Compensating and Dual-readout Calorimetry

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Linear Collider Detector R&D Review
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Contents

June 4, 2007: GLD+LDC will presumably propose a PFA calorimeter; 4th will propose a dual-readout calorimeter.

• DREAM and 4th Concept

- Proof-of-principle beam test in June 2003; EM fraction fluctuations in hadronic showers (*five papers published in NIM*)

- Crystal dual-readout (*two more papers*)

- Neutrons for BE loss fluctuations (*one more paper*)

- Design of an ILC concept detector incorporating these results:
  - *excellent energy resolution for W,Z reconstruction to jets*
  - *novel particle identification*
  - *near-perfect hermeticity*
  - *readout at rear (depth segmentation a hindrance, not a help)*

Four distinct benefits of dual-readout calorimetry

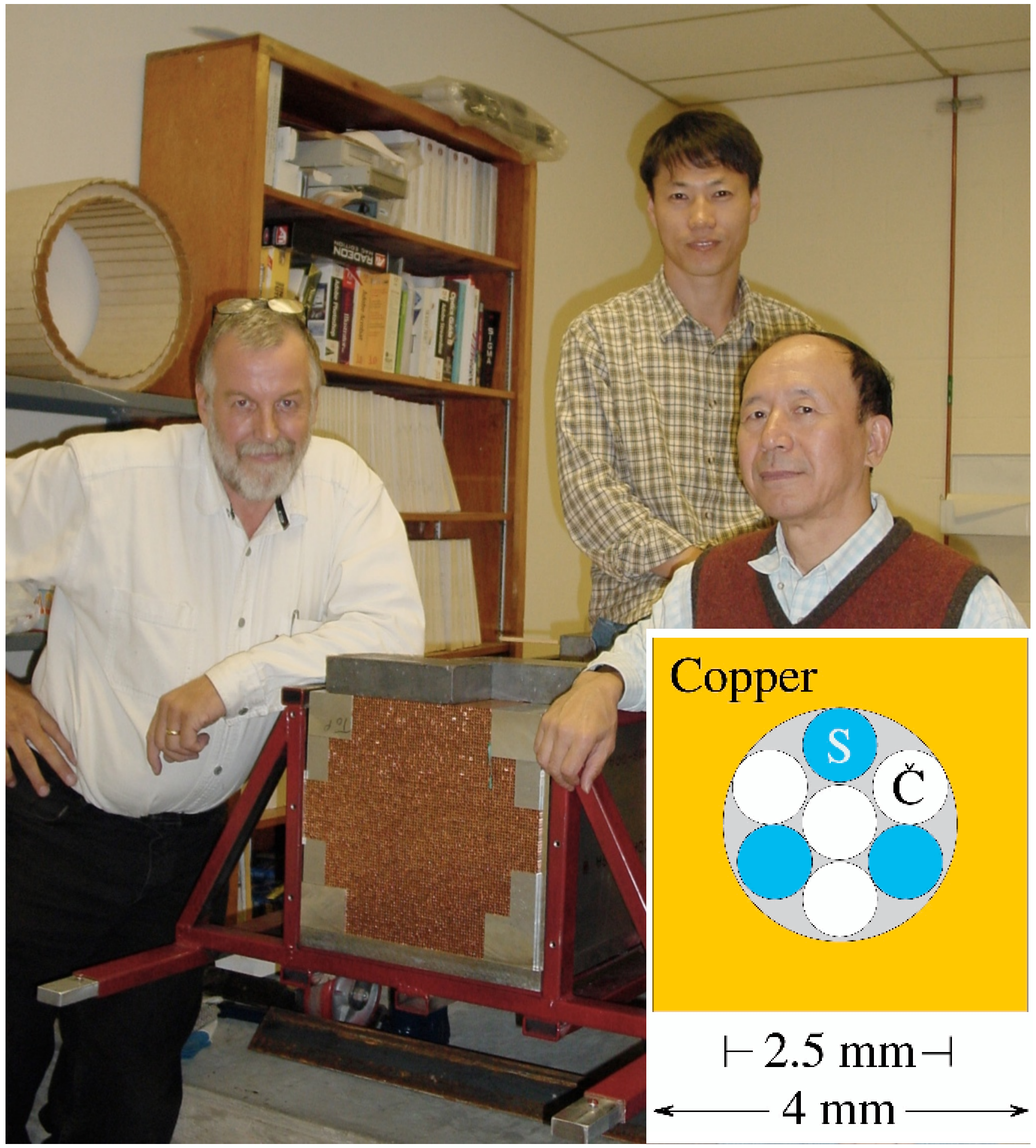
(1) Dual-readout is easy and robust;

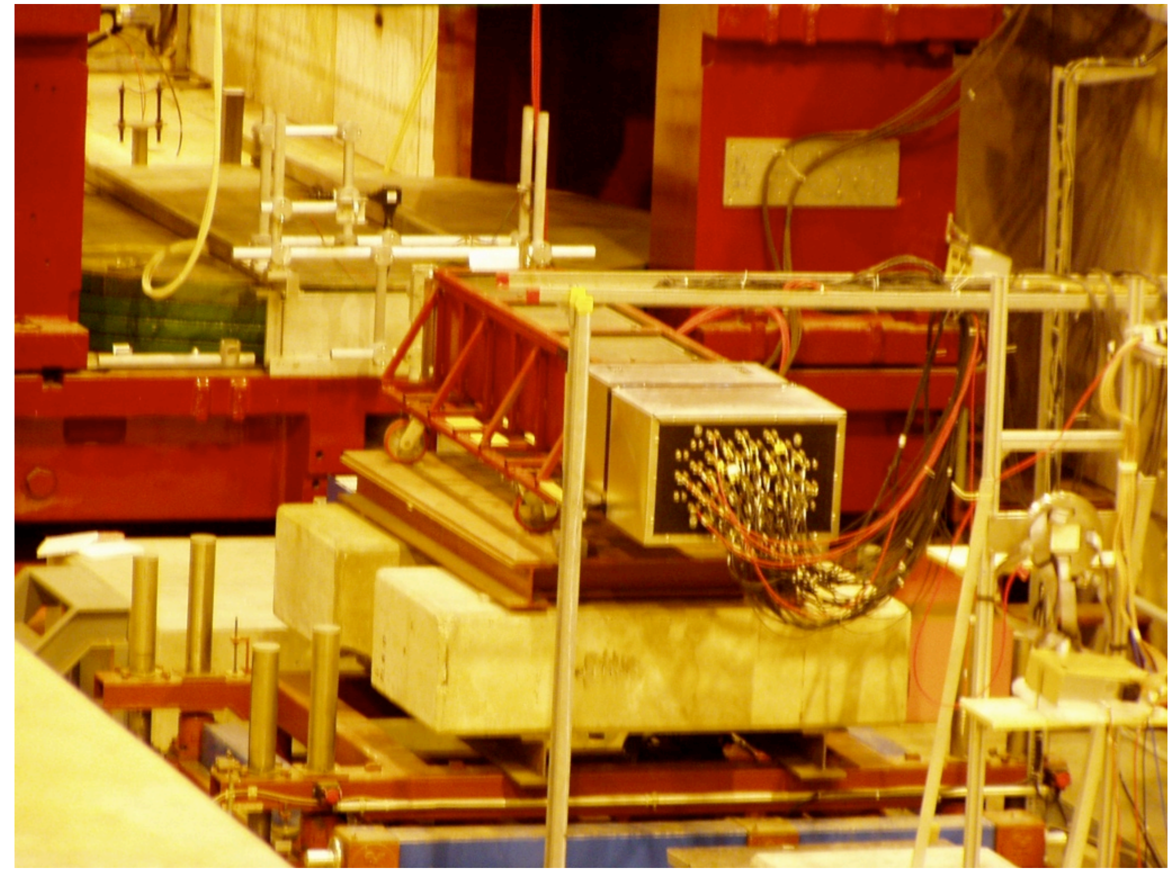
(2) Possibility of excellent energy resolution;

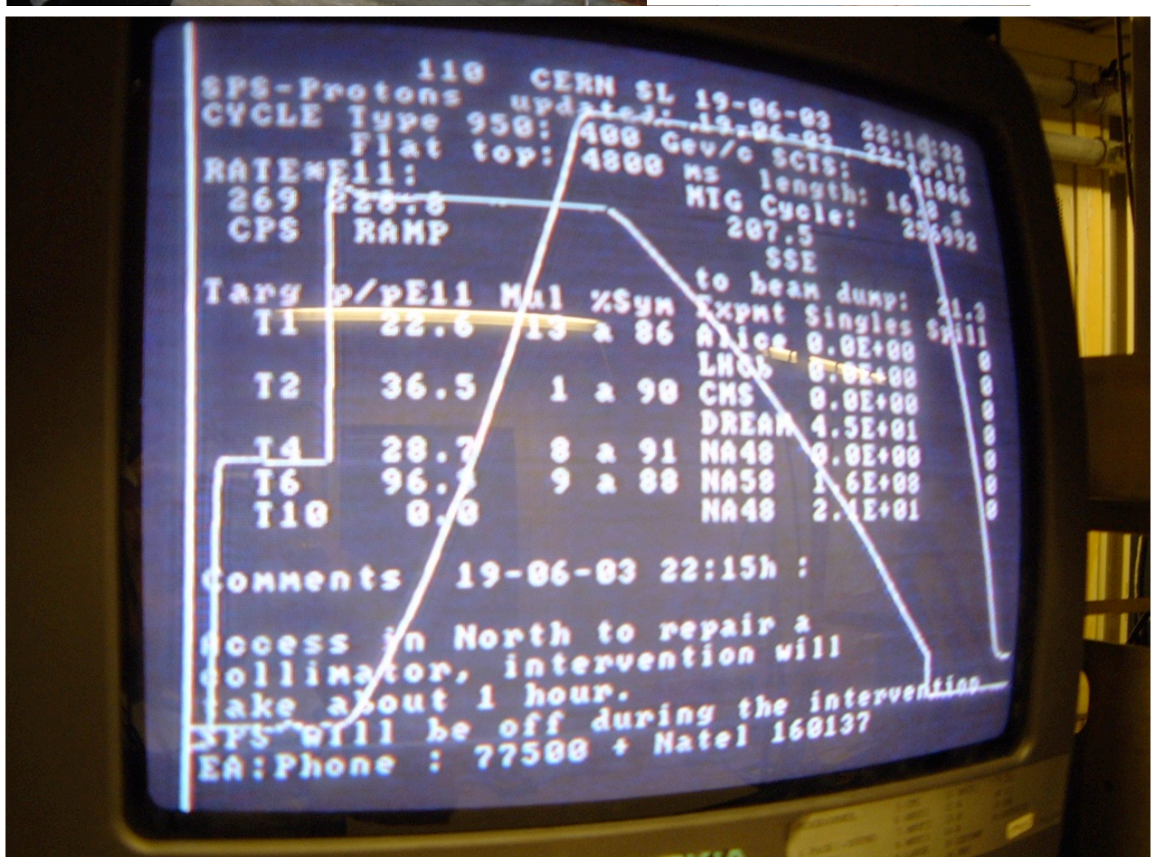
(3) Absolute hadronic energy linearity;

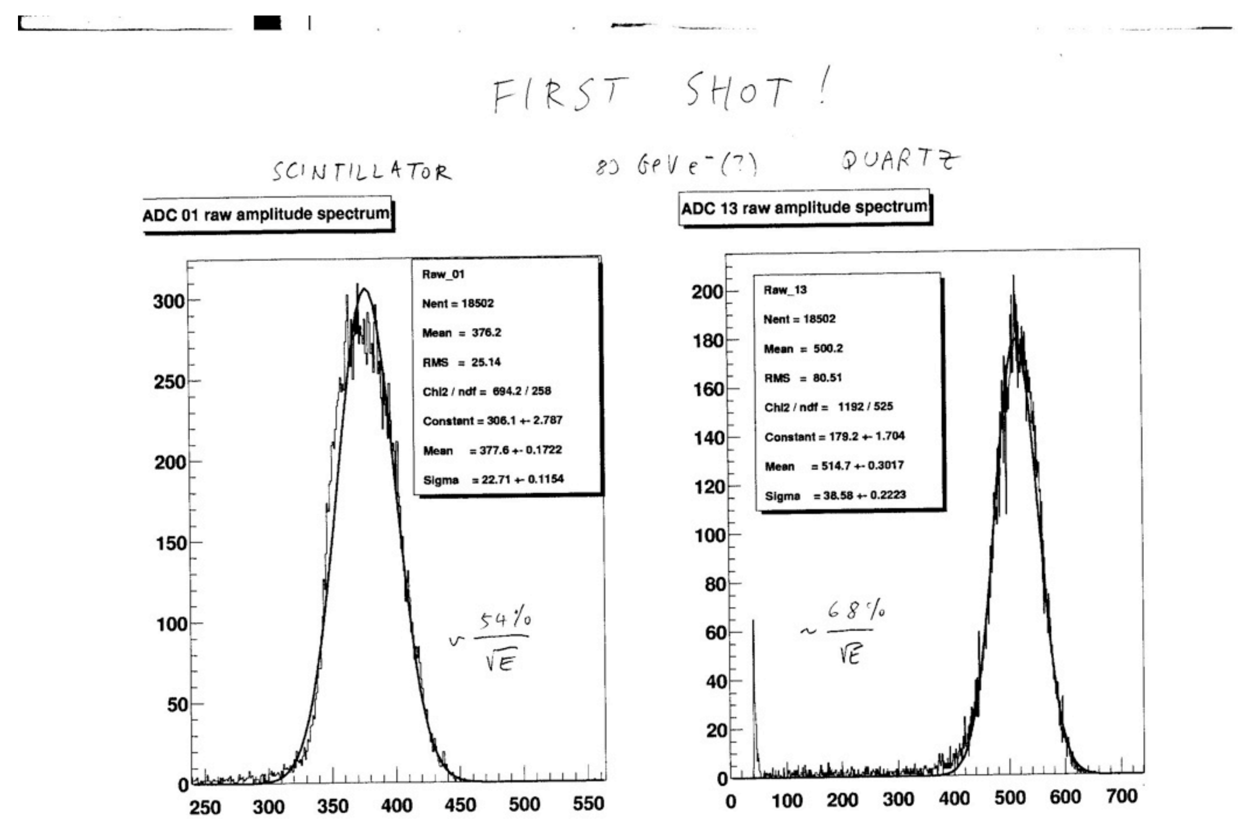
(4) Excellent and novel particle identification

DREAM module, 2003 *(easy)*

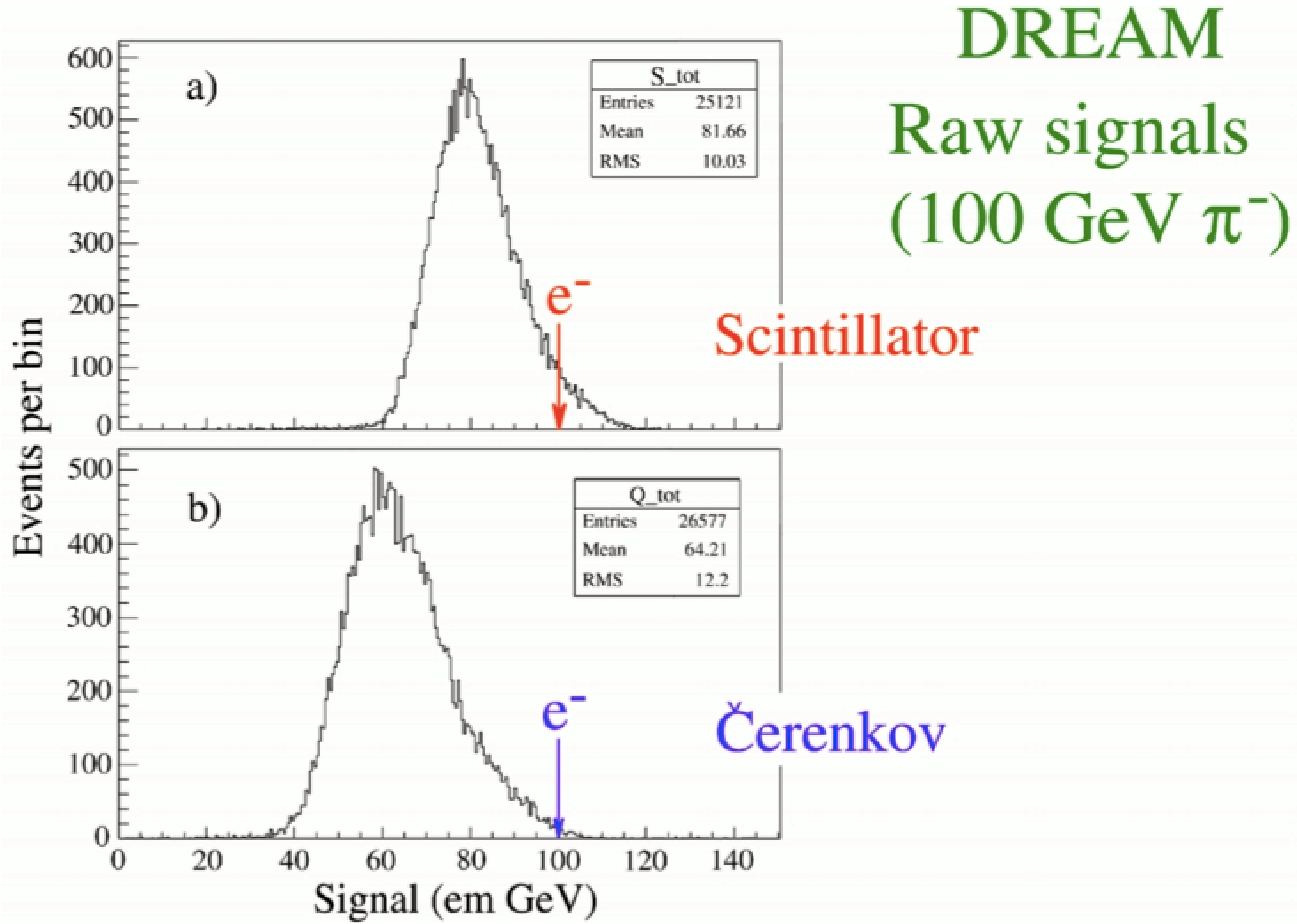








Calibrated with electrons at 40 GeV



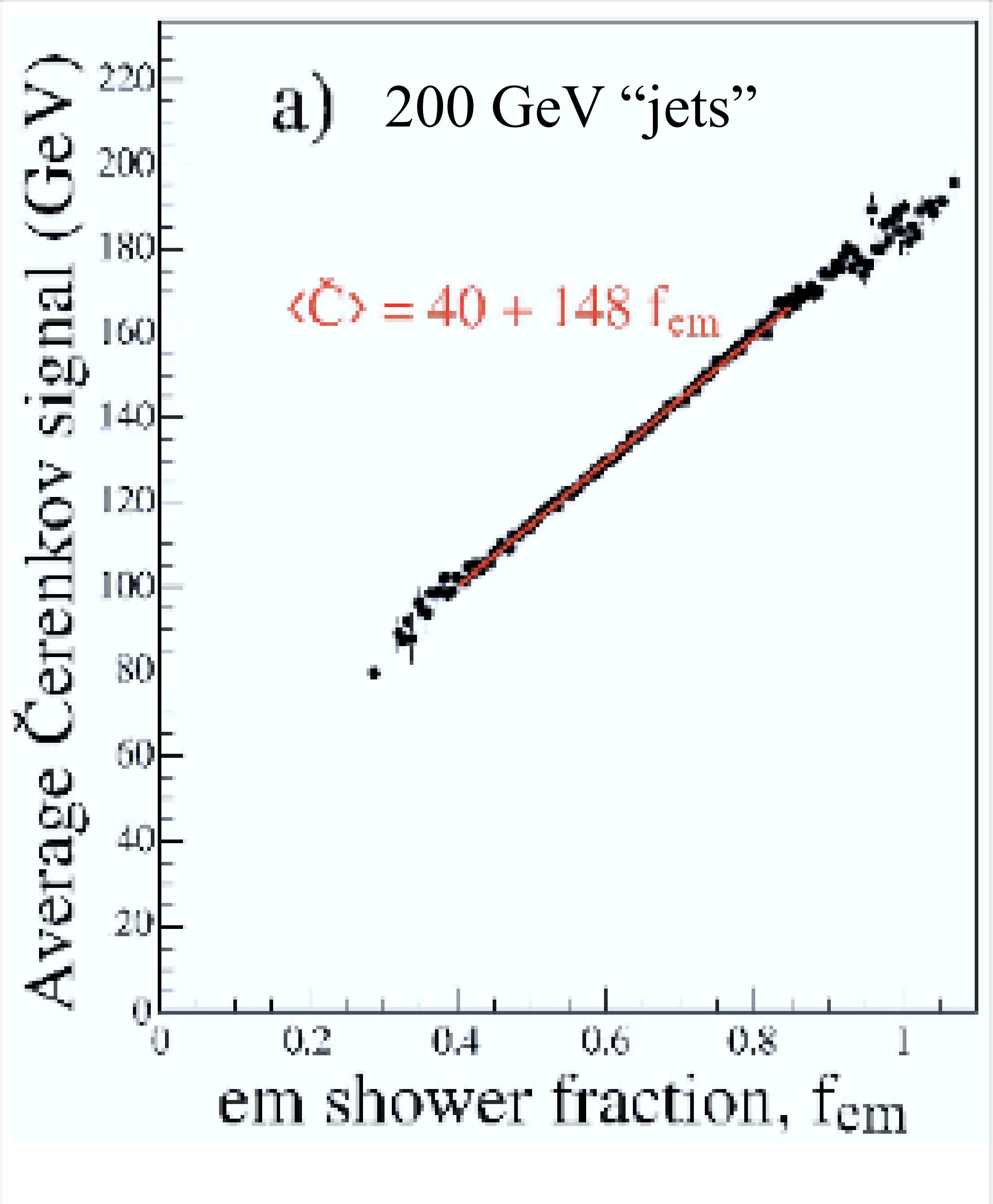
Measure EM fraction shower-by-shower ... nicely and linearly correlated with the Cerenkov signal.

The simplest possible description of the calorimeter Cerenkov and scintillation response to hadronic energy E

$$(e/h)_C = \eta_C \approx 5$$
$$(e/h)_S = \eta_S \approx 1.4$$

$$C = [f_{em} + (1 - f_{em})/\eta_C]E$$
$$S = [f_{em} + (1 - f_{em})/\eta_S]E$$

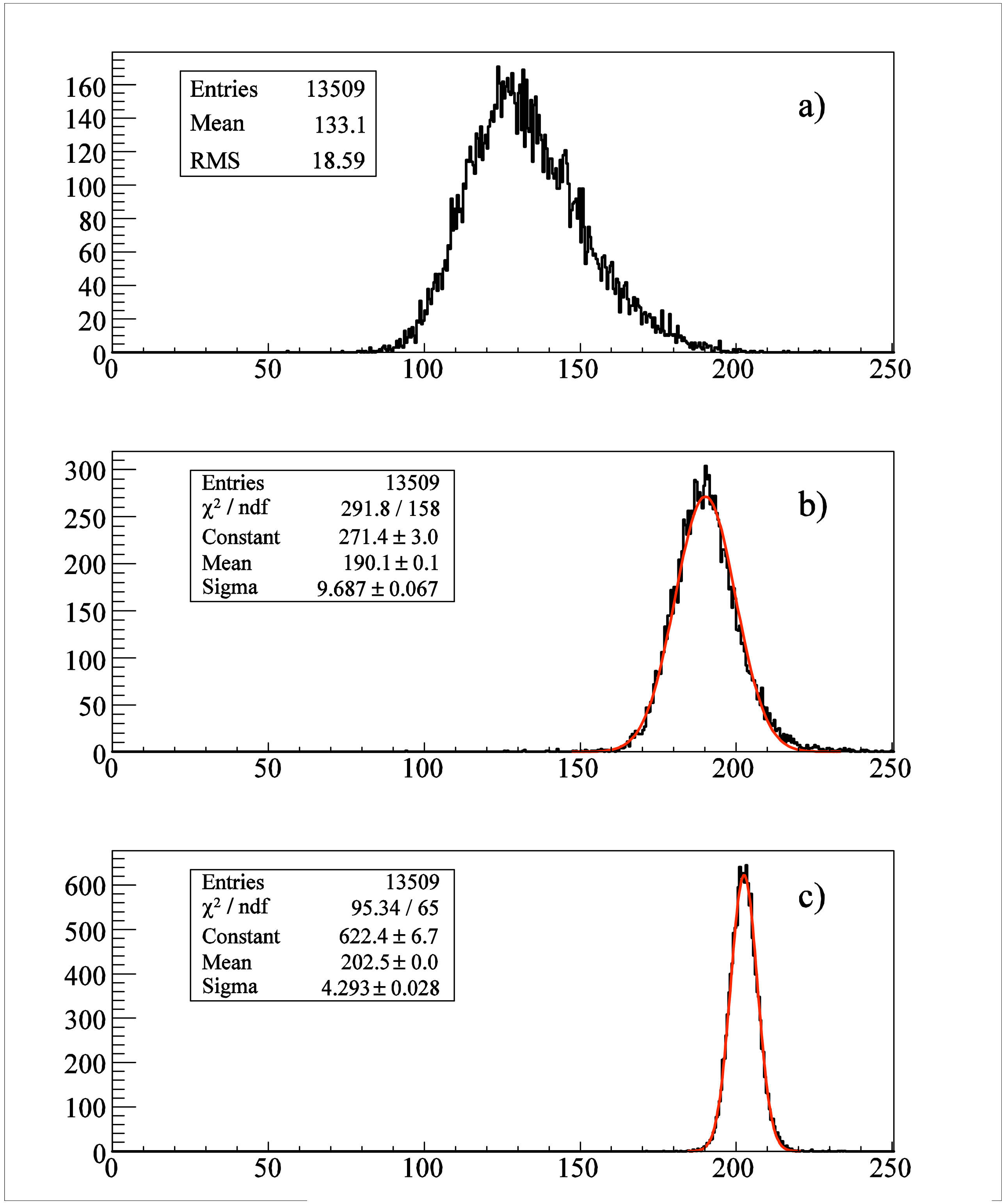
$$\rightarrow C/E = 1/\eta_C + f_{em}(1 - 1/\eta_C)$$



Data NIM A537 (2005) 537.

Possibility of excellent energy resolution

DREAM data 200 GeV π^-: Energy response



Scintillating fibers only

Scint + Cerenkov fibers

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

(4% leakage fluctuations)

Scint + Cerenkov

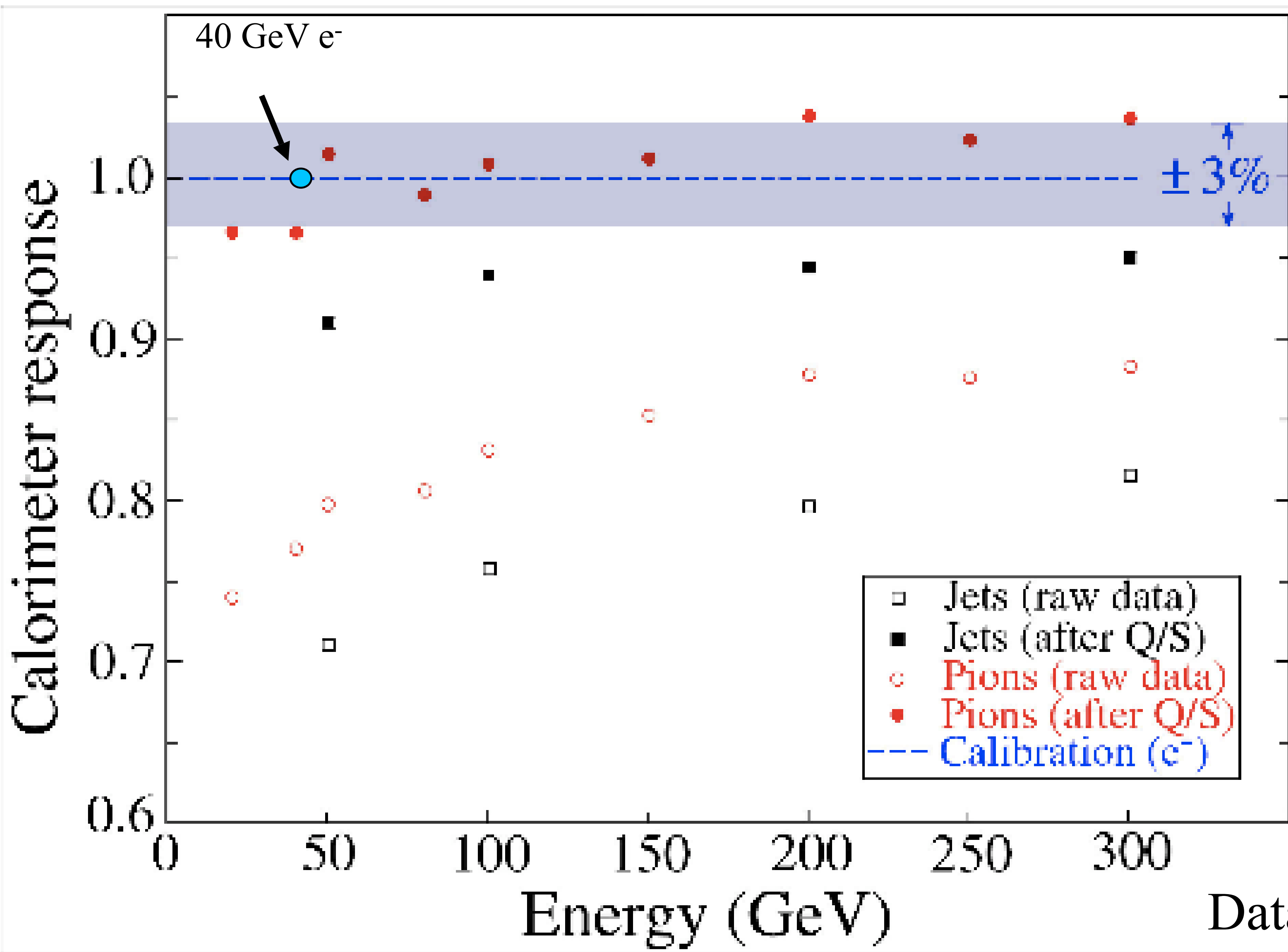
$f_{EM} \propto (C/E_{beam} - 1/\eta_C)$

(suppresses leakage)

Data NIM A537 (2005) 537.

Absolute hadronic energy linearity

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



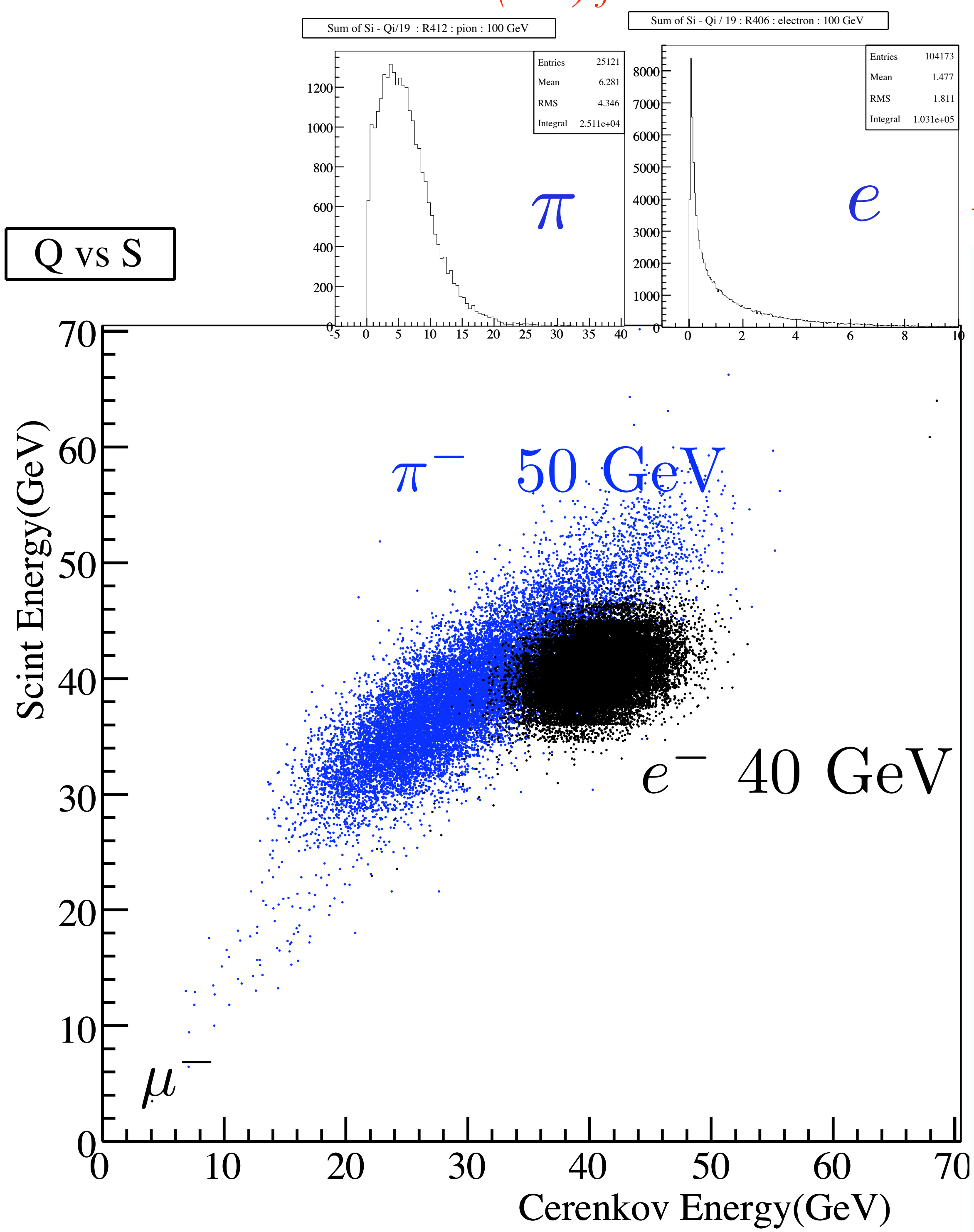
ILC

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

Data NIM A537 (2005) 537.

Novel particle Identification: $e,\ \pi,\ \mu,\ q \rightarrow jet$

Third axis: (S-C) fluctuations within shower



Particle ID does NOT require segmentatic

e/π separation using time structure signals

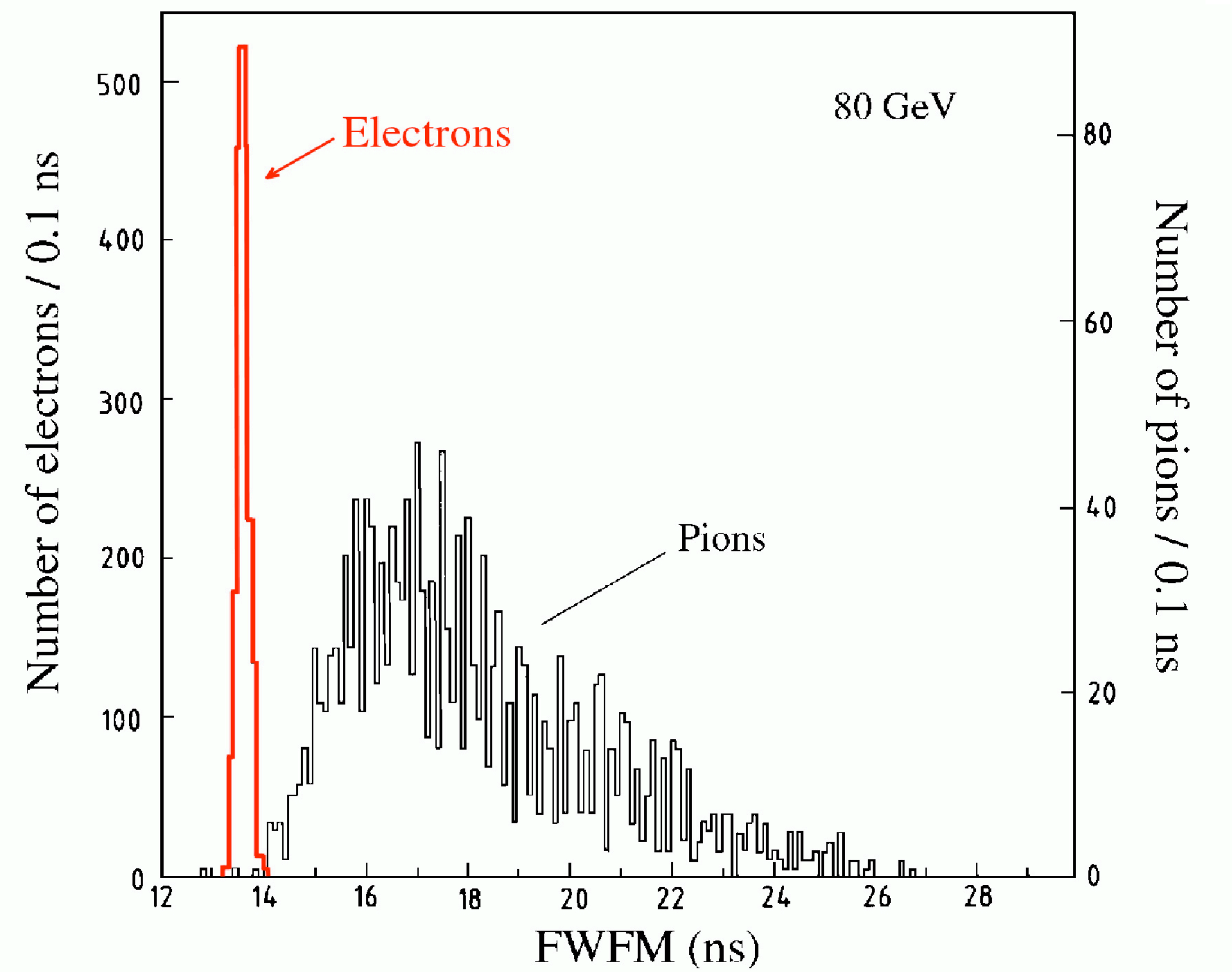
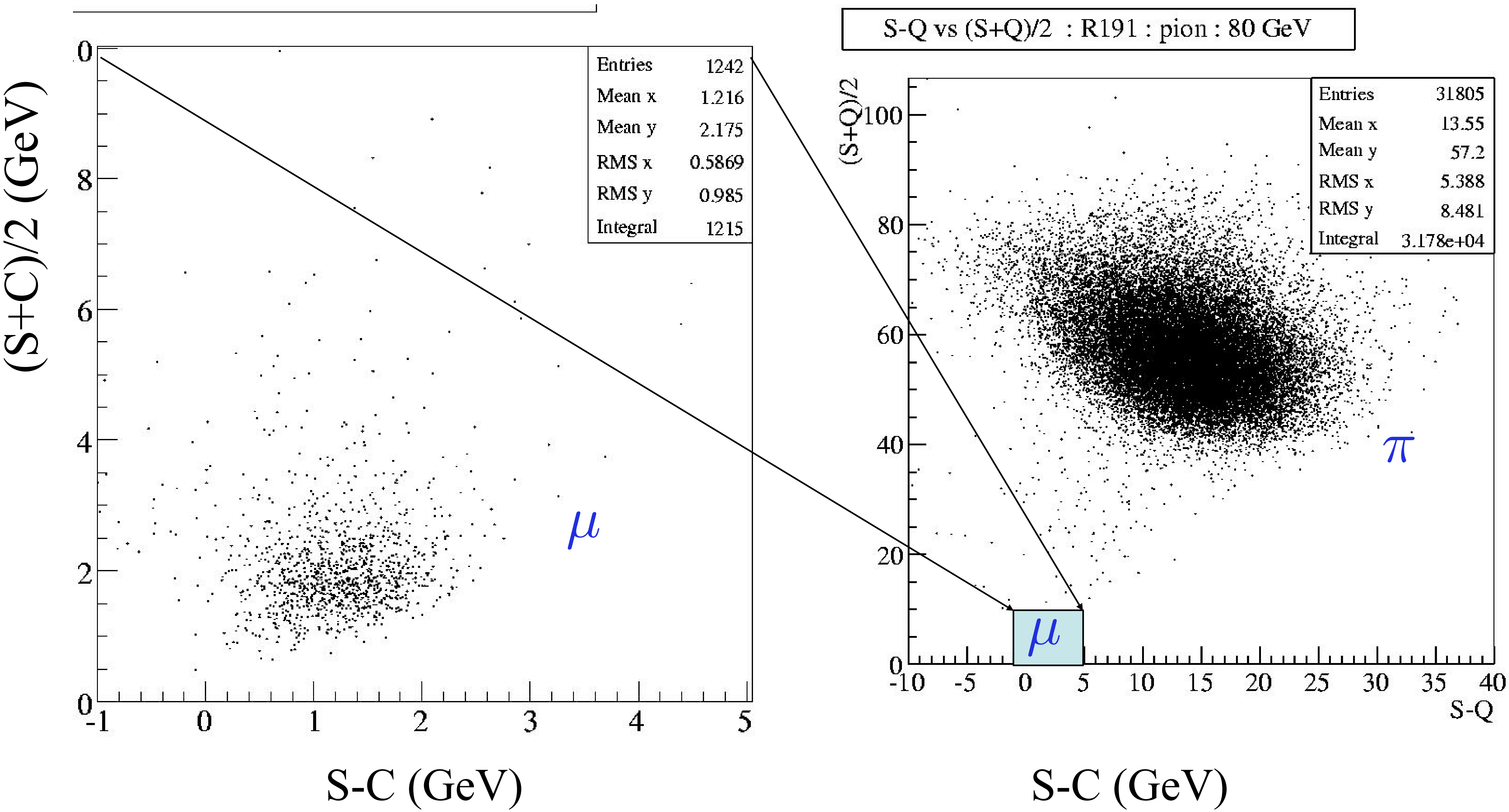


FIG. 7.33. The distribution of the full width at one-fifth maximum (FWFM) for 80 GeV electron and pion signals in SPACAL [Aco 91a].

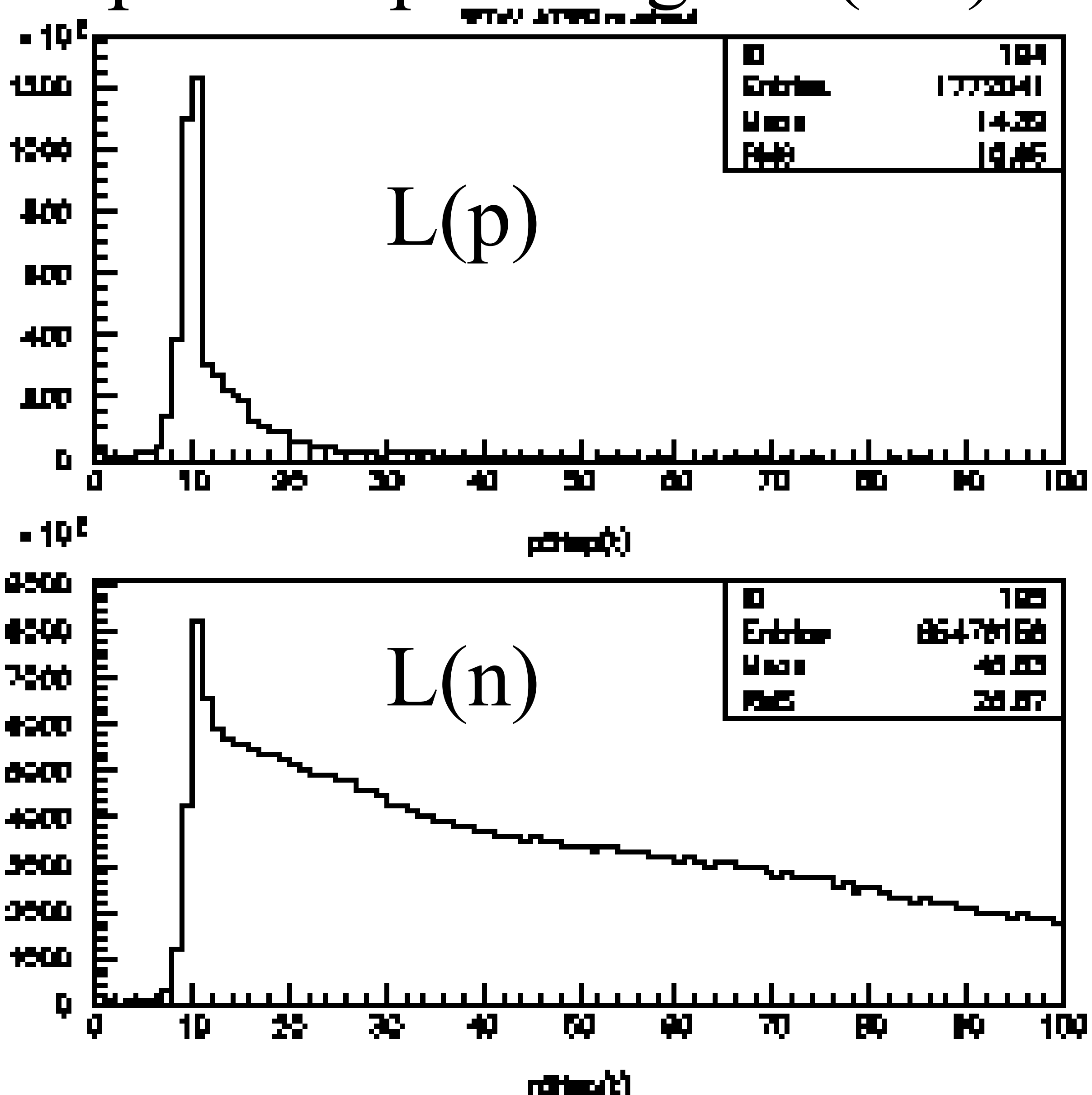
Muon identification: muons and pions (80 GeV)



Next: measure neutrons in hadronic showers

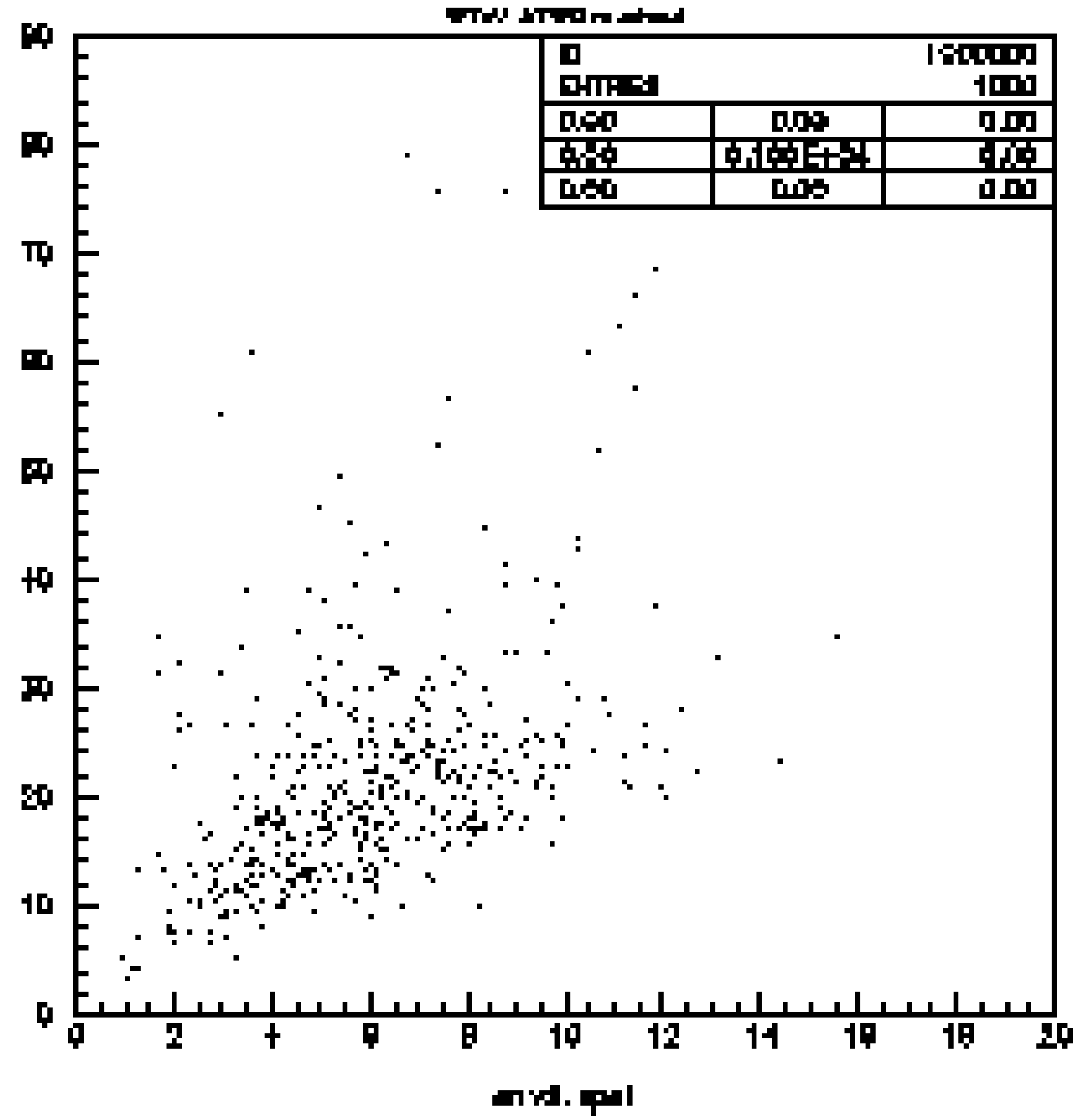
(GEANT3 calc.)

particle pathlength L(cm)



t(ns) ⟶

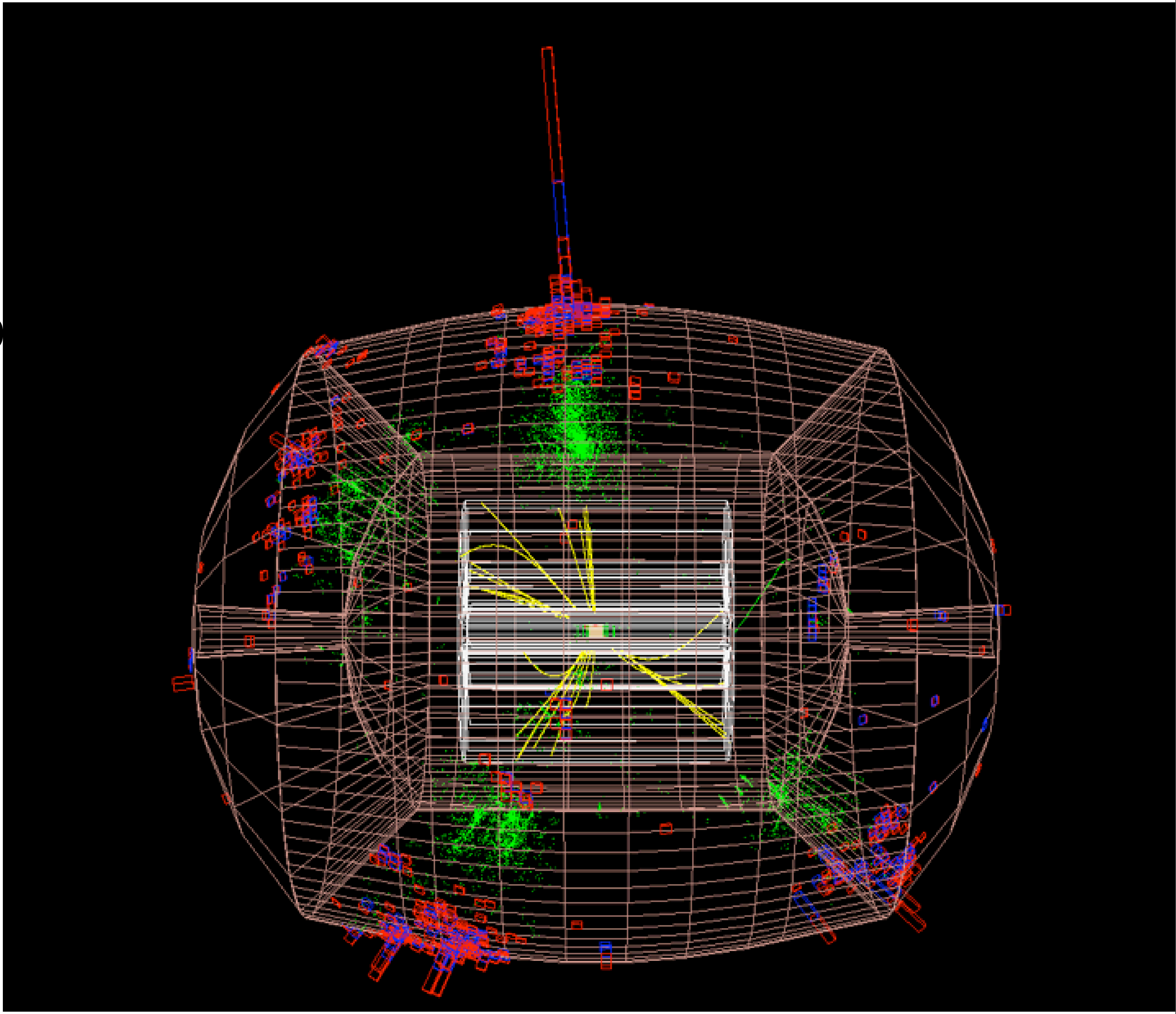
Spe (t > 20ns)



En (GeV) ⟶

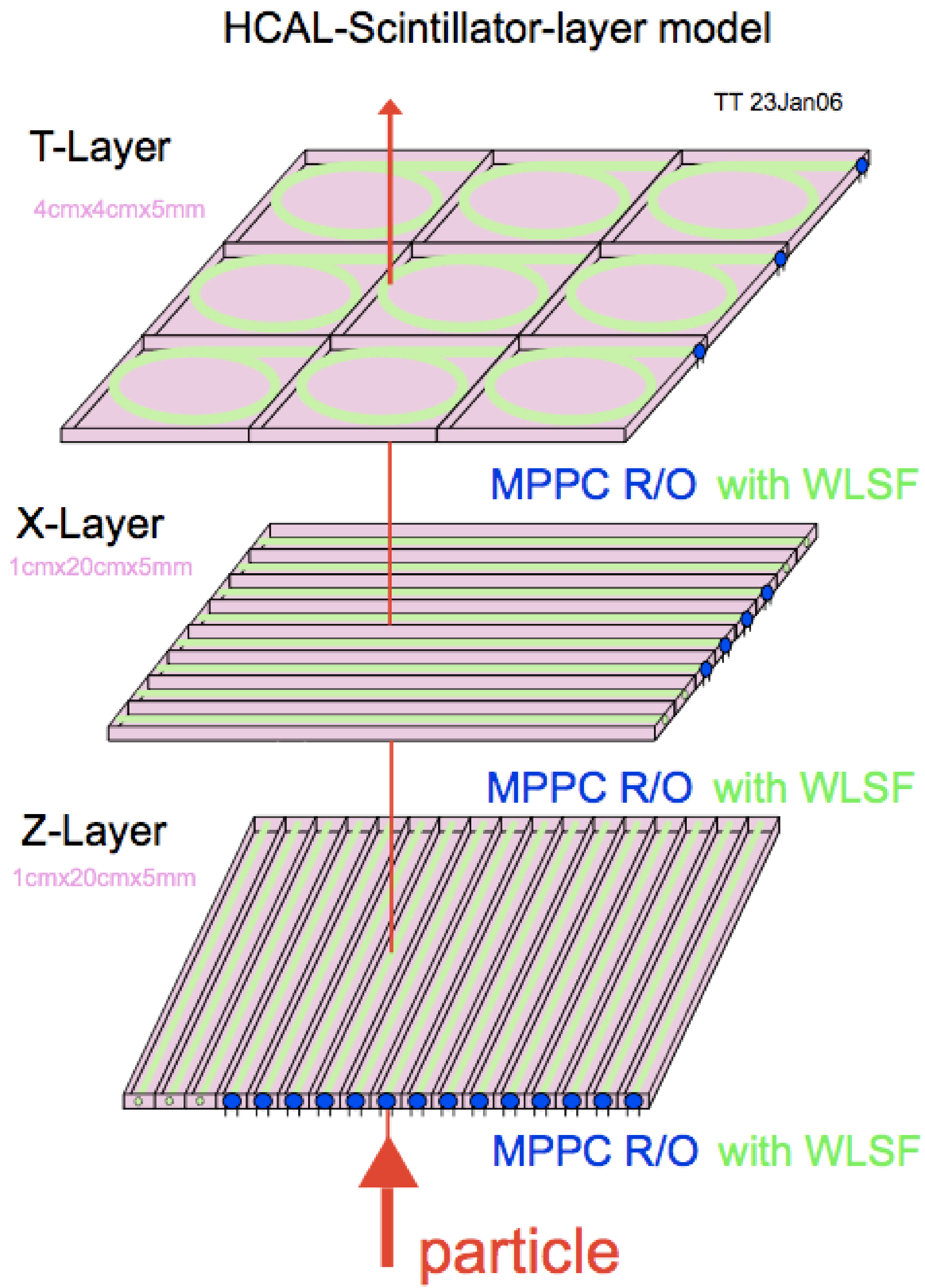
... to reduce effects of fluctuations in BE losses on energy resolution

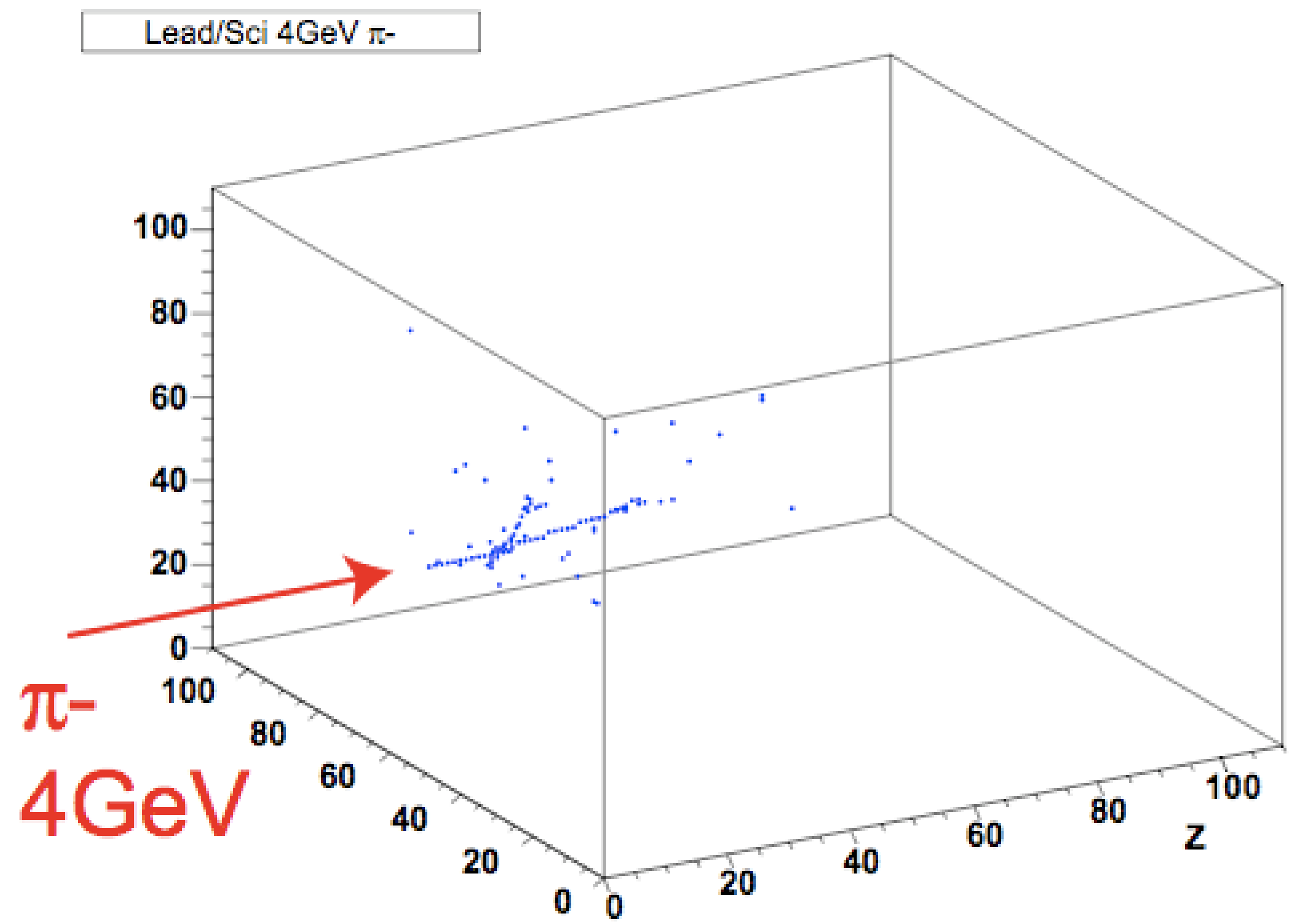
$$e^+e^- \rightarrow H^0Z^0 \rightarrow b\bar{b}q\bar{q}$$



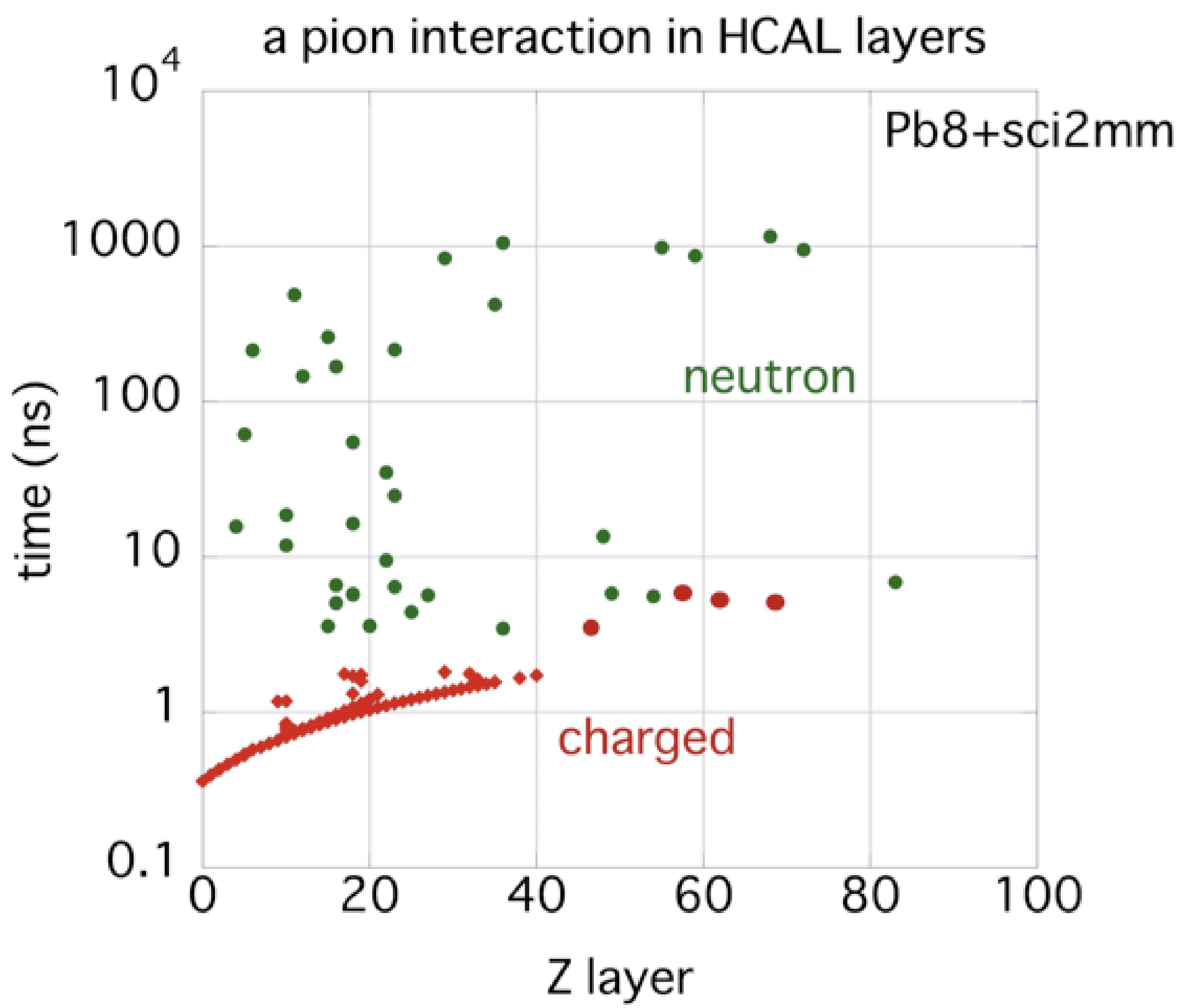
•GLD Compensating PFA calorimeter

Detailed design:
* 8mm Pb+2mm Scintillator
* Light collection, calculations
* Excellent understanding of the neutrons

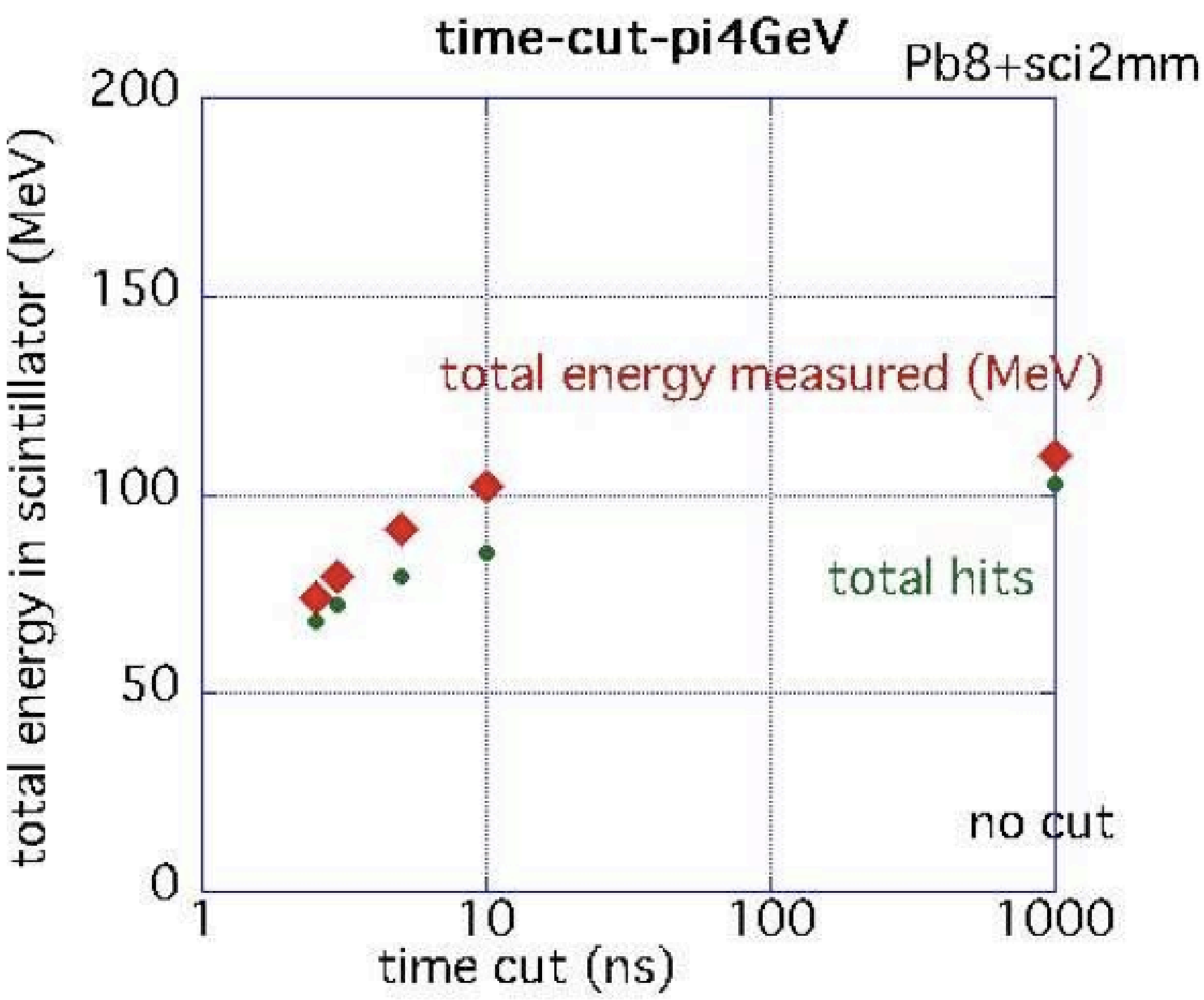


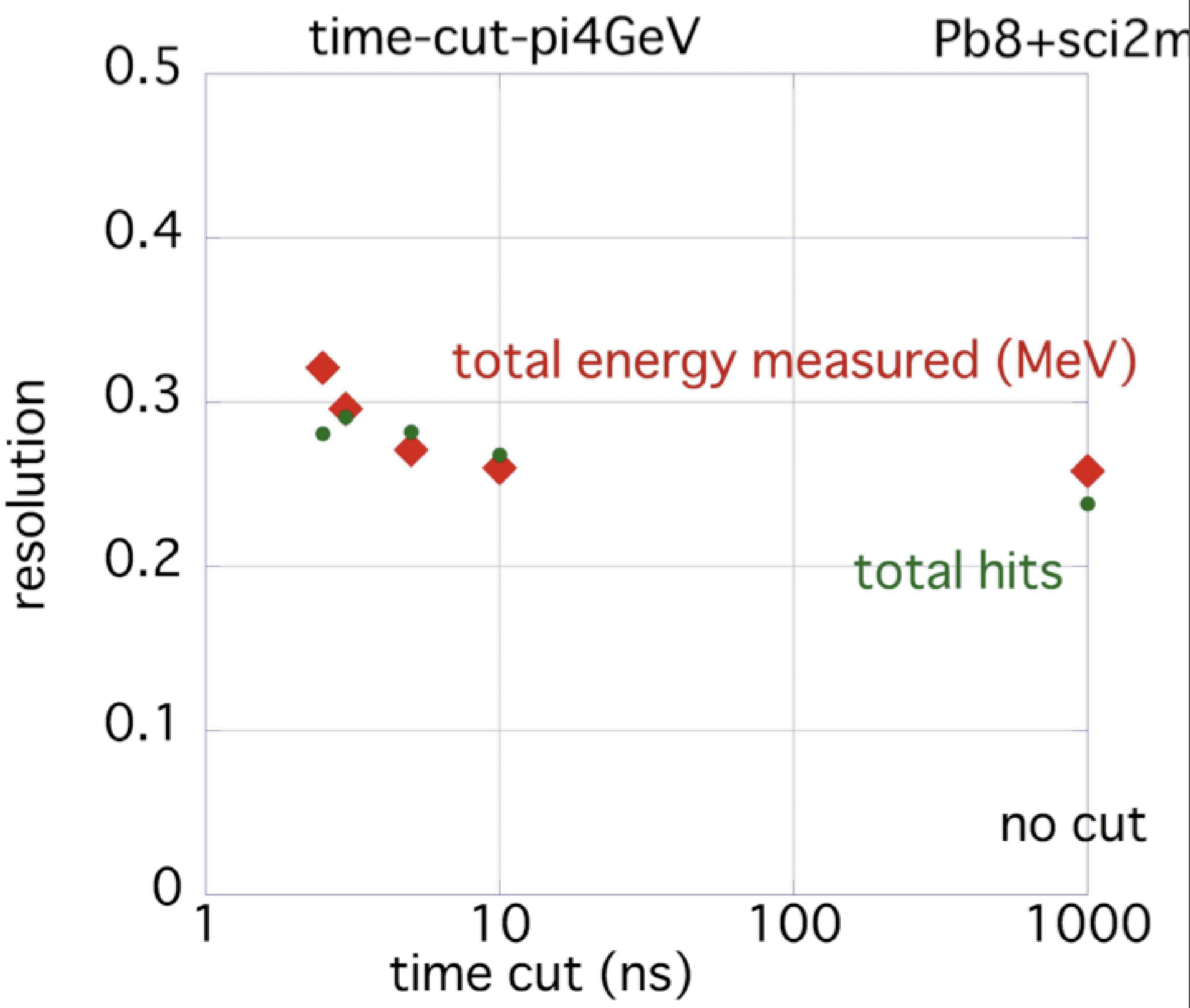


GLD: neutrons in space and time - a good understanding



GLD: scintillator energy vs. time & energy resolution vs. time

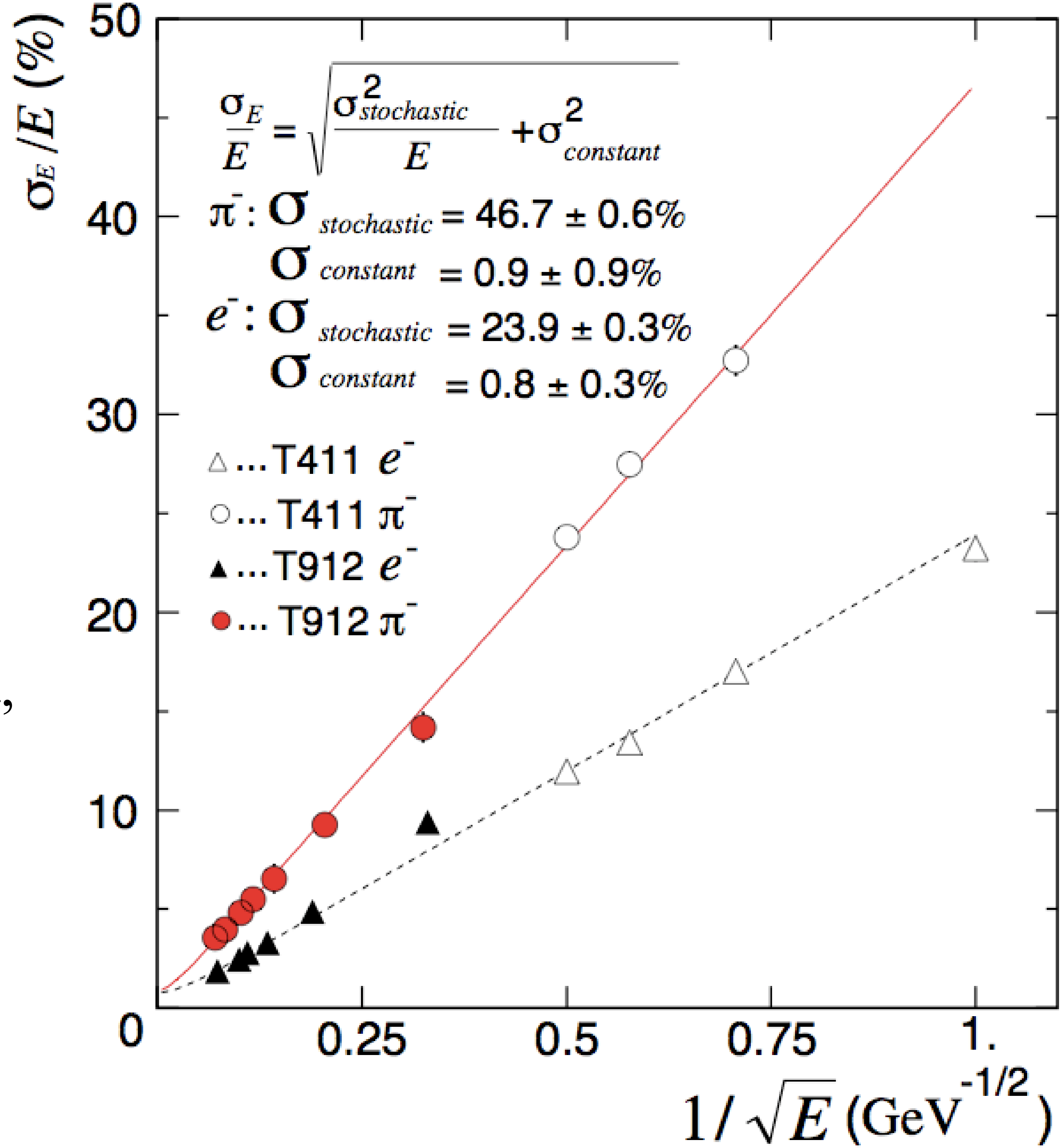




GLD: energy resolutions and constant terms for electrons and pions

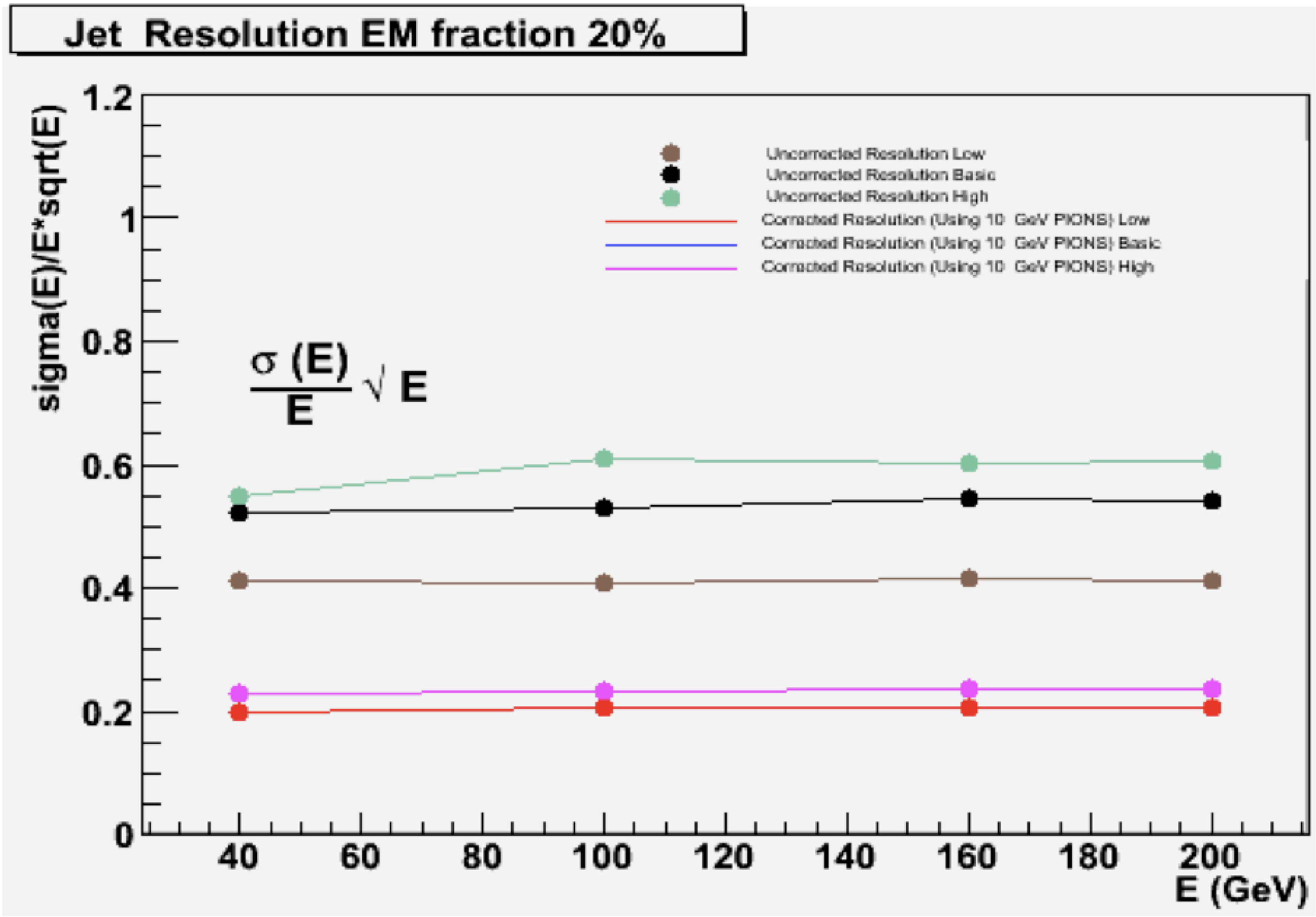
Fermilab
1999 test

Looks like
ZEUS Pb/Scint data,
Bernardi '87 NIM



•Planar Dual Readout

- The proponents have done a GEANT calculation with several fractions of pions and photons mixed together in a "large homogeneous medium" and claim 20%/sqrt(E).
- There is no 'detector GEANT'.
- No data.
- Nevertheless, claims are made that mirror DREAM results.



What is needed over the next 5 years

- Support for continuing DREAM tests (ADR funding is limited)
- Support for design and building of the 'best possible' fiber dual-readout module with time-history readout
  (about $600K + electronics)
- Support for crystal dual-readout (about $200K + electronics)
- Laboratory engineering of fiber and crystal calorimeters as "scalable" modules for an EDR (begun at Fermilab)

This totals to about $1.7M over five years.
Colleagues, visitors, and collaborators welcome.

Dual readout calorimetry: support, goals, priorities and resource needs

Task	Prior support	Goals & Priorities	Milestones	Resource needs
DREAM tests	ADR/TTU $ 125K/2y	1. proof-of-principle 2. neutron measurements 3. fiber readout 4. electronics and DAQ	2003 Jun: achieved 2006 Nov: achieved 2007 Jun: crystal & neutrons	electronics, test: $100K photoconverters $ 50K personnel: $100K
"Best" fiber	LCRD/ISU $ 10K/'06 ISU/4th $ 25K/'07	1. Eres = 30%/sqrt(E) 2. "scalable" module 3. fiber volume uniformity 4. Cpe = 100 pe/GeV	2007 Jun: n test 2007 Dec: design 2008 Sep: first module 2009 Feb: next 8 modules	full modules: $700K personnel: $300K
Crystal	LCRD/TTU $ 20K/'06	1. Sc & Cer separation 2. suitable crystal or glass 3. Sc & Cer separation 4. photoconverter	2006 Nov: achieved 2008 Mar: suitable crystal 2008 Dec: for experiment 2008 Dec: pc/elec/readout	small module: $200K personnel: $ 50K
Engineering	ISU/Fermilab $ 5K	1. conceptual ideas 2. truncated pyramid; hermetic; scalable module and supports 2. ILC concept structure	2007 May: achieved 2007 Dec: concep'l design 2008 Feb: module design 2009 May: built prototype 2010 Aug: calorimeter EDR	fiber+crystal modules: $150K
Total	$ 155K/2y (non-LCRD) $ 30K/2y (LCRD funds)			$1650K

ADR is Advanced Detector Research program of DoE; additional funds from State of Texas.
ISU is Iowa State University overhead kick-back funds in J. Hauptman account. About $10K (of $25K total) spent on calorimeter.
Fermilab engineering support by Bob Wands, Ingrid Fang, and Zhijing Tang.

version, 18 June 2007.

Summary and pitch: dual readout & 4th in the US

- Excellent progress since 4th cold start at Snowmass Aug 2005
  60 members 14 institutions 8 countries 3 regions

- GLD+LDC will most likely propose a detector with TPC tracking, PFA calorimeter, Fe-based muon

- We will propose a dual readout calorimeter as a tested, known and superior technology

- We need LCD R&D support to keep this only other calorimeter option alive. It is the heart of 4th.

- It might also be important for SiD, or GLD/LDC ...

- Orthogonality, and more: no-Fe dual solenoids for muons, cluster counting KLOE for tracking, ILCroot for software and analysis (ilc.fnal.gov/detector/rd/physics/detsim/ilcroot.shtml)

We can lose dual-readout to INFN (now in DREAM); "use it or lose it"

Extras

1. “triple readout”
2. DREAM details
3. particle ID - rms per channel
4. energy resolutions

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.

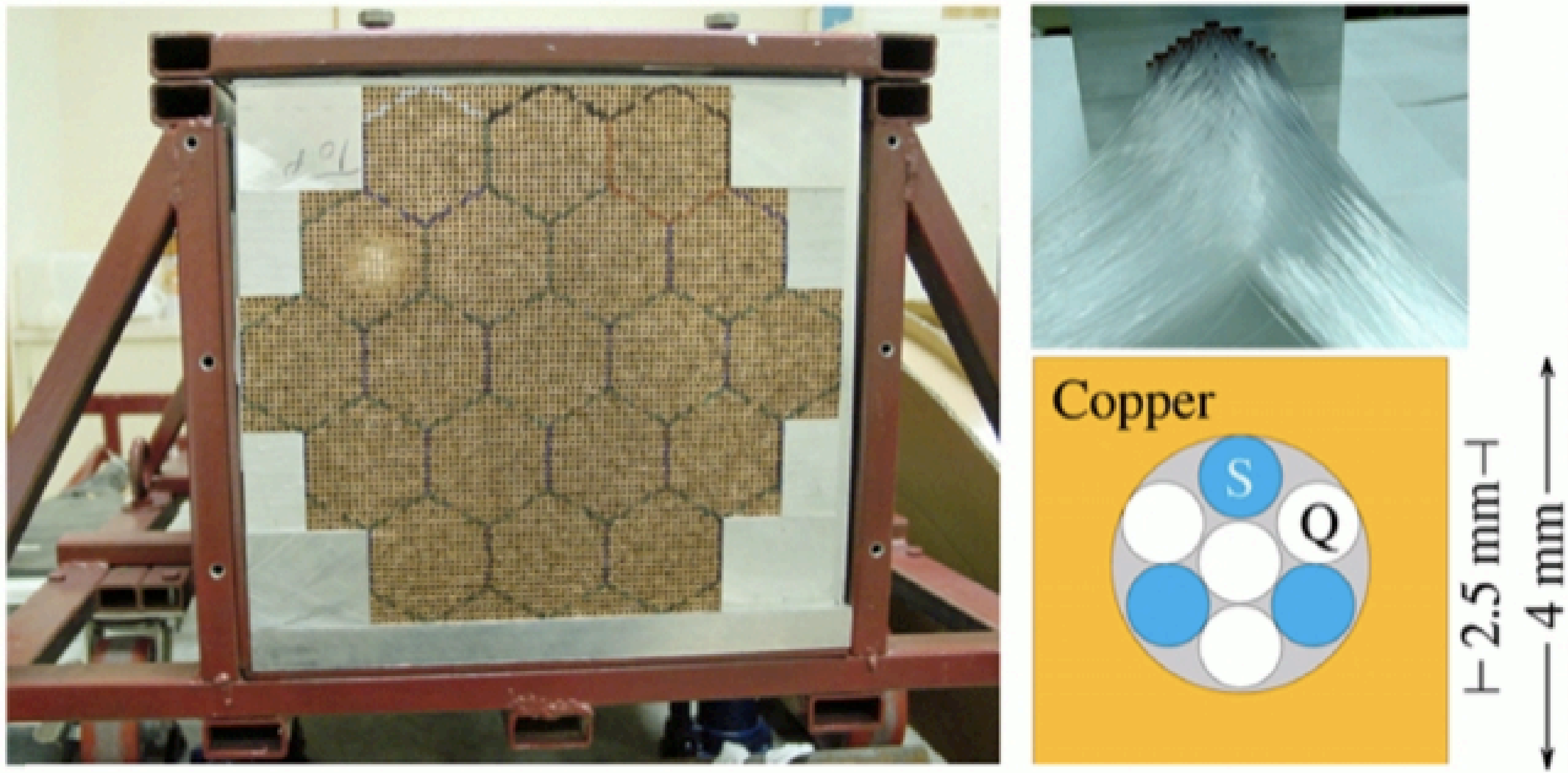
➡ measure EM content with Cerenkov fibers, Eth ~ 0.25 MeV, mostly electrons from $\pi^0 \rightarrow \gamma\gamma$

• 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.

DREAM: Structure

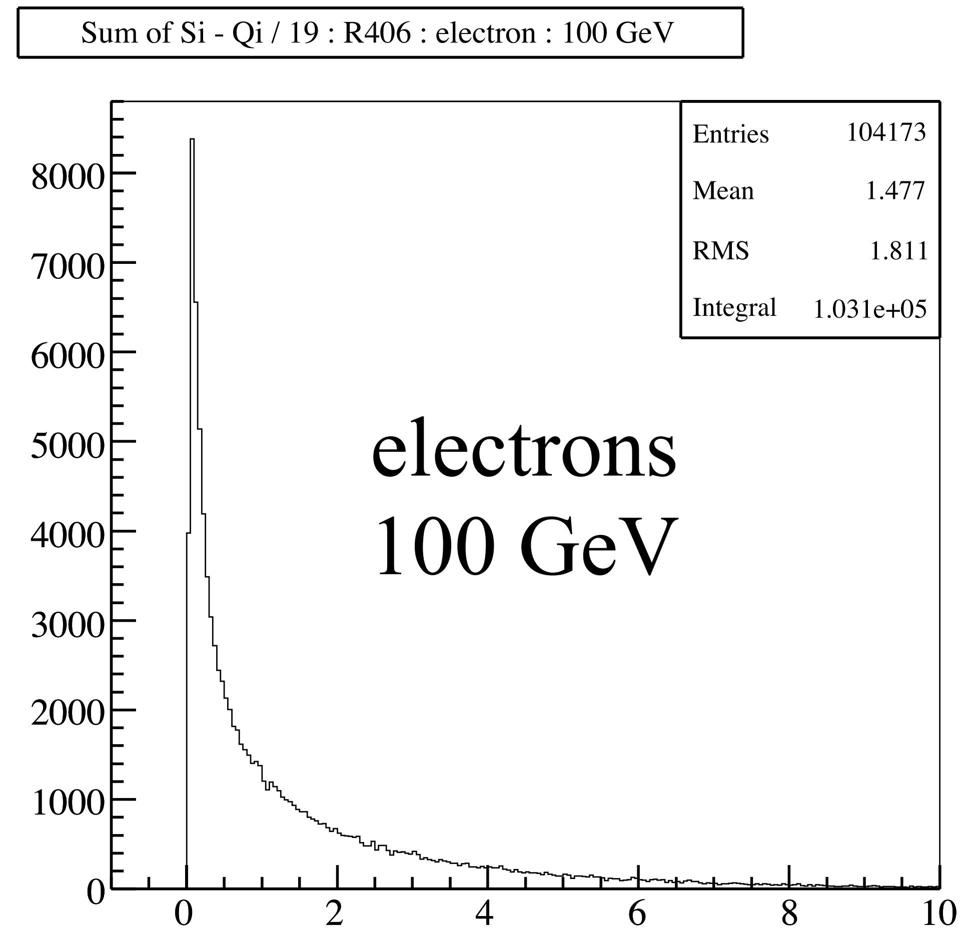


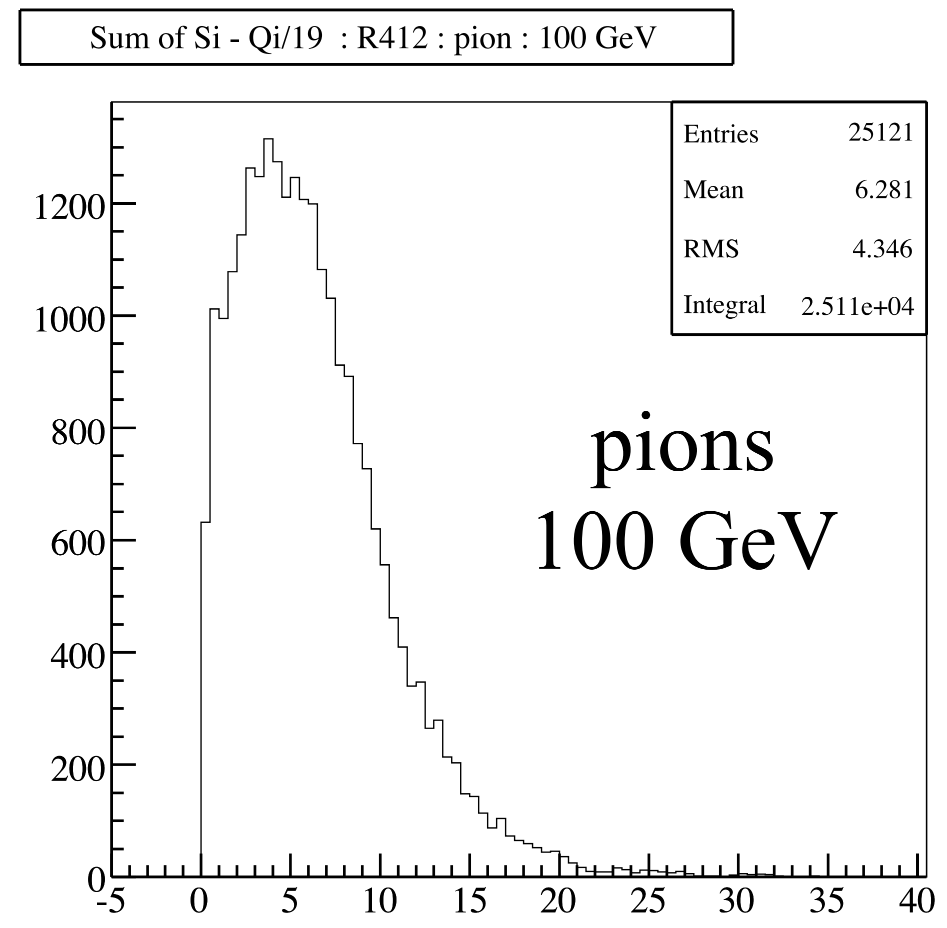
- *Some characteristics of the DREAM detector*
  - Depth 200 cm (10.0 λ_{int})
  - Effective radius 16.2 cm (0.81 λ_{int}, 8.0 ρ_M)
  - Mass instrumented volume 1030 kg
  - Number of fibers 35910, diameter 0.8 mm, total length $\approx$ 90 km
  - Hexagonal towers (19), each read out by 2 PMTs

rms fluctuations *within* a shower

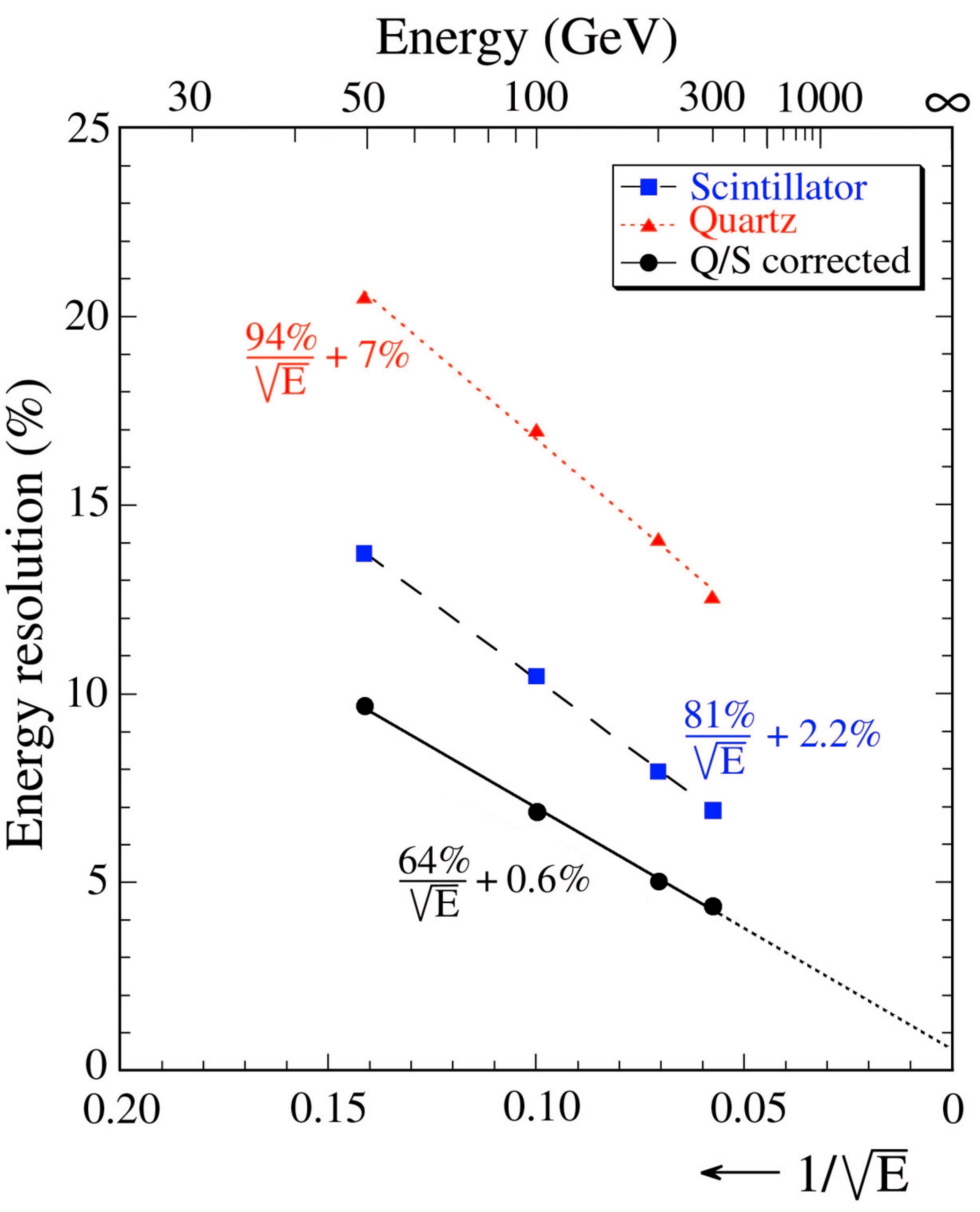
$$\sum_i^N [C_i - S_i]^2 / N$$

(N=19 channels)

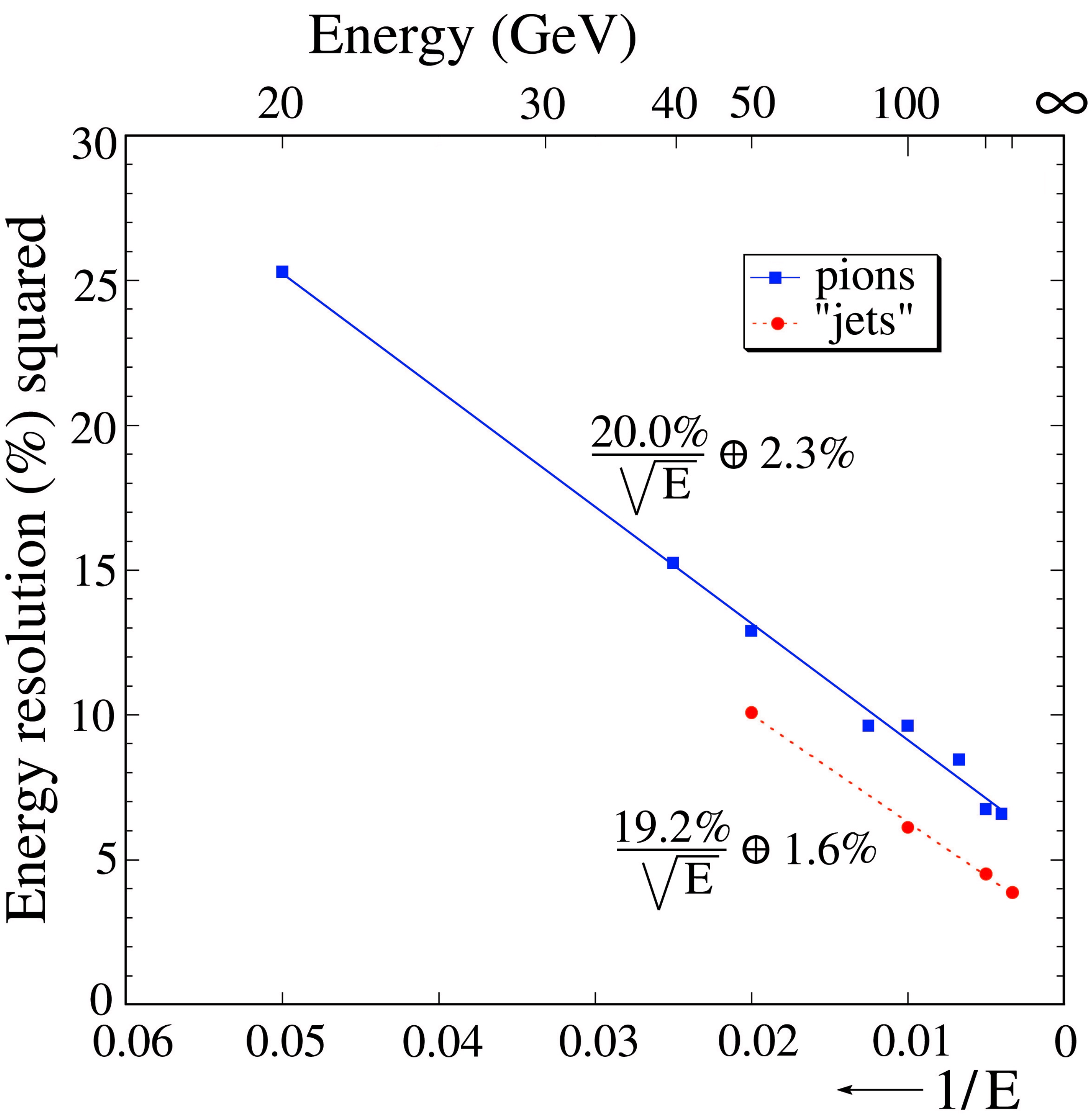




"Worst" for dual-readout



"Best" for dual-readout



What 20% buys you for W and Z decay to 2-jet mass reconstruction:

Both jets are sampled from DREAM data with measured spatial and energy fluctuations