Leakage correction for the totally active dual readout calorimeter

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Outline

- Introduction
- Calorimeter composition and geometry
- Calorimeter response calibration
- S/C correlations and the DR correction
- Leakage corrections

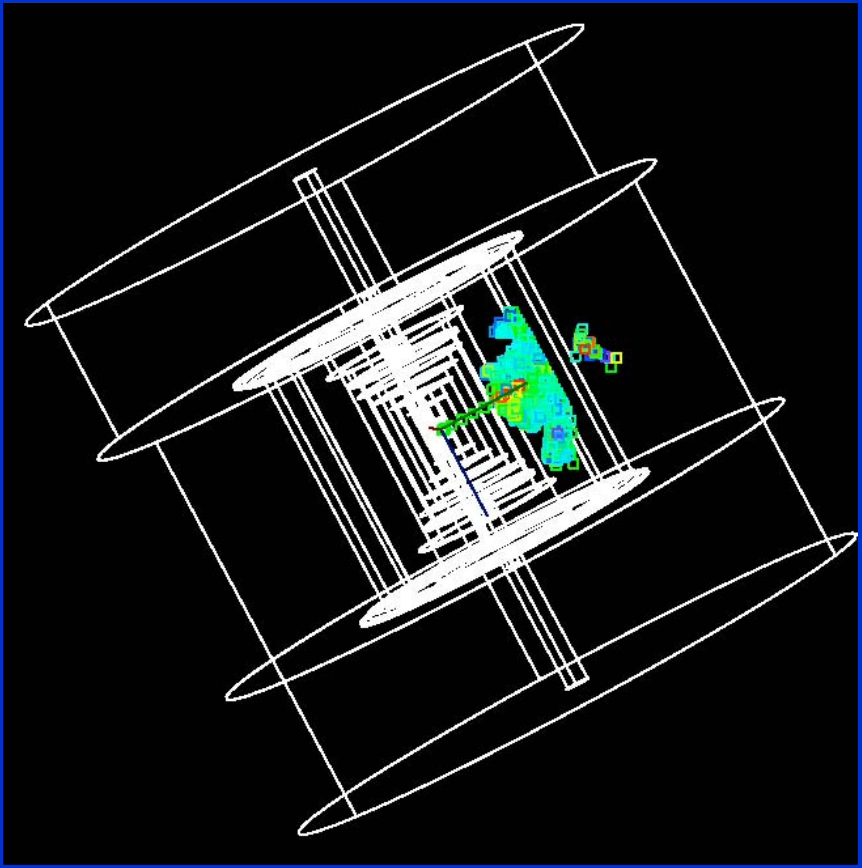
Related presentations:
A Para: Wed. Calorimetry session:
"Dual Readout in Totally Active Calorimeters
Hans Wenzel: Friday Simulation and Reconstruction Session:
"Implementing a dual readout clorimeter in SLIC and testing GEANT4 physics"

Introduction

Practical considerations limit calorimeter dimensions → leakage energy loss

The leakage energy fluctuates and the fractional fluctuation increases with energy until

it exceeds the stochastic term and sets the limit on the achievable energy resolution

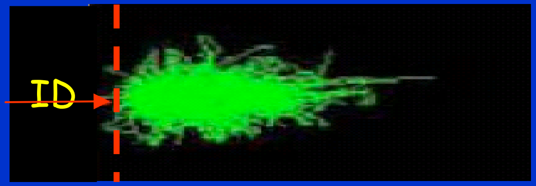


Leakage is of particular concern for compact detectors such as SID

Introduction ctd.

The **goal** of the simulation study reported here is to:

- understand the effects of leakge fluctuations on the energy resolution of **totally active dual readout calorimeters**
- investigate methods for correcting them



Leakage fluctuations depend on:

- the starting point of the hadron shower ("Interaction Depth or ID")
- the extension of the shower

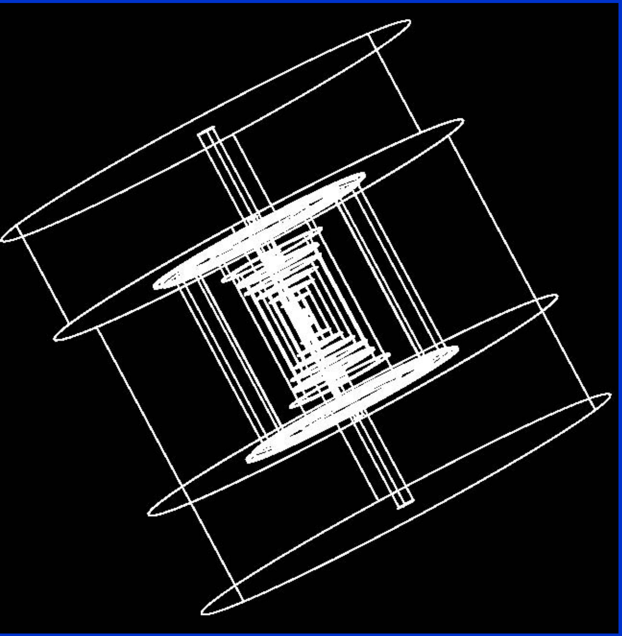
→it is expected that the segmentation might be exploited to correct for leakage

*We report on first attempts to exploit segmentation to this end.
*Algorithms exploiting information from a muon detector/tail catcher are also devoped for comparison.
*The magnetic field is set to zero for the study reported here

Calorimeter composition and Geometry

The SiD calorimeter volume is filled with sensitive BGO-like material of uniform composition. Only the (finer) segmentation distinguishes the initial "EM" section from the remaining "Had" volume.

Different compositions and segmentations were investigated. Most of the results reported here were for BGO-like crystal (density =7.13 g.cm^3)



- **EM calorimeter**:
  6 layers 5 cm thick, with a transverse segmentation of 5x5 cm.
- **HAD calorimeter**:
  9 layers 10 cm thick, with a readout transverse segmentation of 10x10 cm.
- **The muon system/ tail-catcher**
  is implemented as a 48 layer sampling calorimeter

Total cal. thickness: 120cm ←→ ~5.5 λ_{int} → significant leakage

-

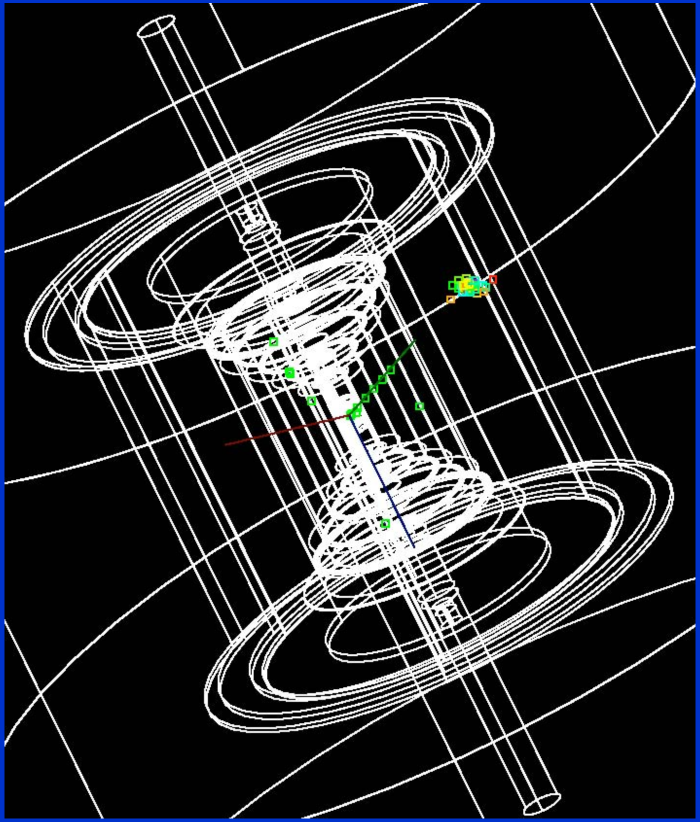
Calorimeter response calibration

Data is simulated for incident pions and electrons. Both ionisation (S_i) and Čerenkov (C_i) energy depositions are recorded for each calorimeter element i and summed to form total raw signals S_r and C_r signals, respectively.

Assuming no energy loss for electrons, the corresponding raw signals are normalized to the incident electron energies:

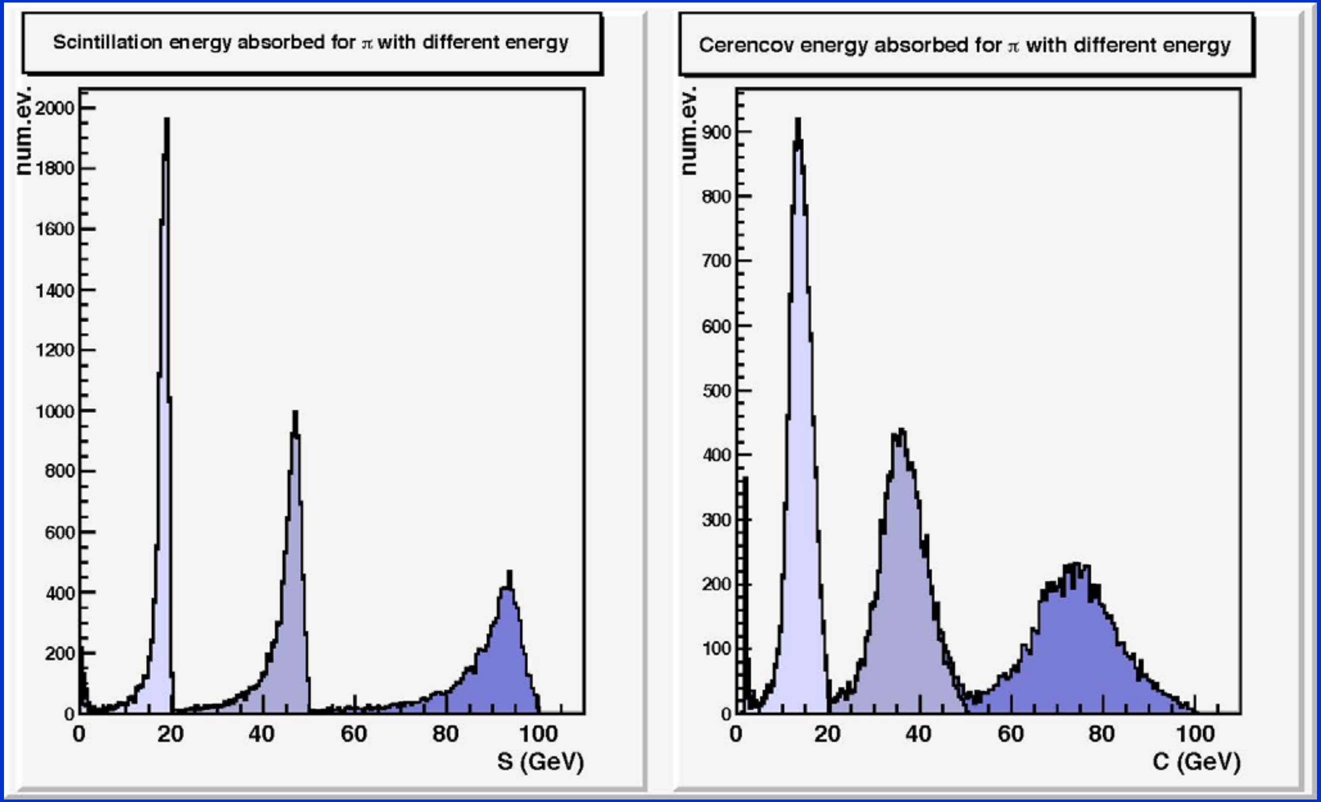
$$E_e = A_S \langle S_r \rangle \quad \text{and} \quad E_e = A_C \langle C_r \rangle$$

for all of the data shown here calibration were calculated at 100 GeV (A_S = 1.0014 and A_C = 8251) and applied at all energies.



The same calibratrions are the applied to the pion data:

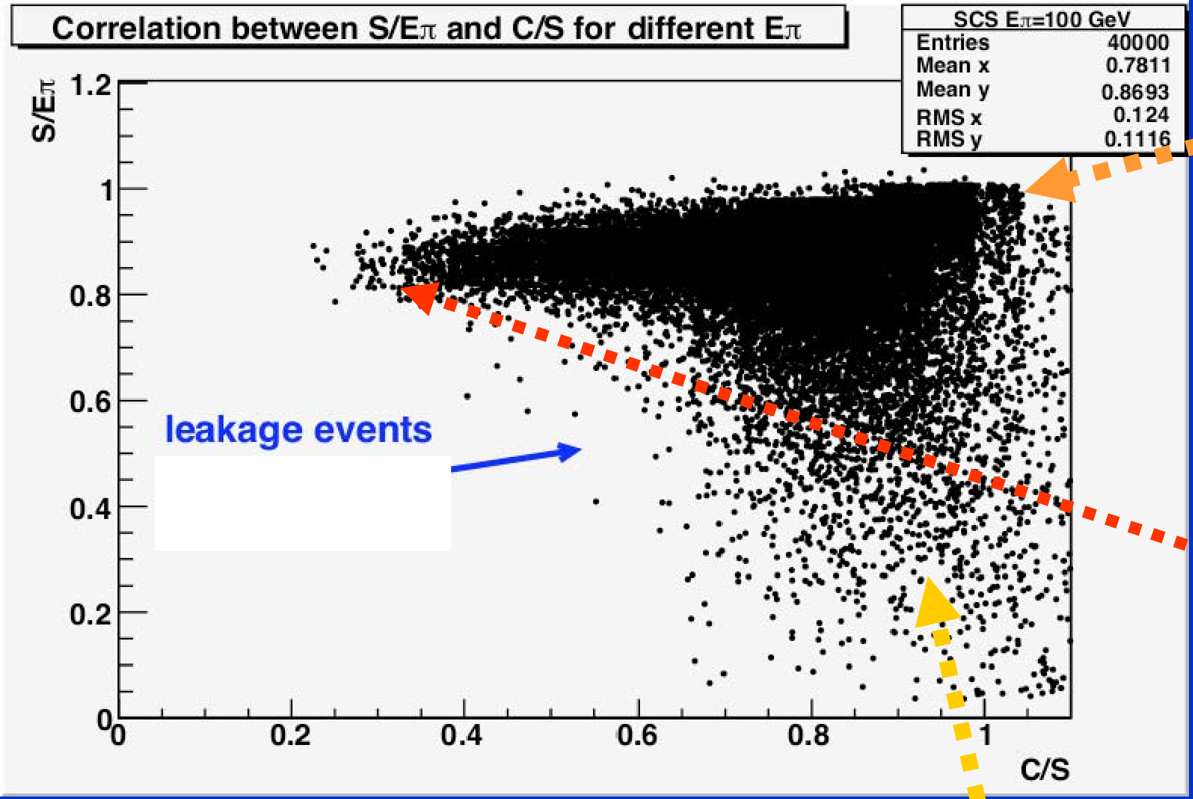
The calibrated responses for a shower produced by with 20, 50, 100 GeV π^- s which impact the calorimeter at 90° to the beam direction are shown



These are the situations where the leakage is most significant and the S-distributions (left plot) shows a long tail at lower energies (in addition to a peak near zero corresponding to punch-through pions).

S/C correlations and the DR correction

Plotting S/E_{π} vs. C leads to the usual correlation. Shown together in the figure are correlations for 20, 50 and 100 GeV pions (it is worth nothing that the correlation does not seem to depend on energy).



Given our calibration, C/S ratios close to 1 imply predominantly EM energy, and no energy loss → S/E_{π} =1 as observed.

Low values of C/S ratio mean large missing energy and predominantly ionization (Had) energy

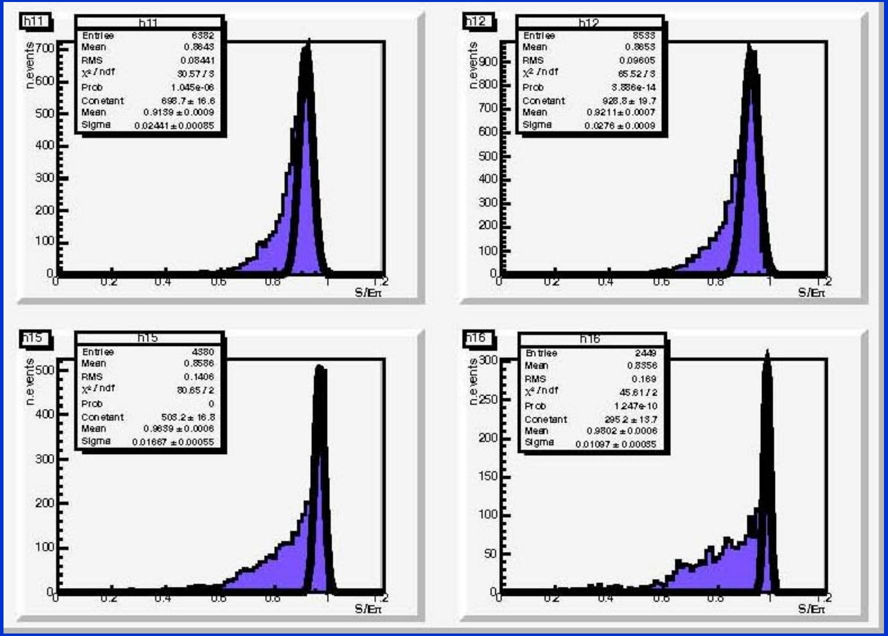
Leakage is most manifest for the higher energy pions

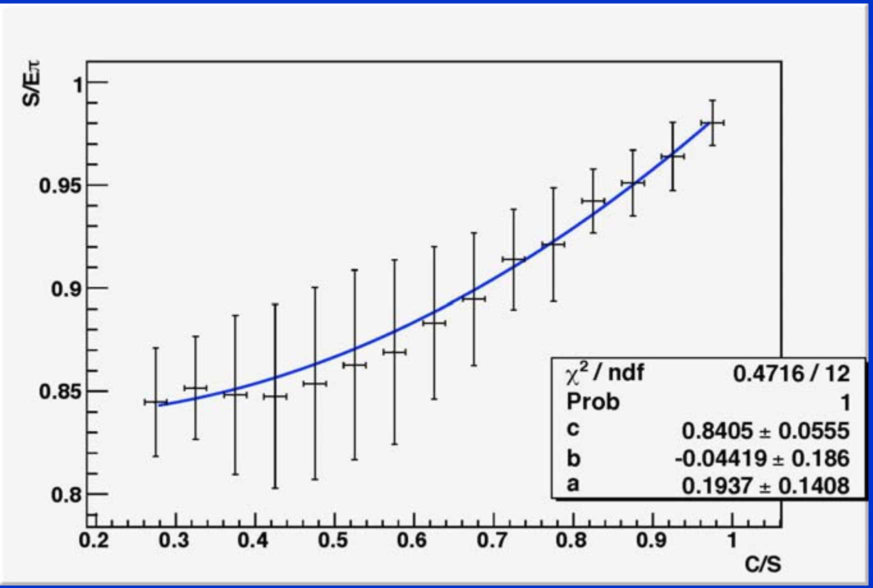
DR Correction

The need to account for leakage first arises when determining the correct correlation function.

A rough method:

1) Divide C/S distrib. into slices
2) Plot S/E_{π} distrib. for each slice
3) fit only leading edge to extract the peak position independently of leakage tails



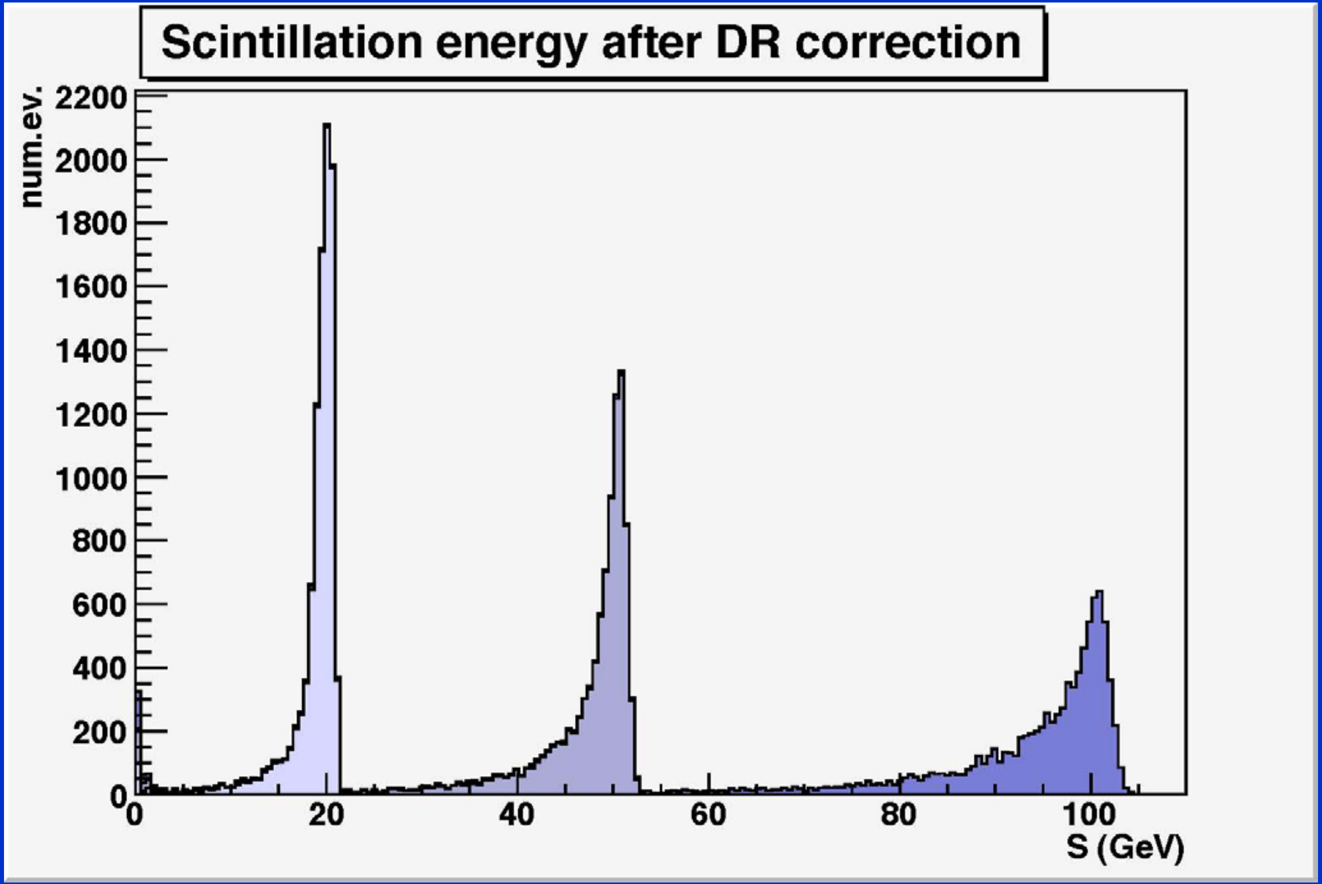


The resulting correlation is fitted with:

$$S/E_{\pi}=a(C/S)^2 + b(C/S) + c$$

which was used for the DR correction

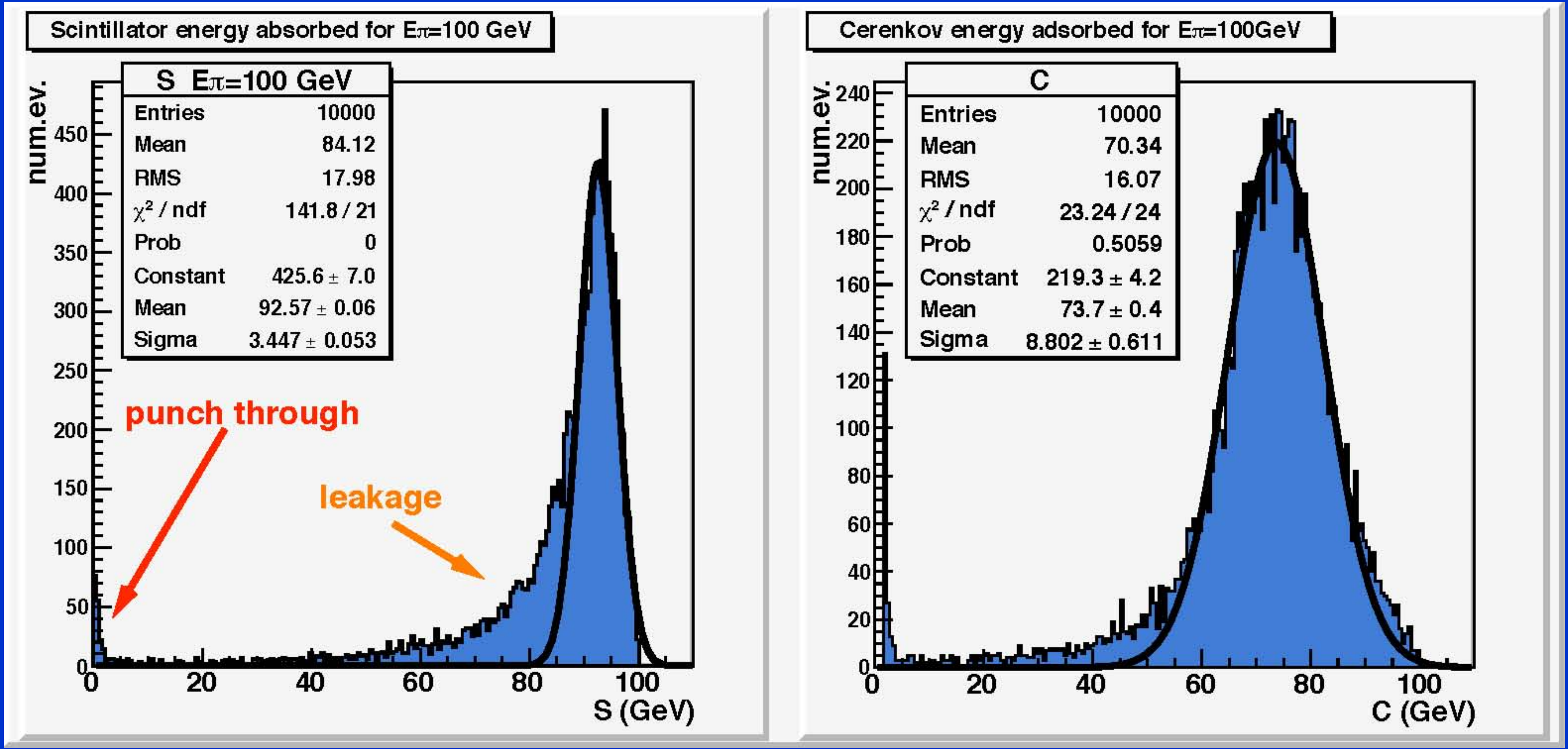
Applying DR corrections: $S_{corr}= \frac{S}{(C/S)2 + b(C/S) + c}$



The peak energy is corrected but we still have large leakage tails which needs to be corrected for.

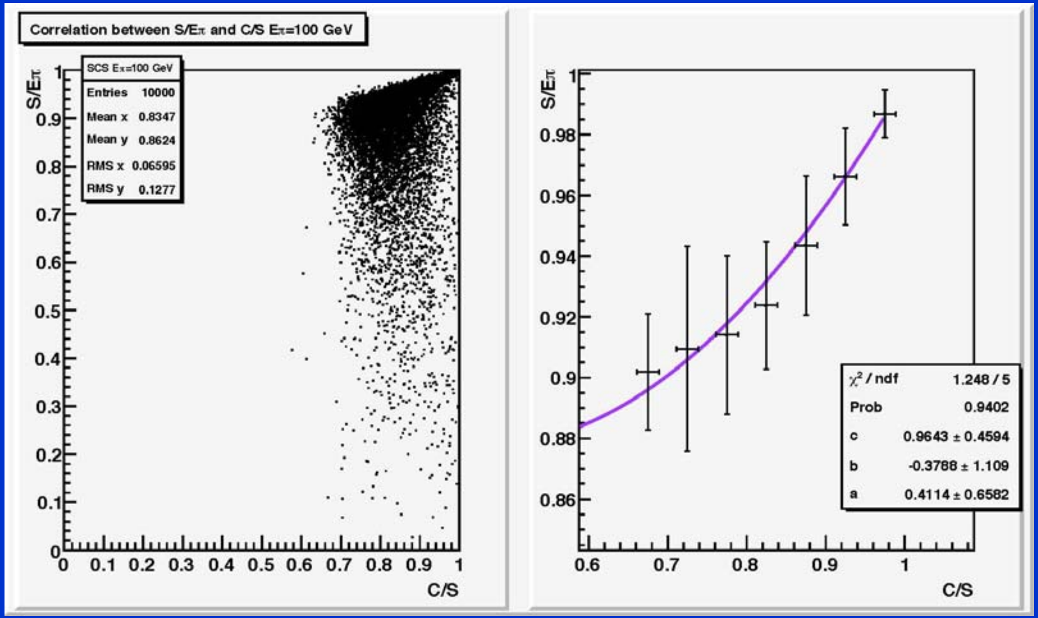
Begin with worst case: 100 GeV pions

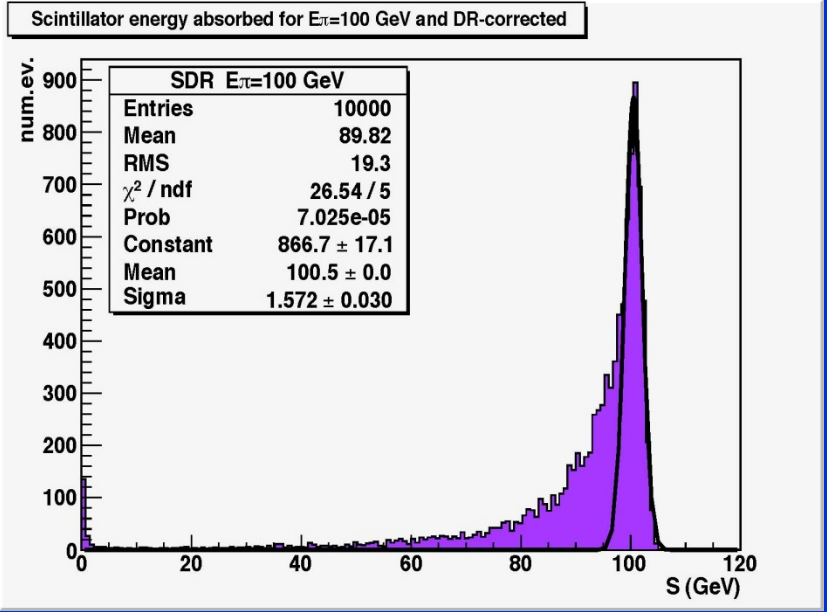
Leakage and “punch-through” (non-interacting pions) effects are particularly evident in the calorimeter reponse to deposited ionization energy S



DR Correction for 100GeV-pion

Determine the (S/E_{π}) vs. (C/S) Correlation in the usual way and use it for DR correction

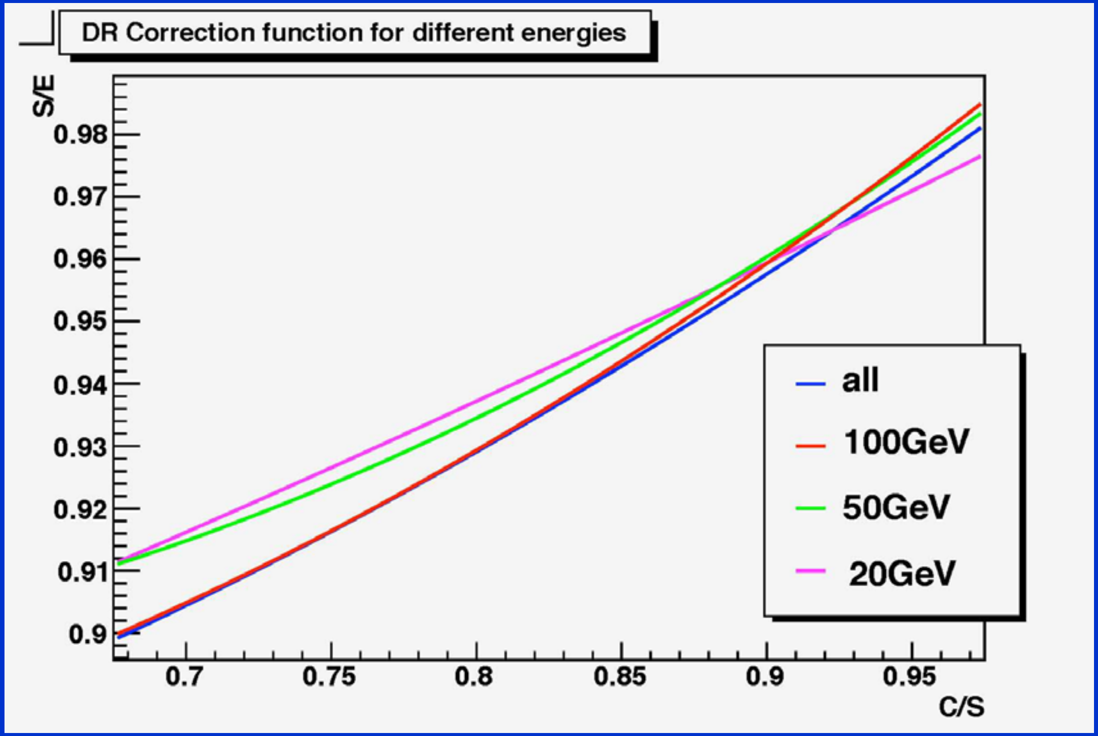




The corrected energy is 100.5 GeV (the uncorrected was 92.6 GeV) and it is consistent with the input pion energy. The resolution is improved to 16% if leakage is excluded – but this can not be done in a real (multiple particles at different energies) situation – we need to correct for leakage

DR Correction Function Energy Invariance

It is worth noting that, when the correlation function is determined indipendently at different energies, it is seen to be almost indipendent of energy

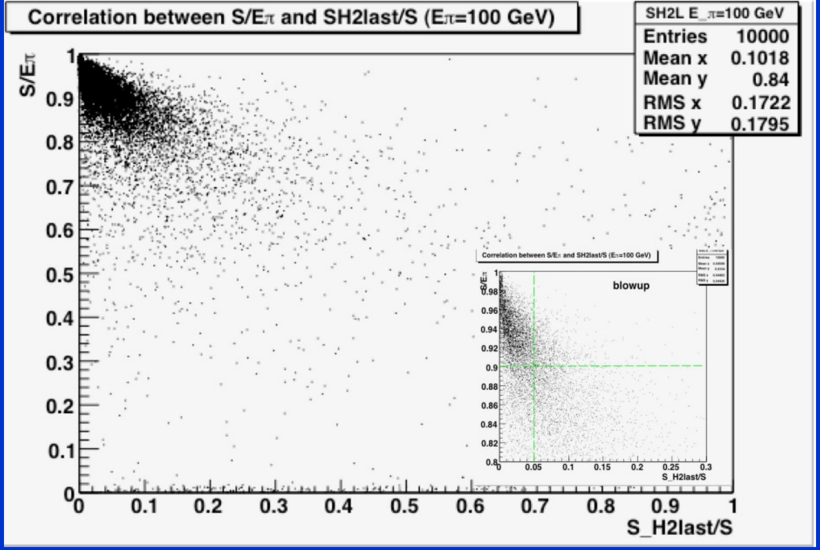


…and similar to the correlation function determined using the data generated at all energies

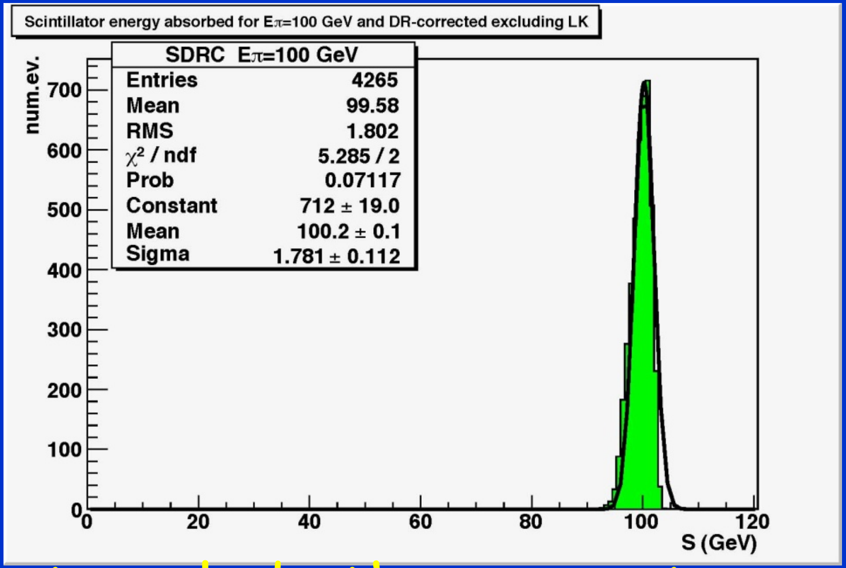
Leakage Events Exclusion

Exploit the longitudinal segmentation to exclude the leakage?

-- “late” showers or “long” showers can be identified from the fraction of energy they deposit in the outermost layers:



Define leakage events as ones that deposit less than 90% of their energy in the calorimeter and lose more than 0.05% in the last two layers.



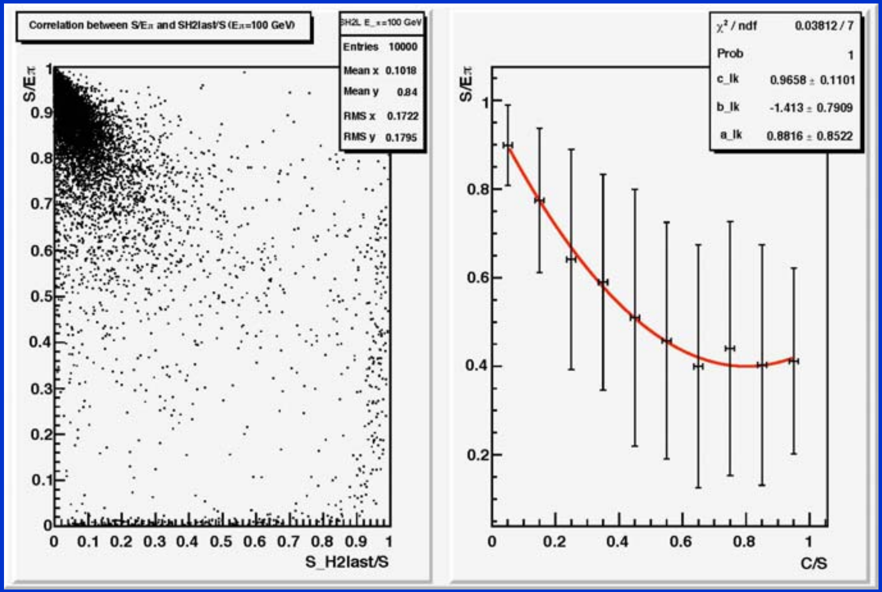
Excluding these events before the DR correction leads to a symmetrical energy spectrum with good resolution

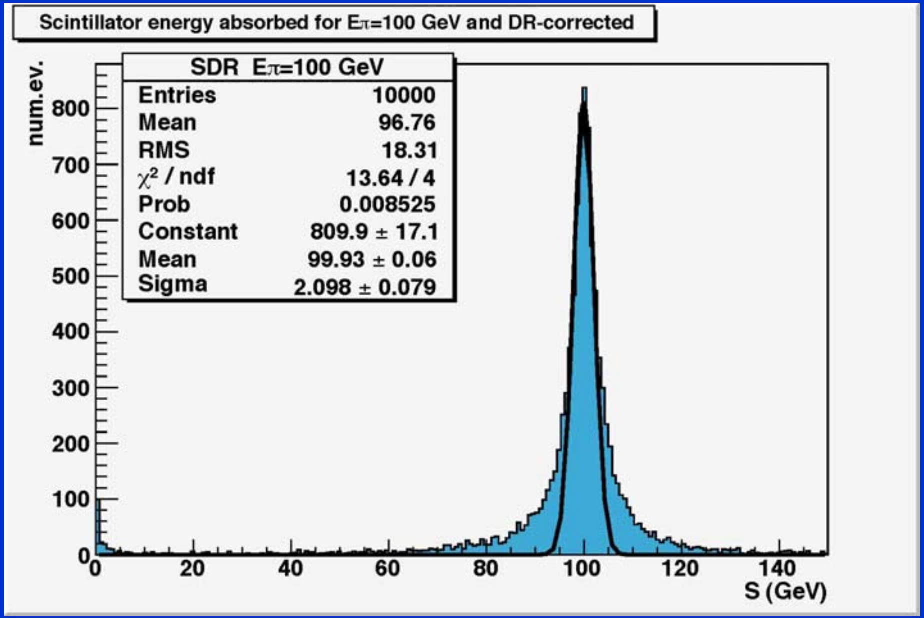
…but we would evidently rather not exclude these events

LK correction using the longitudinal segmentation (SLK algor.)

More information is available from the longitudinal segmentation than that needed for exclusion. At first apporximation, plot (S/E_π) against the fractional energy deposited in the two outermost layers:

A correlation function is extracted using the same technique as was used to extract the DR correlation





This correlation function is then used to correct for the leakage. The DR correction is then applied

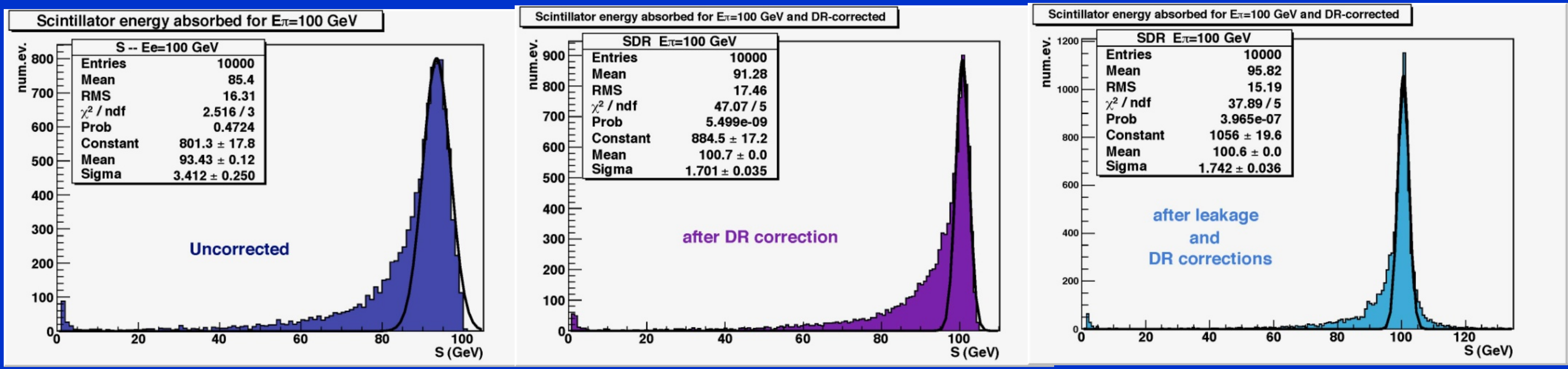
→ A symmetric distribution with good resolution (~2%)

The exercise was repeated for a calorimeter with different composition and segmentation, e.g.:

- **EM section**: 6 layers of crystals, 3 cm thick, with a transverse segmentation of 3x3 cm;
- **HAD section**: 22 layers of crystals, 5 cm thick, with a transverse segmentation of 5x5 cm;

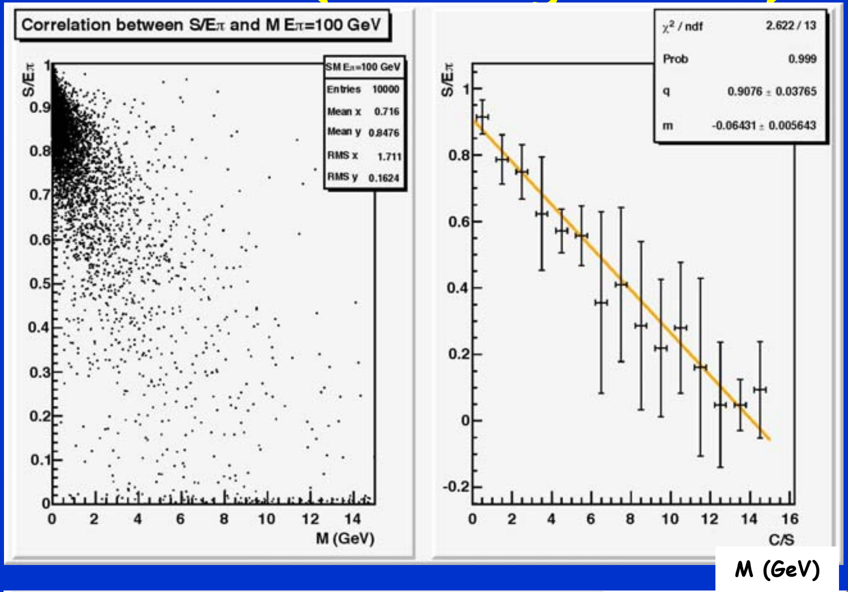
For a total thickness of 128 cm (5.8int)

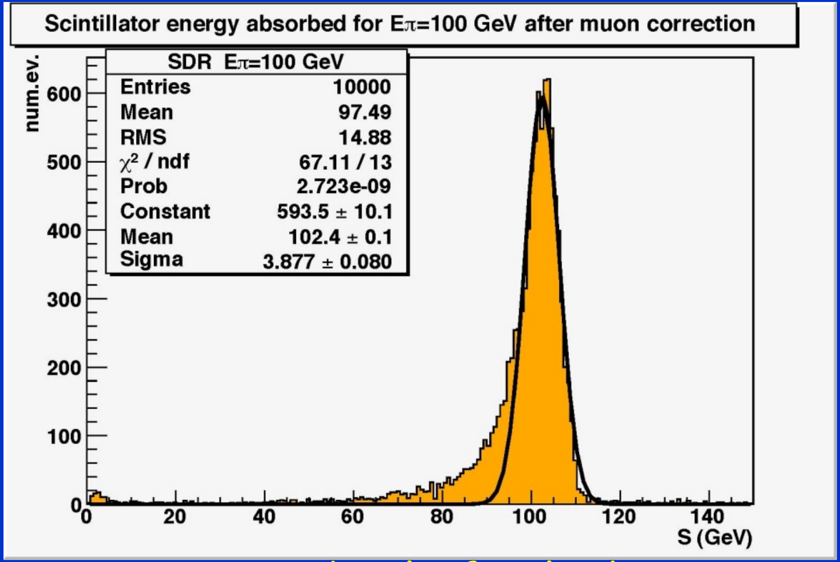
We are still able to correct the leakage using the last two layers (the last 10 cm wheras, before, we used the last 20cm):



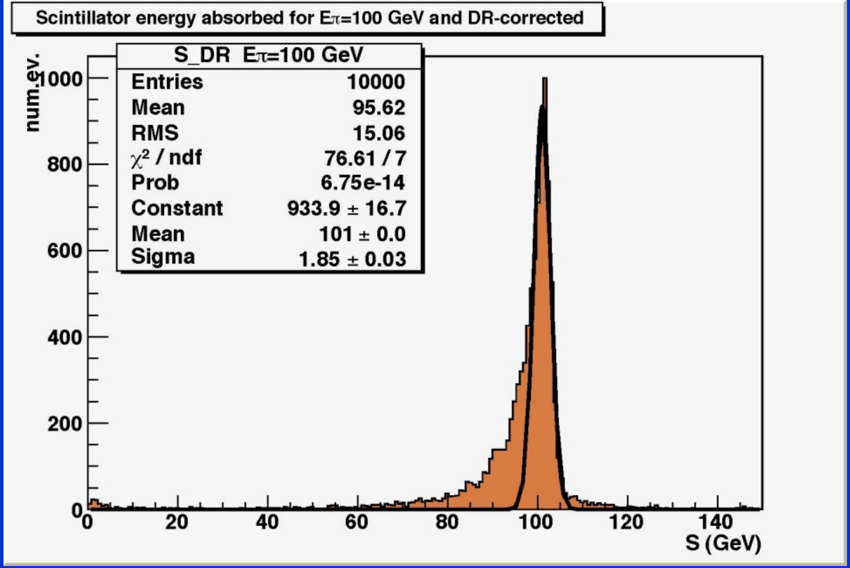
LK correction using the muon tail-catcher (MLK algorithm)

For this correction, we use the correlation between the the fraction of energy deposited in the calorimeter and the energy detected in the tail-catcher. The correction is applied before the DR correction and also partially corrects for punch-through



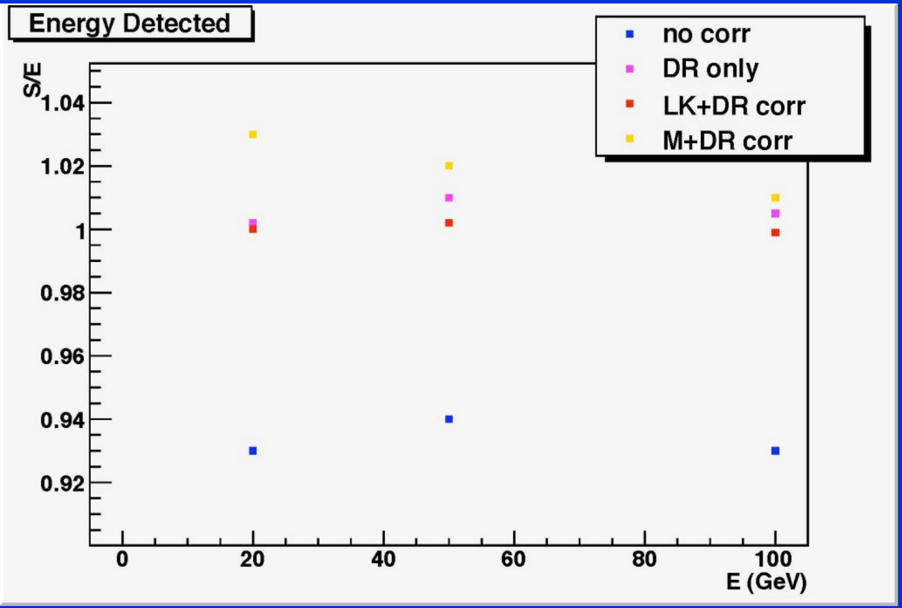


S corrected only for leakage detected in the tail-catcher



DR correction applied after muon correction

Results & conclusions – so far

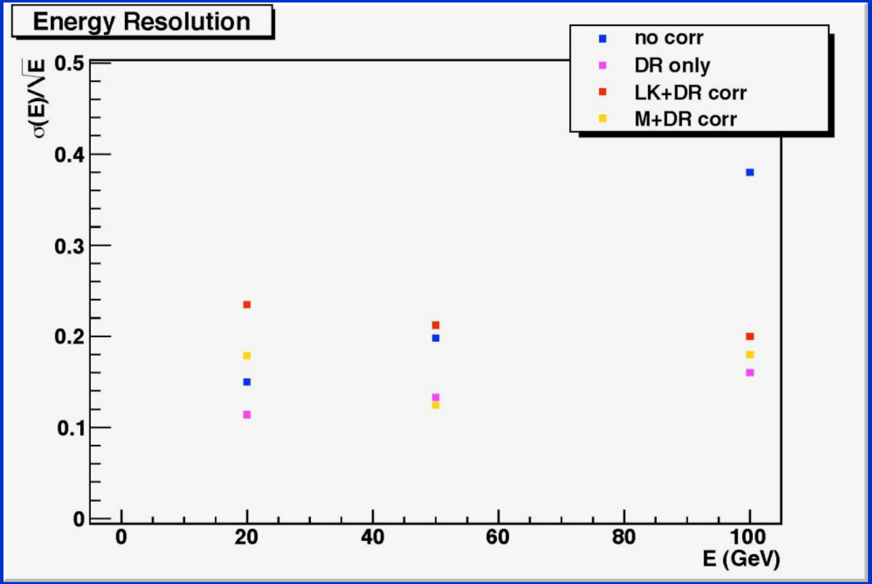


The algorithms considered (LK+DR and M+DR) are clearly able to correct for leakage loss: corrected mean energies are the same as to those obtained by excluding leakage (one way or another e.g DR only).

Tail-catcher – based corrections (M+DR) are overestimated at low energy but are able to correct for punch-through

The uncorrected resolution (blue) deteriorates with increasing energy as expected .

Leakage corrections maintain σ/sqrt(E) at a costant value of ~ 18%



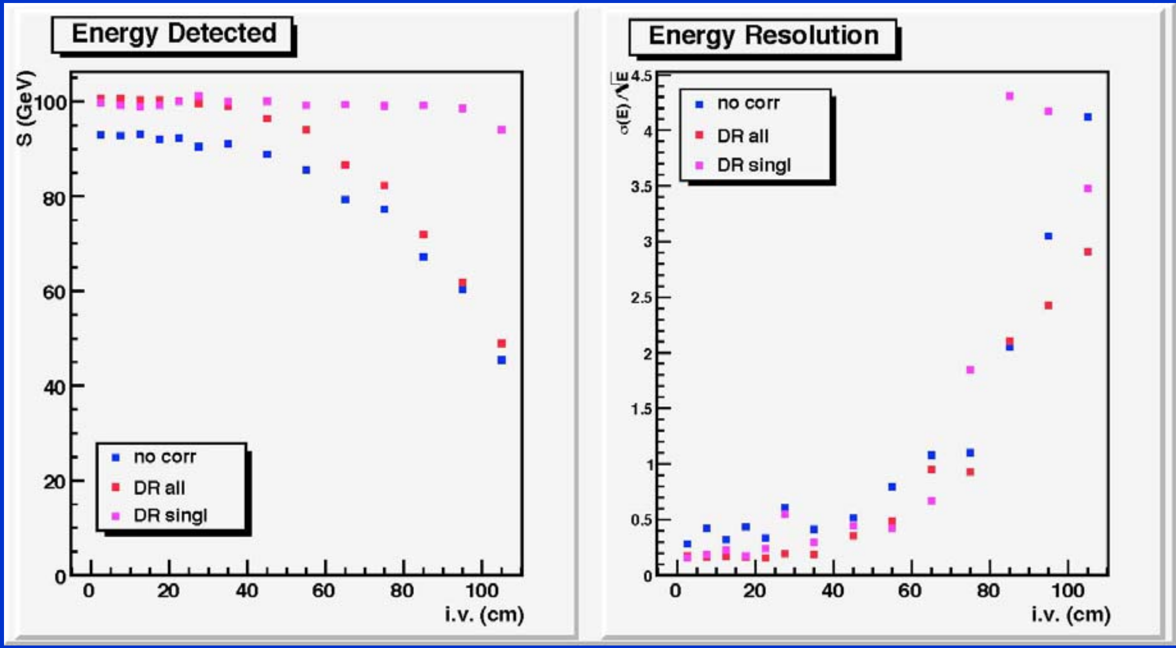
However, algorithms we developed do not exploit all the information available: the depth segmentation of the energy deposited in our calorimeters can clearly be used to model the shower evolution and calculate the leakage with greater precision and smaller fluctuation.

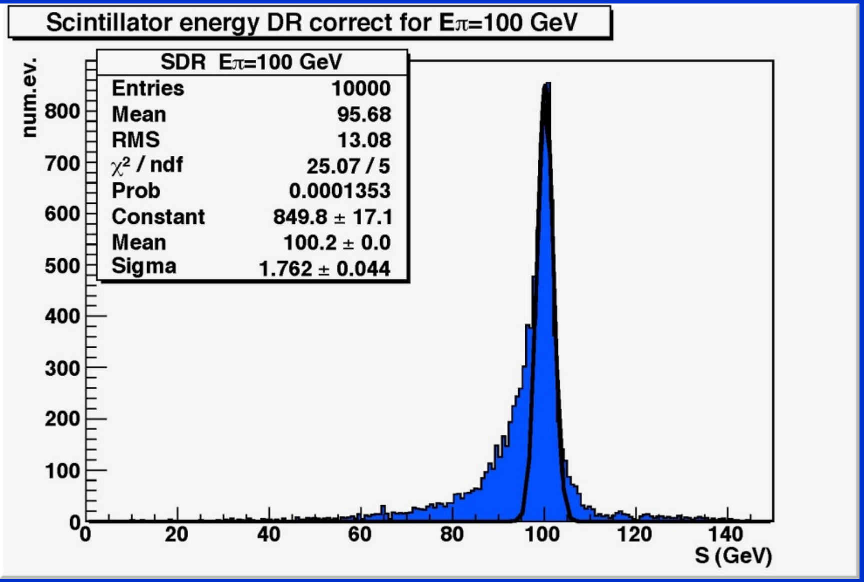
The depth segmentation in the tail-catcher can be used to the same end and to obtain a more reliable correction for punch-through,

As a first step in this direction, the data was subdivided according to the depth of the segment in which the hadron shower started (the “interaction depth” or ID) . Correlations for the DR and for the MLK corrections were then evaluated separately for each ID

DR corrections using this method (DR singl)

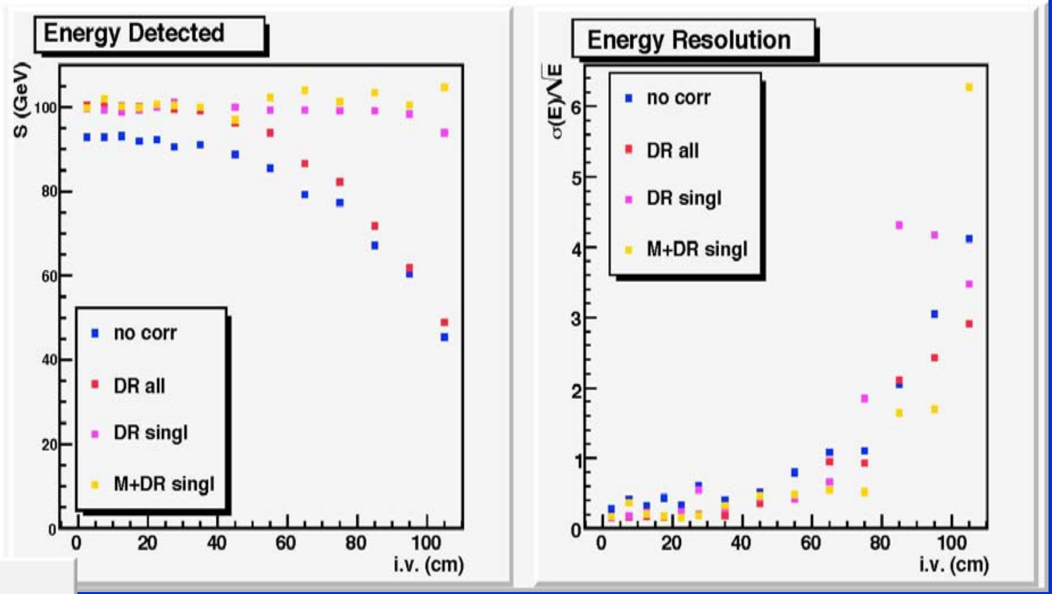
are compared with those corrected using a single "global" DR algorithm. The improvement is evident



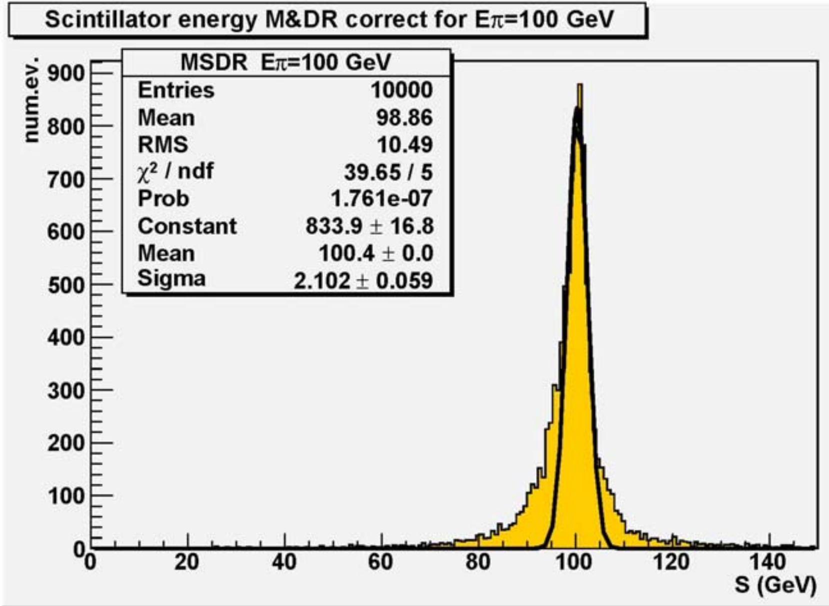


The residual leakage tail is then corrected for using the ID – dependent MLK correlations

subsequent application of ID – dependent MLK corrections



Improves resolution



and symmetrizes the energy distribution

Note the reduction of the non-gaussian tails

Conclusions

- totally active calorimeters with Dual Readout correction can be corrected for leakage
- leakage must be accounted for at different stages: first in determining the DR correction and then in correcting for the energy loss
- calorimeter segmentation is very effective to this end
- muon detector/tailcatcher assemblies are also effective but tend to overcorrect at low energies. However, they are needed to correct for punch-through
- we are still only scratching the surface so far as the potential of segmentation for correction algorithms is concerned

Future work: extend the study to jets in magnetic fields

Backup

Muon System:
The muon system is implemented as a sampling calorimeter composed of 48 layers of:

material	thickness
Iron	5.0cm
G10	0.3cm
PyrexGlass	0.11cm
RPCGas	0.12cm
PyrexGlass	0.11cm
Air	0.86cm

The barrel inner radius is 333.0cm with z extent of +/- 277cm.
The endcap sits outside the barrel at an inner z of 277.5cm and radius from 26.0cm to 645.0cm
The field is solenoidal, constant 5 Tesla along z up to half the coil thickness and -0.6 outside.

Sampling fraction SF=0.000057

http://confluence.slac.stanford.edu/display/ilc/sid01