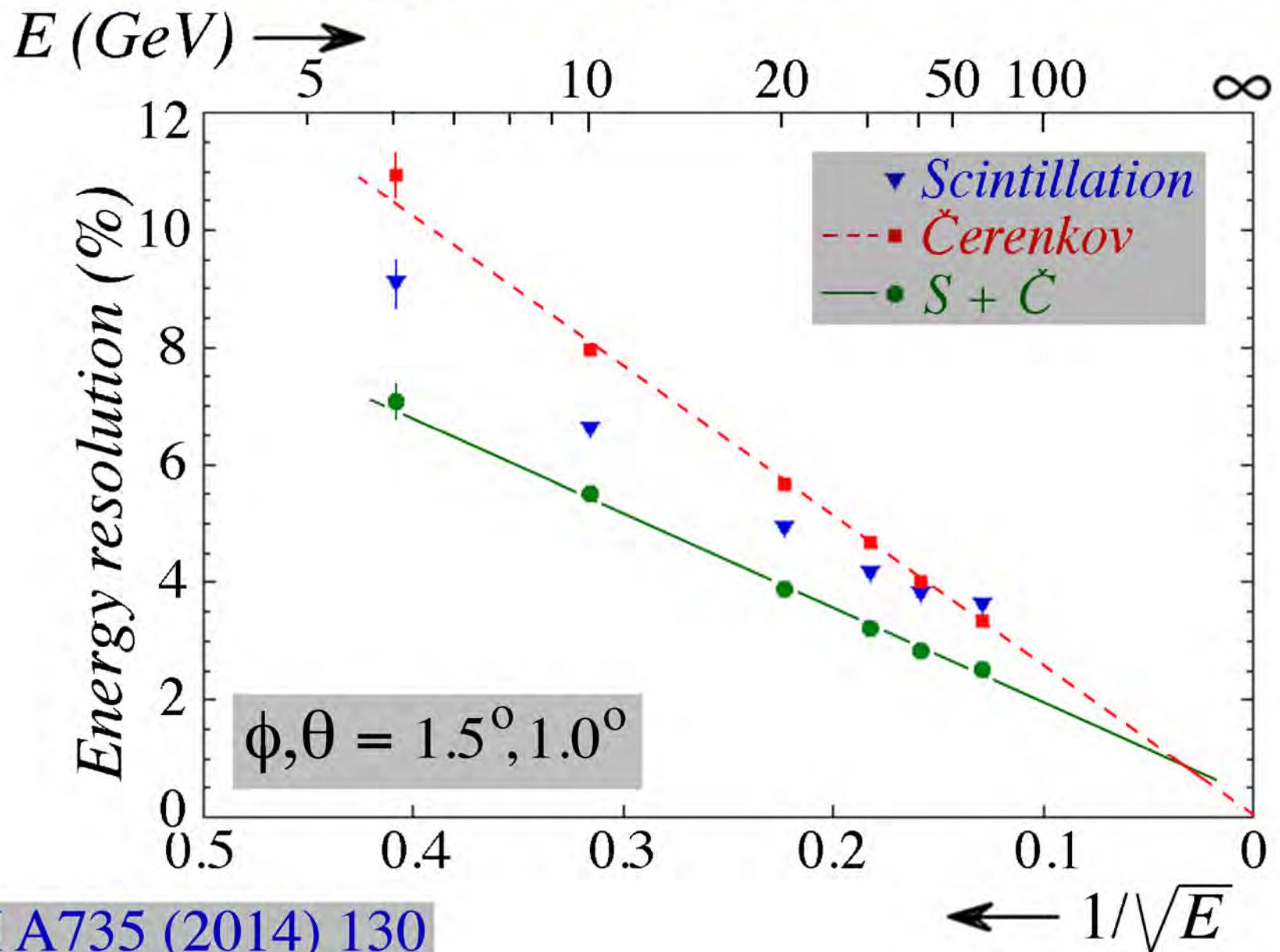
Number of events per bin



Calorimeter signal (GeV)

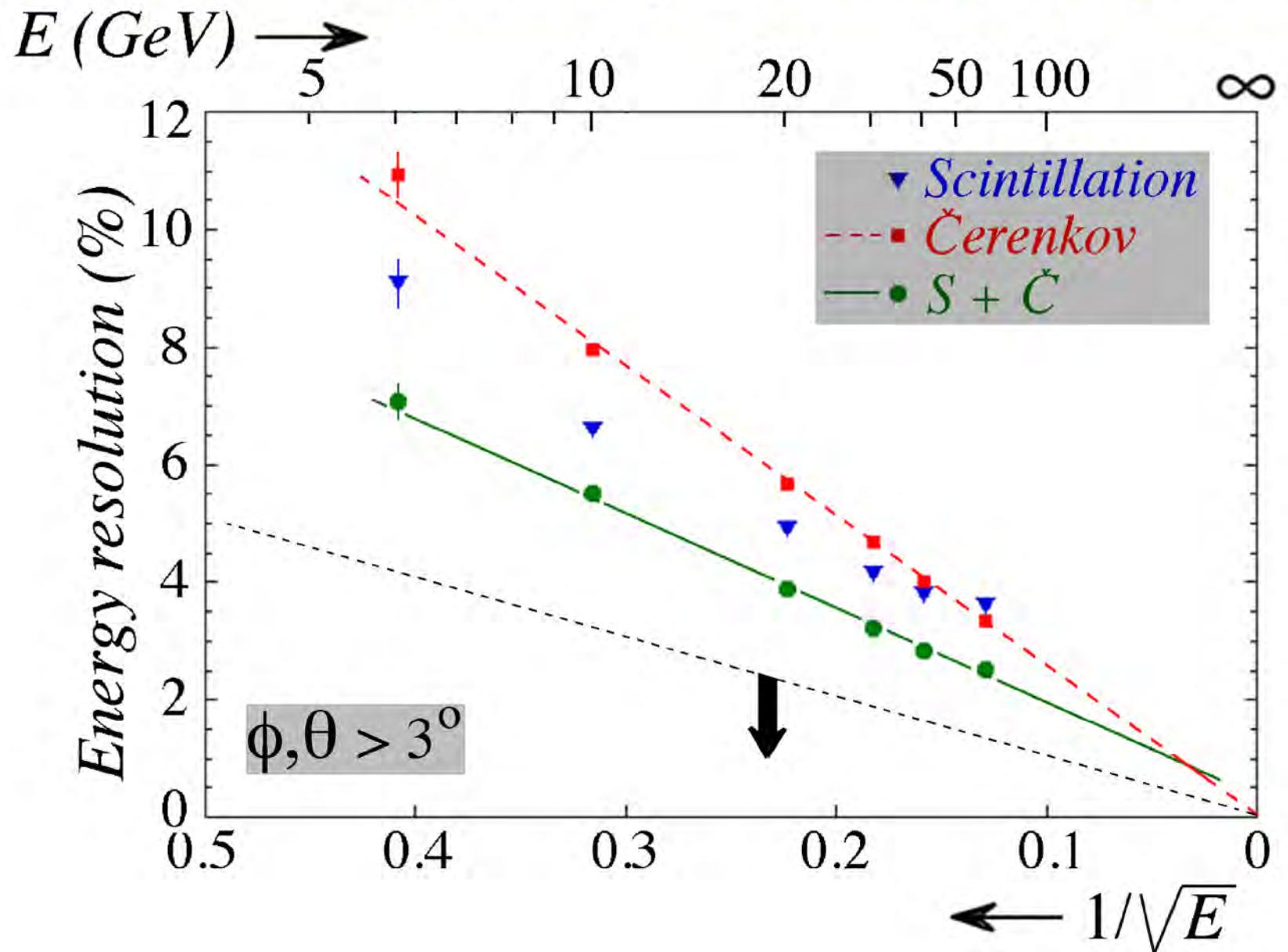
Electromagnetic performance RD52 calorimeter

Moreover, combining S and C signals further improves resolution



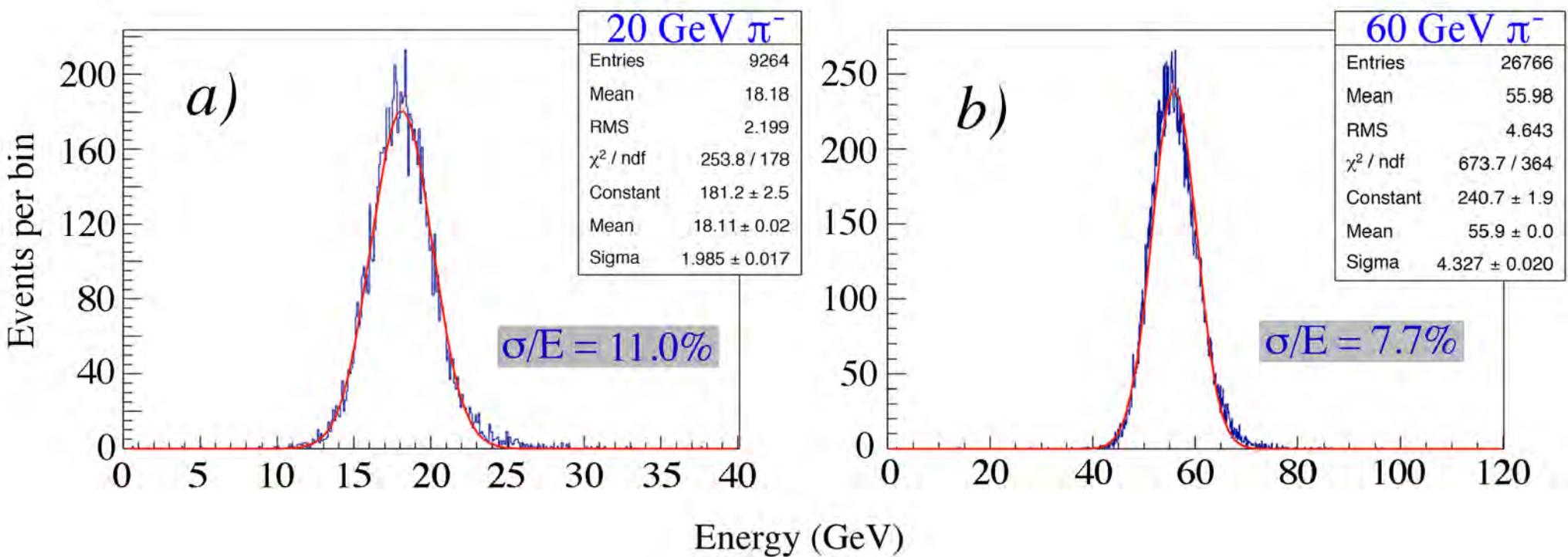
Electromagnetic performance RD52 calorimeter

Moreover, combining S and C signals further improves resolution



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

Hadronic performance (1.2 ton RD52 Pb based calorimeter)



NIM A732 (2013) 475

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

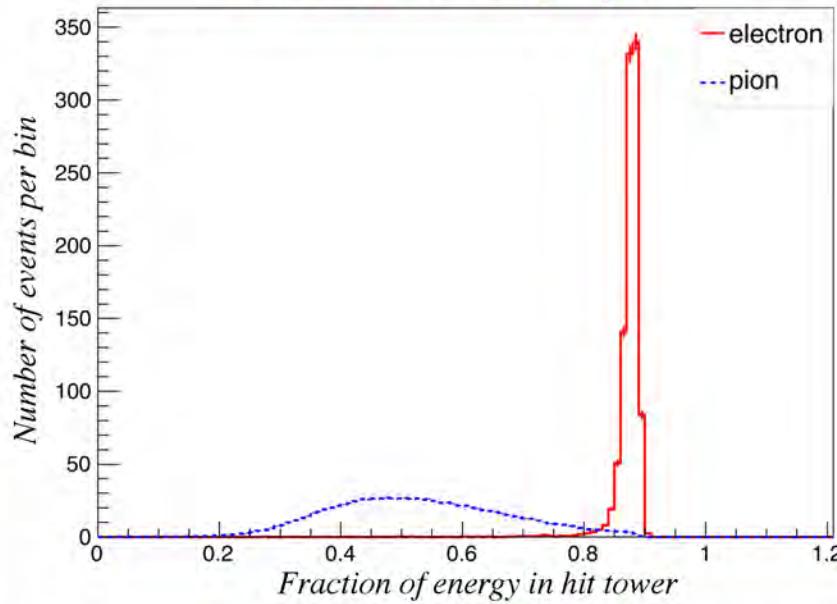
A crucial feature: No longitudinal segmentation

- *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*

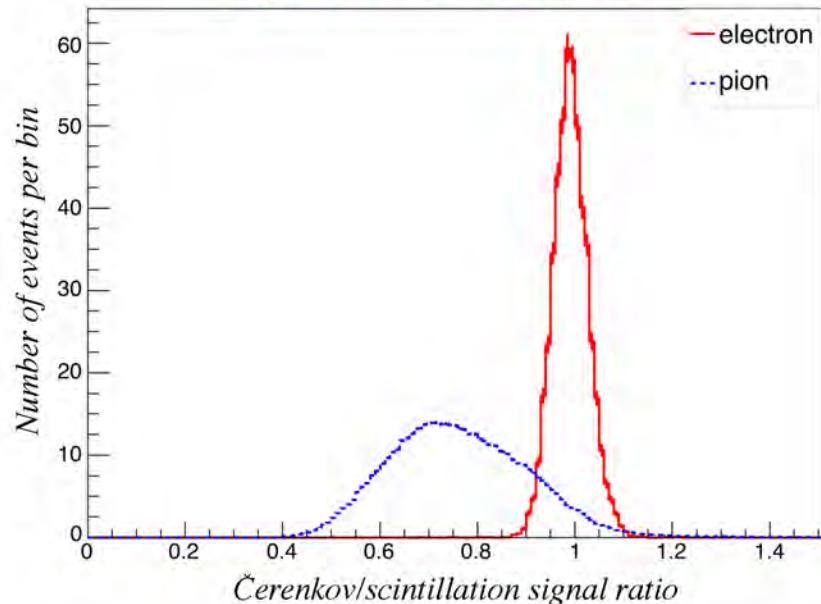
Methods to distinguish e/π in longitudinally unsegmented calorimeter

NIM A735 (2014) 120

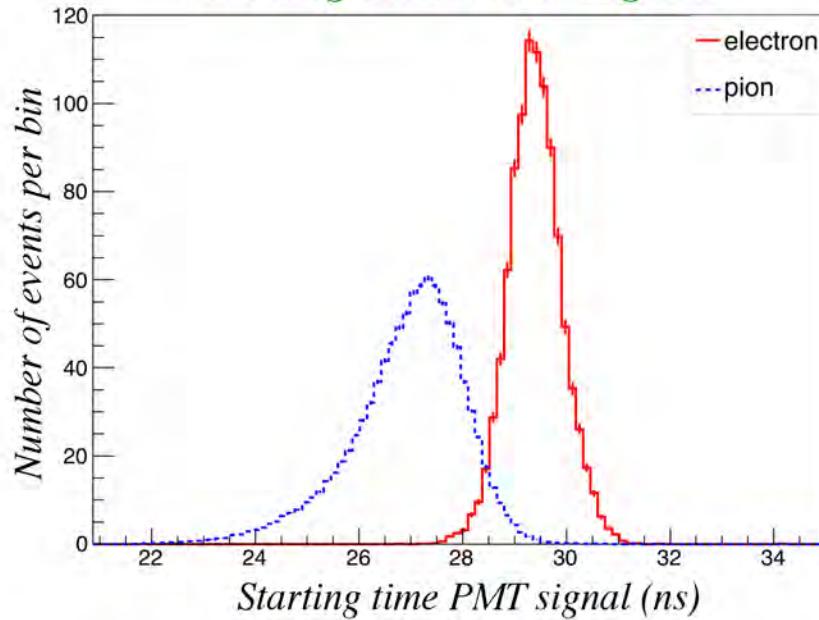
Lateral shower profile



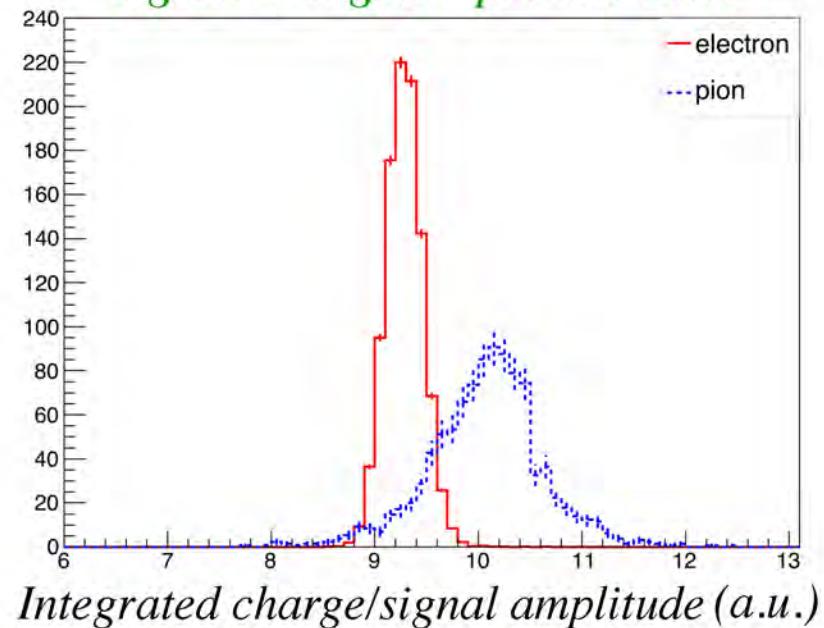
Difference C/S signals



Starting time PMT signal



Signal charge/amplitude ratio



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

Attractive features of dual-readout fiber calorimeters

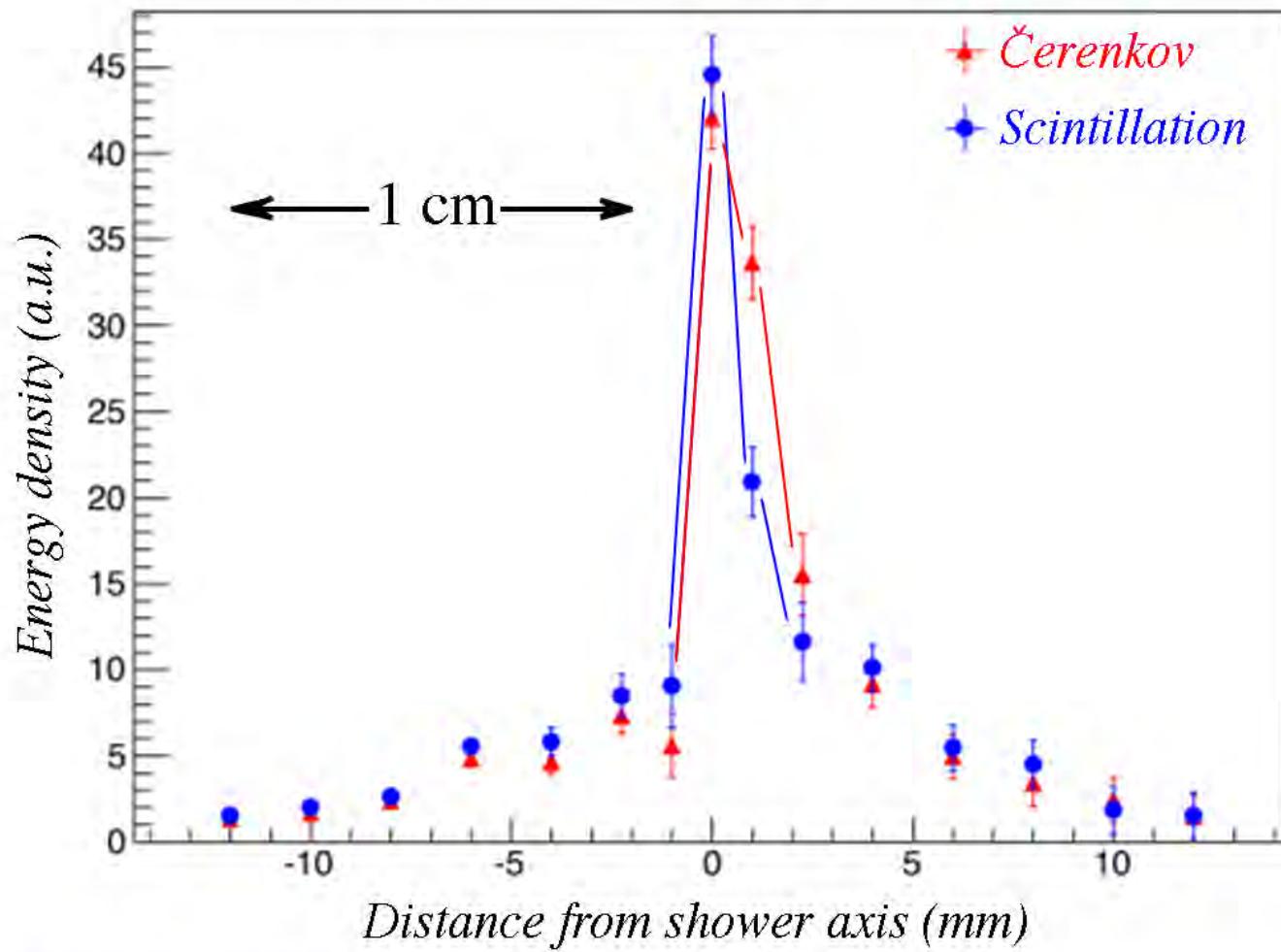
- *No intercalibration problems of longitudinal segments!
Calibrate with electrons and you are done*
- *Uniform structure throughout detector, crucial for avoiding calibration problems*
- *Excellent resolution, for all particles
provided resolution is limited by sampling fluctuations*
- *Possibility 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

Lateral shower profile



Future research plans

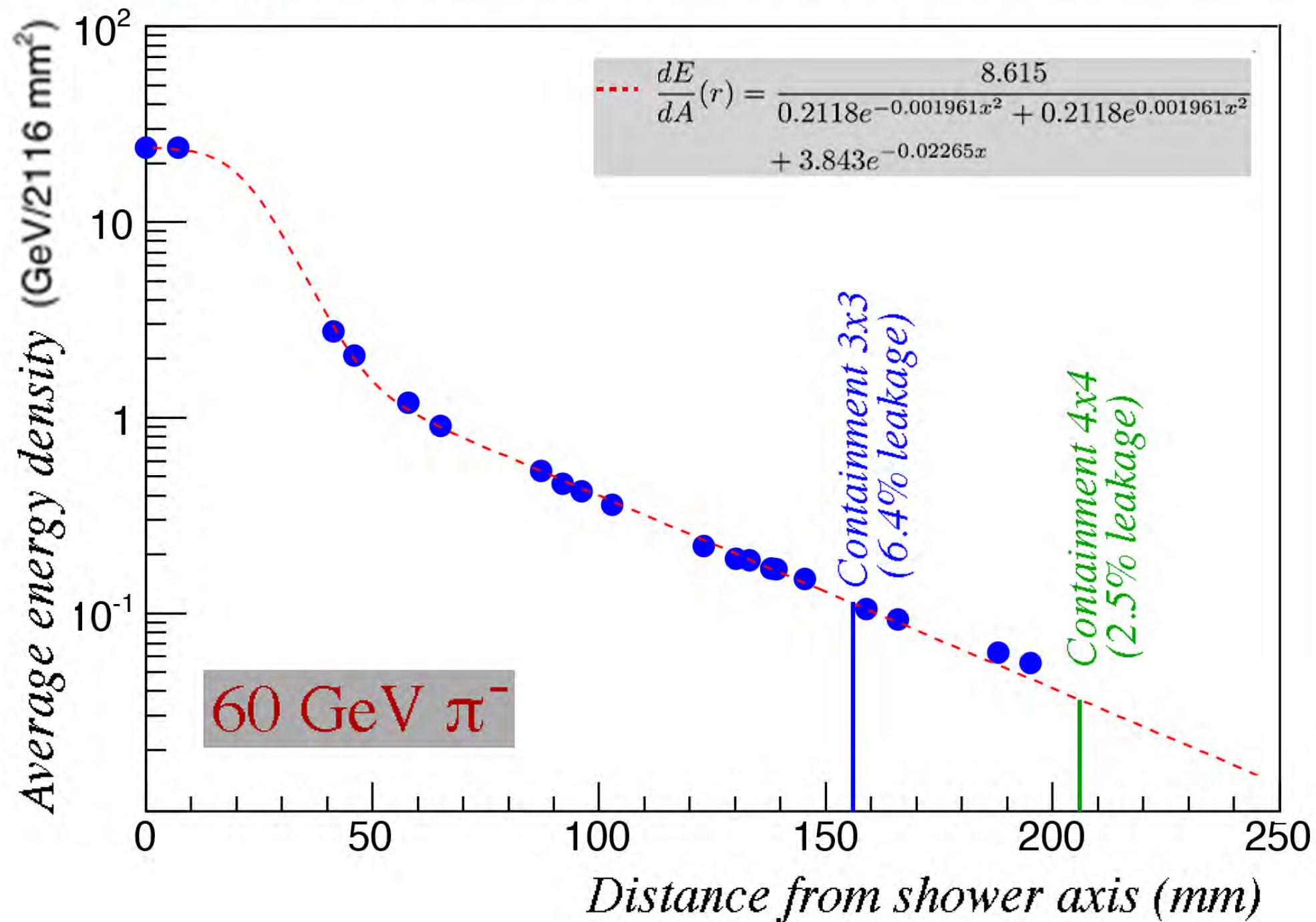
- Increase the size of the SuperDREAM calorimeter as much as possible for next SPS tests

*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

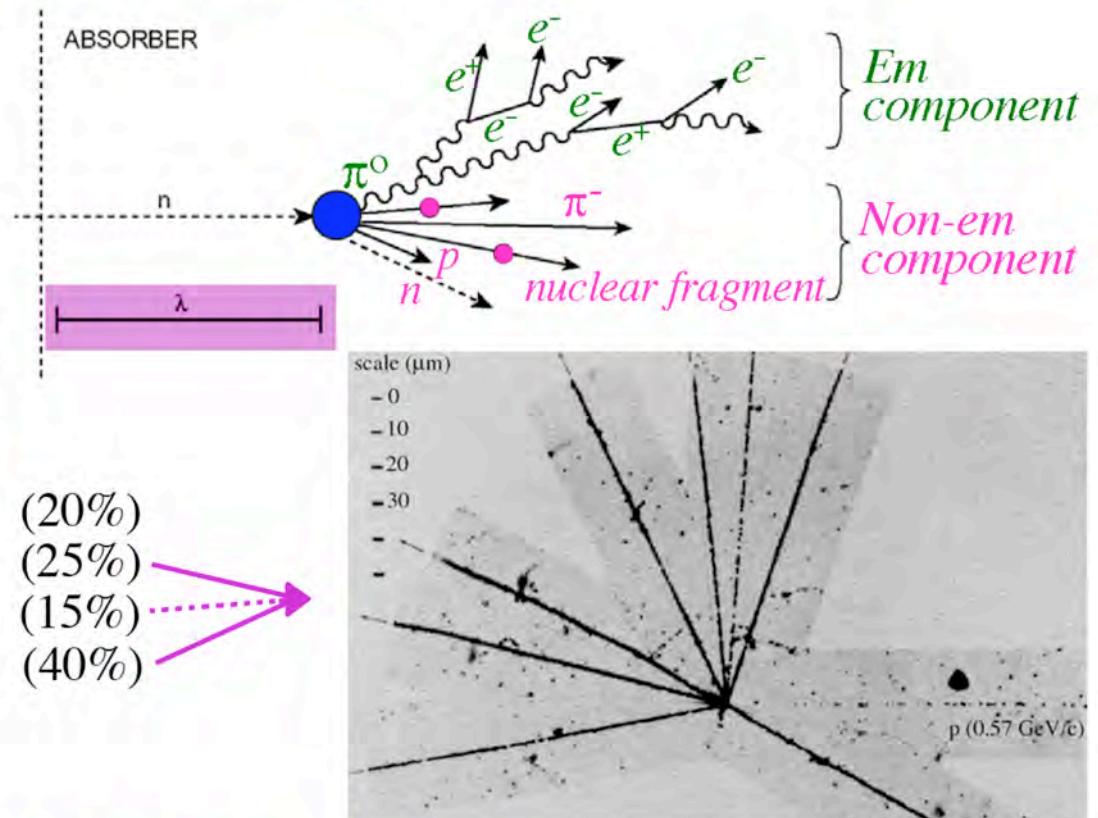
- A hadronic shower consists of two components

- Electromagnetic component**

- electrons, photons
- neutral pions $\rightarrow 2 \gamma$

- Hadronic (non-em) component**

- charged hadrons π^\pm, K^\pm
- nuclear fragments, p
- neutrons, neutrino's, soft γ 's
- break-up of nuclei ("invisible")



- 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 ($e/h \neq 1$)
- Average em shower fraction increases with energy