Particle Identification in 4th

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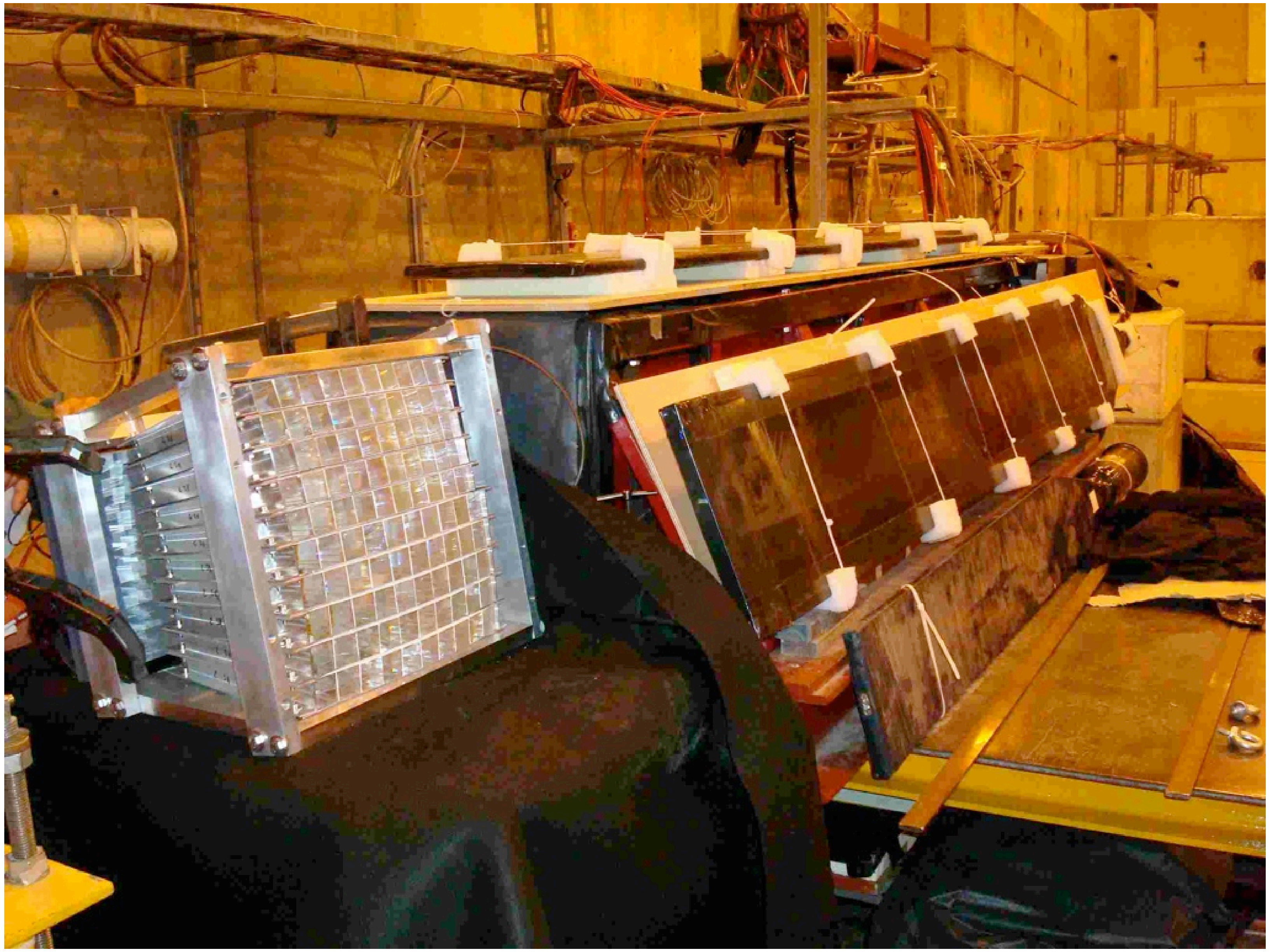
University of Illinois, Chicago



CERN H4 test beam:

- time history all S & C DREAM channels
- several crystals designed for dual readout
- BGO array as EM dual-readout
- "leakage" counters
- new neutron content measurements

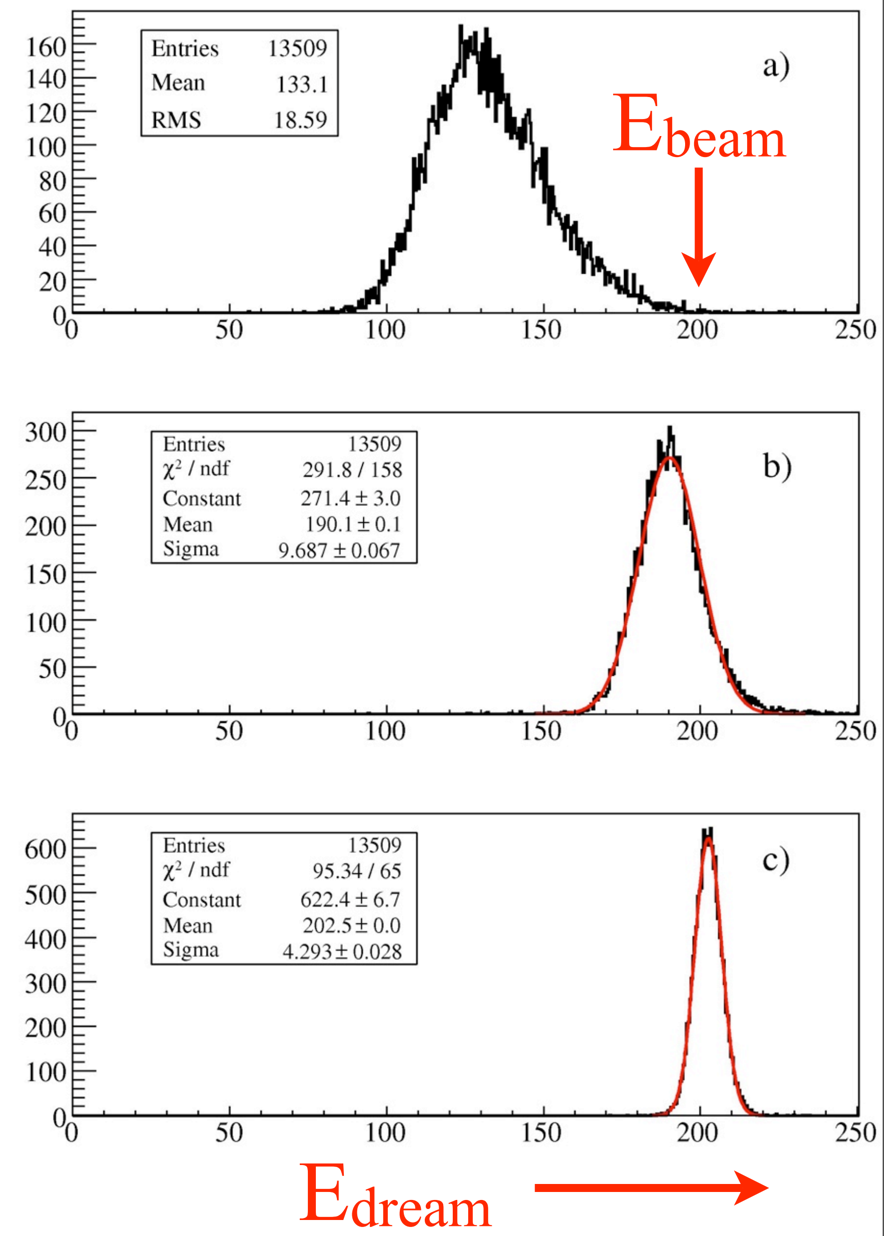
This talk: particle ID

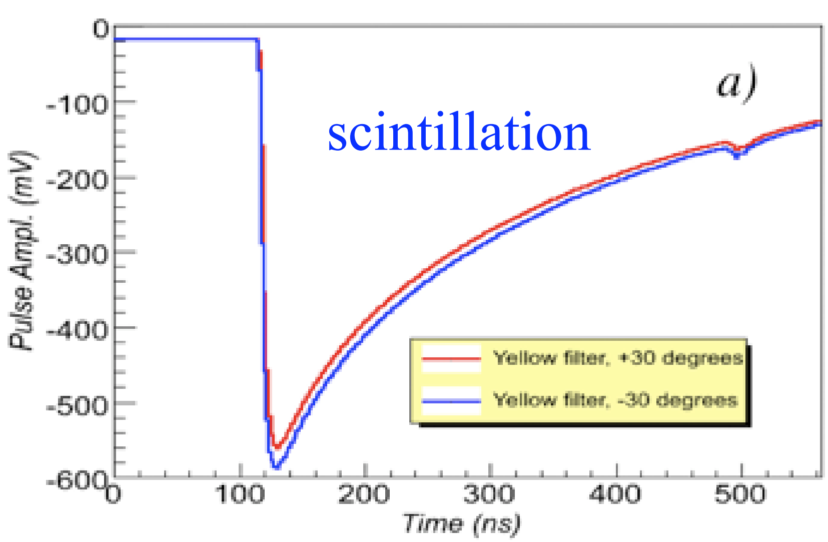
Our goal is identification of every parton with high precision and high purity.

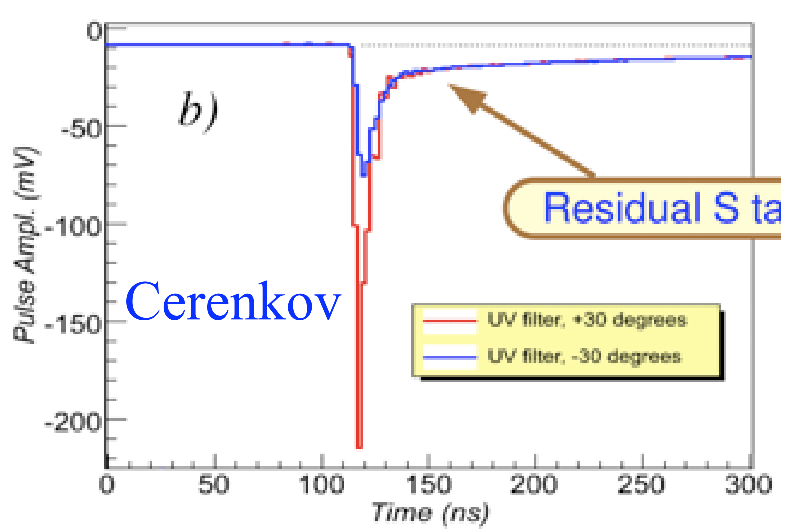
The 4th detector is designed with particle identification (pID) in mind from the beginning. The capability to make physics measurements from an ensemble of high purity depends on the efficiency of securing that ensemble, which in turn is often the product of several small efficiencies. In this physics sense, high efficiency is equivalent to high luminosity.

Consider the high-precision high-luminosity B factories: pID efficiency is luminosity, too.

Hadronic energy resolution (fibers)







Dual-readout in BGO:

scintillation and Cerenkov lights separated

(Will answer K. Hara's question.)

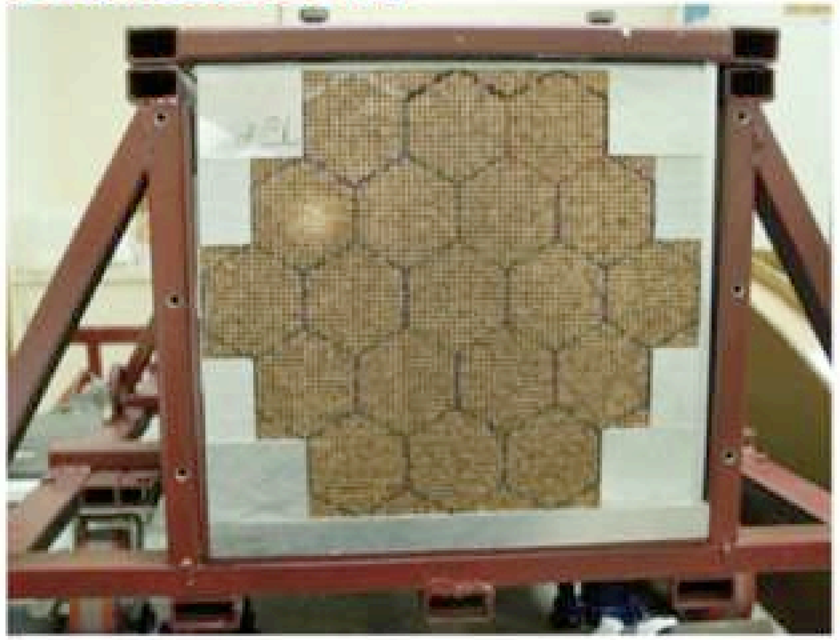
	Physical measurement	Partons/particles discriminated	Subsystems used	
1.	$\Sigma_i C_i$ *vs.* $\Sigma_i S_i$	$e^{\pm}$ *vs.* $\pi^{\pm}$ *vs.* $\mu^{\pm}$	dual-readout fiber (S and C) calorimeter	← *Beam test data*
2.	$\chi^2 \sim \frac{1}{n}\sum_i^n [C_i - S_i]^2/[k(C_i + S_i)]$ $(k \sim 0.10)$	EM *vs.* non-EM *vs.* "hadronic"	dual-readout fiber and crystal calorimeters	← *Beam test data*
3.	$f_n \sim E_n/E_{\mathrm{shower}}$ (slow n's)	"hadronic" *vs.* EM or "muonic"	scintilating fibers $S_{pe}(t)$ long-time history	← *Beam test data*
4.	$(S - C)$ *vs.* $(S + C)$	μ *vs.* π *vs.* e	dual-readout fiber (S and C) calorimeter	← *Beam test data*
5.	Time-history of S fibers	EM *vs.* non-EM *vs.* "hadronic"	dual readout S fibers	← *Beam test data*
6.	dN/dx cluster counting	$e - \mu - \pi - K - p$ (few GeV)	CluCou tracking	← *Bench test data*
7.	EM calor + tracking	$e - \gamma$	CluCou tracking + dual-readout calor's	
8.	$p_{\mathrm{tracking}} \approx E_{\mathrm{dual-readout}} + p_{\mathrm{muon}}$	μ *vs.* punch-through tracks	CluCou, calor, muon	
9.	$\tau^{\pm} \to \rho^{\pm}\nu \to \pi^{\pm}\gamma\gamma$	τ *vs.* hadronic debris	BGO dual-readout CluCou, calor.	
10.	sub-ns time-of-flight	massive SUSY object	Čerenkov pulses in BGO and fiber calorimeter	← *Beam test data*
11.	$W, Z \to jj$ mass	W, Z *vs.* QCD jj	CluCou, jet finding, dual-readout calor's	← *ILCroot*

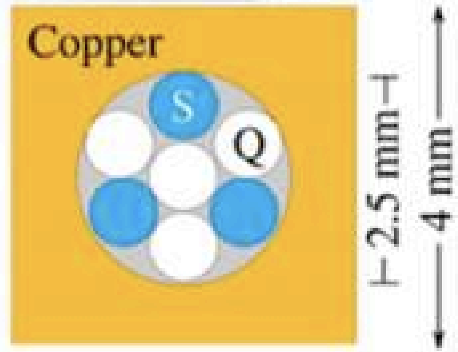
Particle ID in 4th

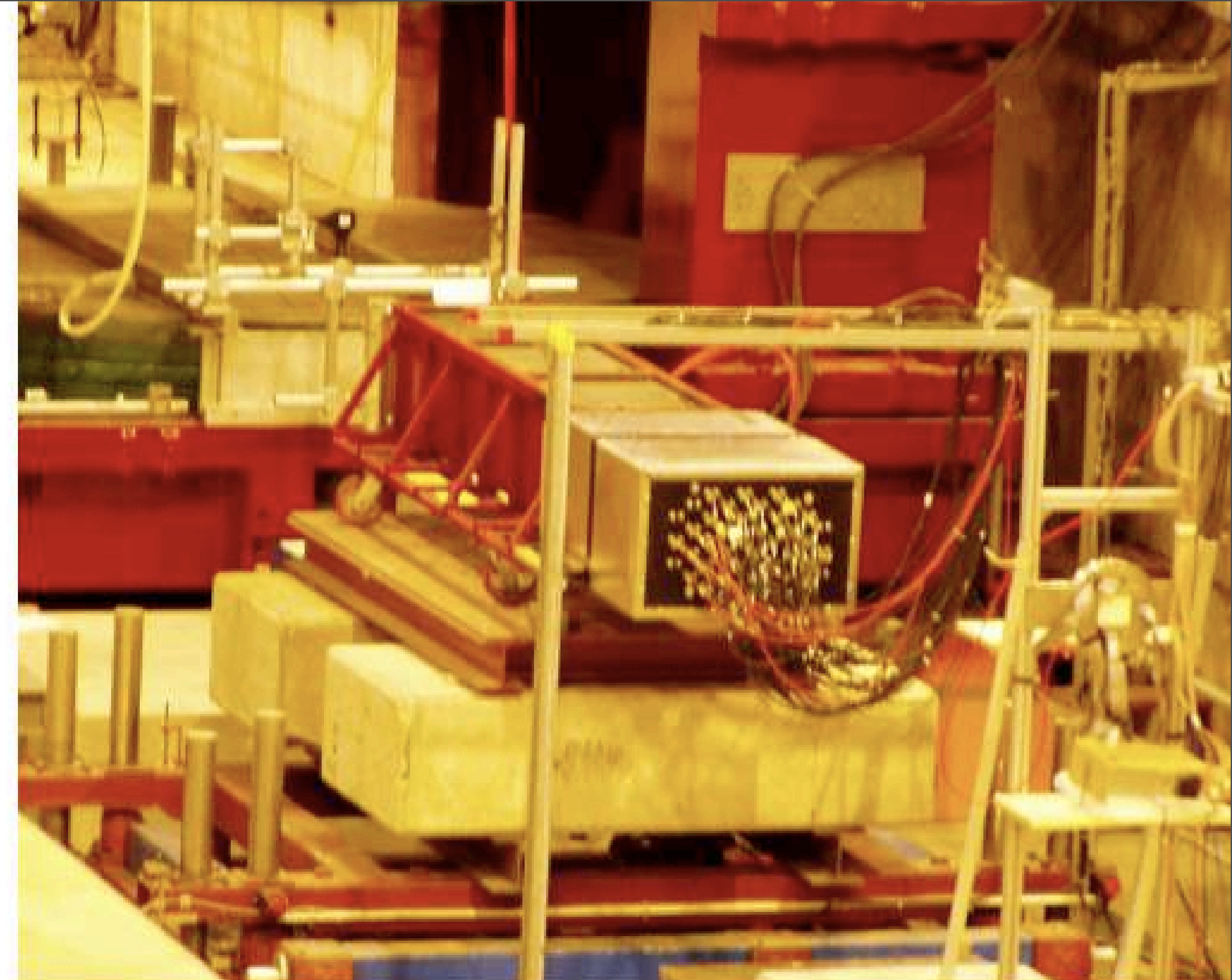
ID discrimination	*measurement*	*item*
e - pi - mu	*S vs. C*	#1 *(measured - beam test data)*
EM vs. hadronic	*channel-to-channel S-C fluctuations*	#2 *(measured - beam test data)*
"neutronic" *(hadronic vs. non-hadronic)*	f_n	#3 *(measured - beam test data)*
mu vs. e,pi	*(S-C) vs. (S+C)*	#4 *(measured - beam test data)*
n & e vs. pi	$S_{pe}(t)$	#5 *(measured - beam test data)*
e-pi-K-p (few GeV)	$dN_{clusters}/dx$	#6 *(bench measurements data)*

ID discrimination	measurement	item
e vs. gamma	Tracking, BGO	#7 (ILCroot)
mu vs. punch-through hadrons	$P_{mu} + E_{dual} + P_{tracking}$	#8 (ILCroot)
tau --> rho nu	BGO + fiber dual readout	#9 (ILCroot)
Massive SUSY, etc.	Cerenkov light timing (BGO+fibers)	#10 (ToF from beam test data)
W--> jj	ILCroot, Tracking, dual-readout	#11 (achieved with ILCroot)

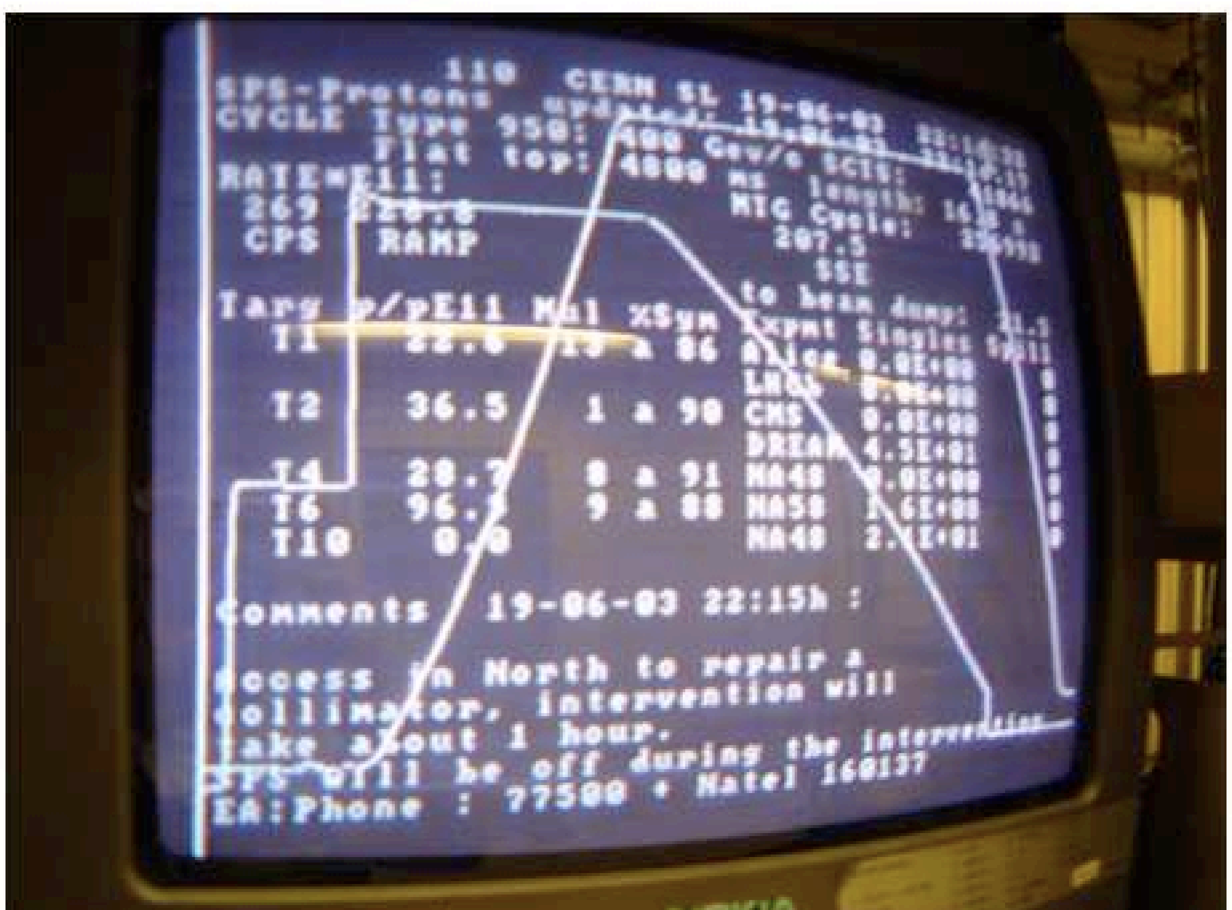
Dual-readout DREAM: Structure

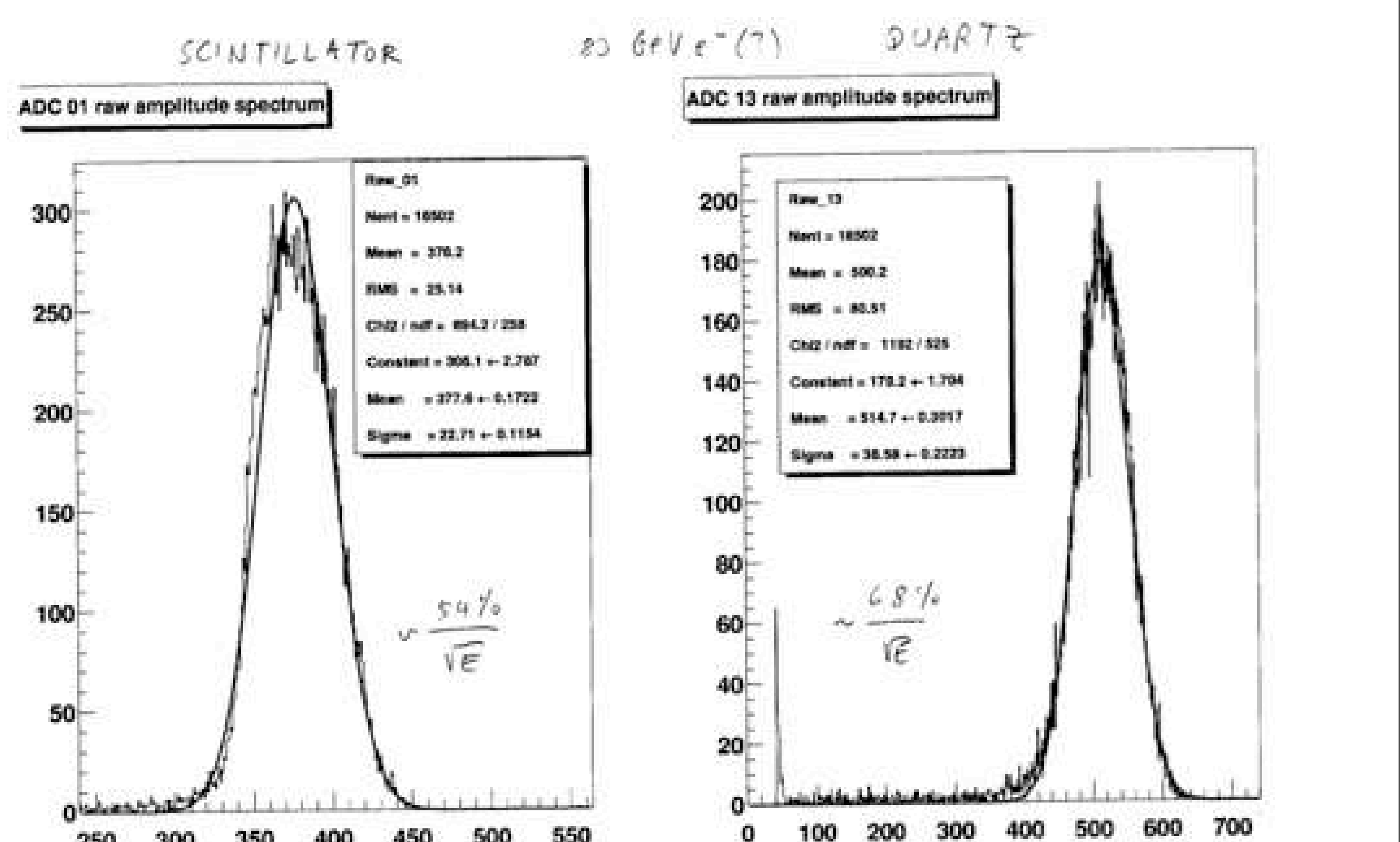




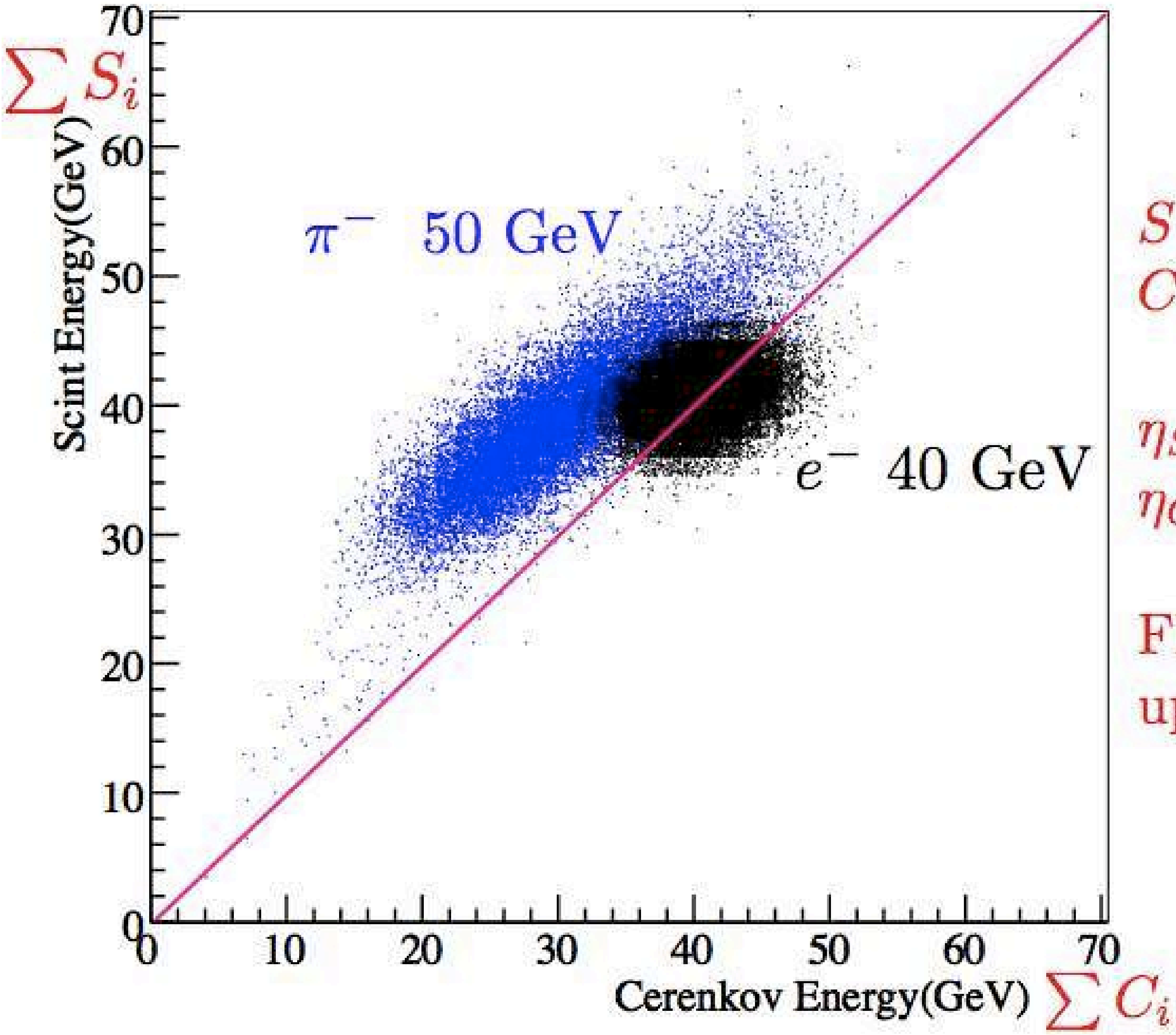


- *Some characteristics of the DREAM detector*
  - Depth 200 cm (10.0 λ_{int})
  - Effective radius 16.2 cm (0.81 λ_{int}, 8.0 ρ_M)
  - Mass instrumented volume 1030 kg
  - Number of fibers 35910, diameter 0.8 mm, total length ≈ 90 km
  - Hexagonal towers (19), each read out by 2 PMTs





1. Basic dual-readout plot of Scintillation vs. Cerenkov



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

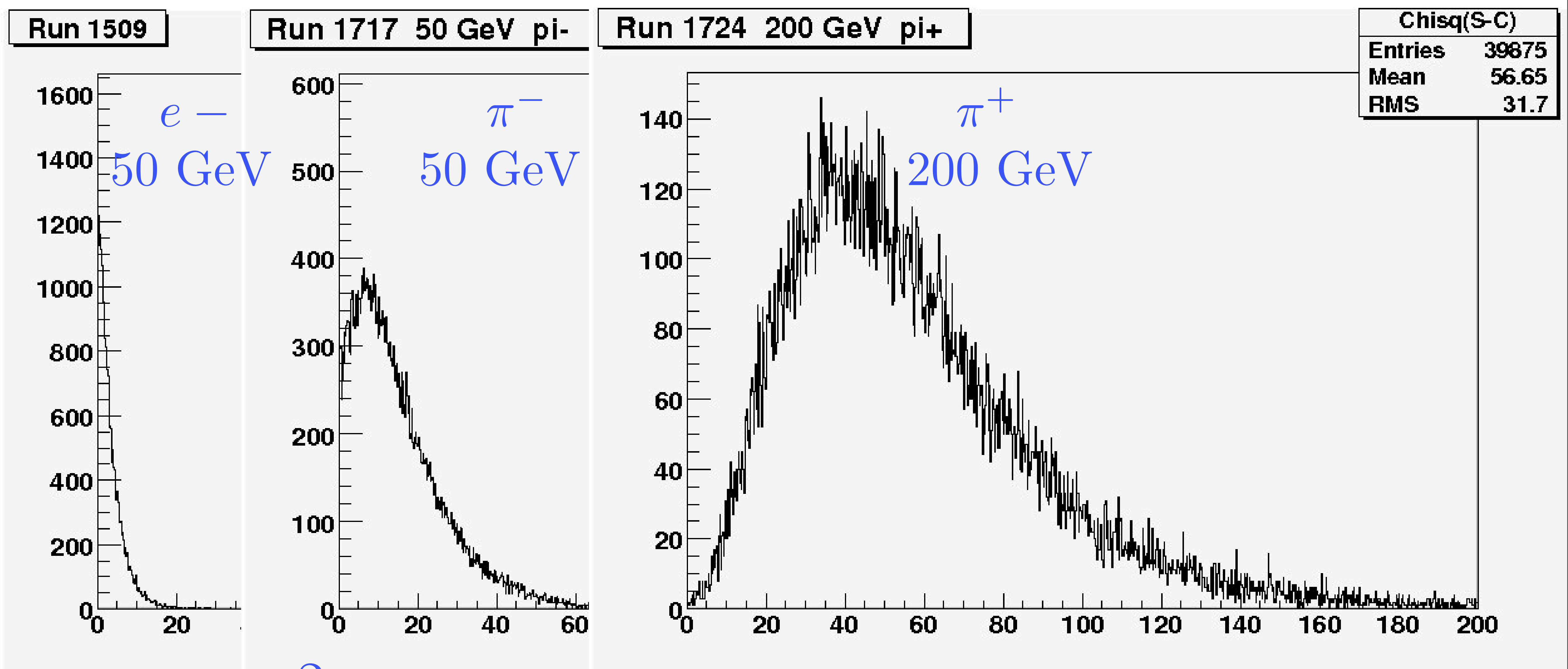
$\eta_S = (e/h)_S \sim 1.4$ (like Sc sampling calor)

$\eta_C = (e/h)_C \sim 5.0$ (like HF of CMS)

Fluctuations in f_{EM} drive S and C up and down, but differently.

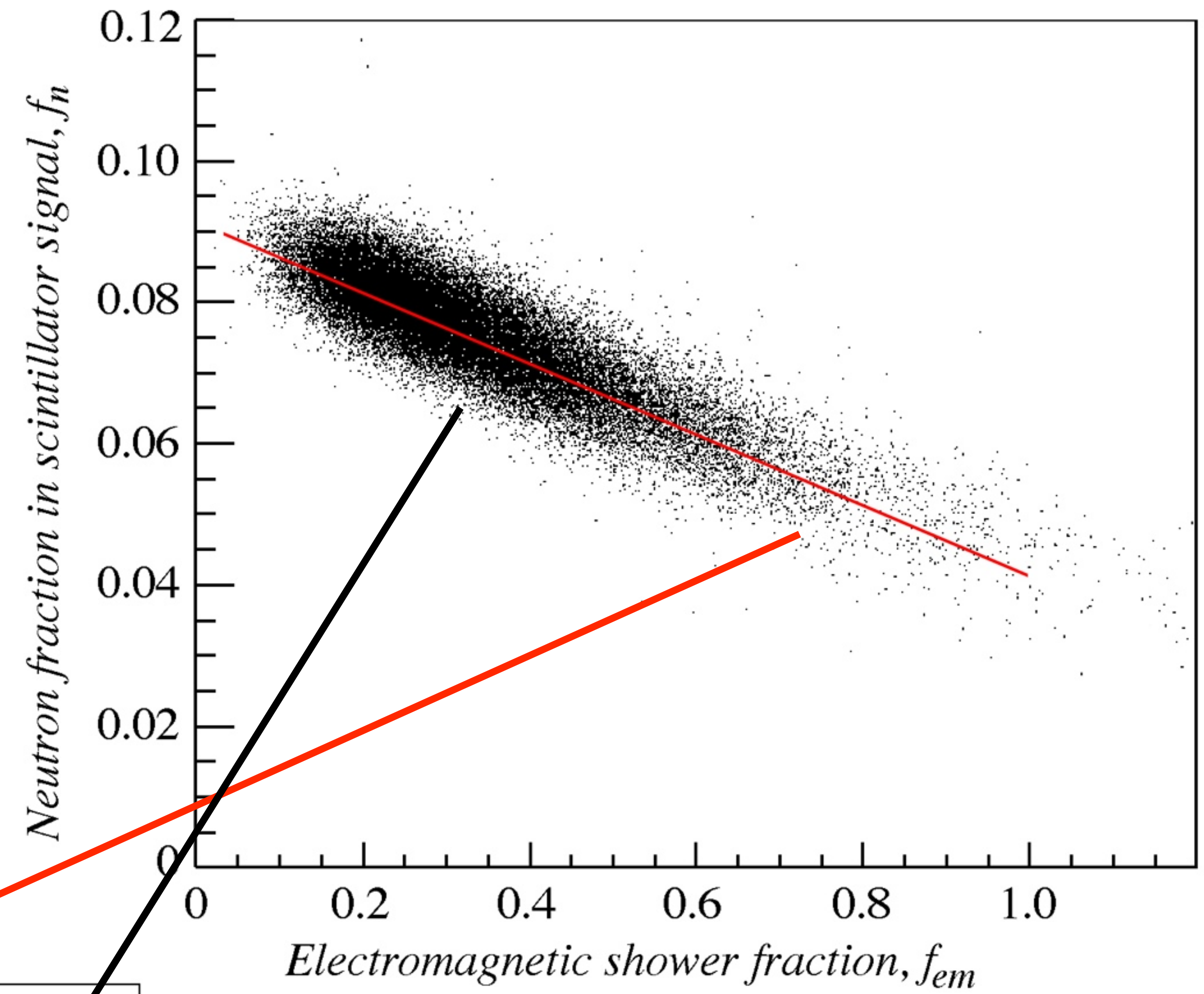
2. Chi-squared of S-C fluctuations among the channels of a shower:

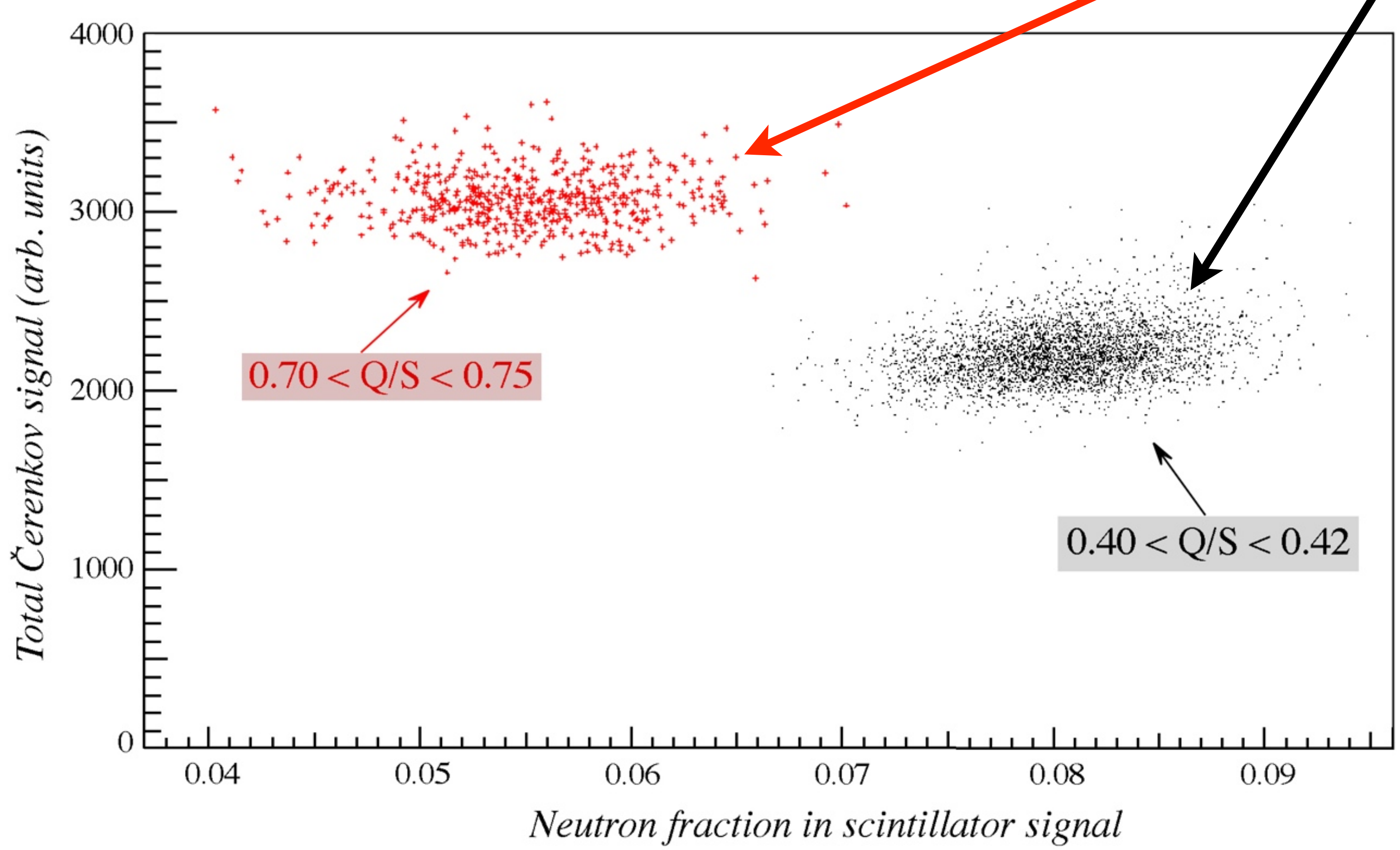
$$\chi^2_{C-S} = \Sigma\left(\frac{S_k - C_k}{\sigma_k}\right)^2 \approx \Sigma_k \frac{(S_k - C_k)^2}{0.1(S_k + C_k)}$$



$\chi^2_{C-S} \rightarrow$

3. neutron fraction is measured by time-history of Scintillation light, and is anti-correlated with the electromagnetic fraction

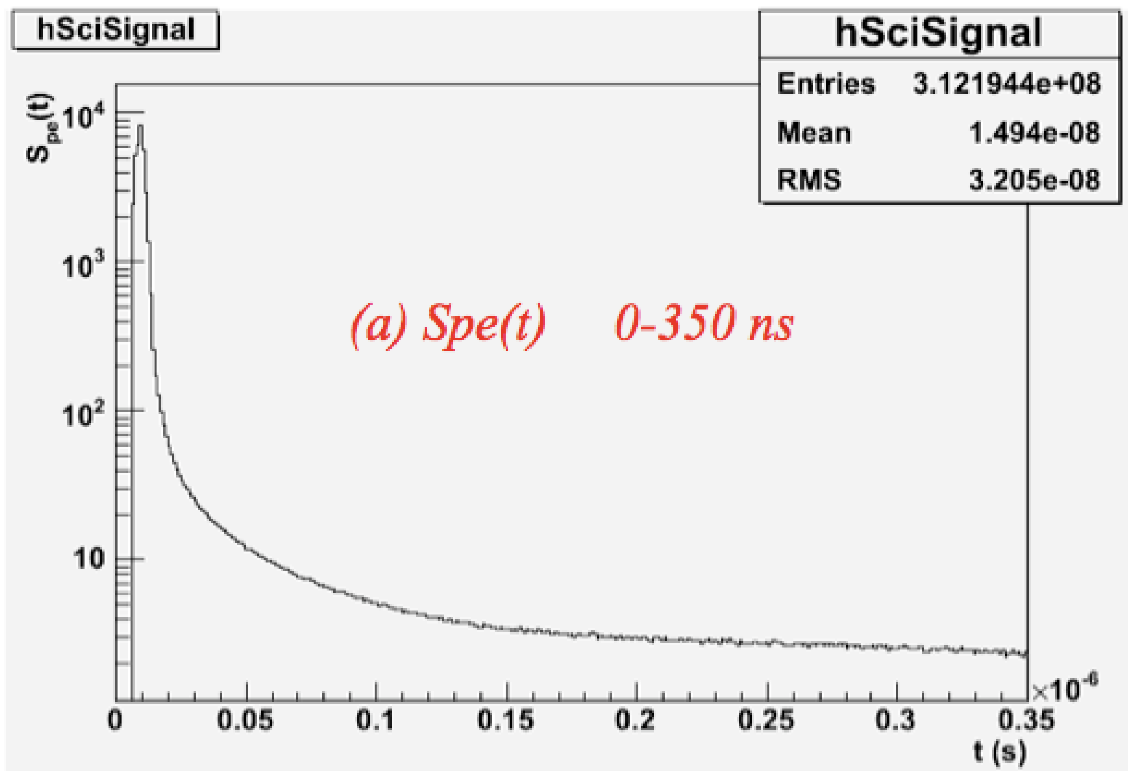




We will not only tag "hadronic" or "neutron-producing" objects, but also use this to improve the hadronic energy resolution.

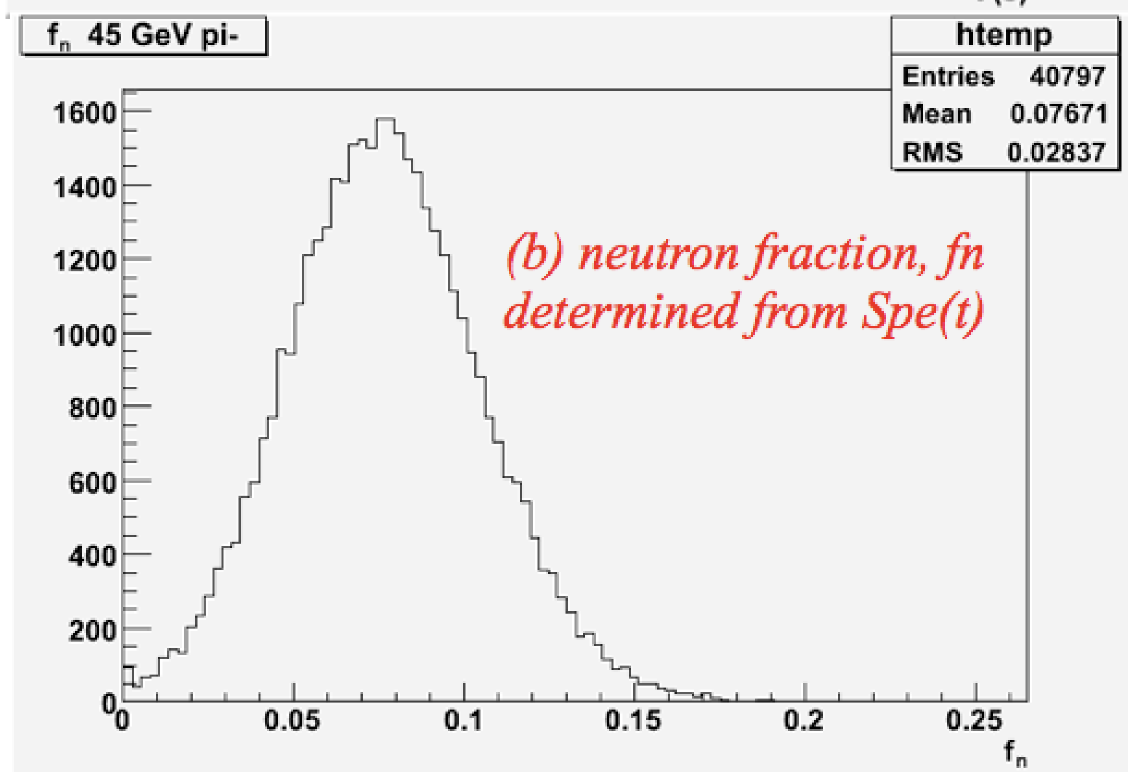
We also *calculate* the same things, so we know what we are doing.

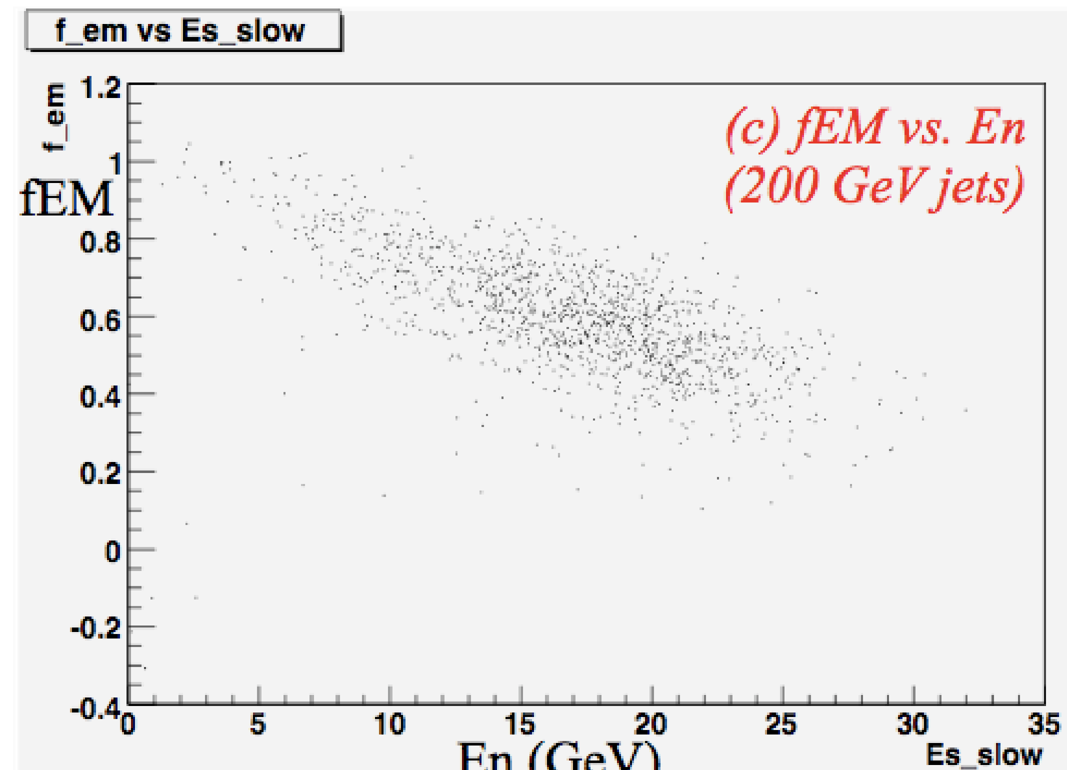
Pavia CALOR08



4th ILCroot V. Di Benedetto

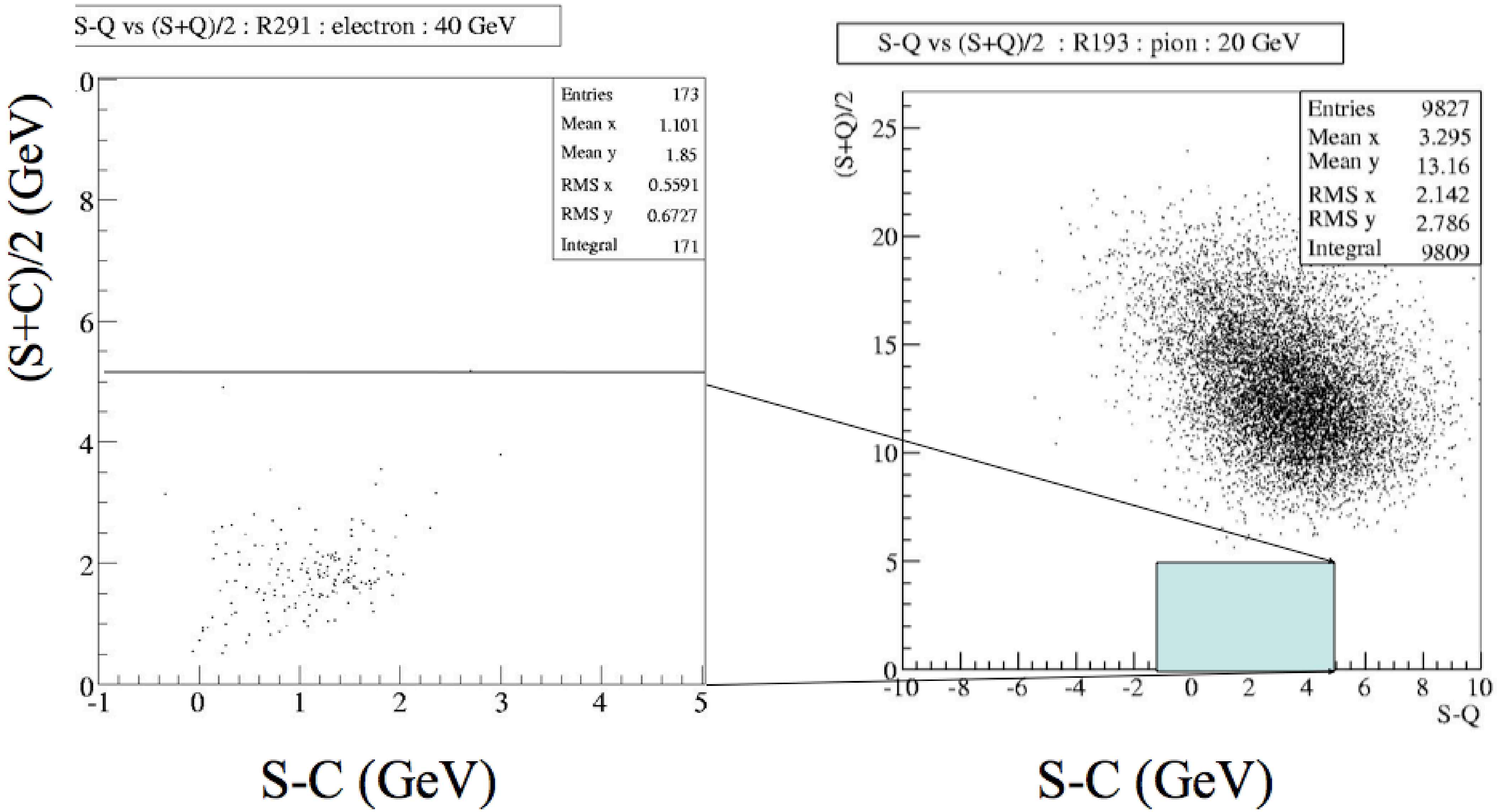
We have a fair understanding of neutrons in both DREAM data and in the 4th detector.





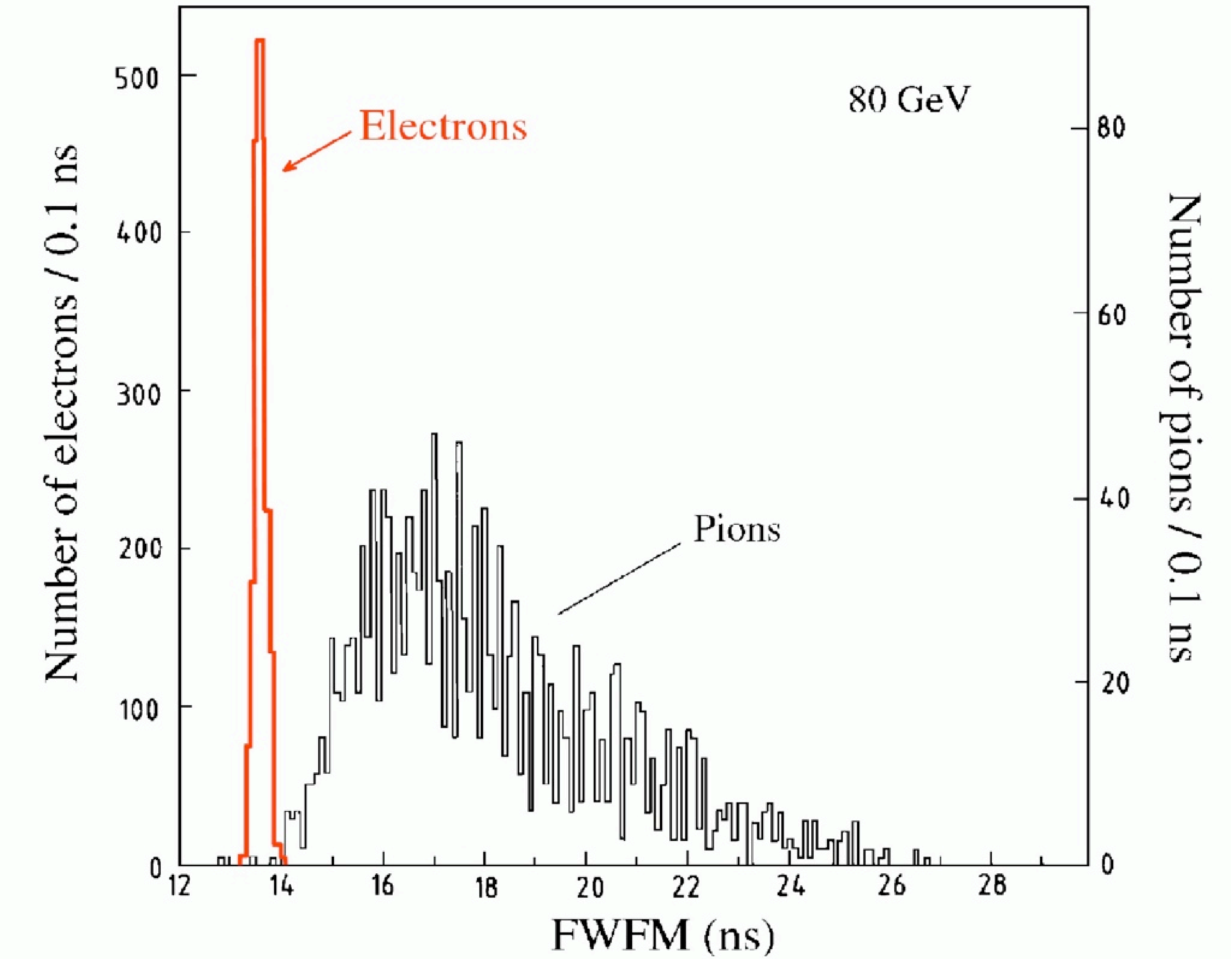
4. Dual-readout offers a unique ID for isolated muons: this is 20 GeV, better at higher energies.

Muons and Pions (20 GeV)



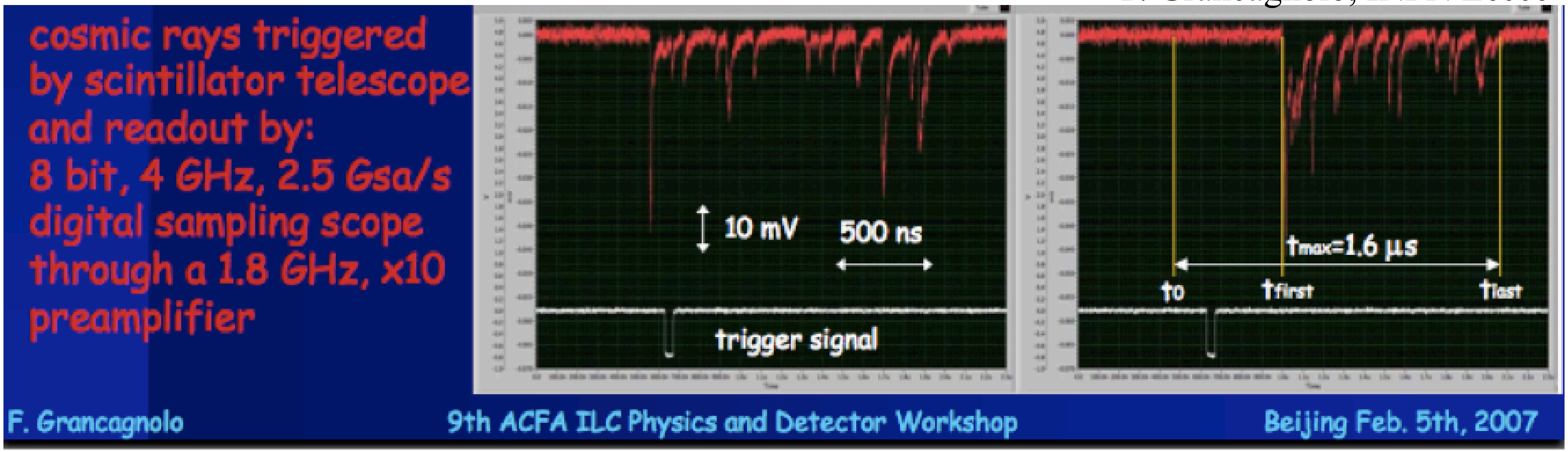
5. Time-history differs for EM and hadronic objects

Distribution of time width of pulses at 1/5-maximum for electrons and pions at 80 GeV in SPACAL



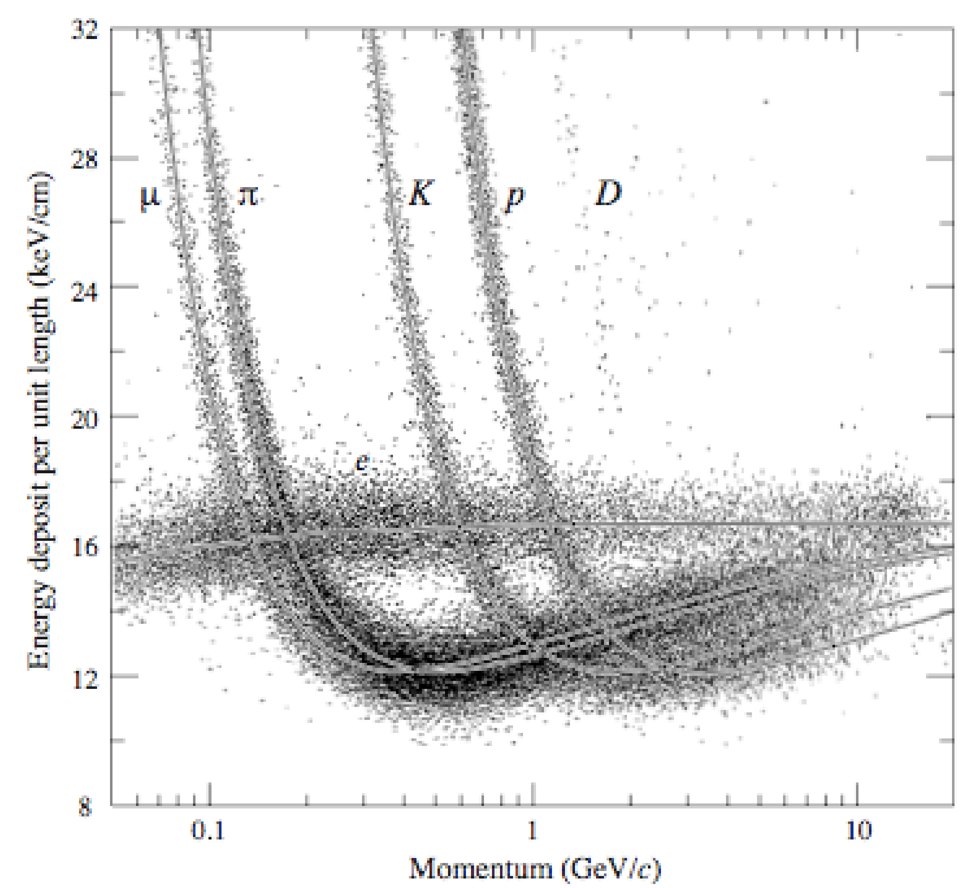
6. *dE/dx by cluster-finding: results in better particle ID since Landau fluctuations are absent: we expect ~3% resolution*

F. Grancagnolo, INFN Lecce



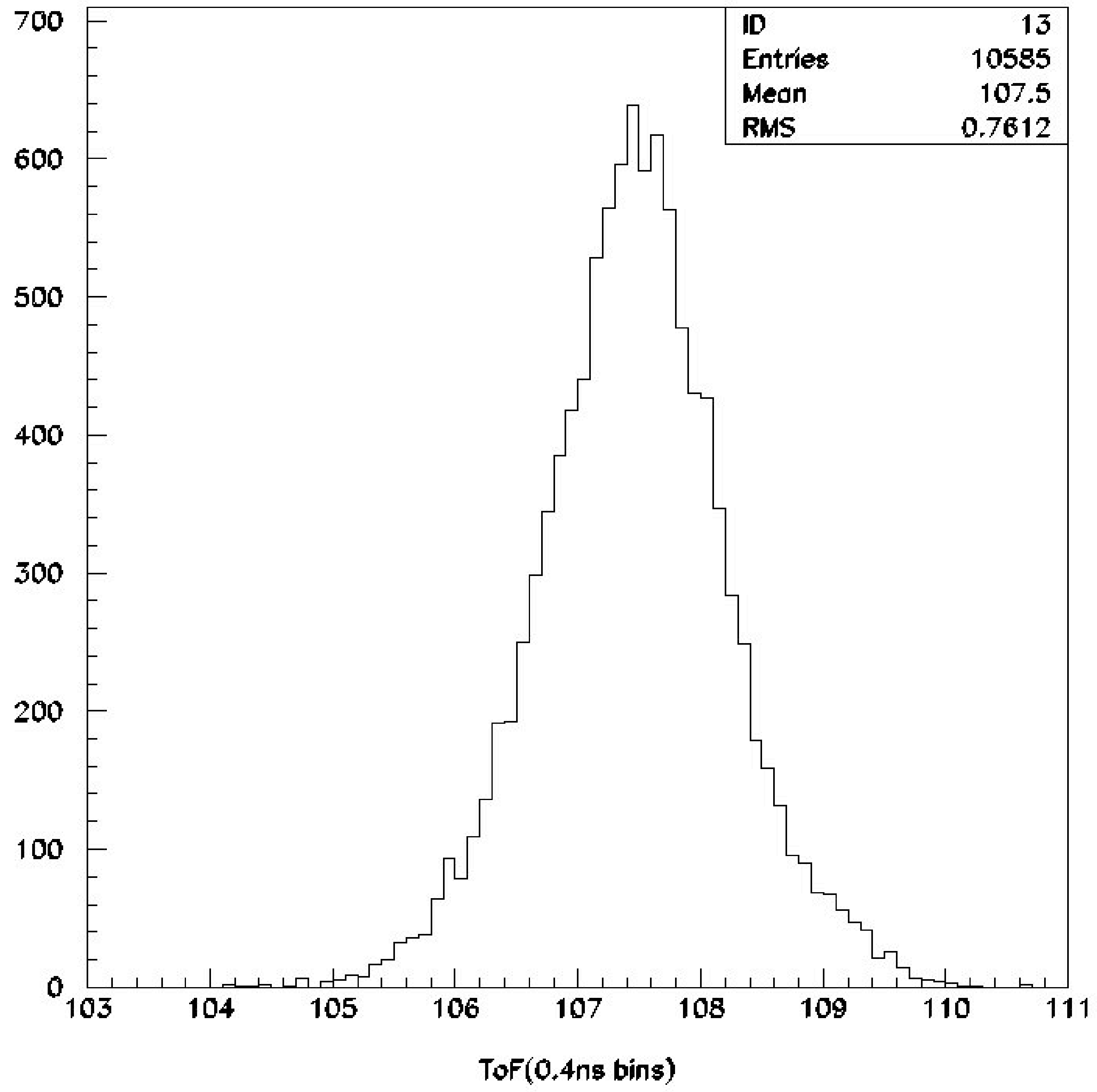
TPC with ~6% *dE/dx* resolution: we expect ~3% with cluster-counting

This TPC built by Dave Nygren, LBL, in 1970's, analyzed by Gerry Lynch.



10. Time-of-flight of Cerenkov light in DREAM fibers

e^- at 50 GeV
fiber Cerenkov light
$\sigma_t \approx 0.30$ ns
Usable for EM decays
of massive long-lived
objects (SUSY, etc.)

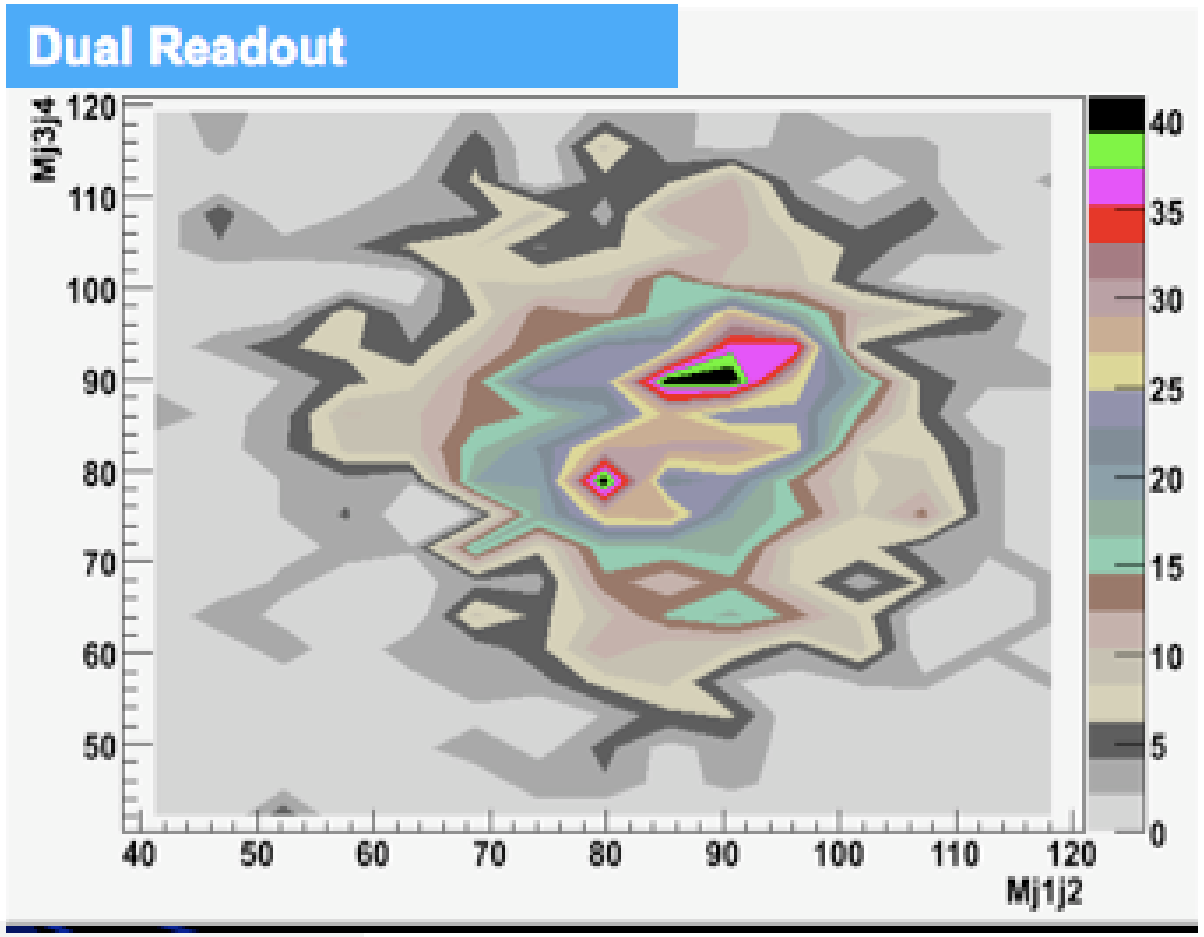


11. $W \to jj$

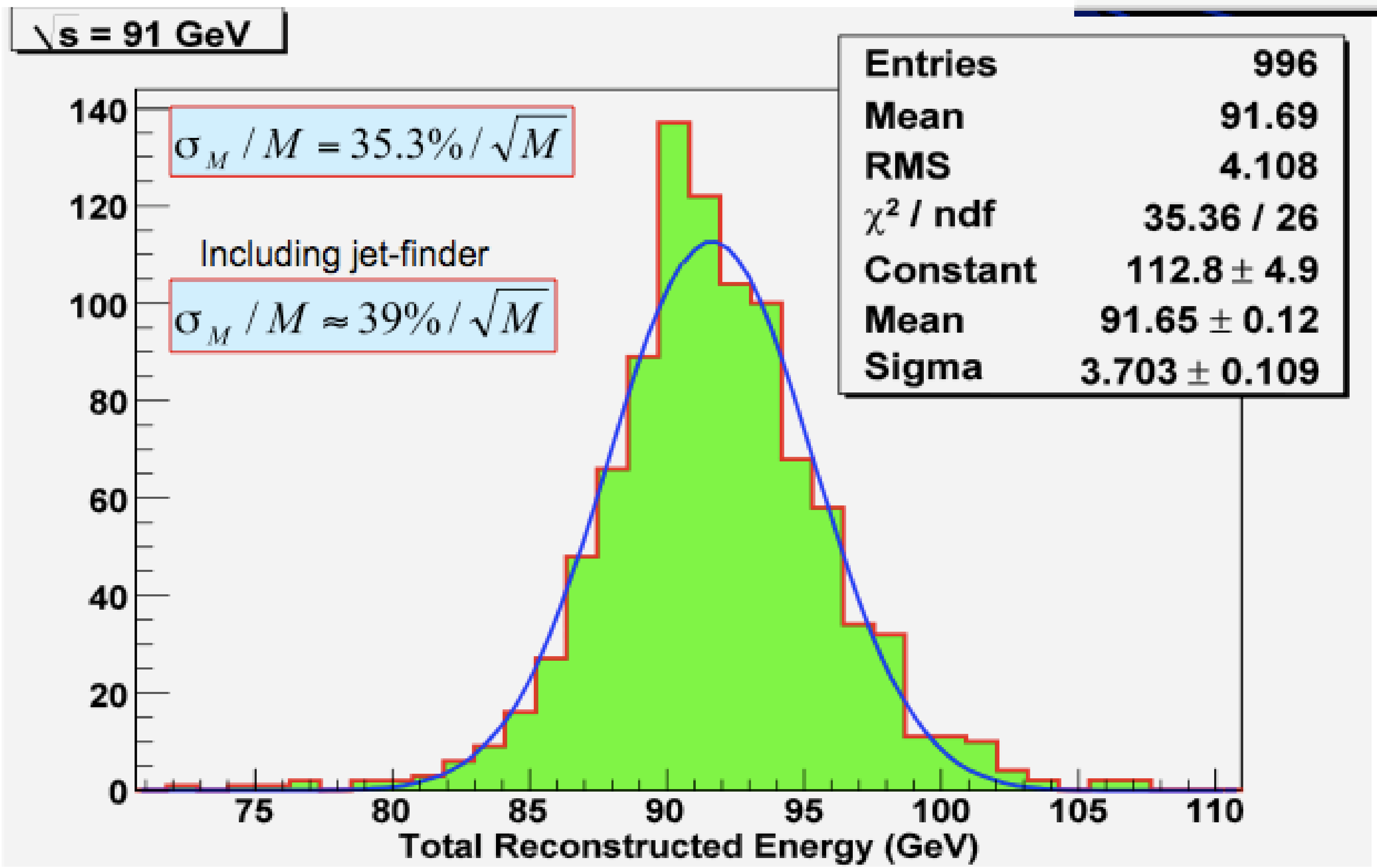
$Z \to jj$

$$e^+e^- \to W^+W^-\nu\bar{\nu}$$
$$e^+e^- \to Z^0Z^0\nu\bar{\nu}$$

$M_{j_3j_4}$



$M_{j_1j_2} \to$



Summary:

4th is rich in particle ID measurements

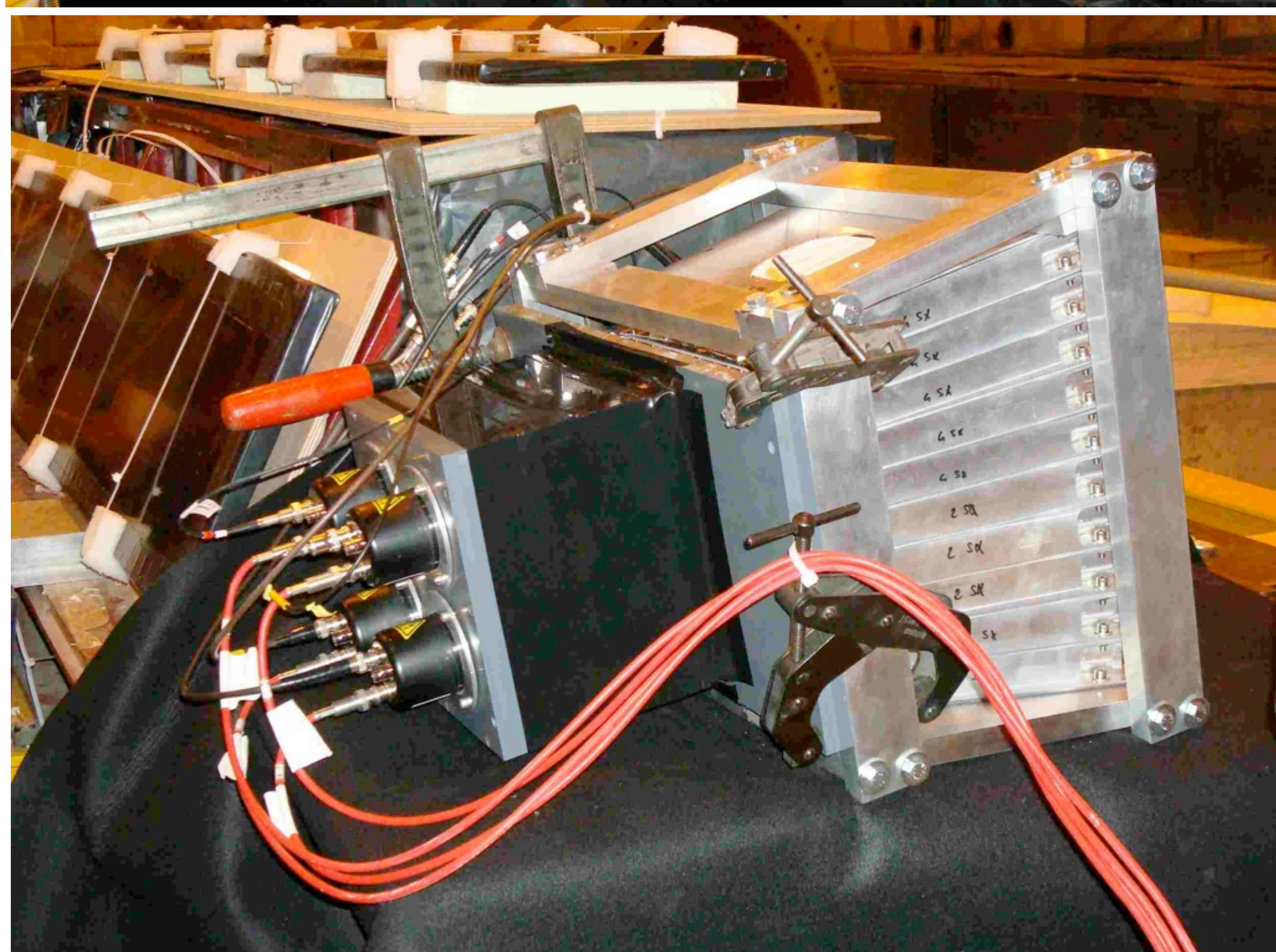
None of these (except W-->jj) have yet been incorporated into ILCroot for physics analyses, but they will be.

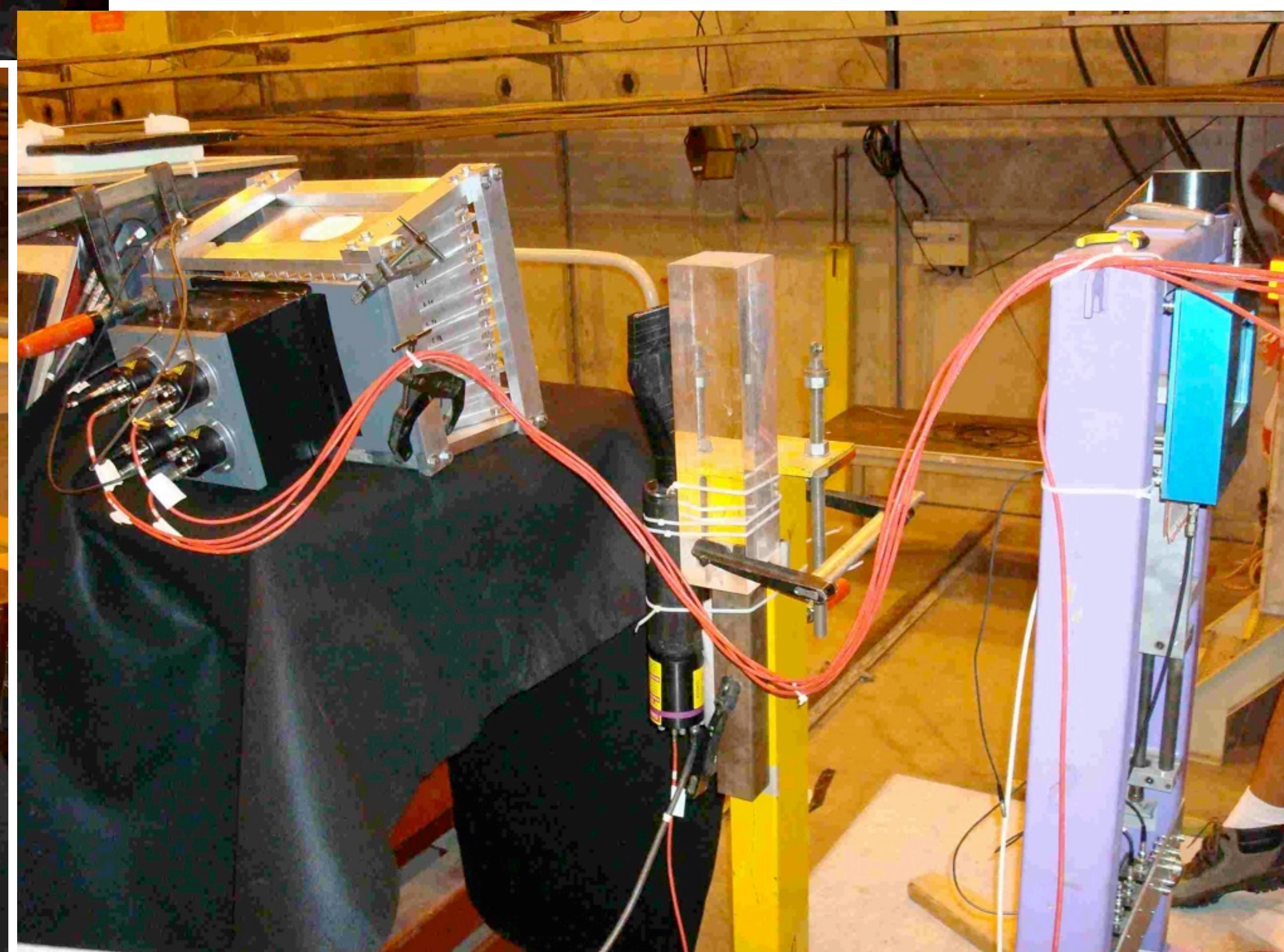
- *Leptons: e, mu, tau*
- *neutrino (by subtraction)*
- *Quarks: uds and t (not cb yet)*
- *Bosons: W, Z and gamma*

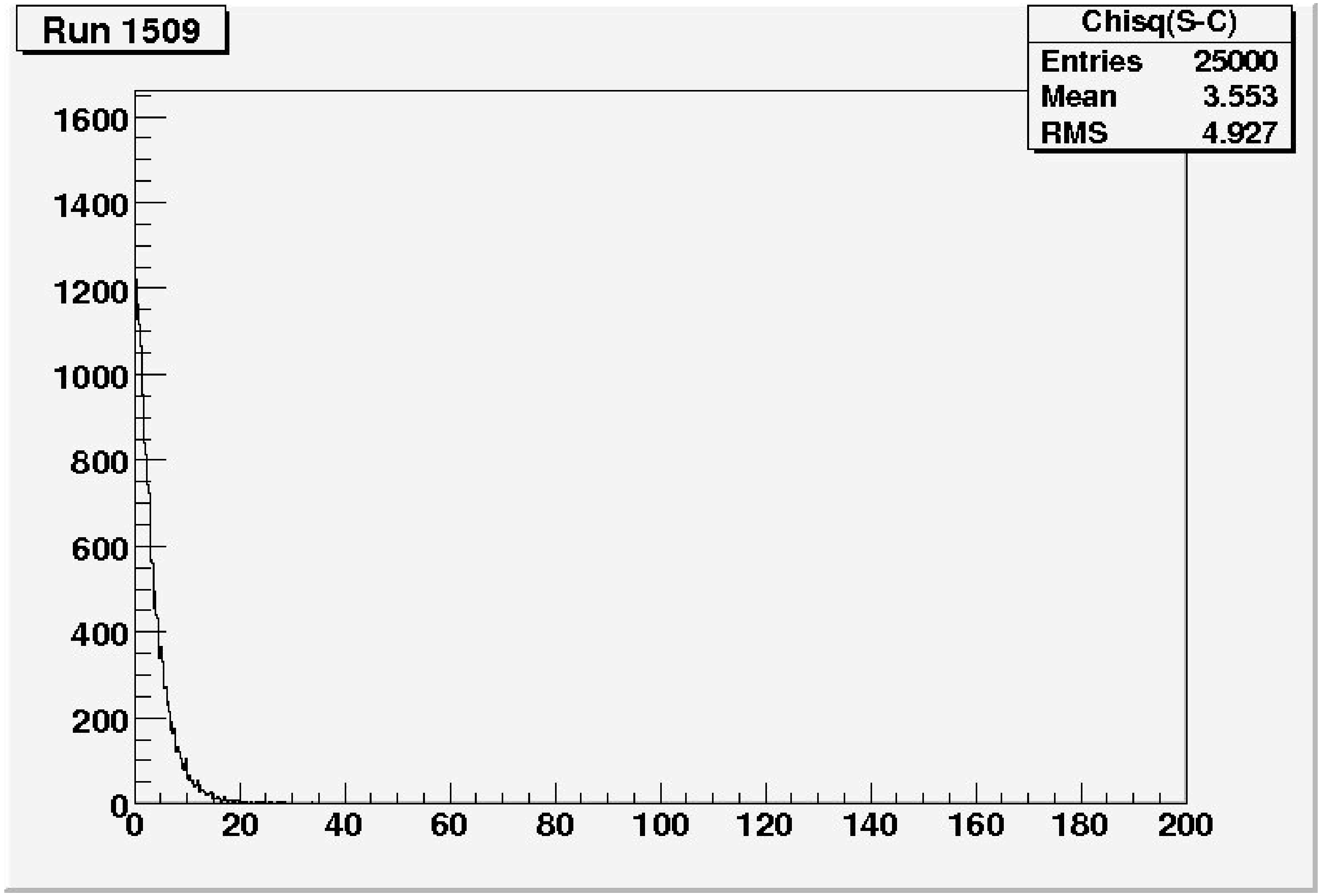
Extras

Test beam setup

(July-Aug ‘08)



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Chisq(S-C)
Entries 25000
Mean 3.553
RMS 4.927
0
200
400
600
800
1000
1200
1400
1600
0
20
40
60
80
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160
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200