Dual-Readout Calorimetry Overview

J. Hauptman
DREAM collaboration and 4th Concept group

DESY LCWS07/ILC07
Calorimeter Review, 29 May - 4 June 2007

Four speakers:

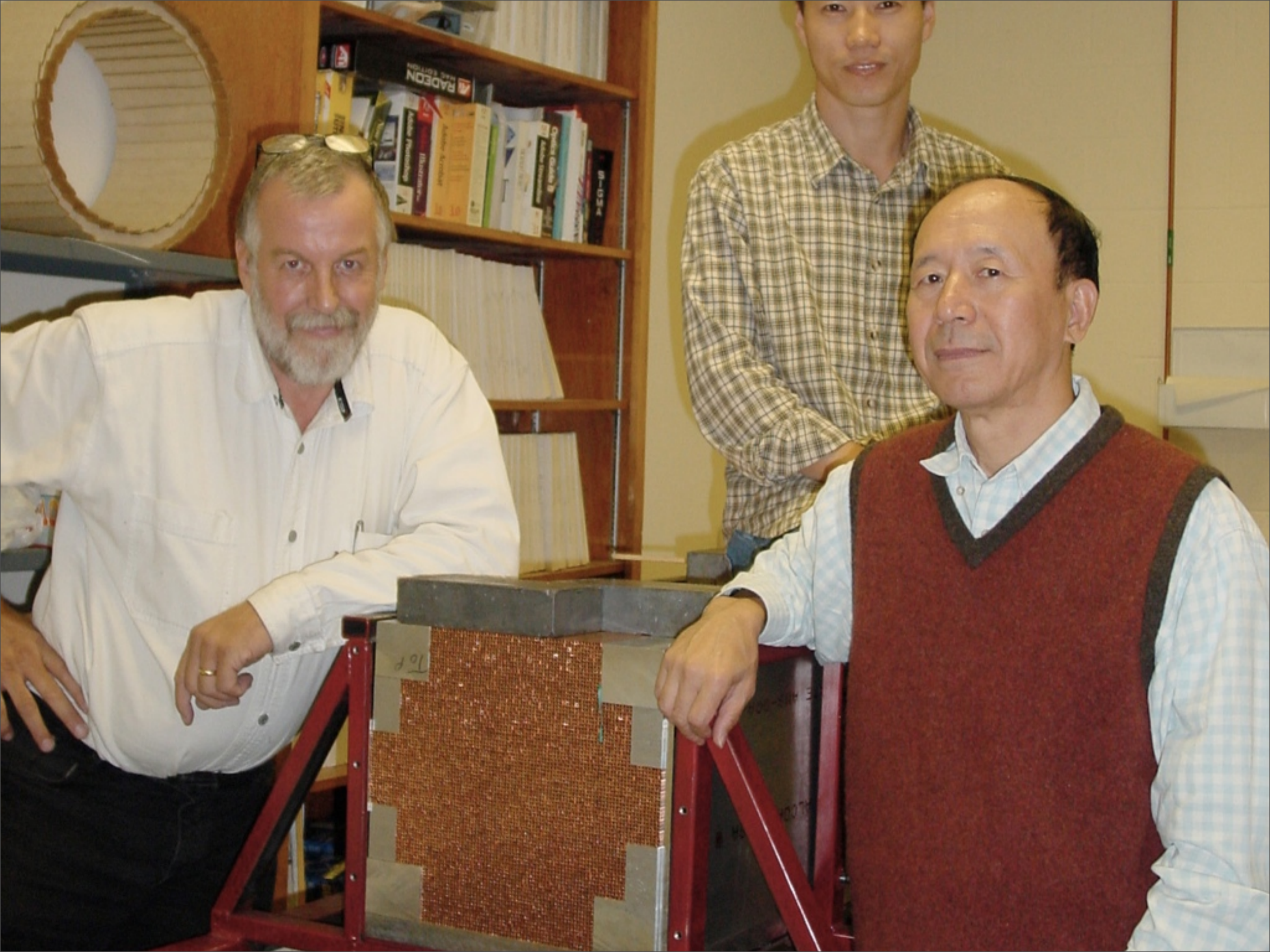
- J. Hauptman "Overview"
- N. Akchurin "DREAM Data, 20-300 GeV"
- S. Popescu "DREAM data analysis of PbWO4"
- A. Mazzacane "Jet Reconstruction and Resolutions"

My purpose is to alert you to four important points

1. Dual-readout is easy and robust
2. Possibility of excellent energy resolution
3. Absolute hadronic energy linearity is also easy and robust
4. Excellent and novel particle identificati

We have published our results: 5 NIM papers, 3 more to be submitted to NIM in mid-June.

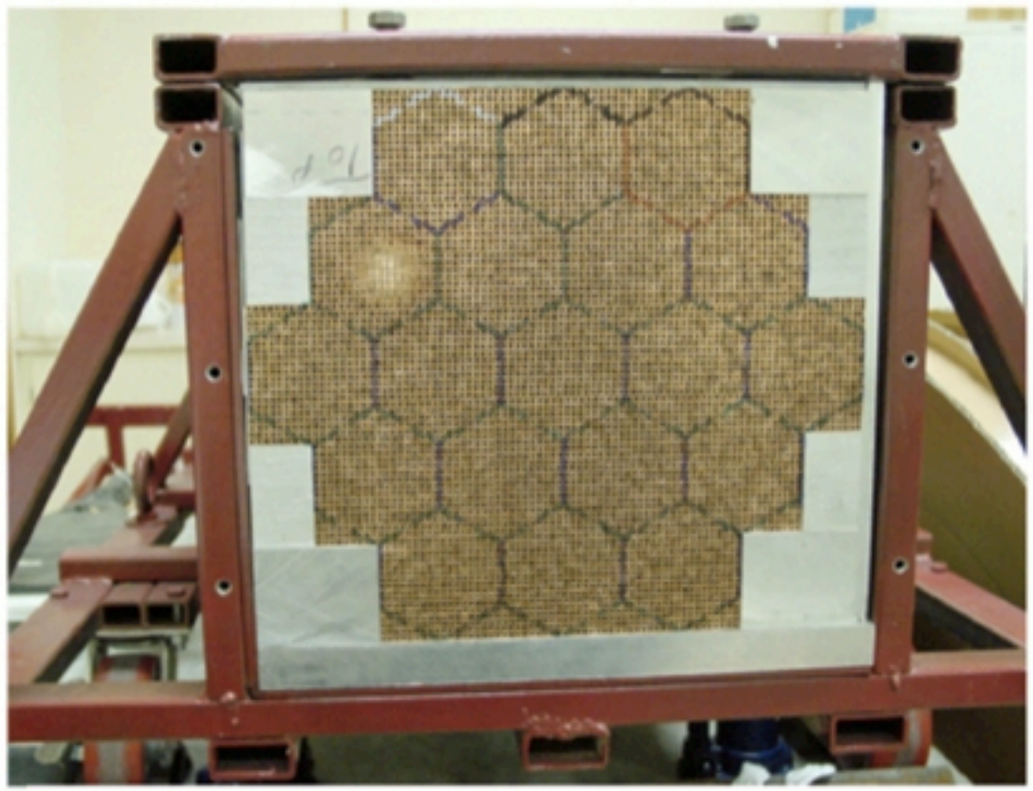
(*One paper per day of beam.)*

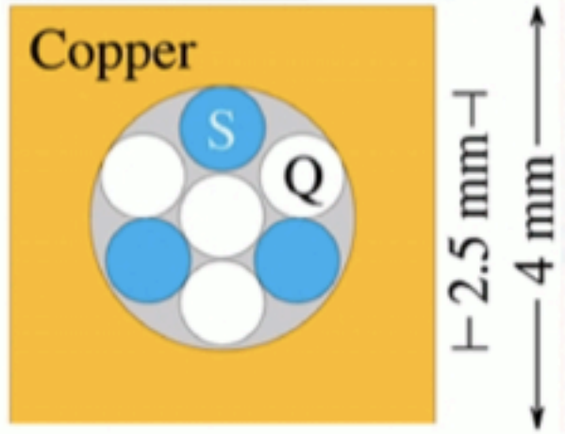

RADEON
SIGMA

DREAM: Dual REAdout Module

Fill the absorber with two kinds optical fibers, Cerenkov (clear) and scintillating fibers. Both "calorimeters" see the same particles. Generated lights in each fiber are exactly separated.

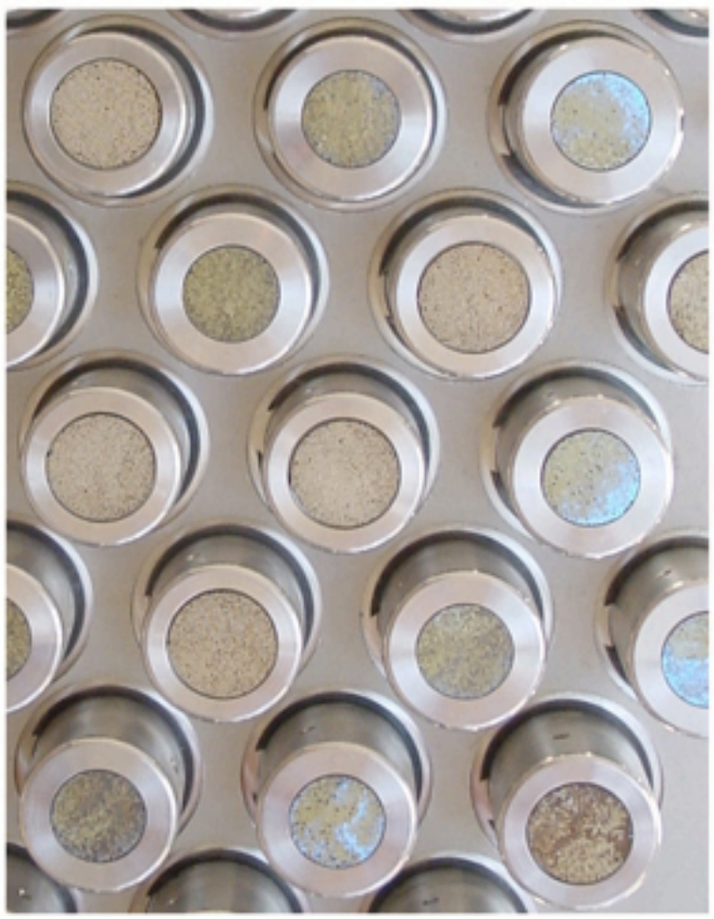
DREAM: Structure

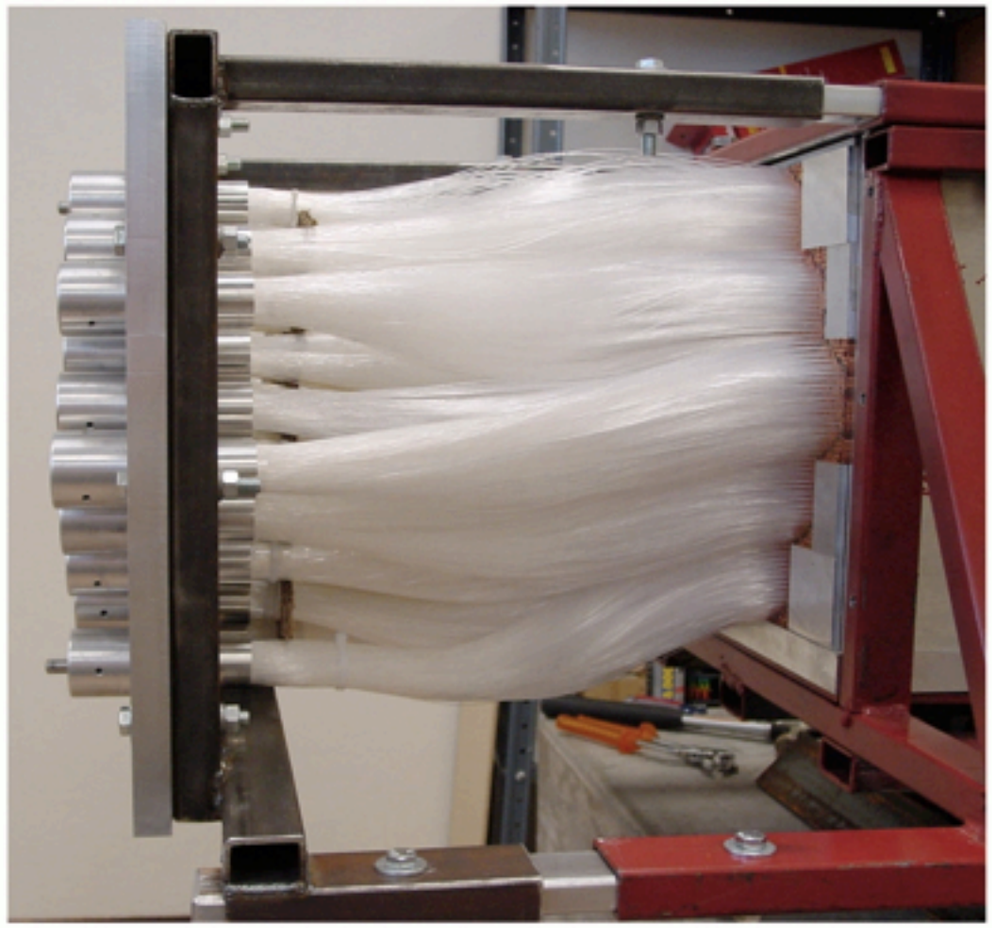




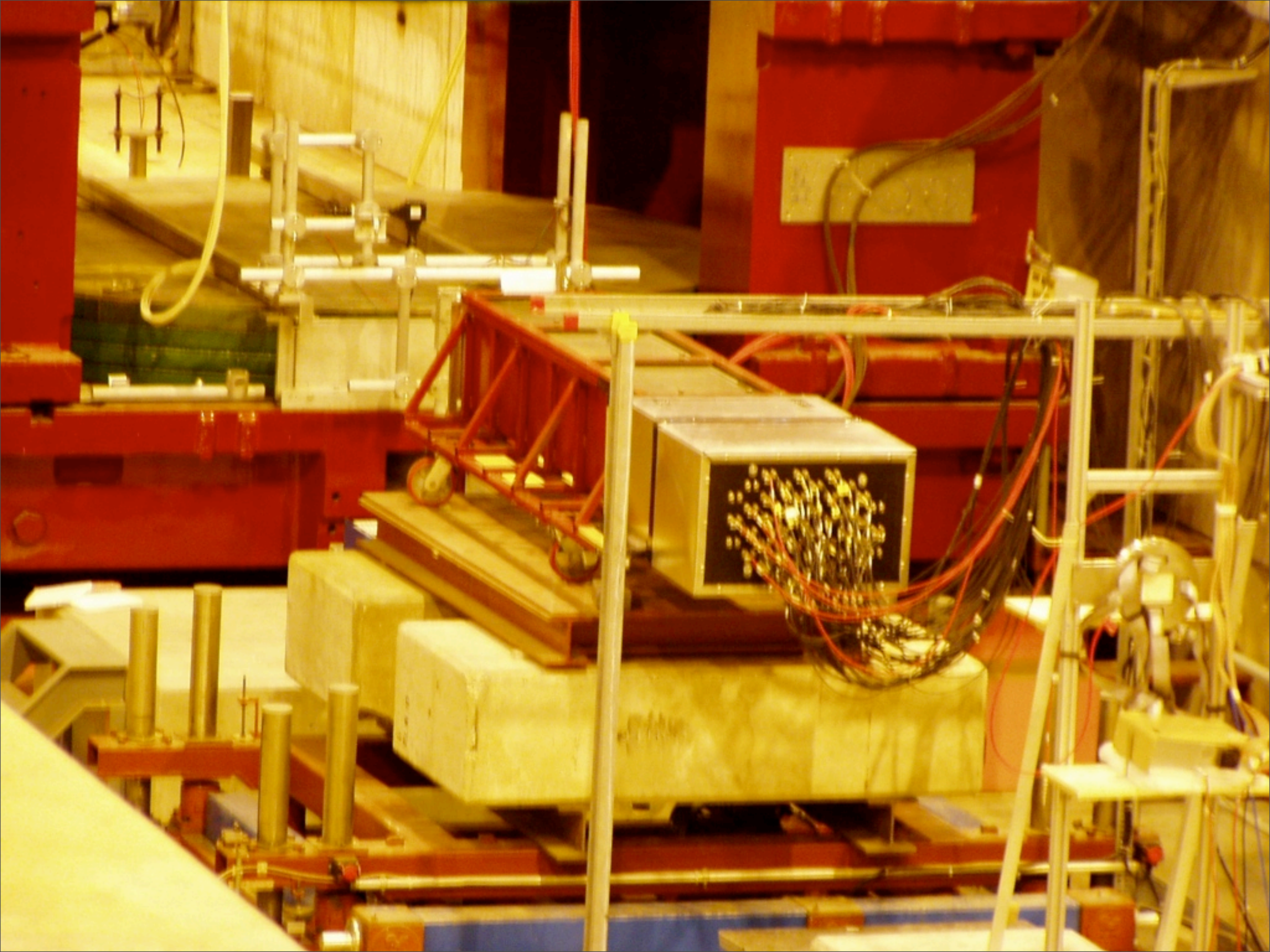
- *Some characteristics of the DREAM detector*
  - Depth 200 cm (10.0 λ_{int})
  - Effective radius 16.2 cm (0.81 λ_{int}, 8.0 ρ_M)
  - Mass instrumented volume 1030 kg
  - Number of fibers 35910, diameter 0.8 mm, total length $\approx$ 90 km
  - Hexagonal towers (19), each read out by 2 PMTs

DREAM readout





For ILC module: integrated SiPM + electronics plug + FADC.



110 CERN SL 19-06-03

SPS-Protons updated: 19-06-03 22:10:32

CYCLE Type 950: 400 Gev/c SCIs: 22:16:17

Flat top: 4800 ms length: 16.8 s

RATE=E11: MIC Cycle: 207.5

269 220.8 SSE

CPS RAMP to beam dump: 21.3

Targ	p/pE11	Mul	%Sym	Expmt	Singles
T1	22.6	13 a	86	Alice	0.0E+00
				LHCb	0.0E+00
T2	36.5	1 a	90	CMS	0.0E+00
				DREAM	4.5E+01
T4	28.7	8 a	91	NA48	0.0E+00
T6	96.1	9 a	88	NA58	1.6E+08
T10	0.0			NA48	2.1E+01

Comments 19-06-03 22:15h :

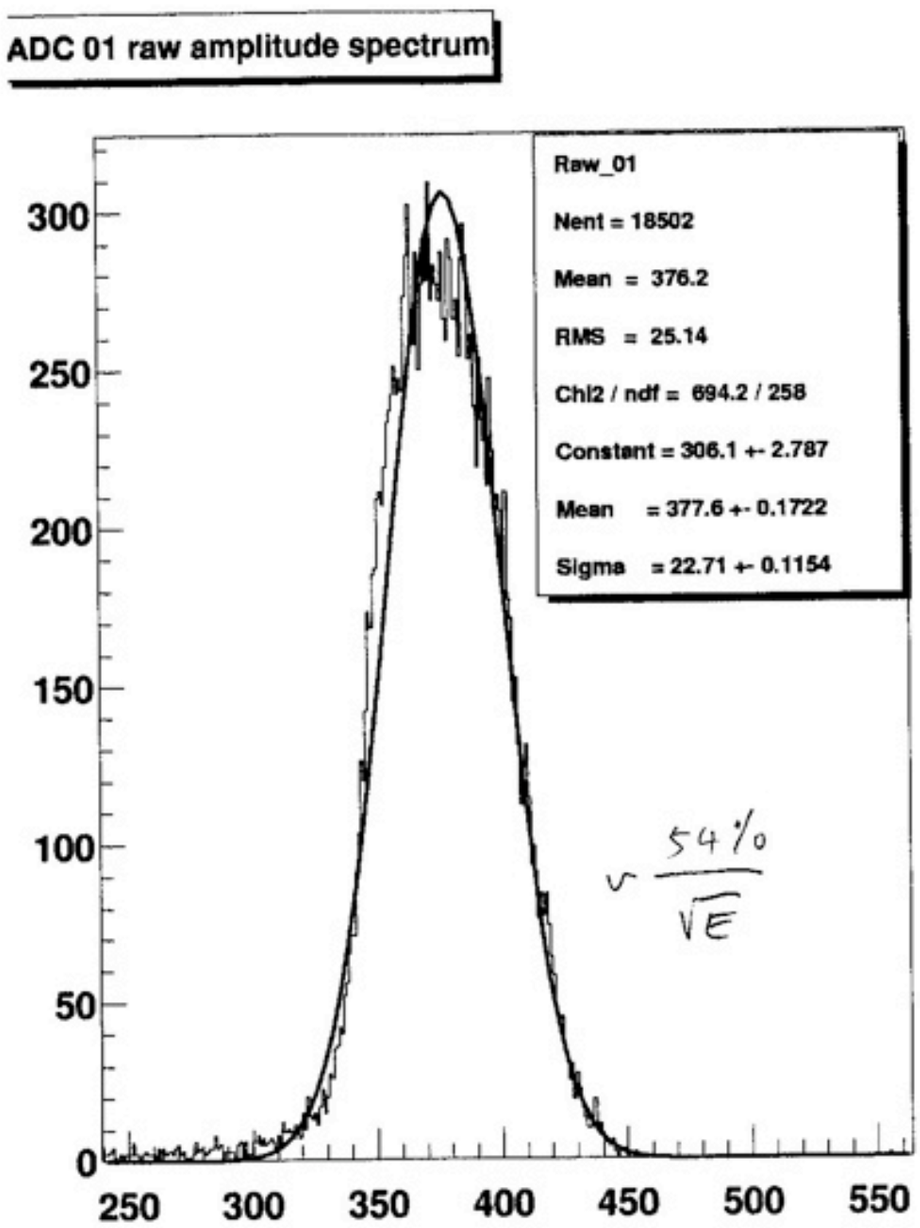
Access in North to repair a
collimator, intervention will
take about 1 hour.
SPS will be off during the intervention
EA:Phone : 77500 + Natel 160137

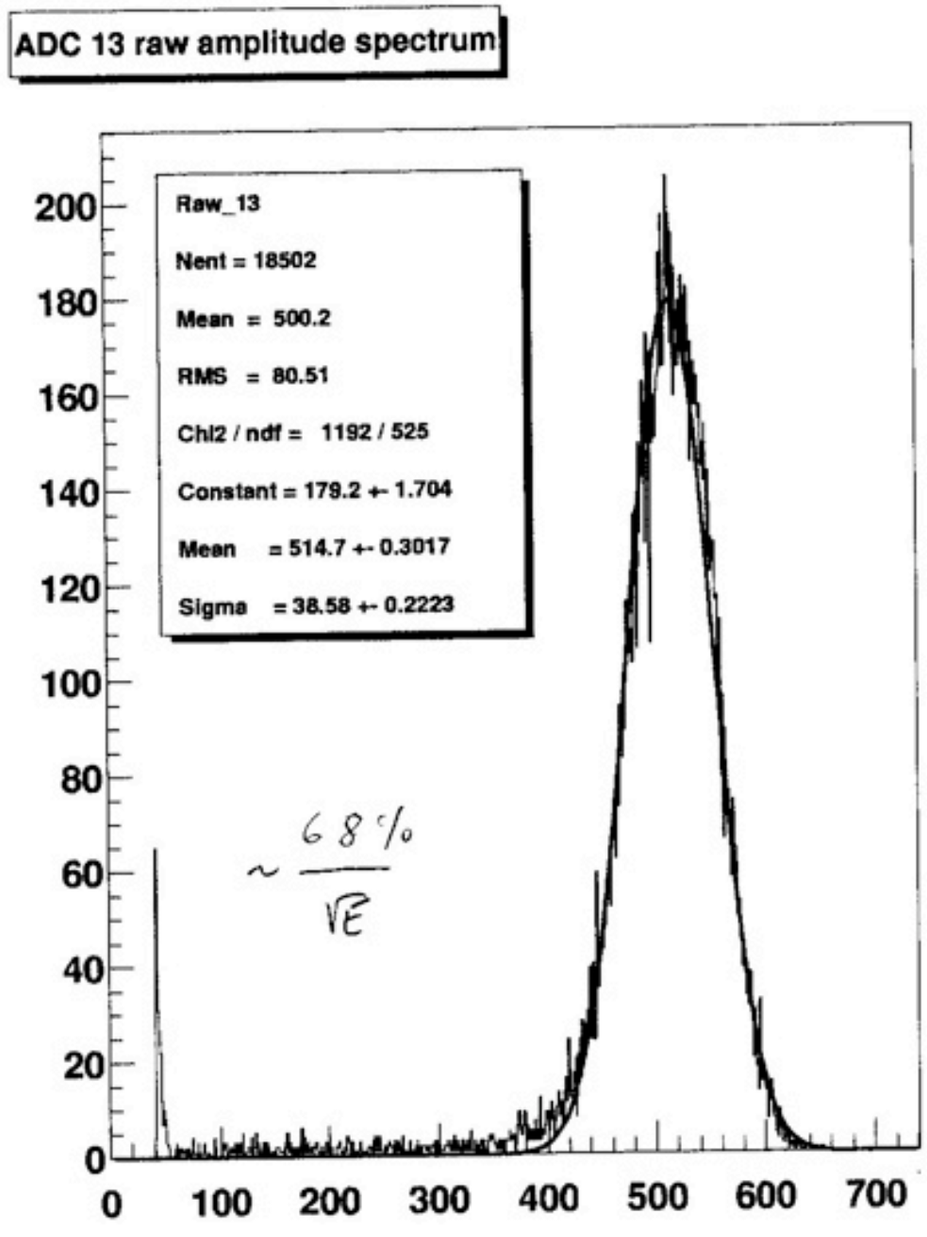
NOKIA

Dual-readout is easy and robust

FIRST SHOT !

SCINTILLATOR 80 GeV e^- (?) QUARTZ

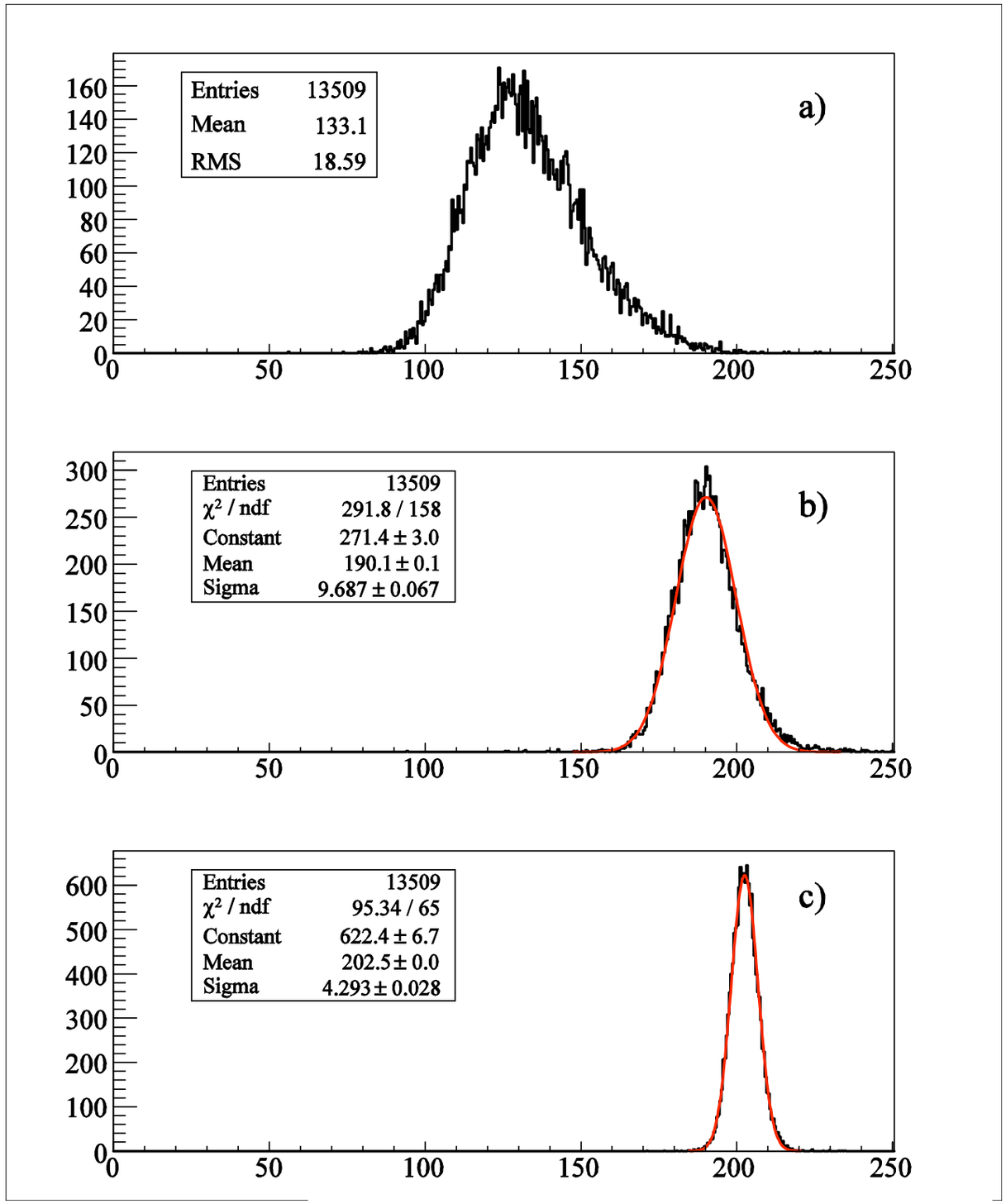




Simple, robust, Korean housewives, "inert", stable, you can even drop it.

Possibility of excellent energy resolution

DREAM data 200 GeV π^-: Energy response



Scintillating fibers

Scint + Cerenkov

$f_{EM} \propto (C/E_{shower} - 1/\eta_C)$

(4% leakage fluctuations)

Scint + Cerenkov

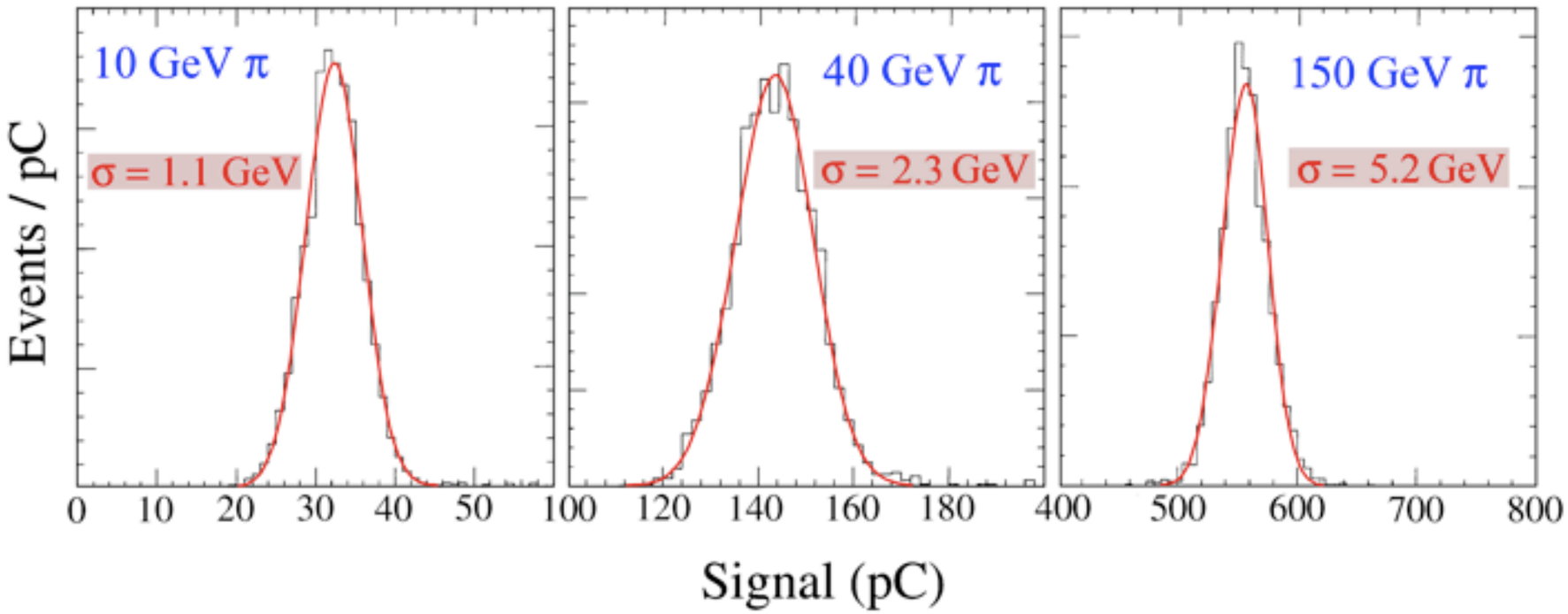
$f_{EM} \propto (C/E_{beam} - 1/\eta_C)$

(suppresses leakage)

Data NIM A537 (2005) 537.

Hadronic signal distributions in compensating calorimeter

$$\sigma/E \approx 35\%/\sqrt{E}$$



from: NIM A308 (1991) 481

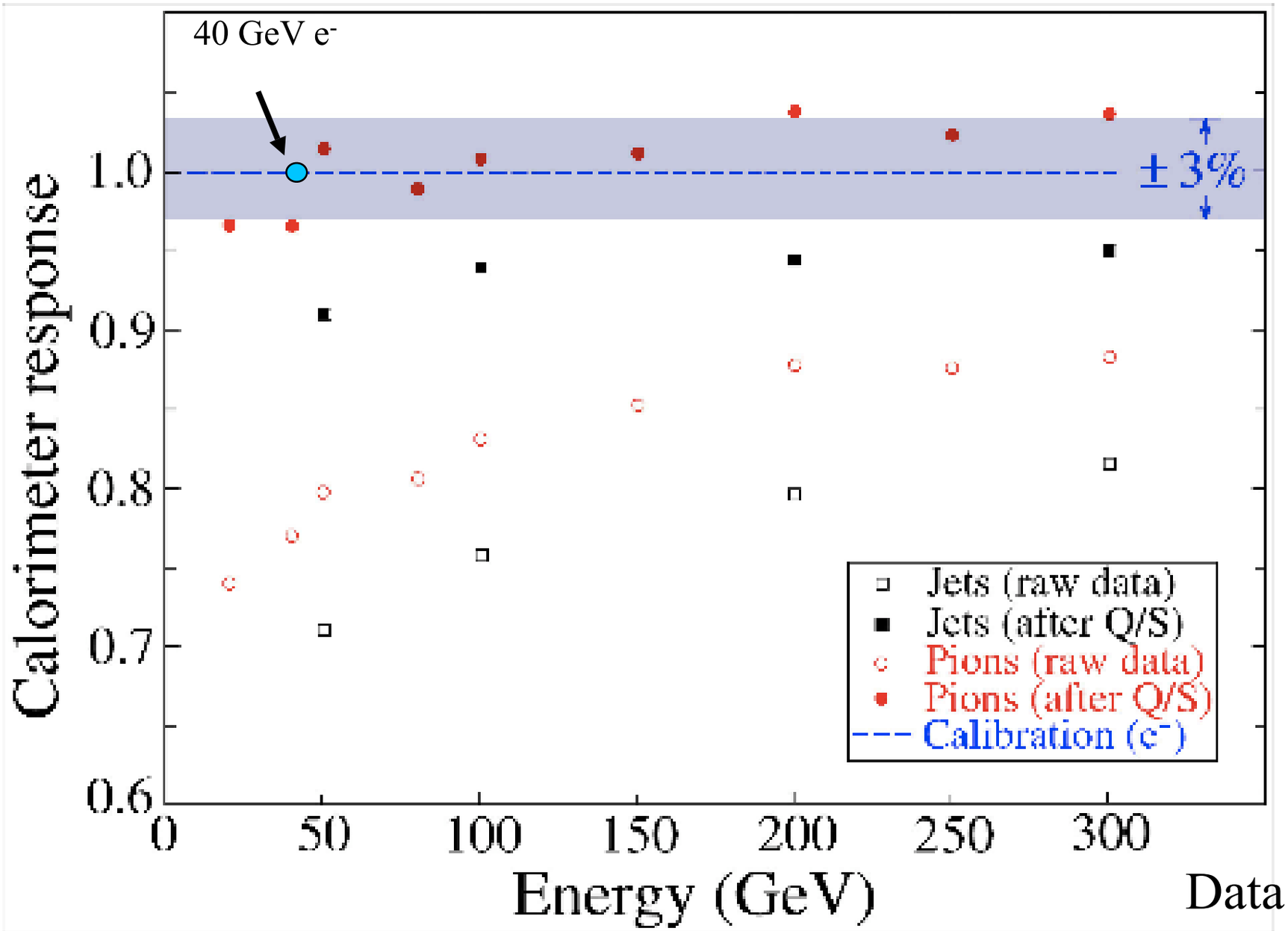
Calorimeter	a(%)	b(%)
Sampling Čerenkov fibers only	**94**	**7**
Sampling Scintillation fibers only	**81**	**2.2**
"Q/S" method: use only Čerenkov and Scintillation	**64**	**0.6**
↓ *Subtract out leakage fluctuations (4%)*	*50*	**-**
↓ *Subtract out Čerenkov pe fluctuations* $(35\%/\sqrt{E})$	*36*	**-**
ZEUS hadron calorimeter (compensating)	**35**	**2**
SPACAL (10 tonnes, 100 ns)	**35**	**<1**
FLUKA simulations (jet reco energy) 4th	**36**	–
FLUKA simulations (calor. energy) 4th	**30**	–
↑ *Add in "jet reco" fluctuations (2-3% ?)*	*38*	**-**
↑ *Add in* E_{shower} *fluctuations (* $30\%/\sqrt{E}$ *?)*	*36*	**-**
$f_{EM} \propto$ *(C/Ebeam - 1/*η_C*)*	*19.2*	*1.6*

Table 1: Measurements (**boldface**) and estimates (*italics*) of the stochastic and the constant terms in the energy resolution of the DREAM dual readout calorimeter. These are all derived from the beam test data of the DREAM module and described in the DREAM papers (1-3). The overall resolution is written as $\sigma_E/E = a/\sqrt{E} \oplus b$ or as $\sigma_E/E = a/\sqrt{E} + b$.

Absolute hadronic energy linearity, also easy and robust

More important than good Gaussian response:

DREAM module calibrated with 40 GeV e^- into the centers of each tower responds linearly to π^- and "jets" from 20 to 300 GeV.



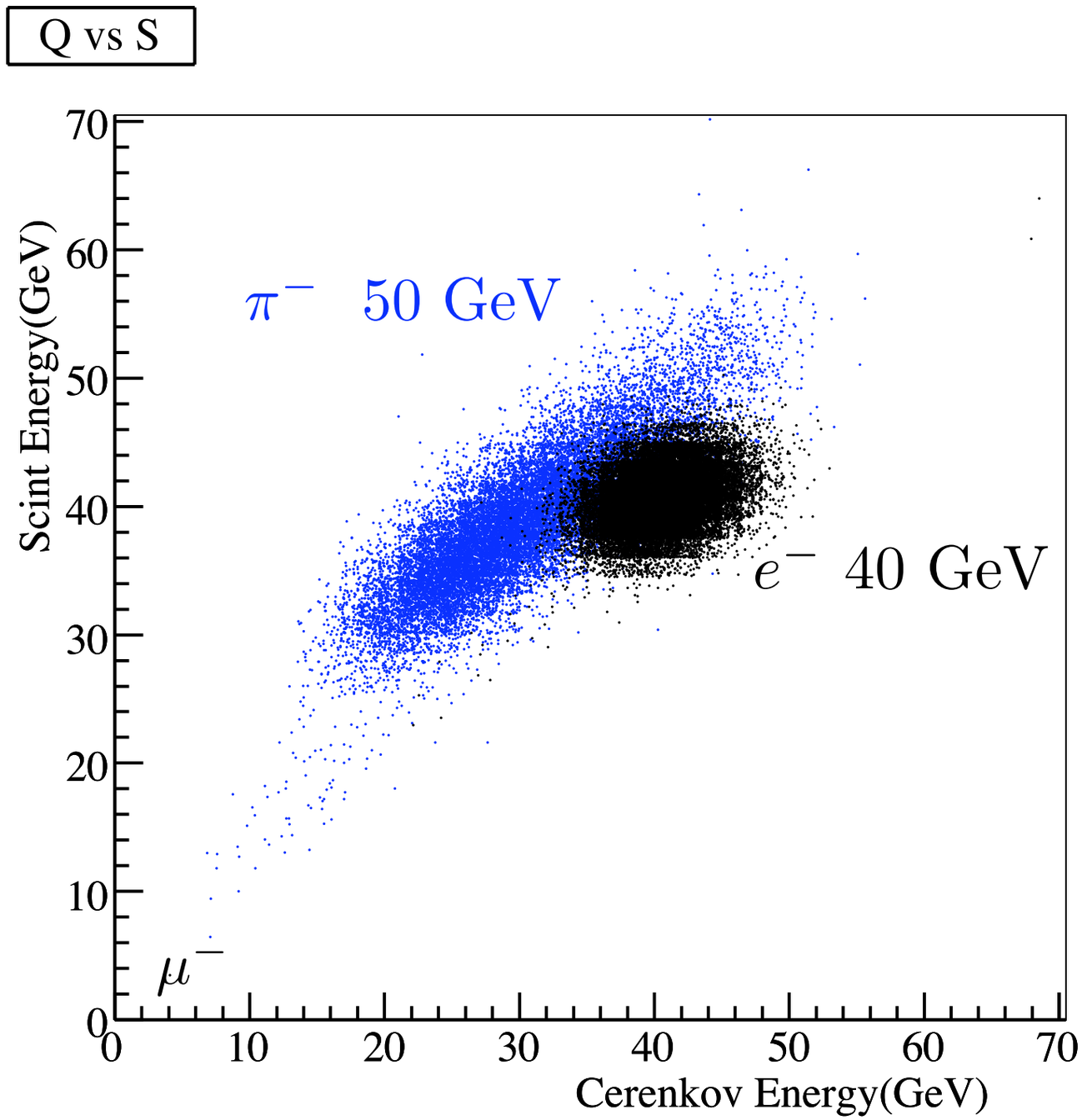
ILC

Hadronic linearity may be the most important achievement of dual-readout calorimetry.

Data NIM A537 (2005) 537.

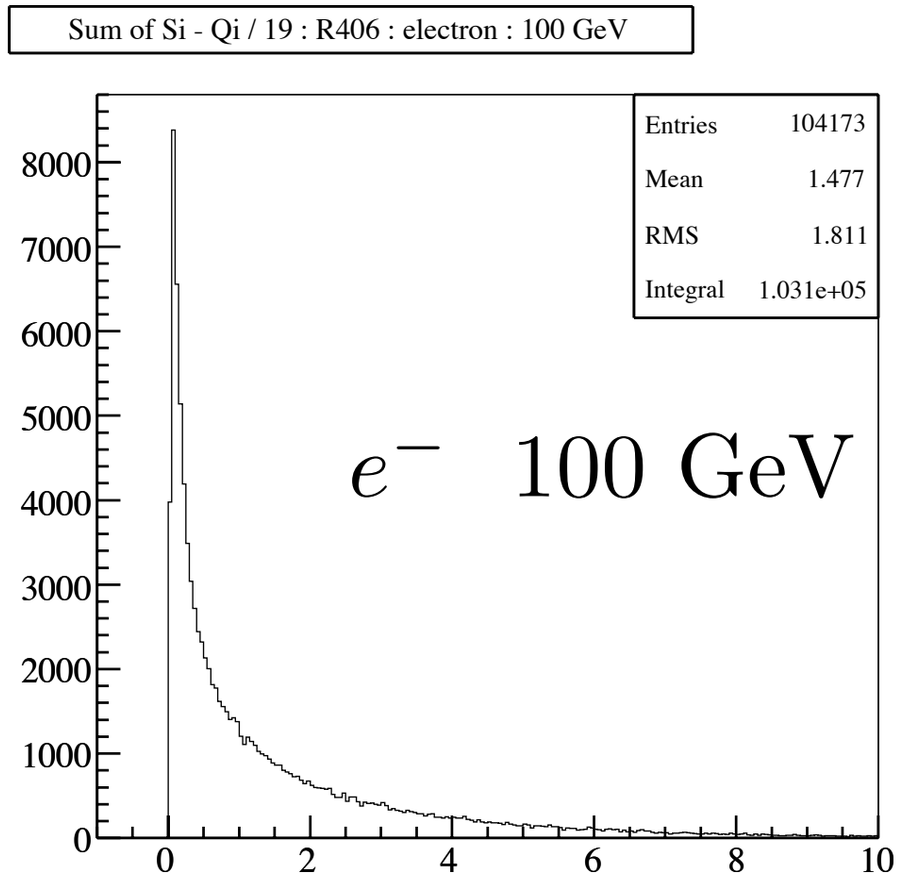
Particle ID: *electron, pion, muon, jets*

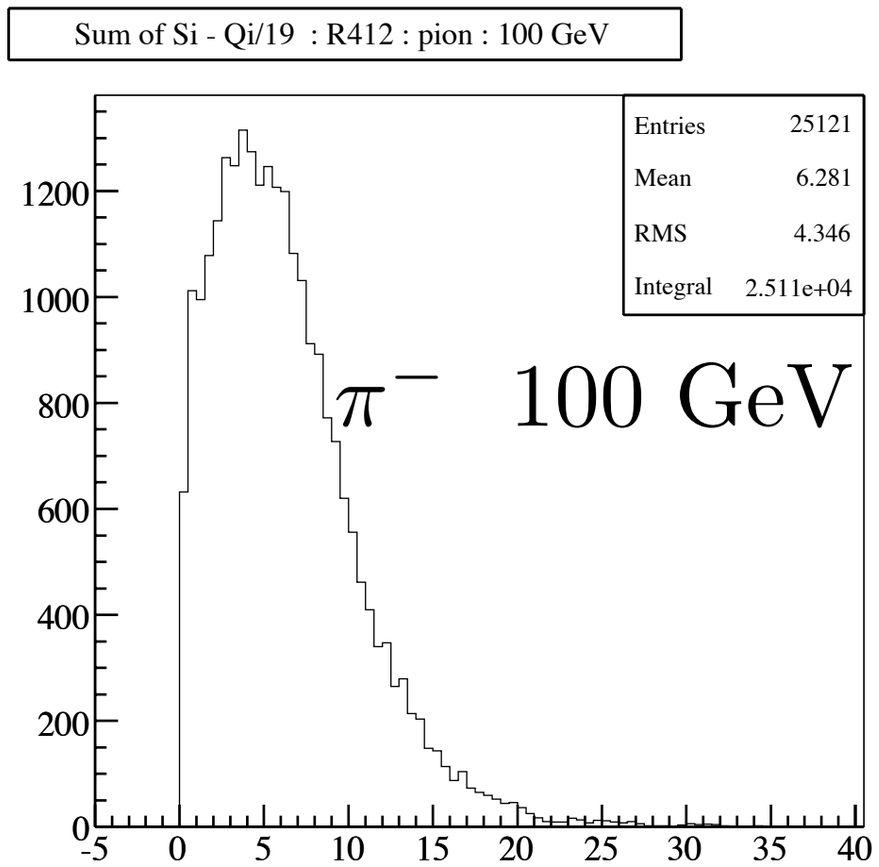
Simplest possible plot: Cerenkov vs Scintillation



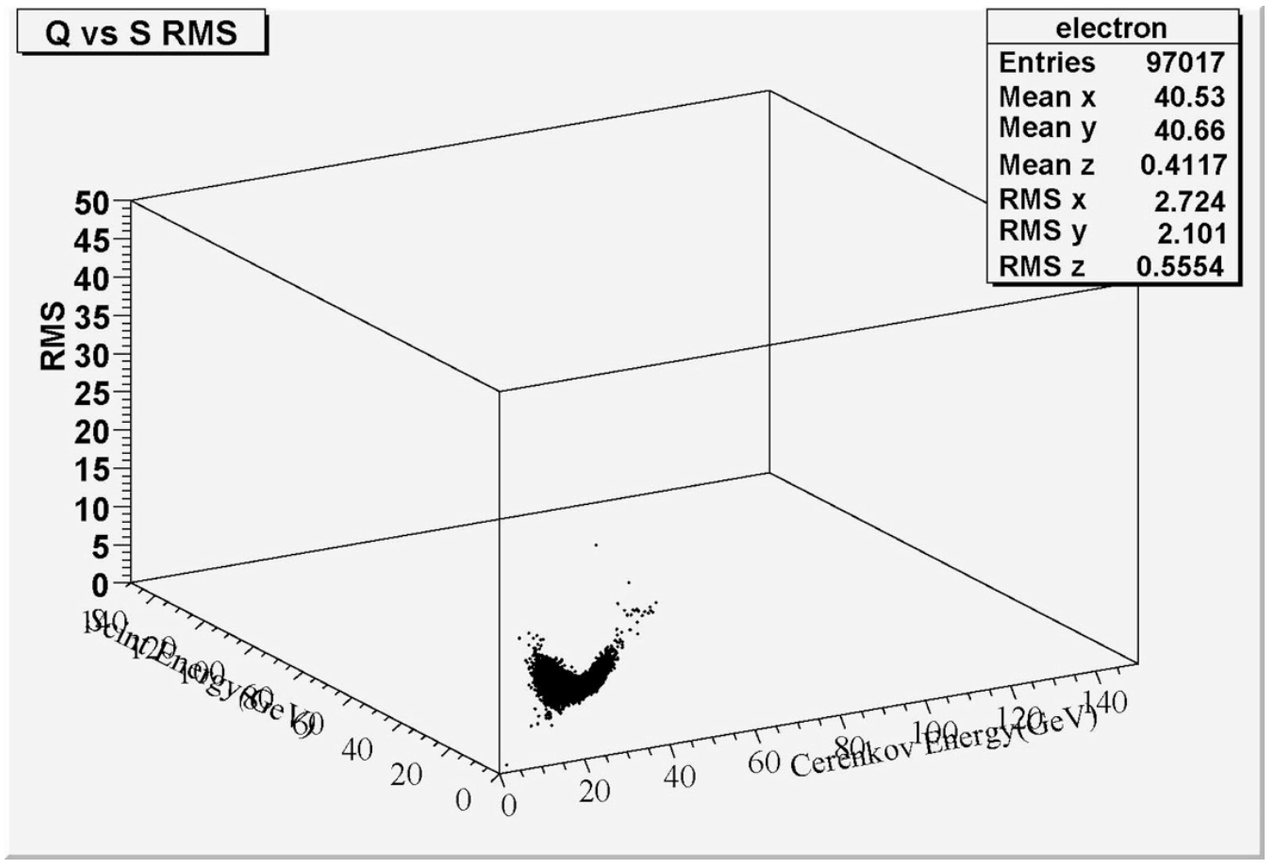
Next, look at variation of C and S channel-by-channel *within* a shower.

$$\sum_i^N [C_i - S_i]^2 / N$$

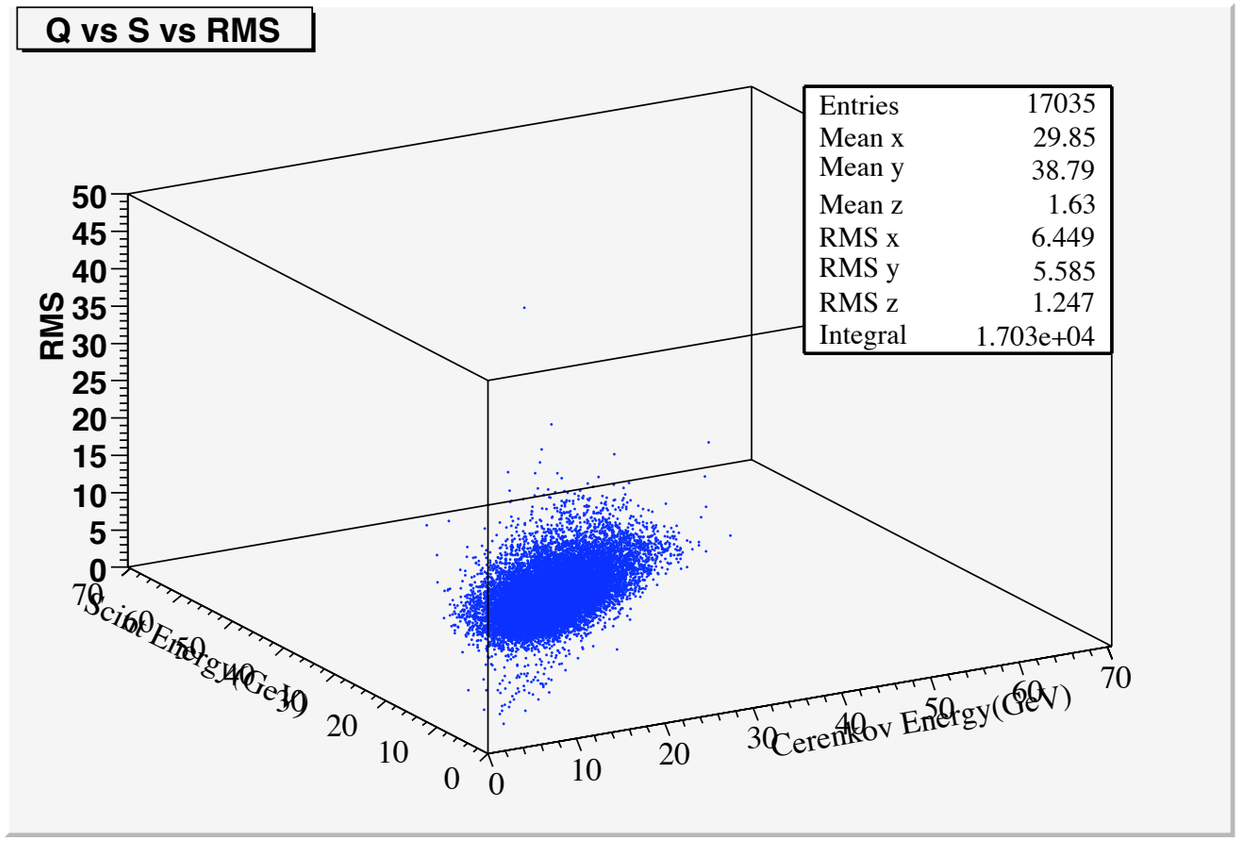




Attempt ... at a 3d (C, S, rms) display



electrons



pions

Next, from time-history readout, measure the width of Scint pulse

Particle ID does NOT require segmentation!

e/π separation using time structure signals

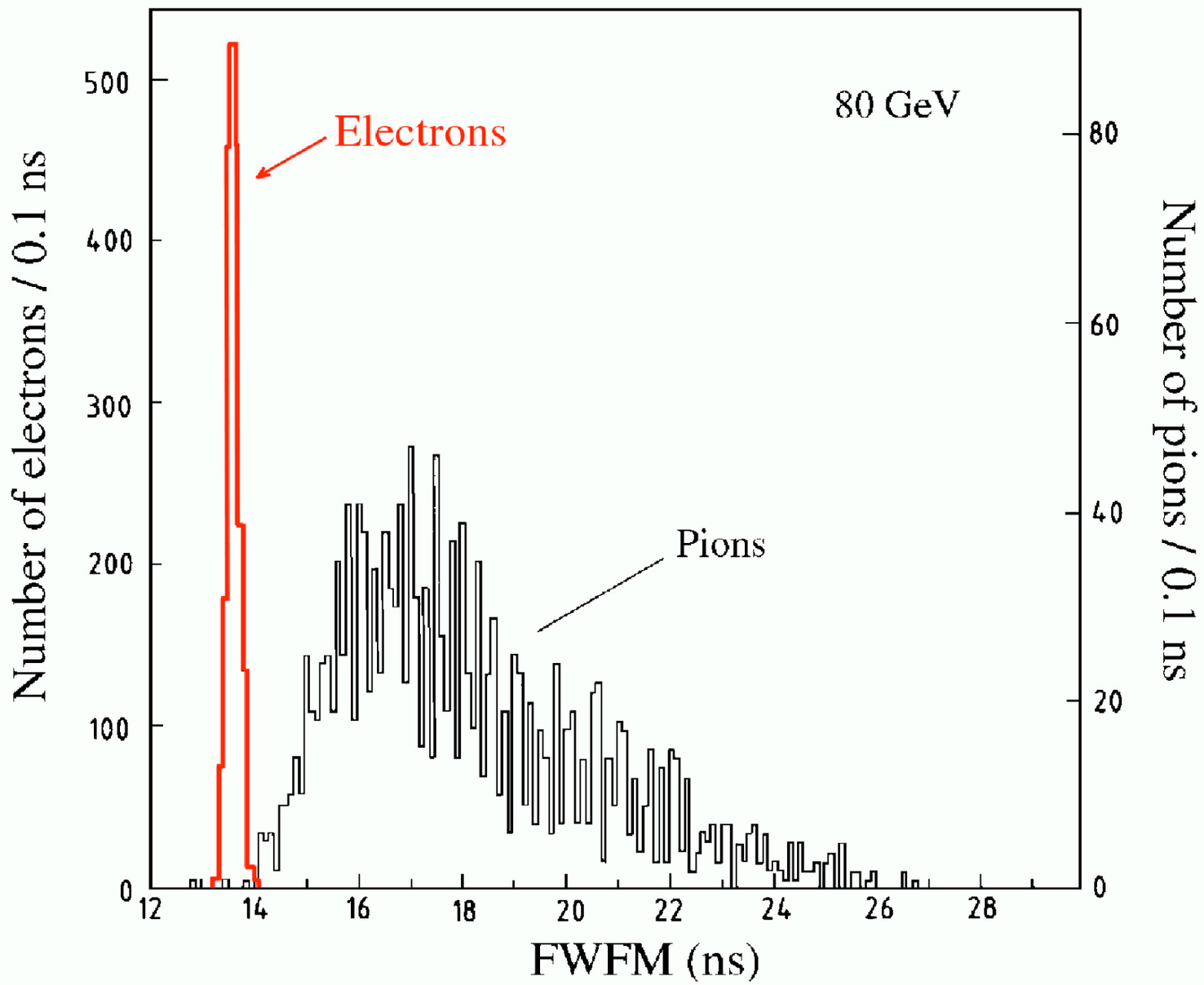
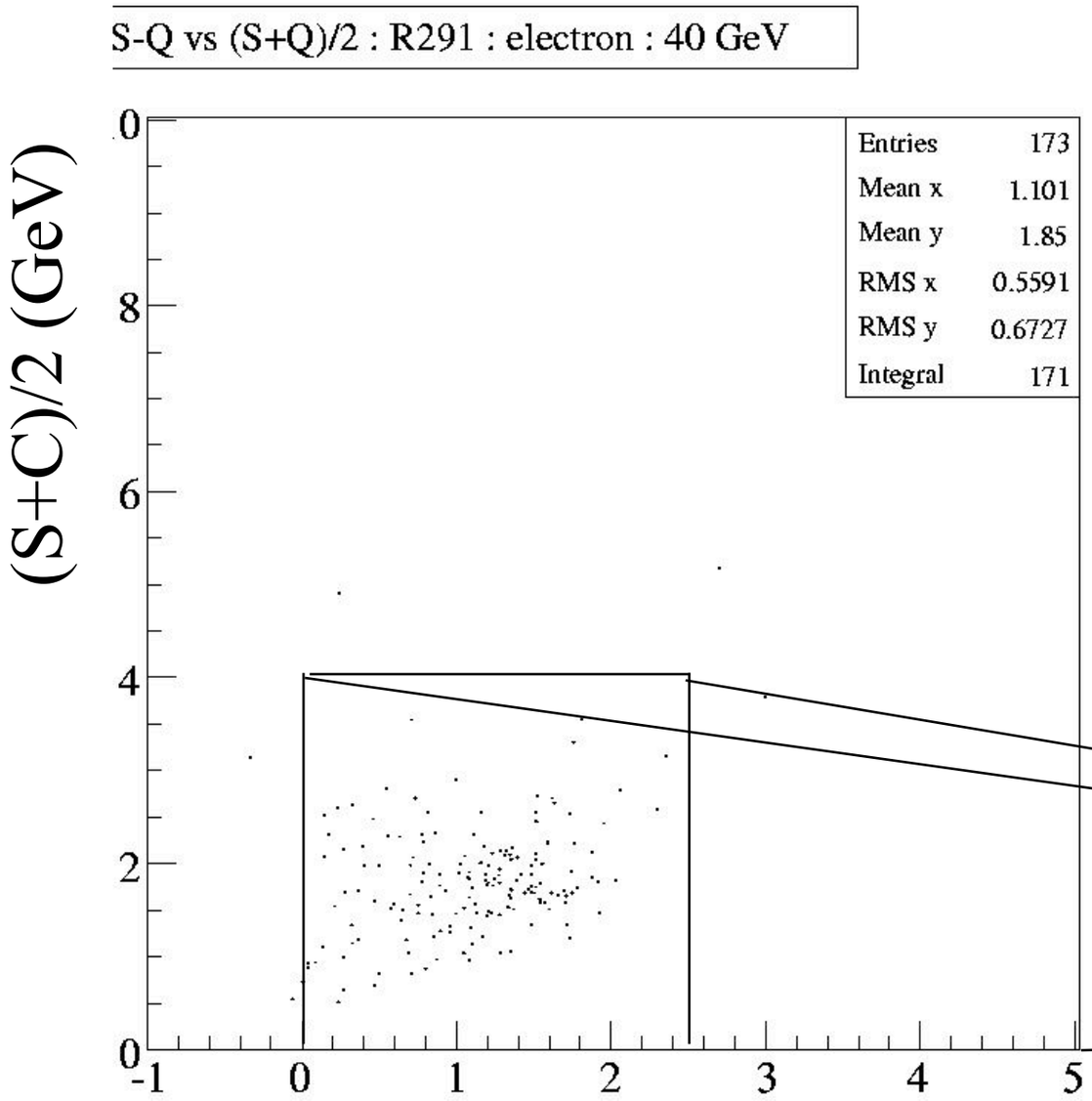
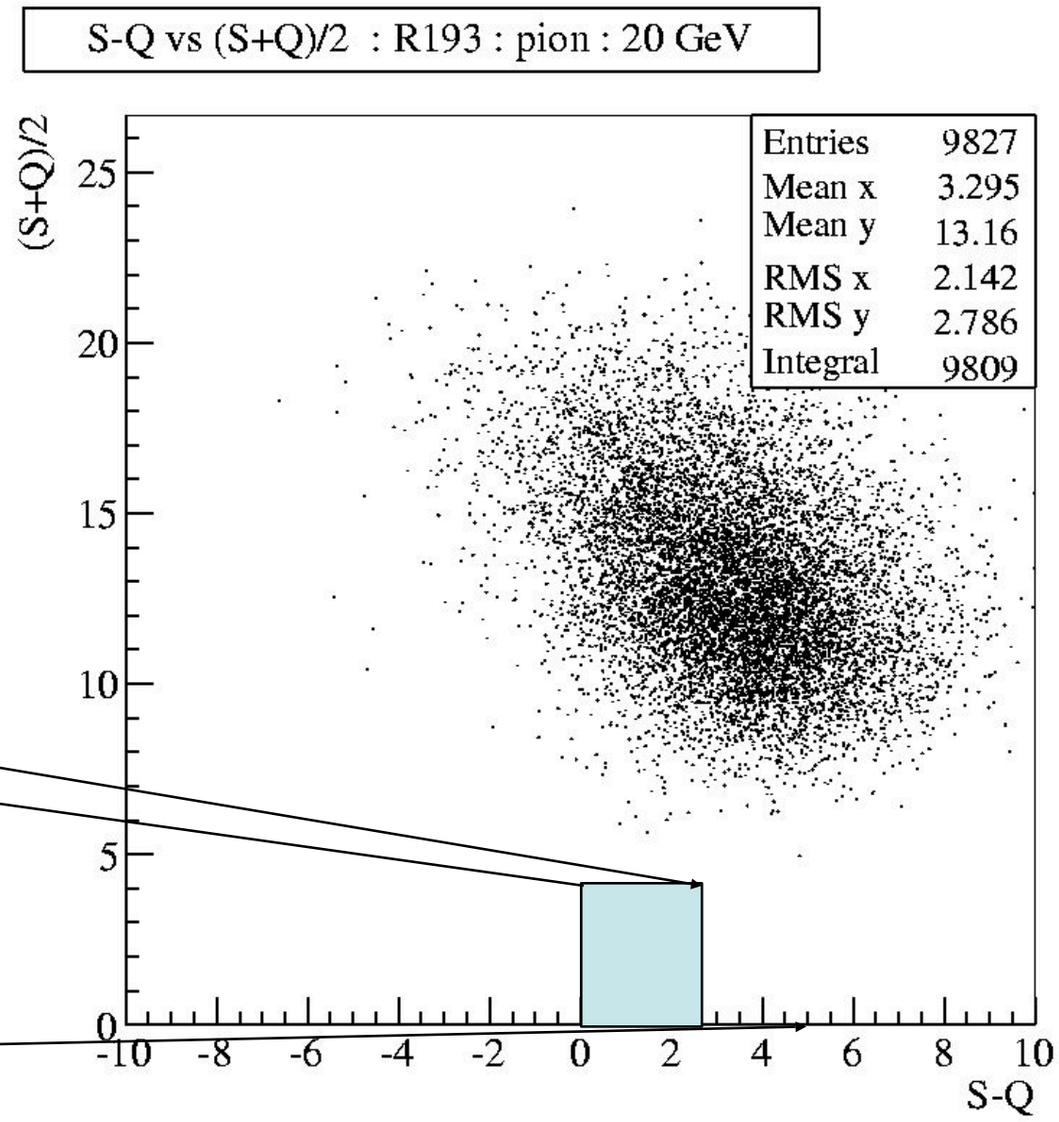


FIG. 7.33. The distribution of the full width at one-fifth maximum (FWFM) for 80 GeV electron and pion signals in SPACAL [Aco 91a].

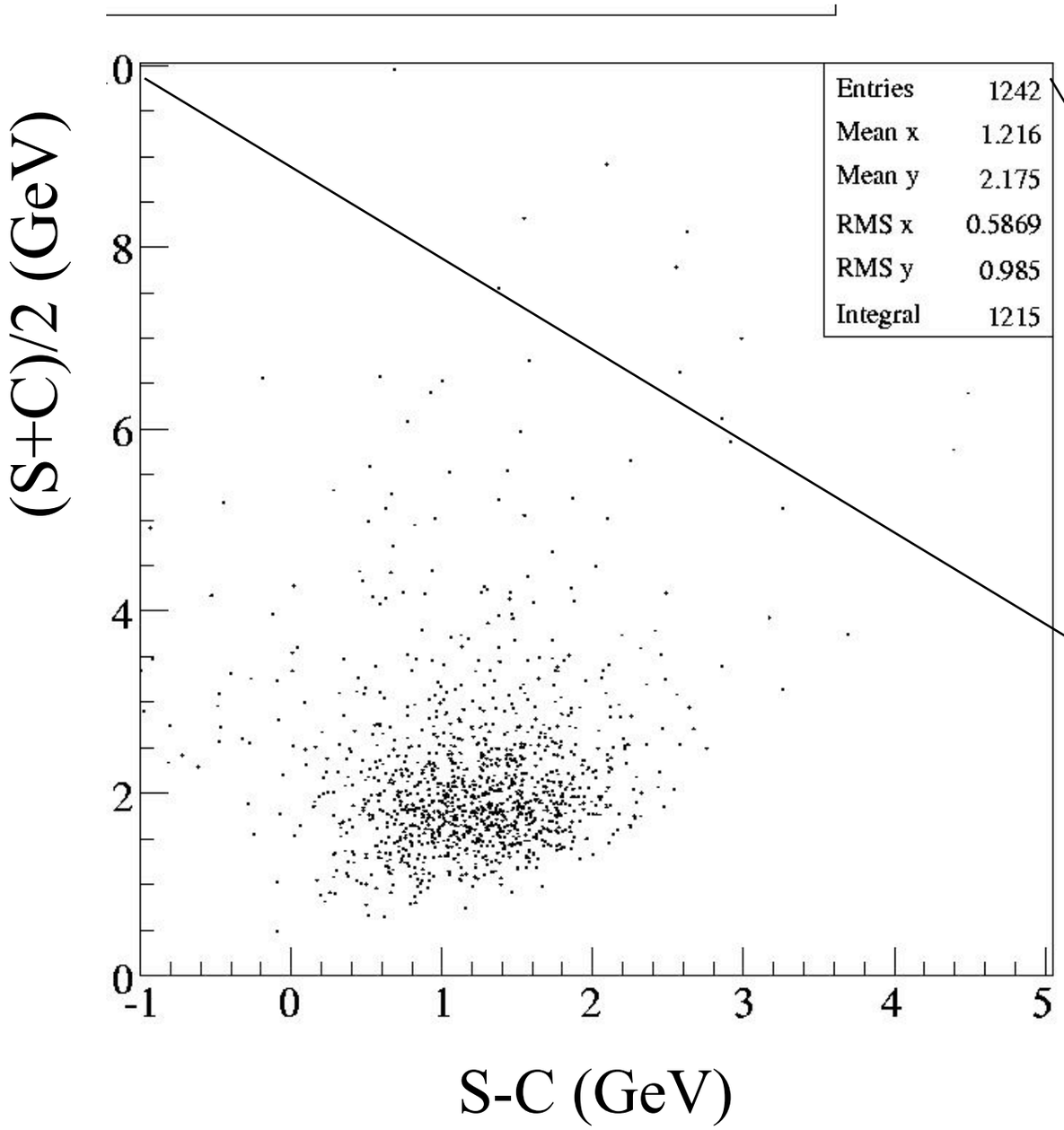
On to muon identification: S-C ~ dE/dx ~ 1 GeV

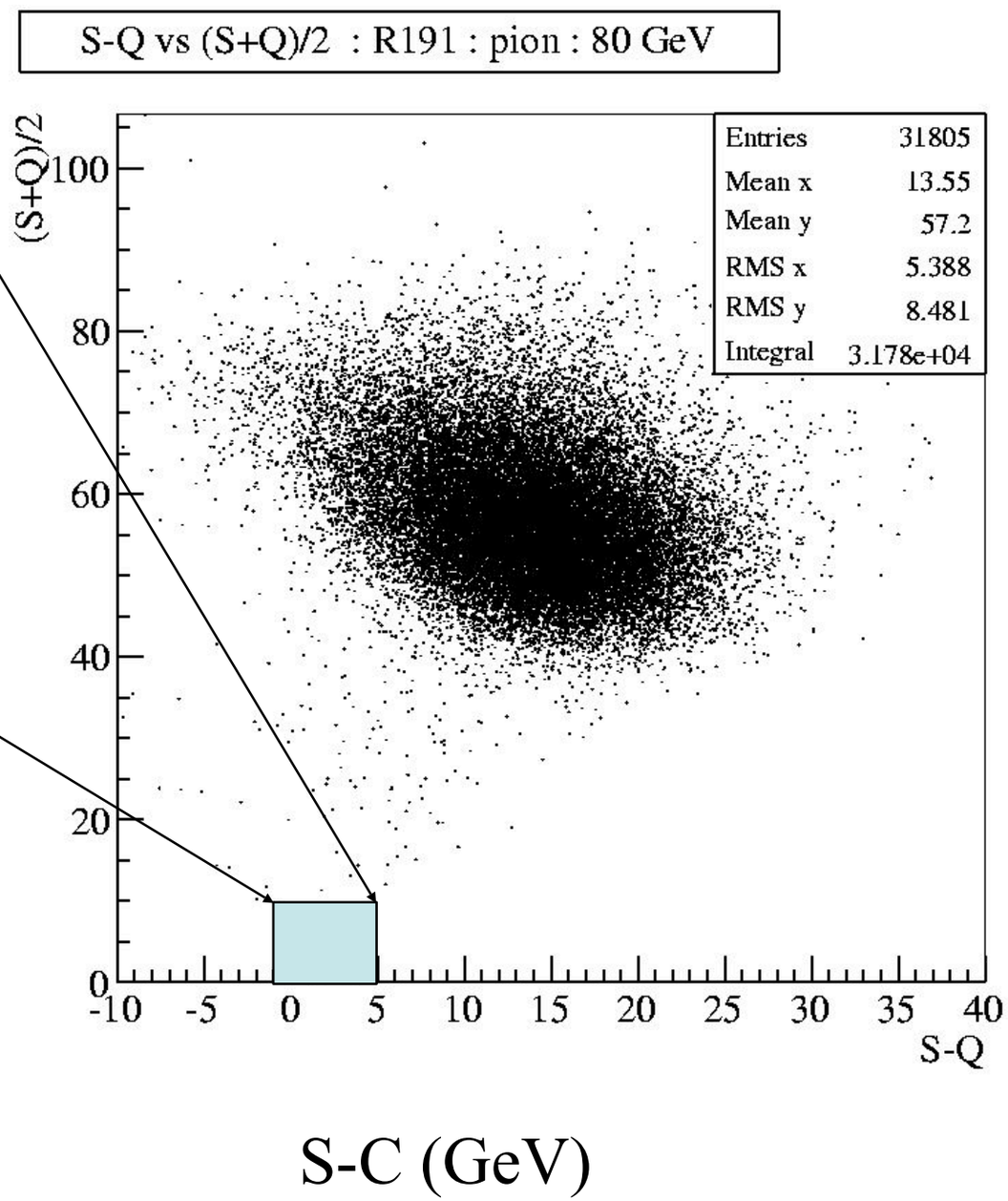
Muons (40 GeV) & Pions (20 GeV)



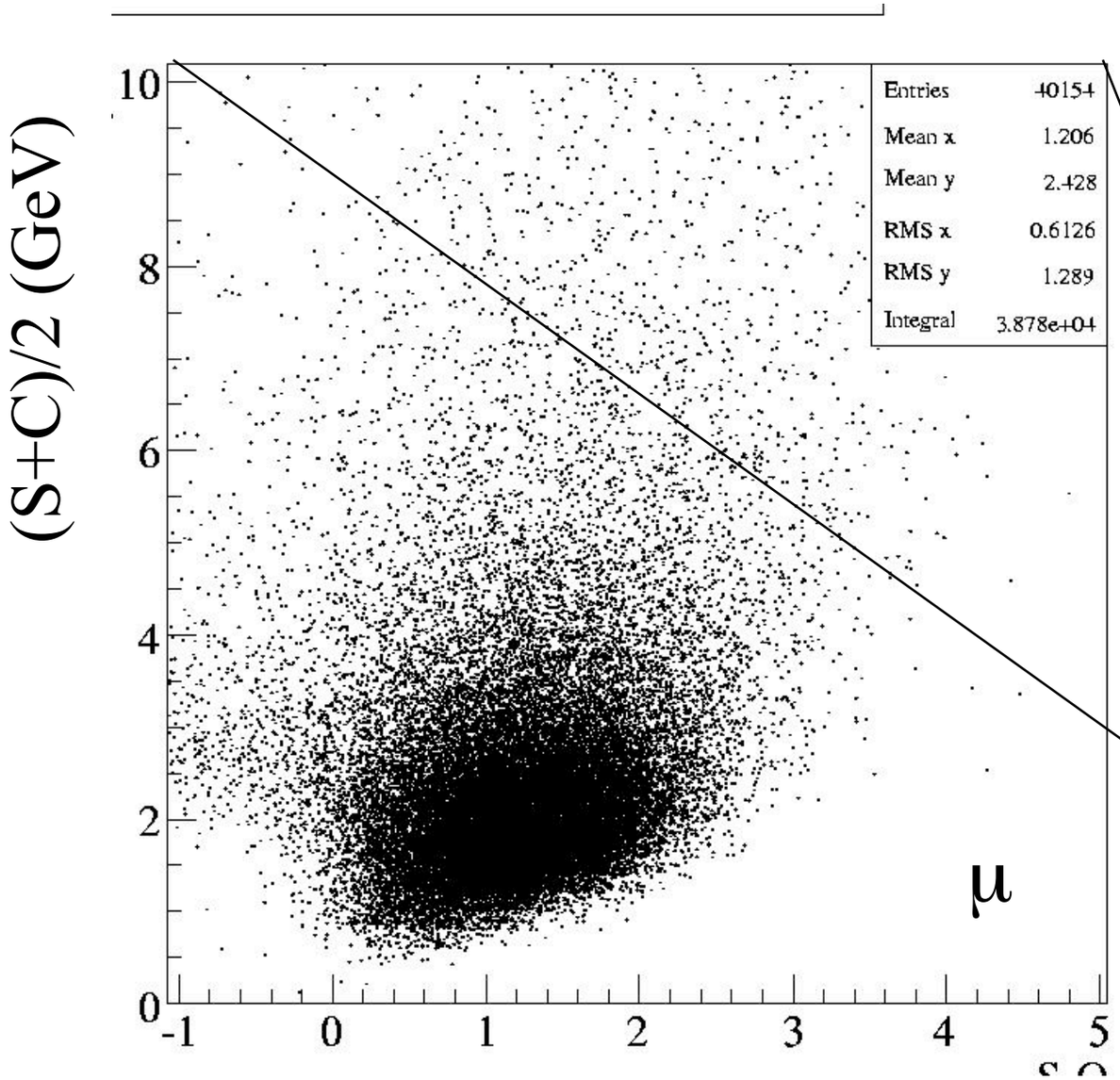


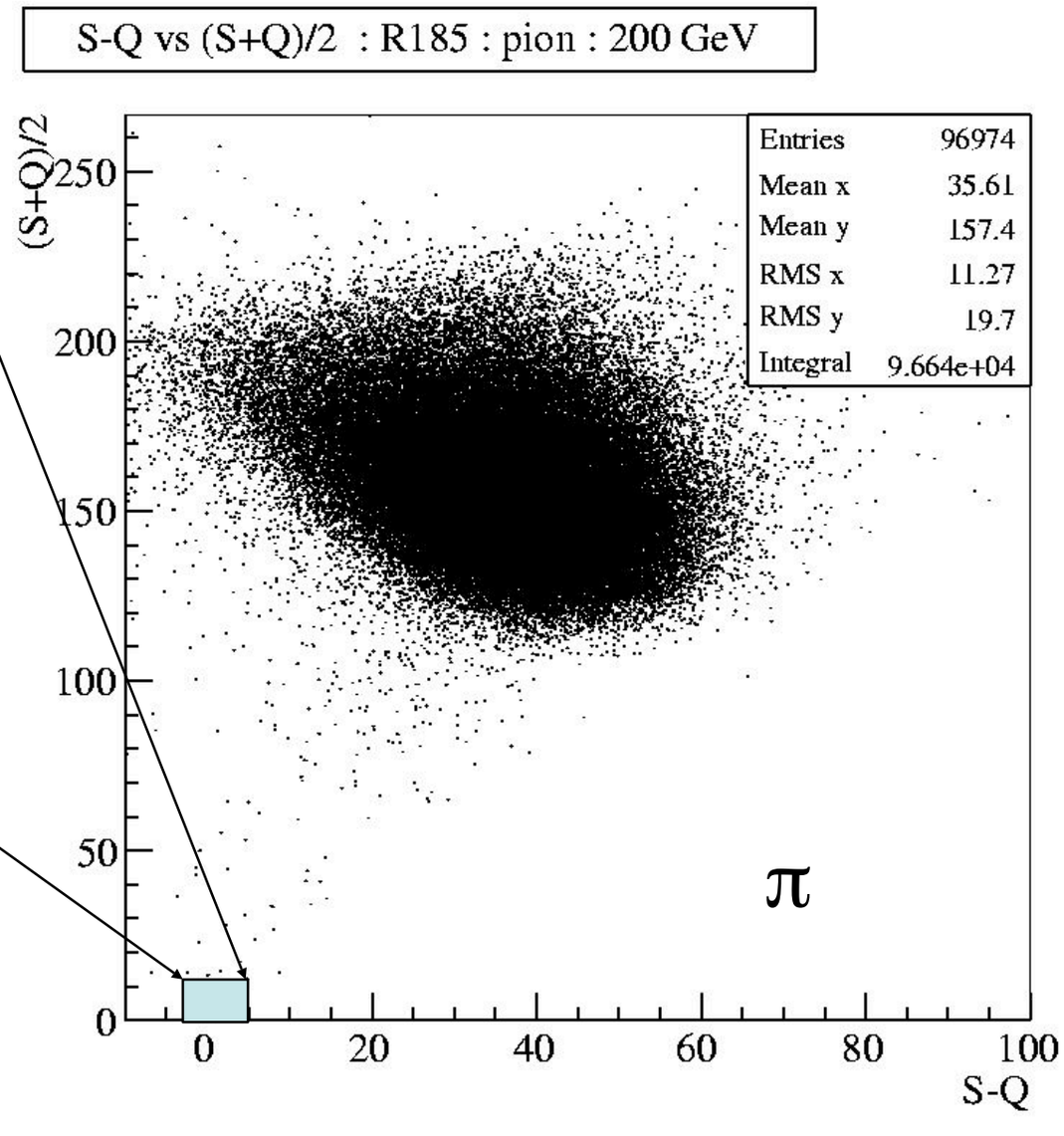
Muons and Pions (80 GeV)



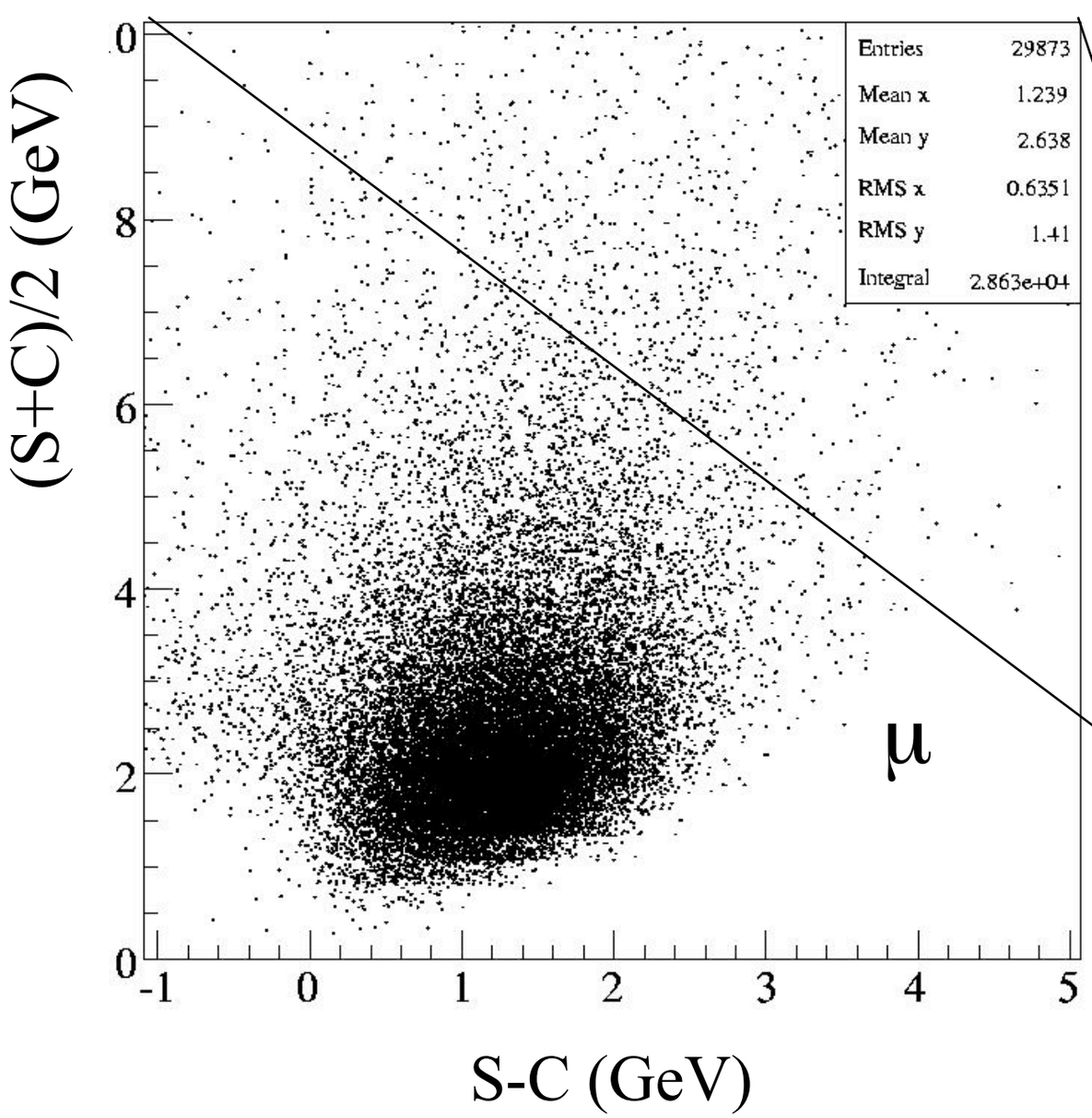


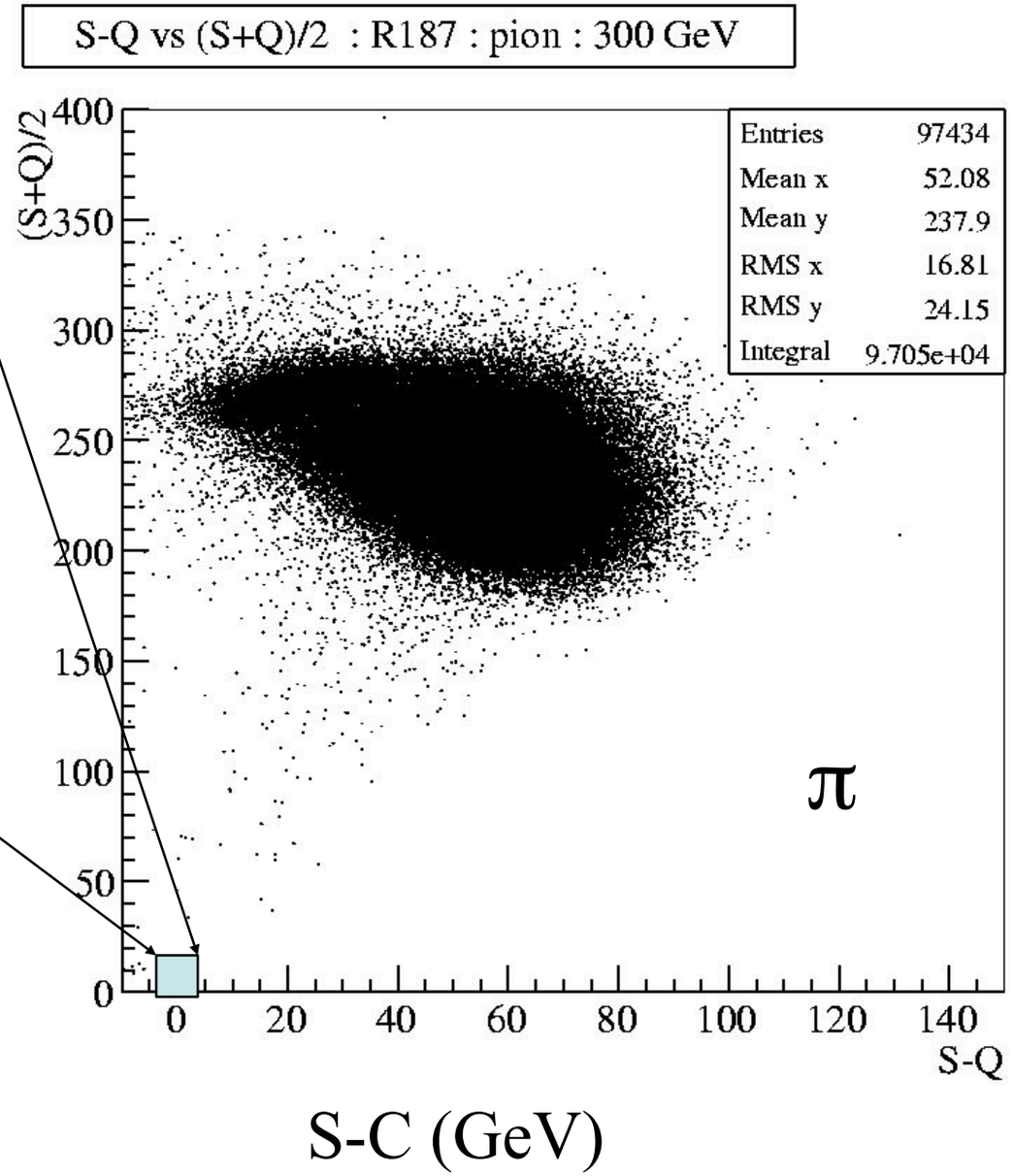
Muons and Pions (200 GeV)





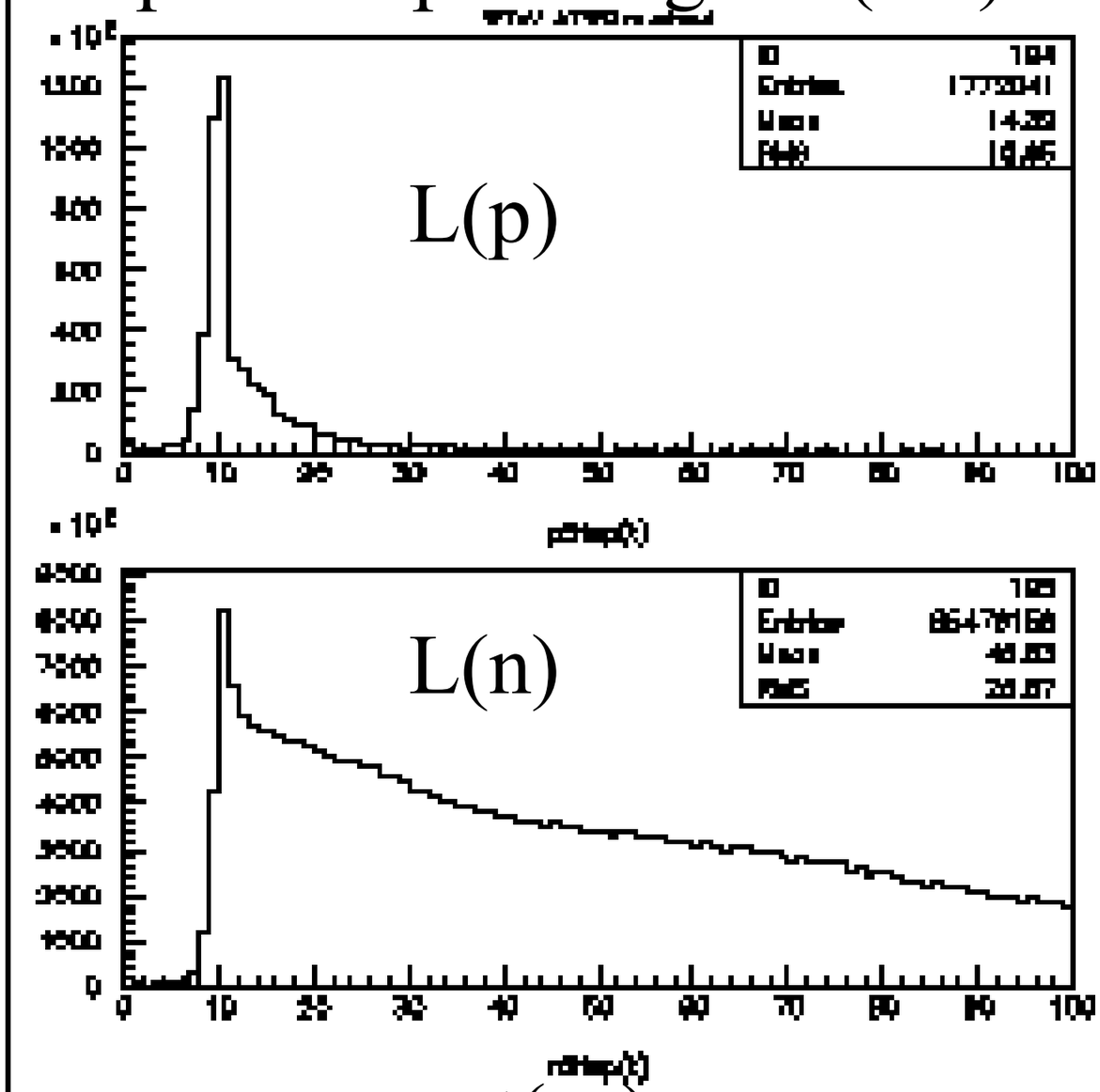
Muons and Pions (300 GeV)



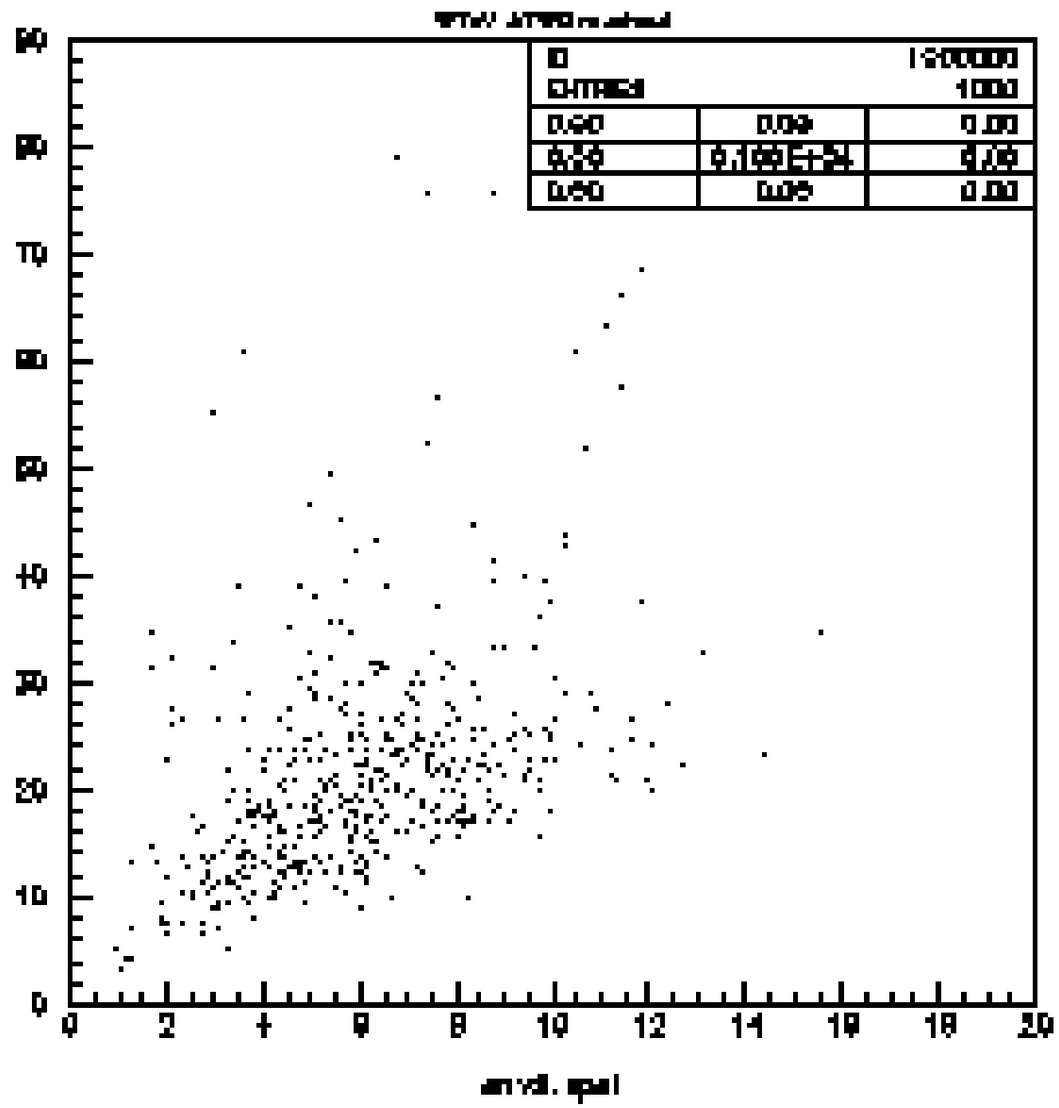


Neutrons in hadronic showers

particle pathlength L(cm)



Spe



Particle ID: *(i)* S vs C, *(ii)* time width of S pulse, *(iii)* channel-to-channel fluctuations within a shower, and *(iv)* measurement of MeV neutrons.

- Fluctuations channel-to-channel within a shower, EM or hadronic

$$\sigma^2_{c-s} = \frac{1}{N}\Sigma_{i=1}^{N}[C_i - S_i]^2$$

$$\sigma_{c-s} \approx 0 \rightarrow \text{EM shower}$$

$$\sigma_{c-s} >> 0 \rightarrow \text{Hadronic}$$

- Few MeV neutron content of showers

E_{neutrons} estimated from late scintillation light

$$f_n = \frac{E_{\text{neutrons}}}{E_{\text{shower}}}$$

$$f_n \approx 0 \quad \rightarrow \text{EM, muonic}$$

$$f_n >> 0 \rightarrow \text{Hadronic}$$

Triple-readout optical fiber calorimeter:

"LESSON 6: To improve energy resolution, measure every fluctuation event-by-event"

- Spatial fluctuations are huge, $\lambda_{\rm Int}$, with local high density EM deposits.

  → fine spatial sampling with scintillation fibers every 2-3 mm.

- EM fraction fluctuations are huge, 10% - 90%, of total shower energy.

  → measure EM content with Cerenkov fibers, Eth ~ 0.25 MeV, mostly electrons from $\pi^0 \rightarrow \gamma\gamma$

- Binding energy (BE) loss fluctuations from nuclear breakup

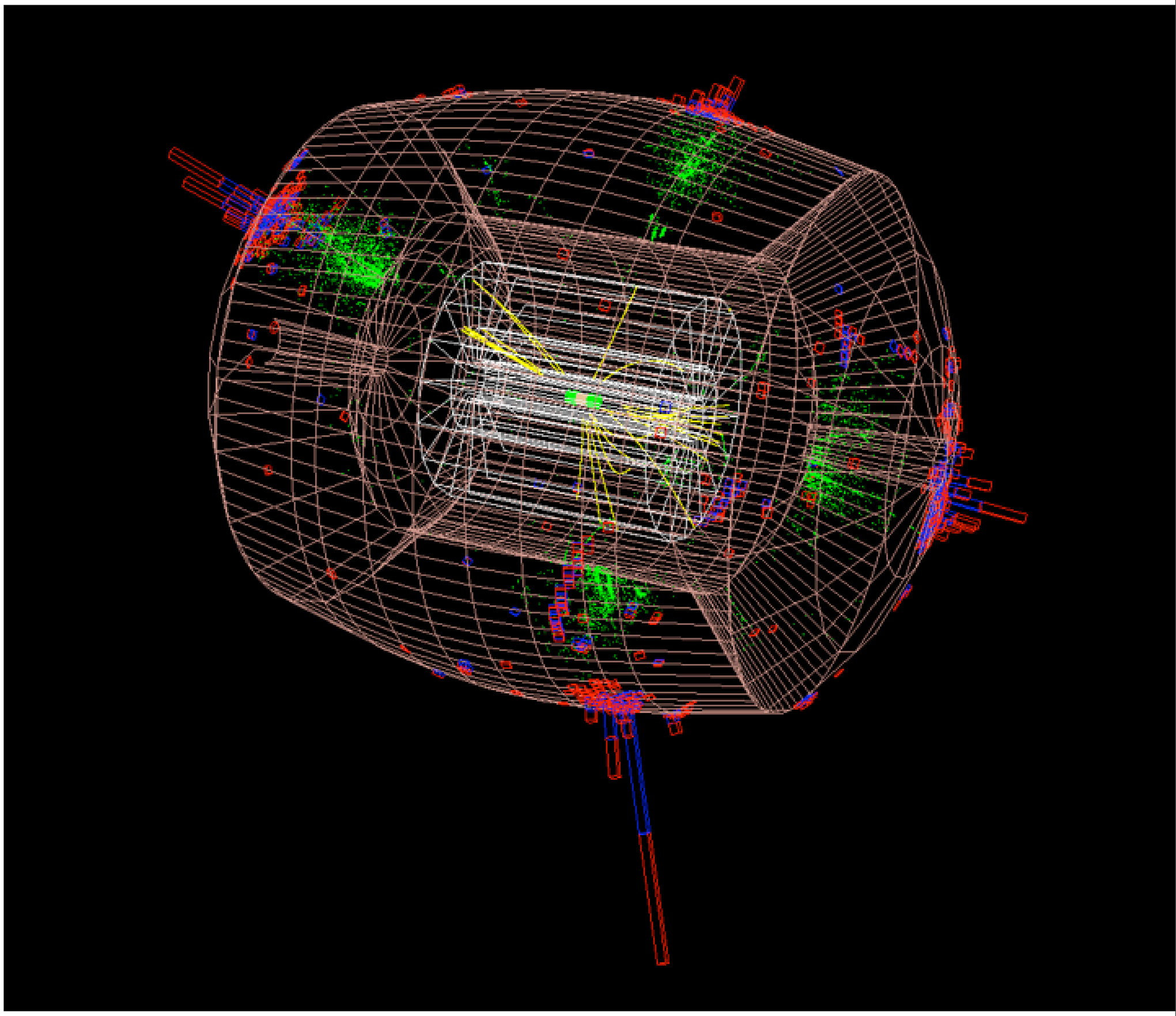
  → measure MeV neutron content of showers

Average values for one particle species or another are of no consequence - only fluctuations from the average are important.

e^+e^-

$\longrightarrow H^0 Z^0$

$\longrightarrow b\bar{b}q\bar{q}$



e^+e^-
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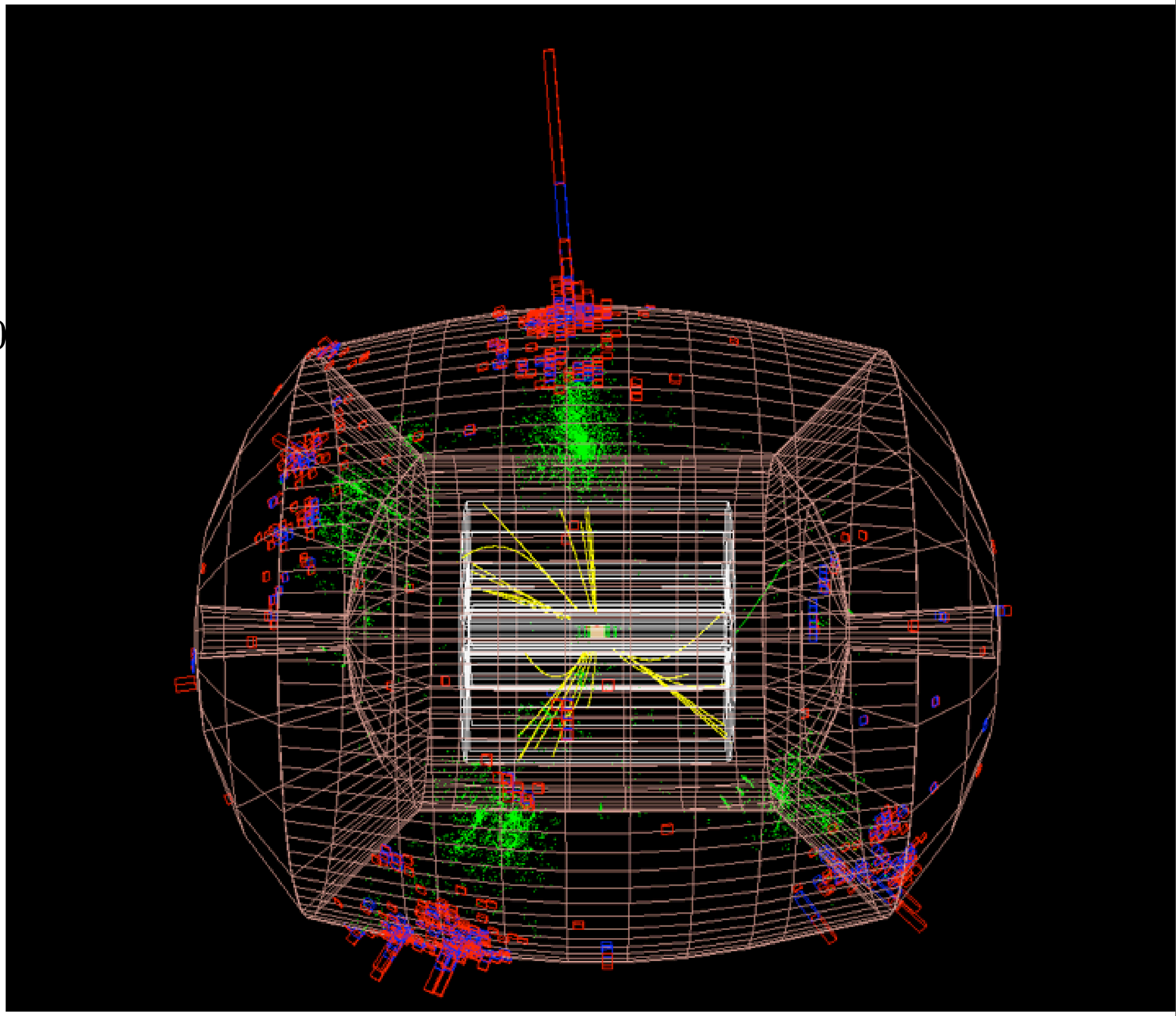

Multiple readout calorimetry and its advantages:

1. Good control of fluctuations in widely and multiply fluctuating hadronic showers;
2. Very rich area for new and clever ideas;
3. Very interesting particle identification strengths;
4. We hope our thinking is clear enough for a good shot at the design of a scalable module;
5. Using FLUKA in ILCsim for precision design calculations;
6. “Ultimate” energy resolution near 15%/√E. We will be quite happy with 20-25%/√E; and,
7. As always, collaborators and observers/visitors welcome.