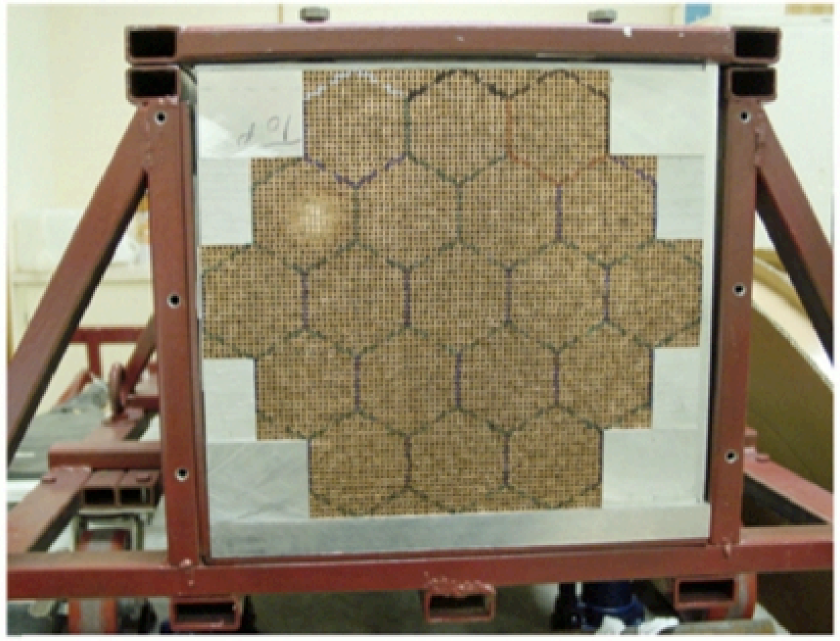
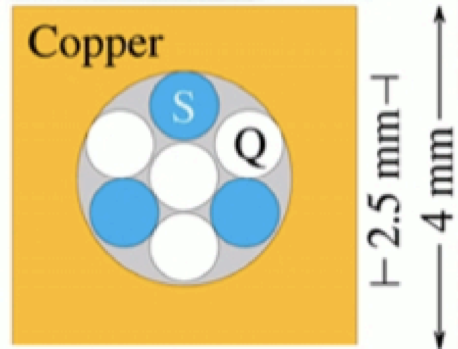
Recent results and plans in dual-readout calorimetry

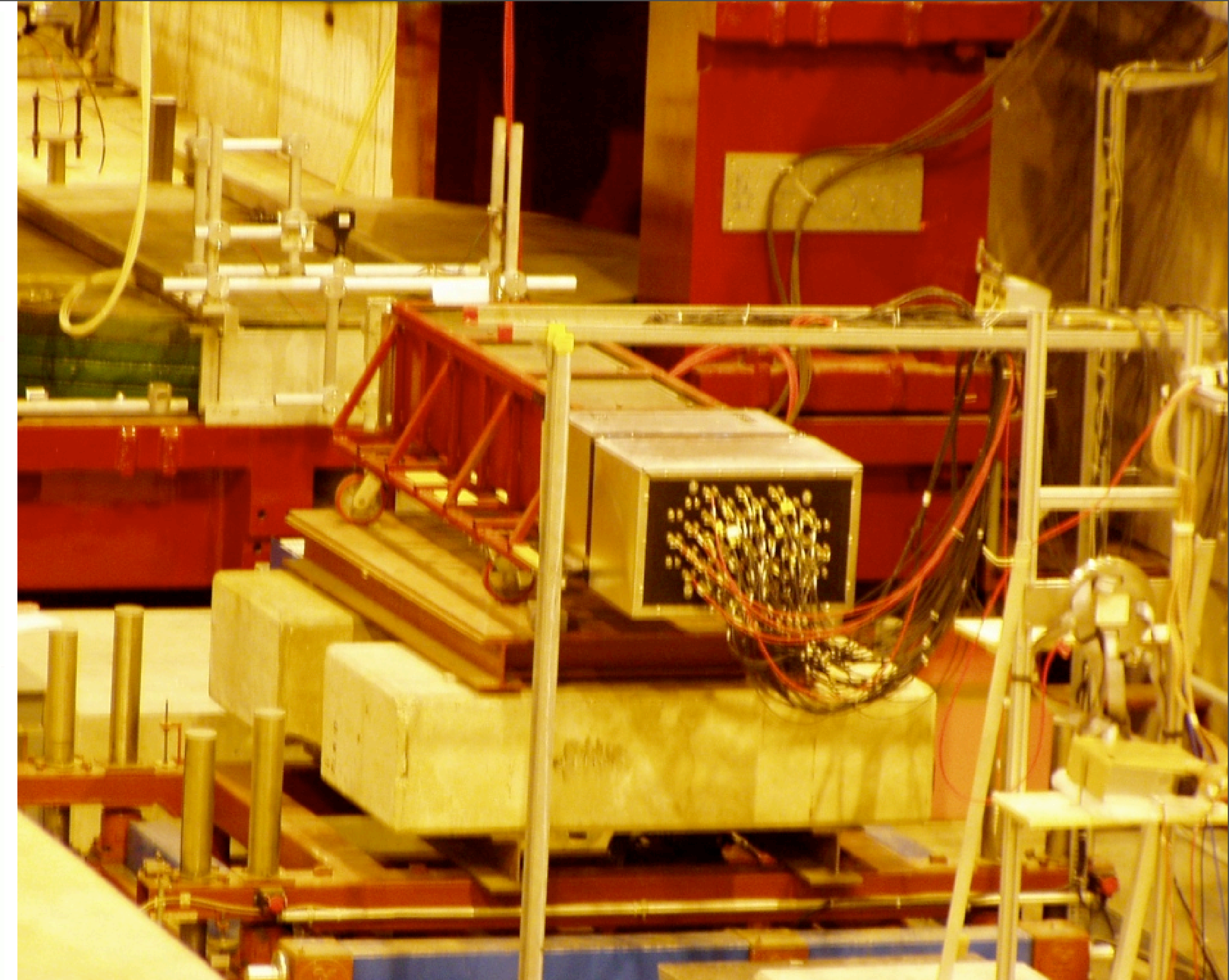
Warsaw, ECFA08, 9-12 June 2008
John Hauptman, 4th LoI collaboration

- The DREAM collaboration has presented results on dual readout of PbWO4 and BGO crystals by direction, wavelength, and time;
- Measured temperature dependence of scintillation light in PbWO4;
- Measured EM-fraction correlations in a combined a BGO+DREAM calorimeter; and,
- Made a first event-by-event measurement of the MeV neutrons liberated in shower development.
- The 4th group is integrating a BGO+fiber design into ILCroot.
- We plan to make further neutron measurements, to measure a complete time-history of the crystals and fibers, and to attempt a measurement of the side leakage in the DREAM module.

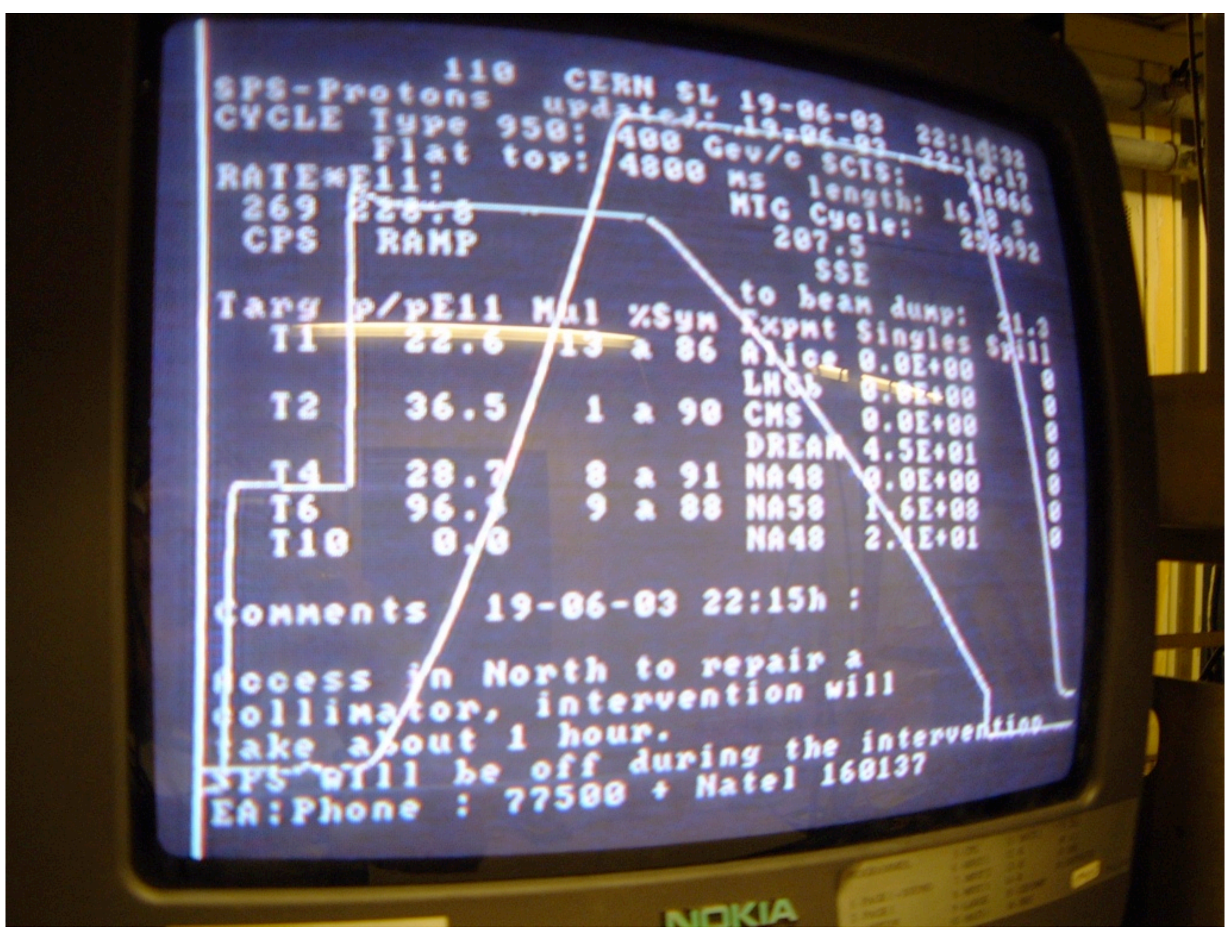
Dual-readout DREAM: Structure

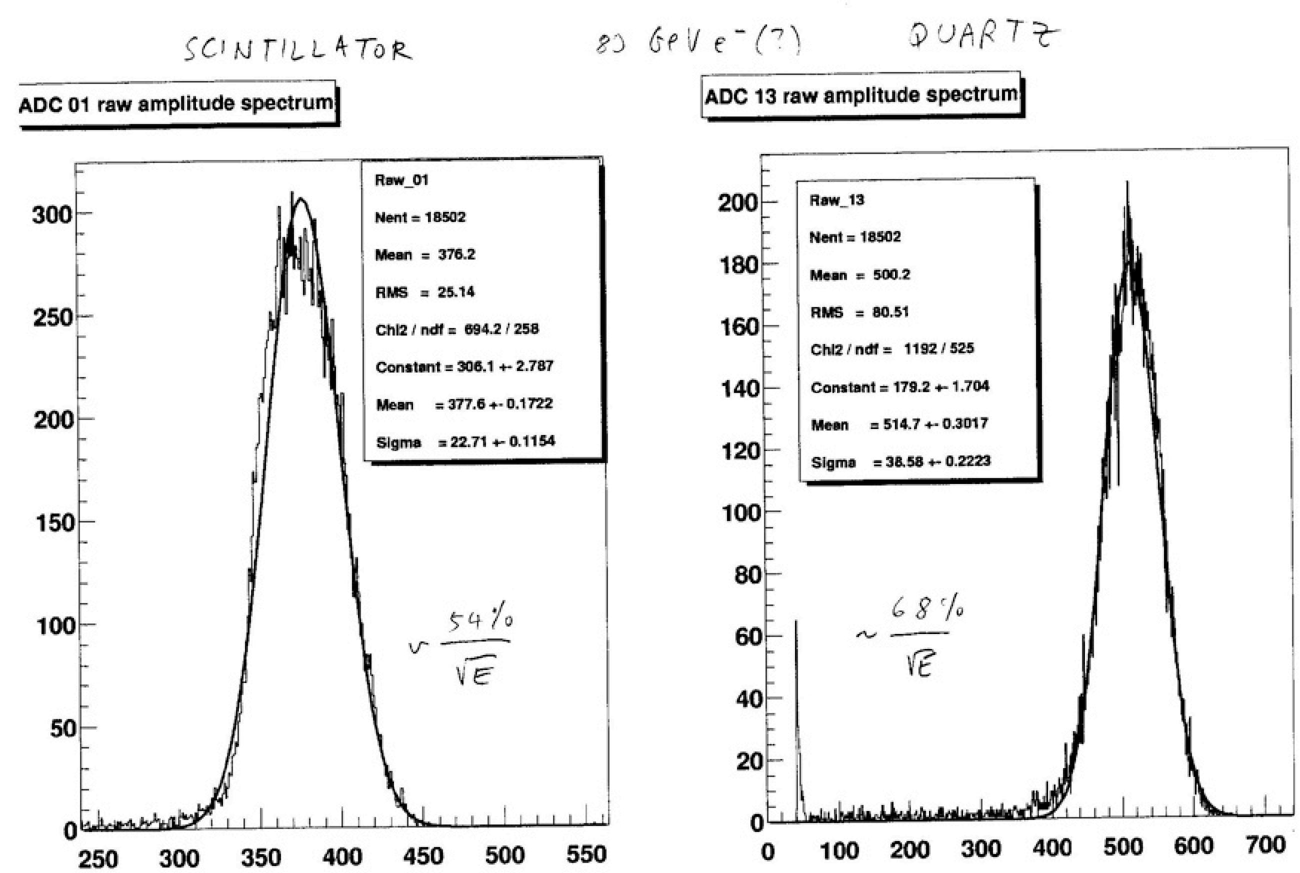




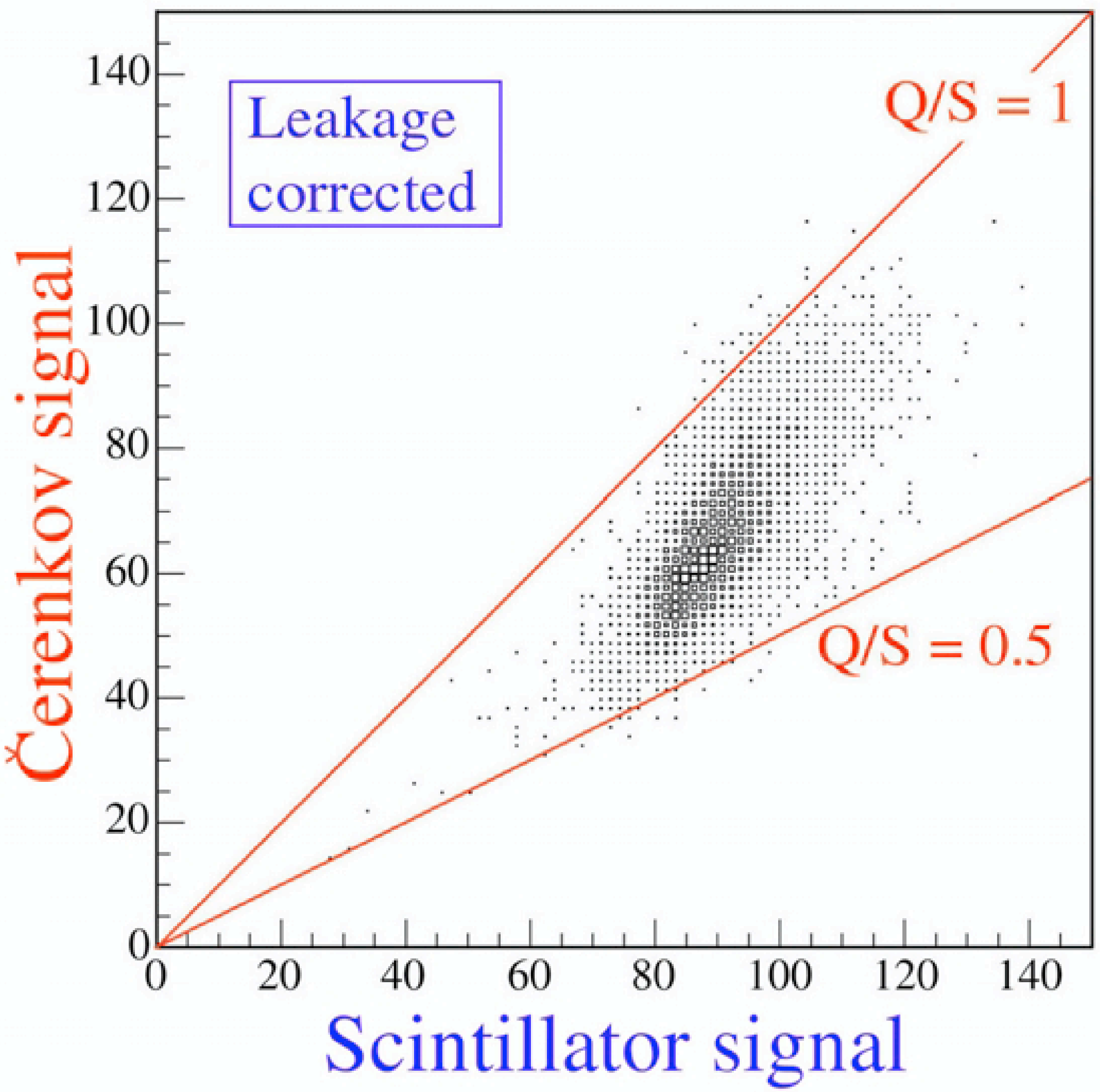


- *Some characteristics of the DREAM detector*
  - Depth 200 cm (10.0 λ_{int})
  - Effective radius 16.2 cm (0.81 λ_{int}, 8.0 ρ_M)
  - Mass instrumented volume 1030 kg
  - Number of fibers 35910, diameter 0.8 mm, total length $\approx$ 90 km
  - Hexagonal towers (19), each read out by 2 PMTs





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



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

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

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

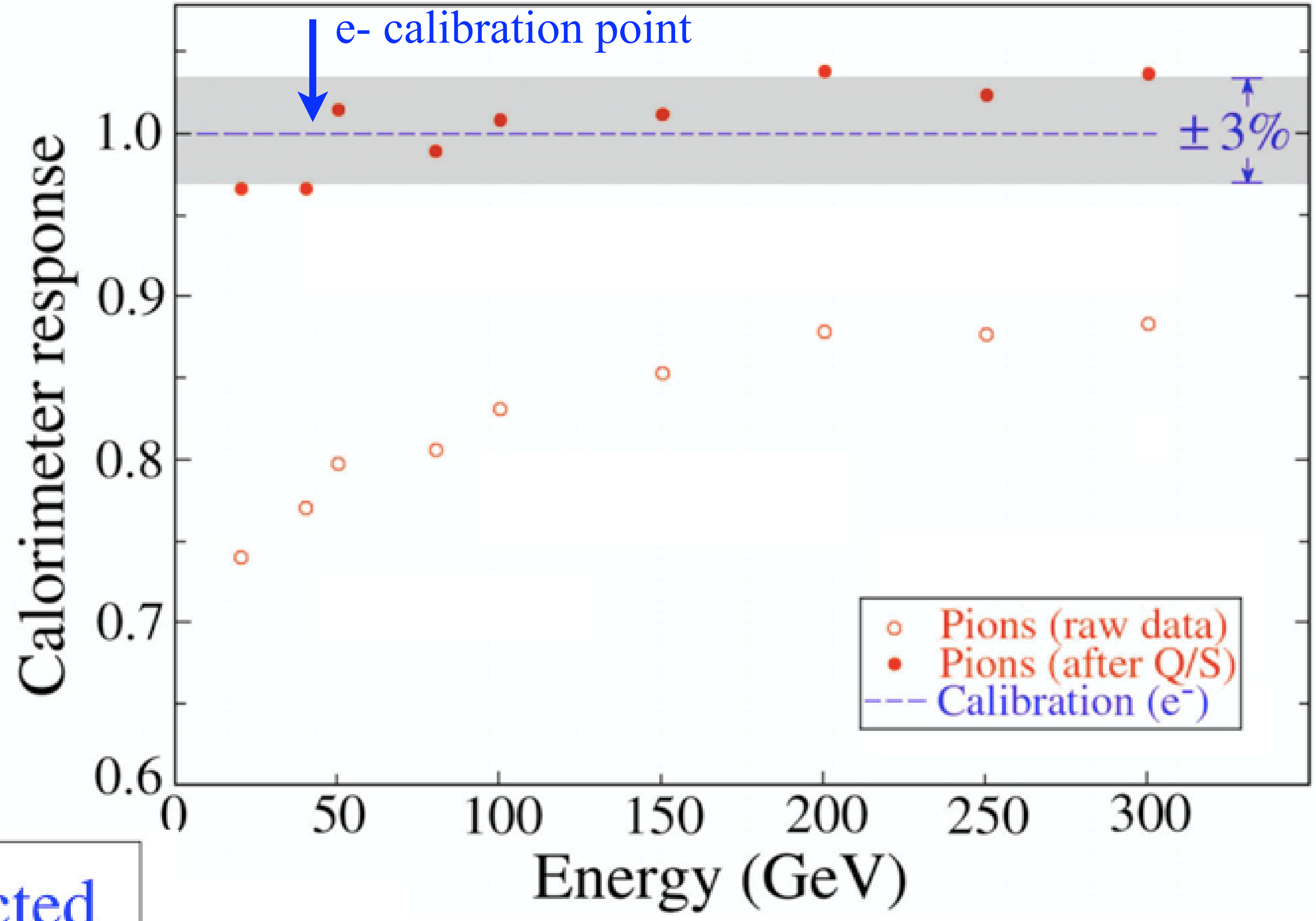
$$\frac{Q}{S} = \frac{f_{\rm em} + 0.21\,(1 - f_{\rm em})}{f_{\rm em} + 0.77\,(1 - f_{\rm em})}$$

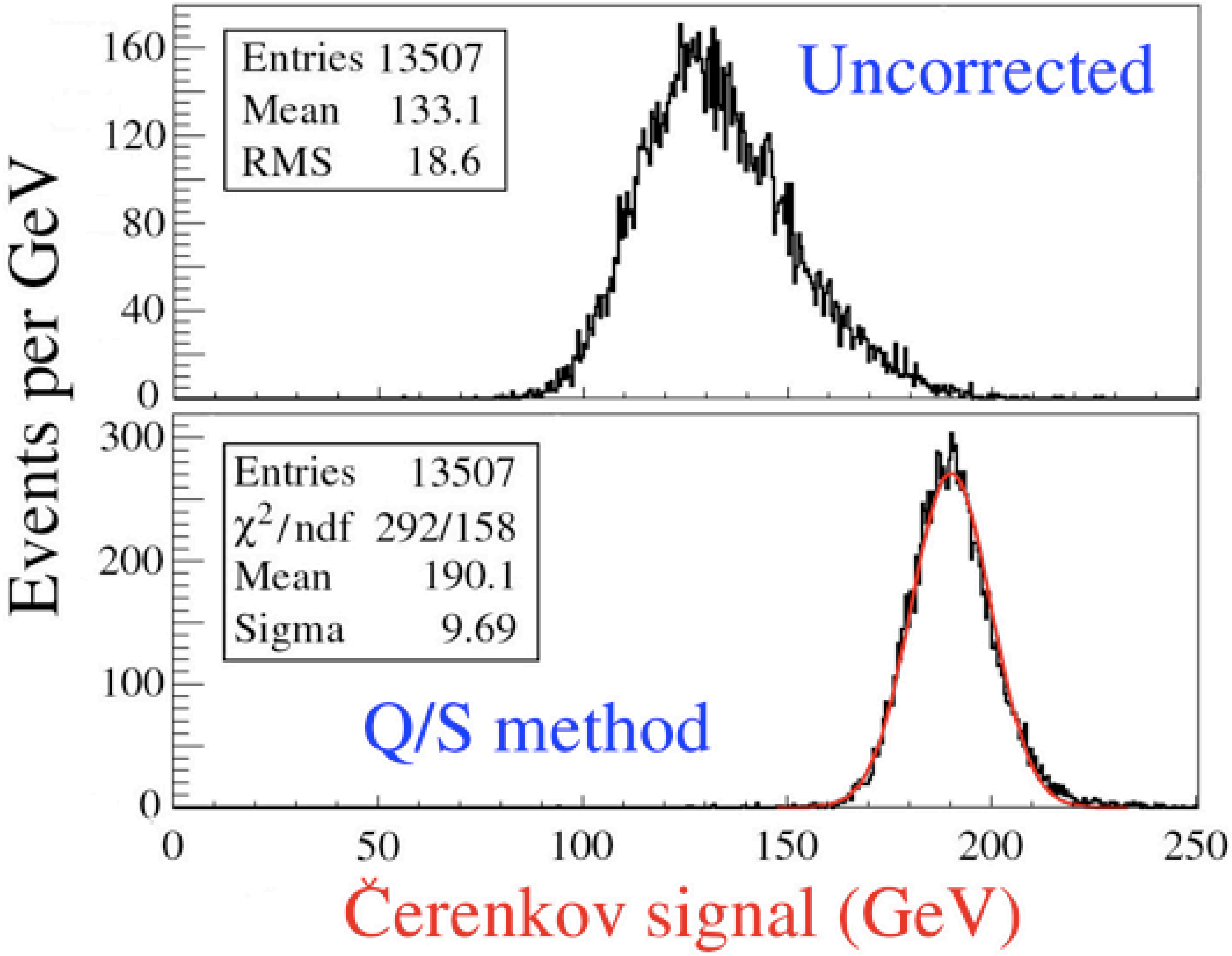
$$E = \frac{S - \chi Q}{1 - \chi}$$

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

Consequences:

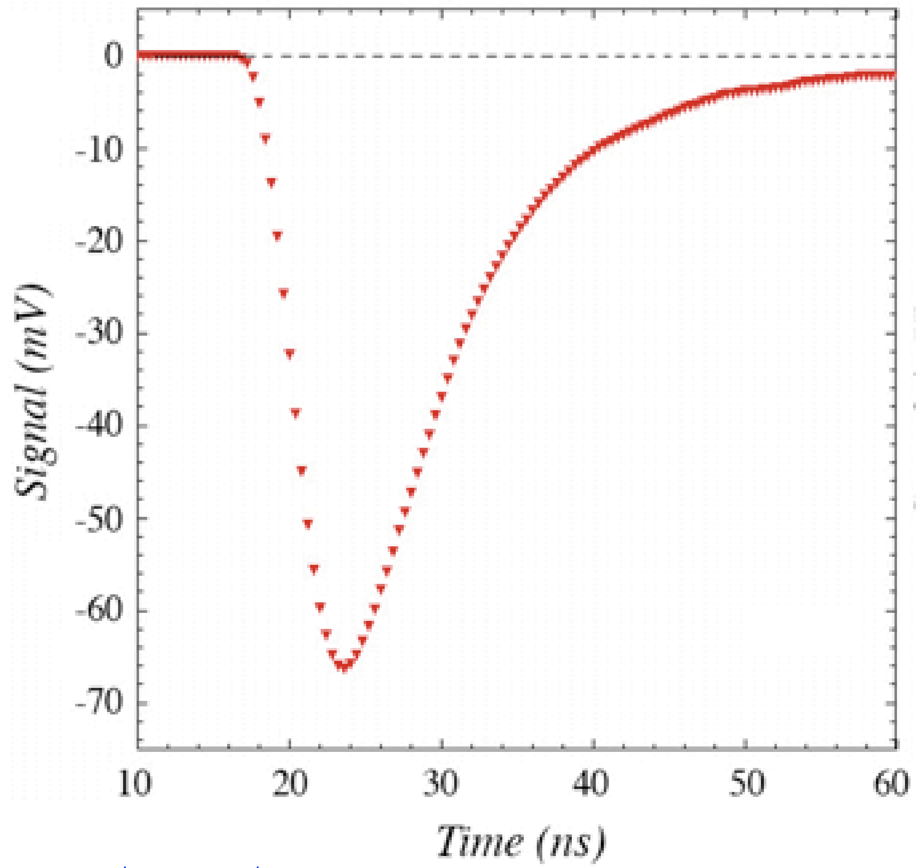
Hadronic energy linearity over the whole SPS range, 20-300 GeV/c.

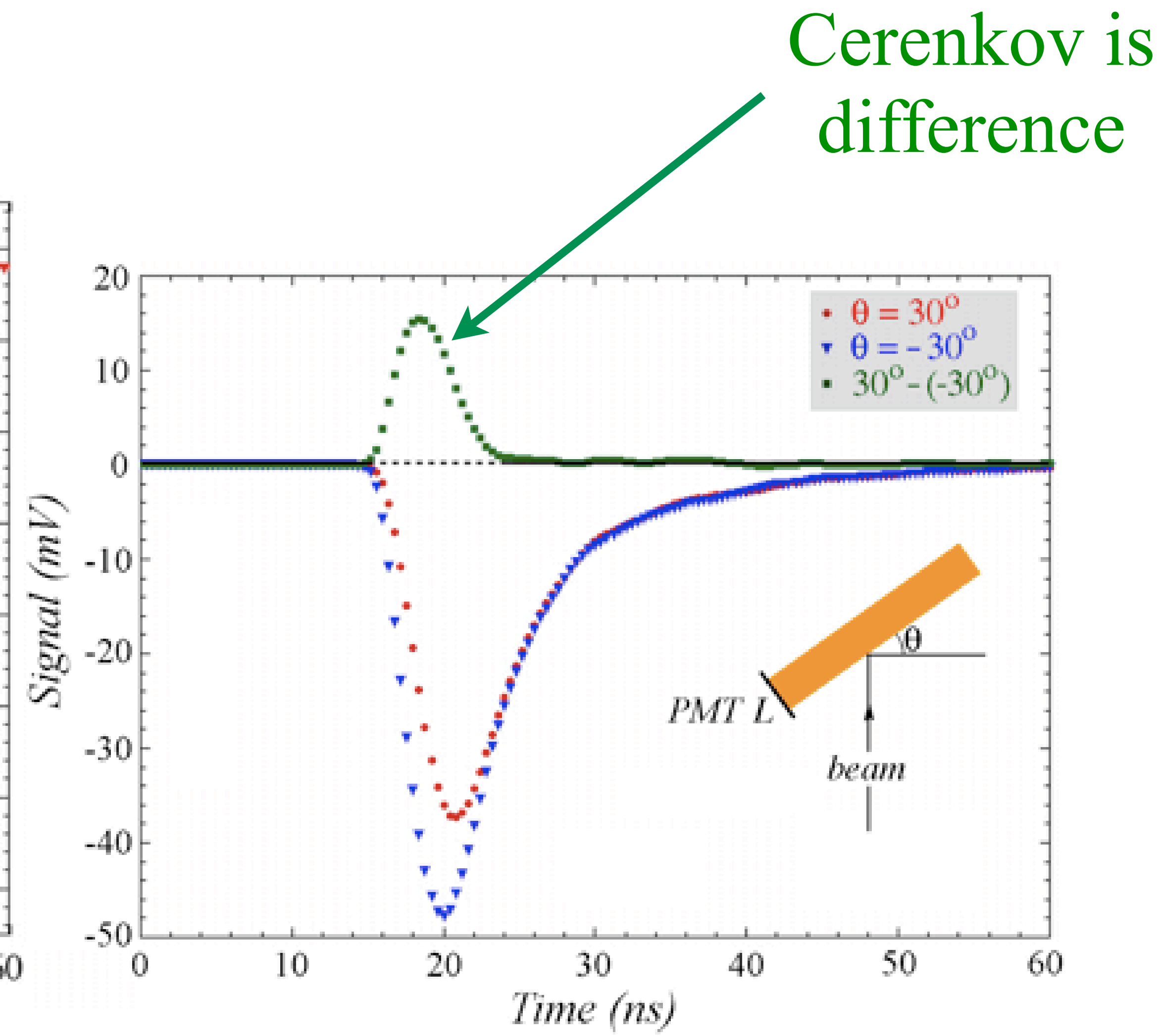




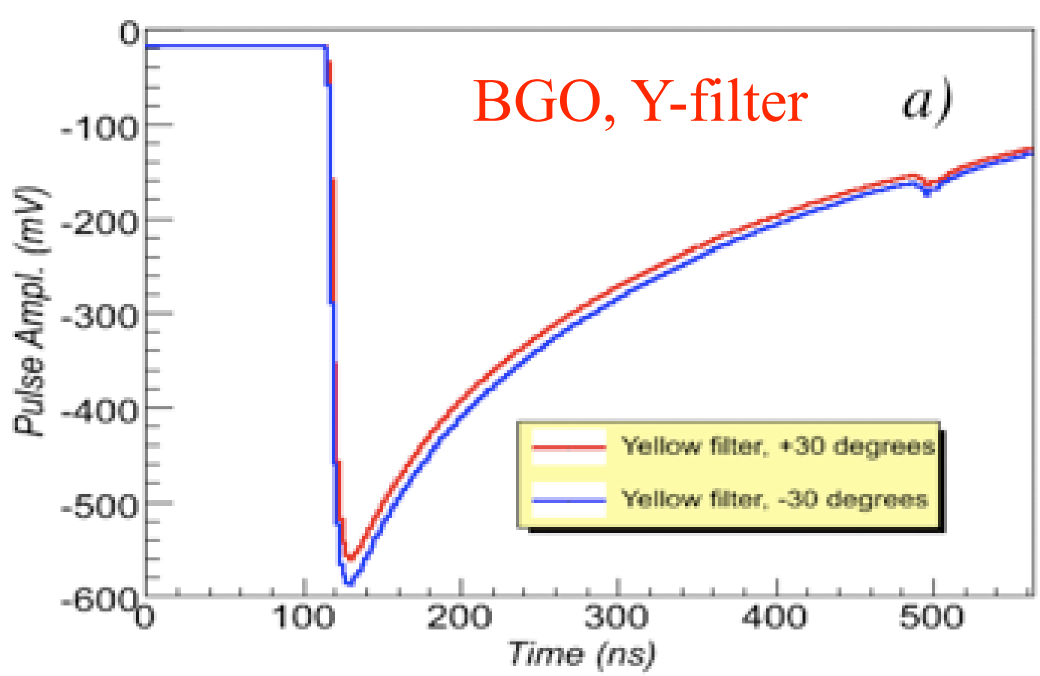
Expectation of excellent Gaussian energy resolution

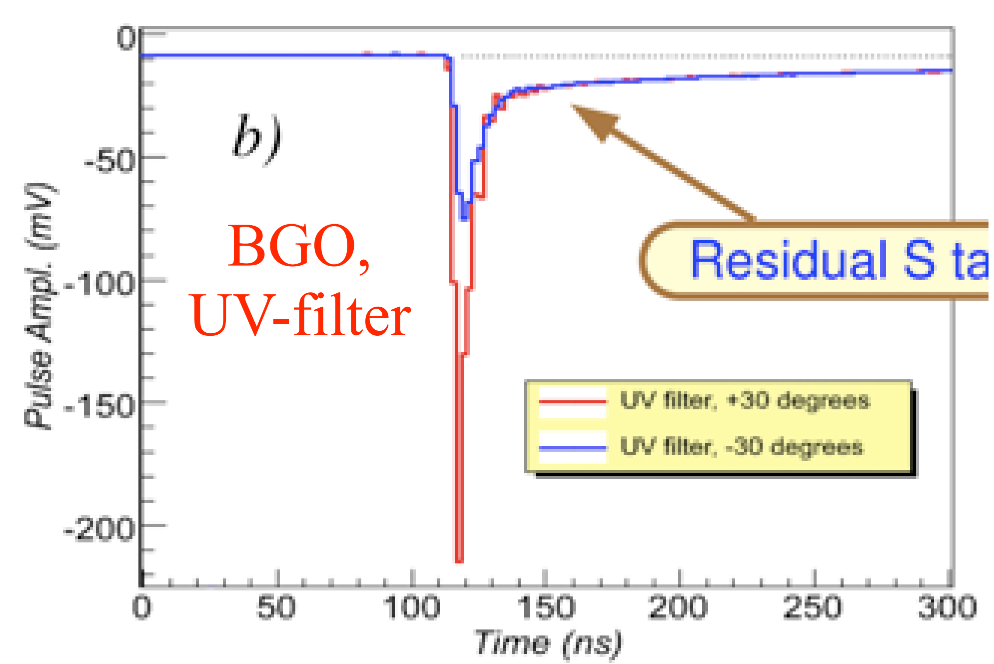
PbWO4 time structure





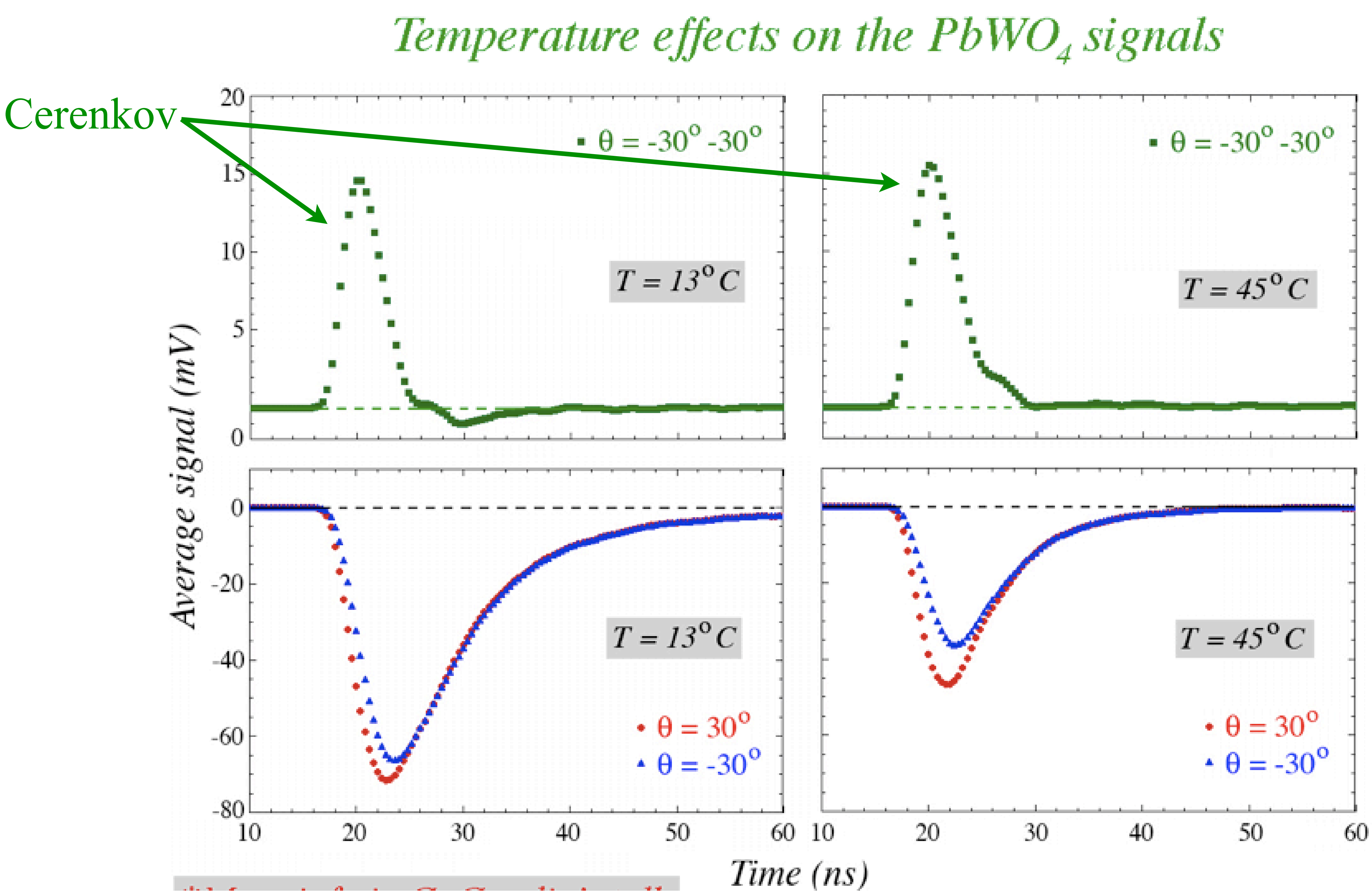
BGO time structure





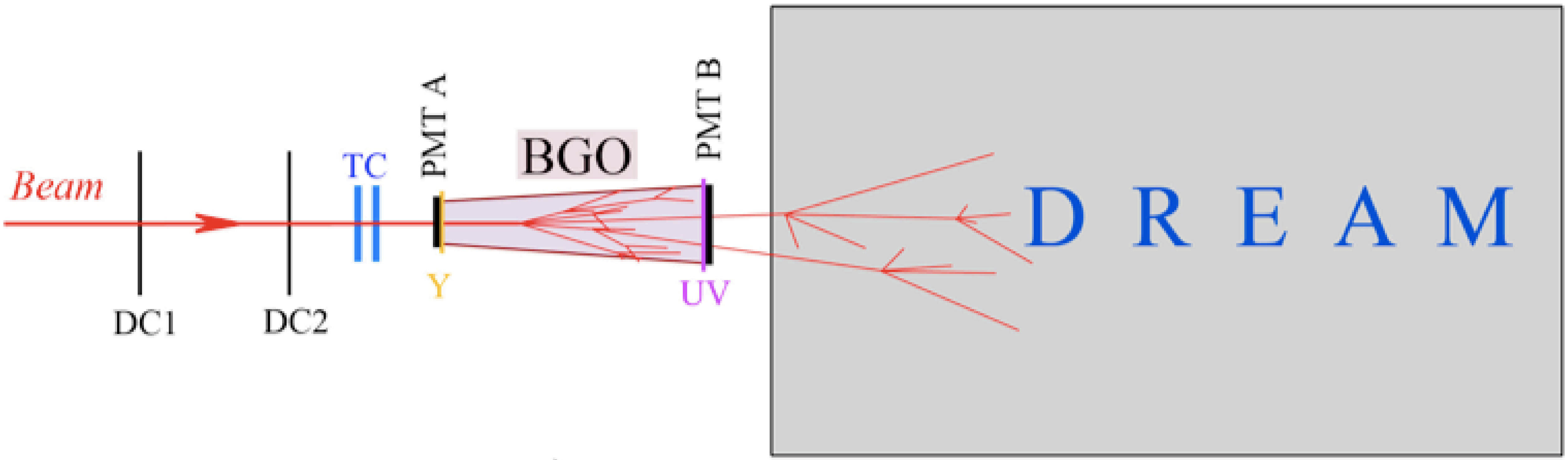
C. Voena, INFN Roma I: CALOR08, Pavia

PbWO4 temperature effects: luminosity down, faster.

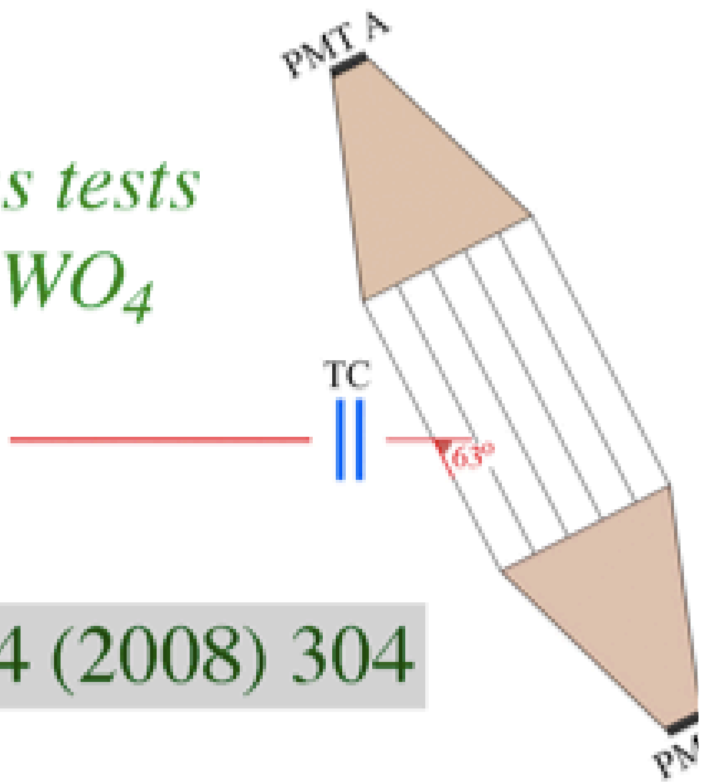


G. Gaudio, INFN, Pavia: CALOR08, Pavia

BGO + DREAM: physical correlations



Previous tests with $PbWO_4$ matrix



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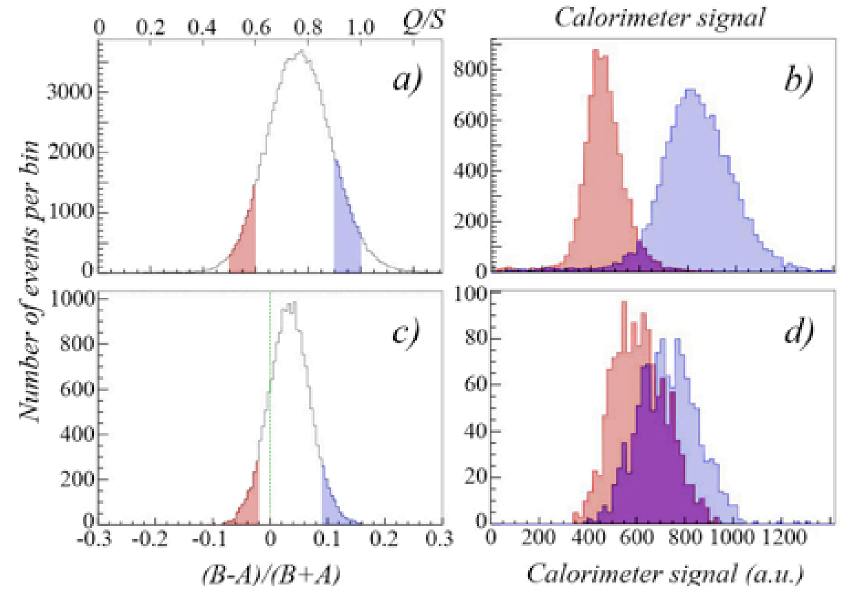
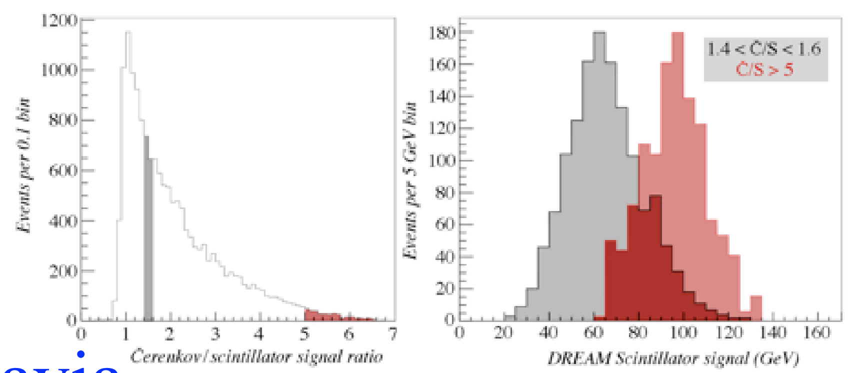


DREAM stand-alone (2 separate media)

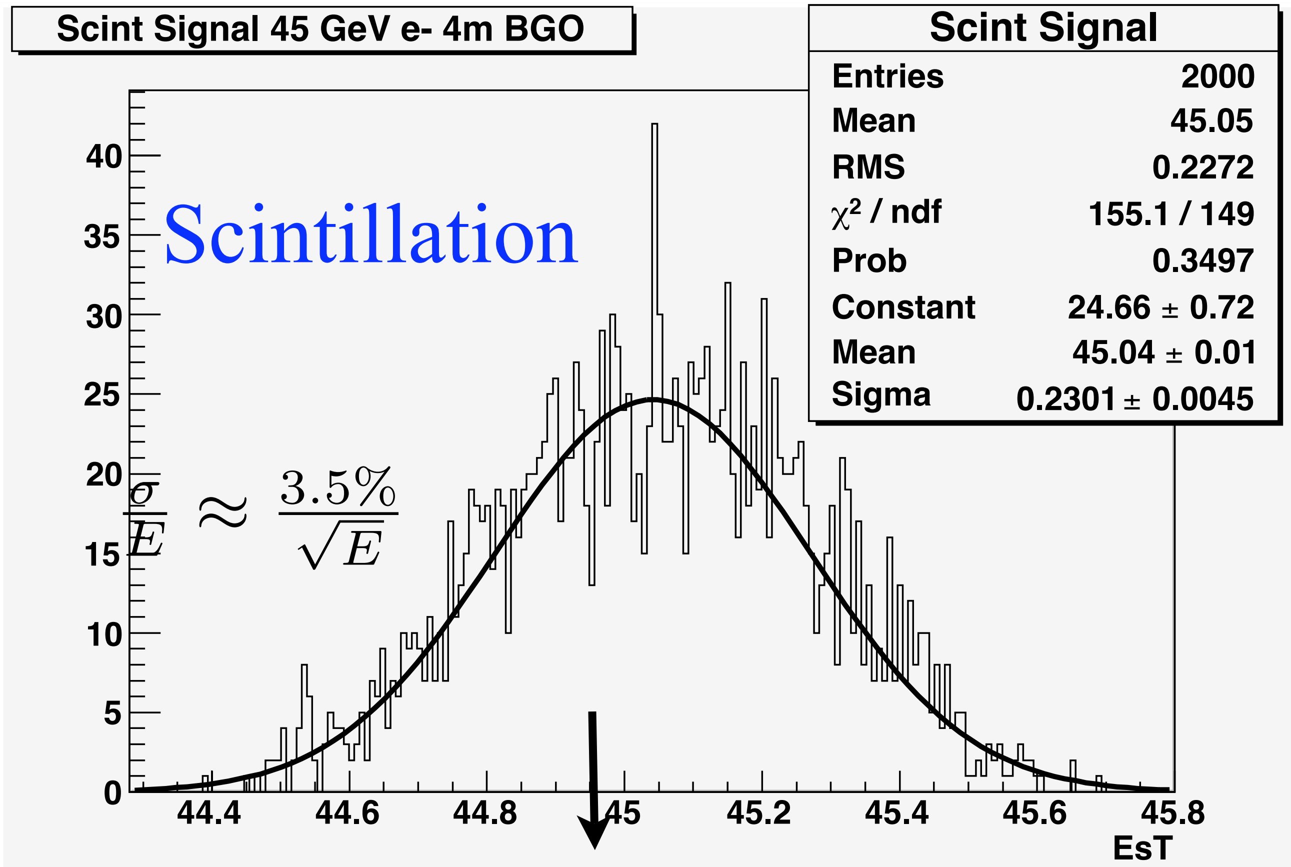
$PbWO_4$ matrix (directionality)

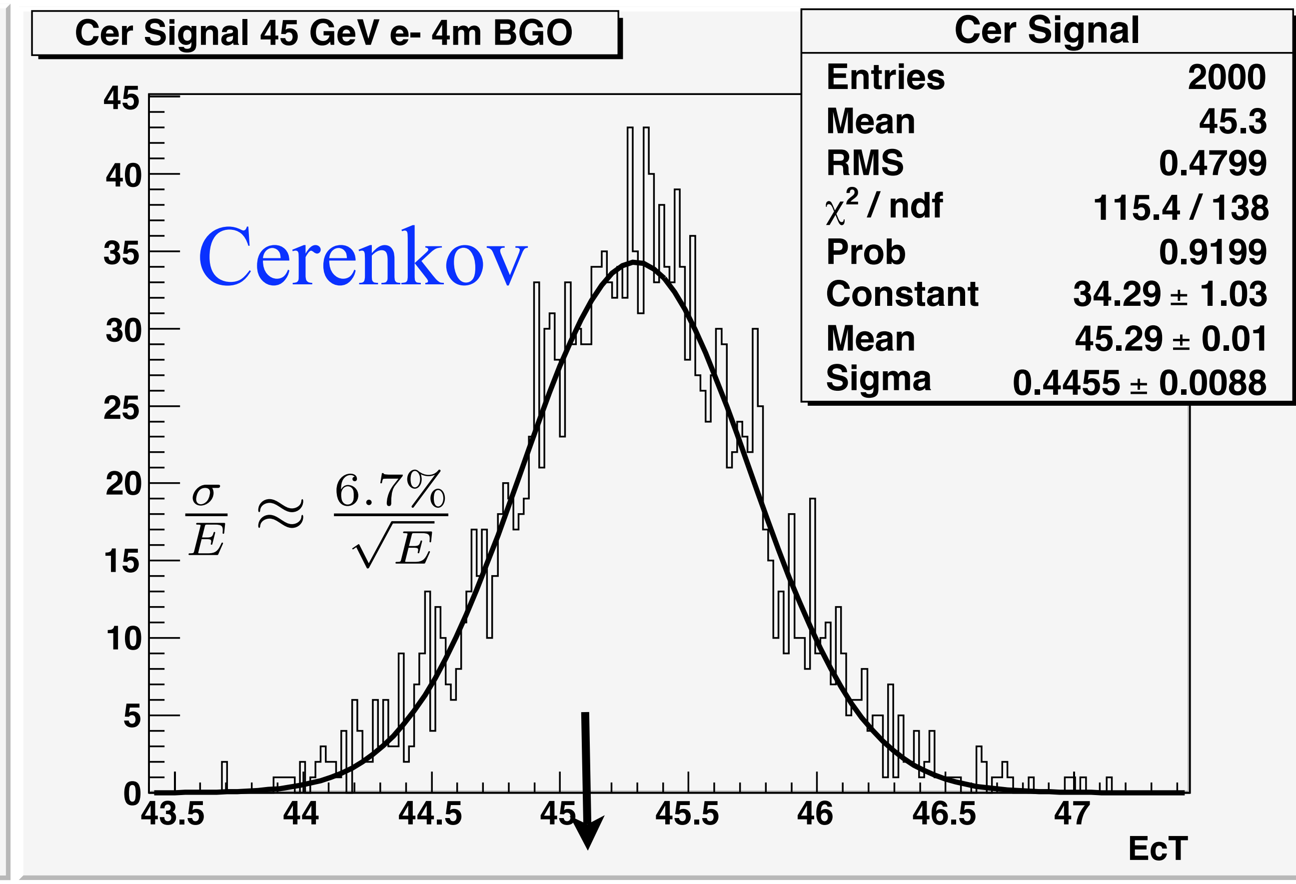


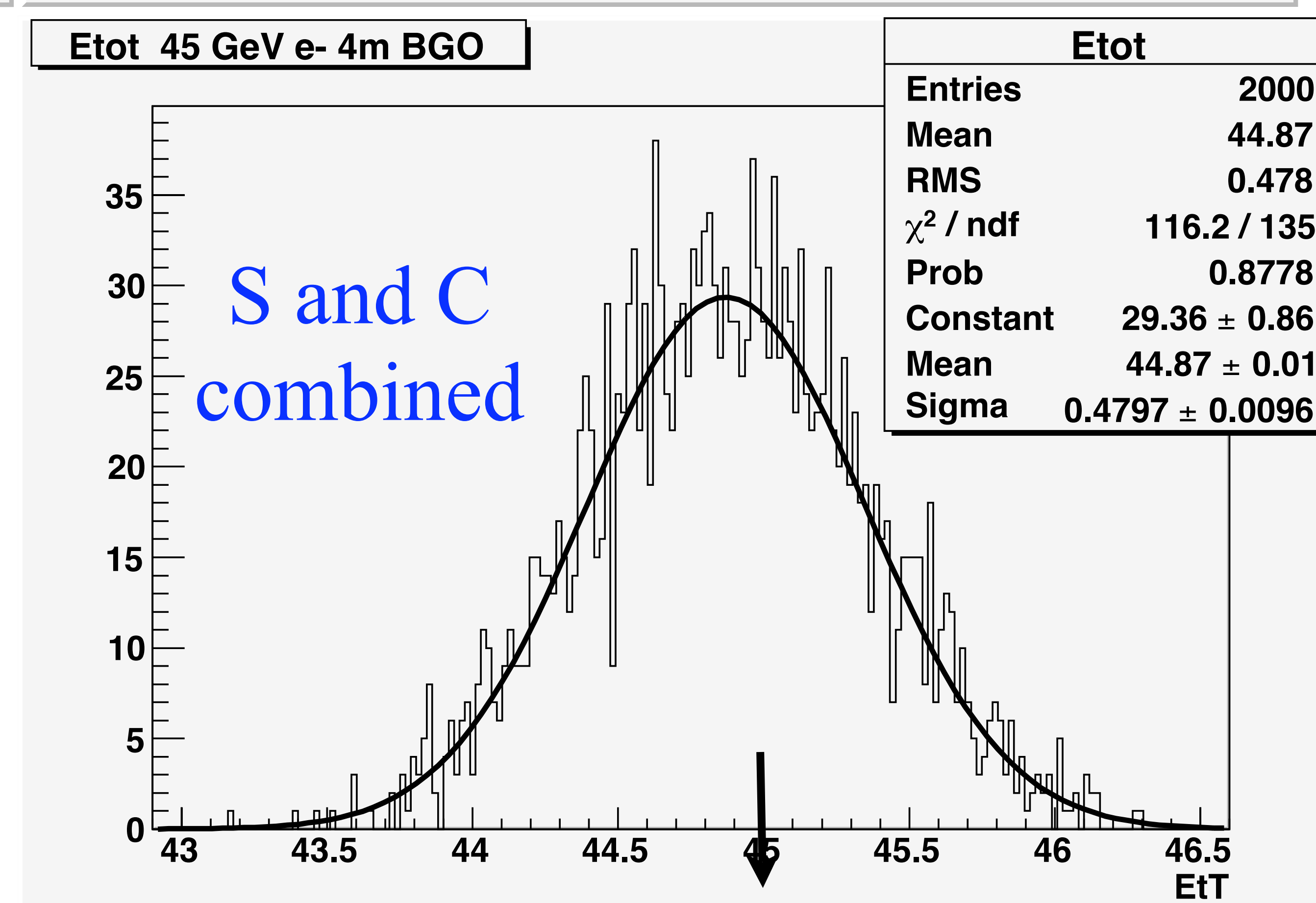
BGO_{UV} (1 crystal)

(time structure + spectrum)

“BGO calorimeter” 45 GeV electrons





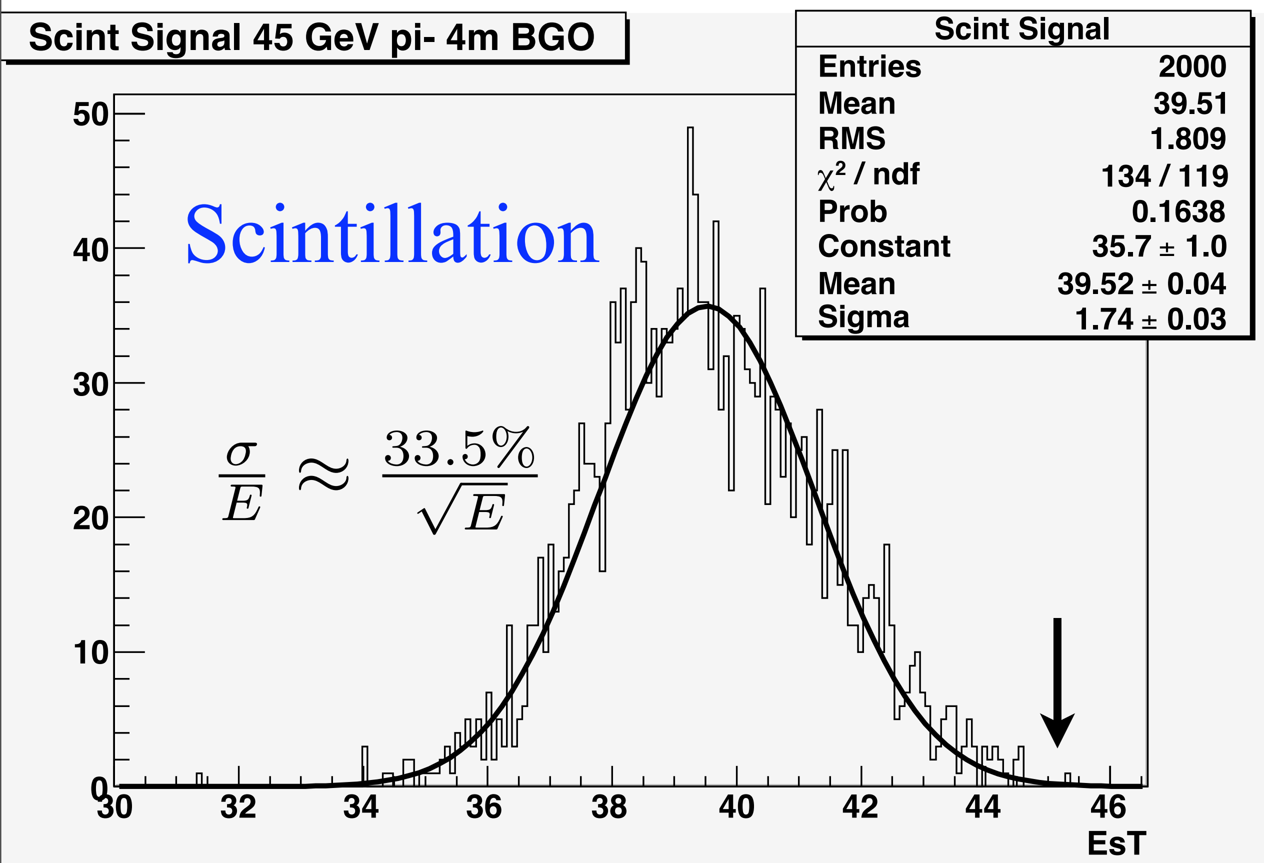


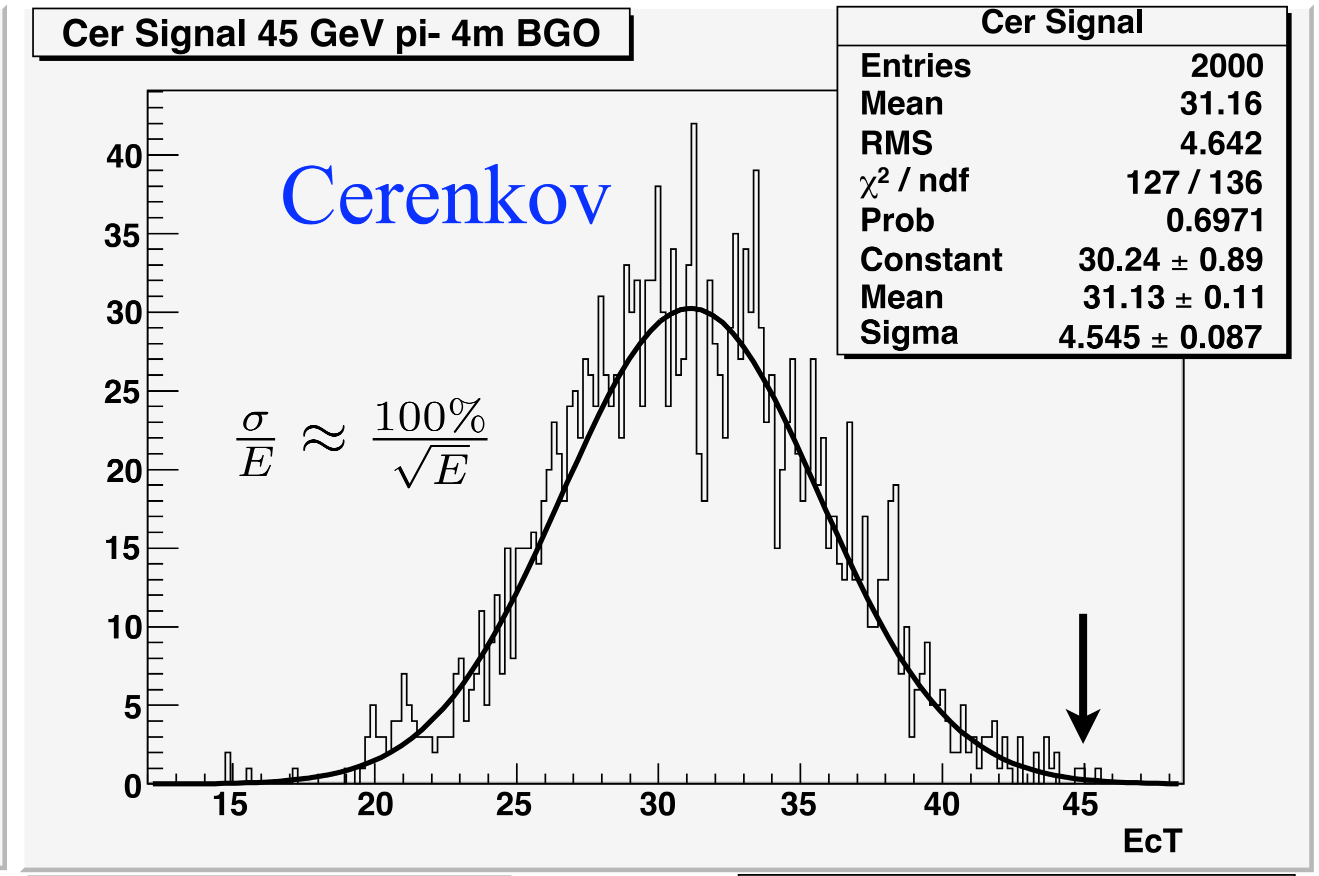
Vito Di Benedetto, INFN, Lecce

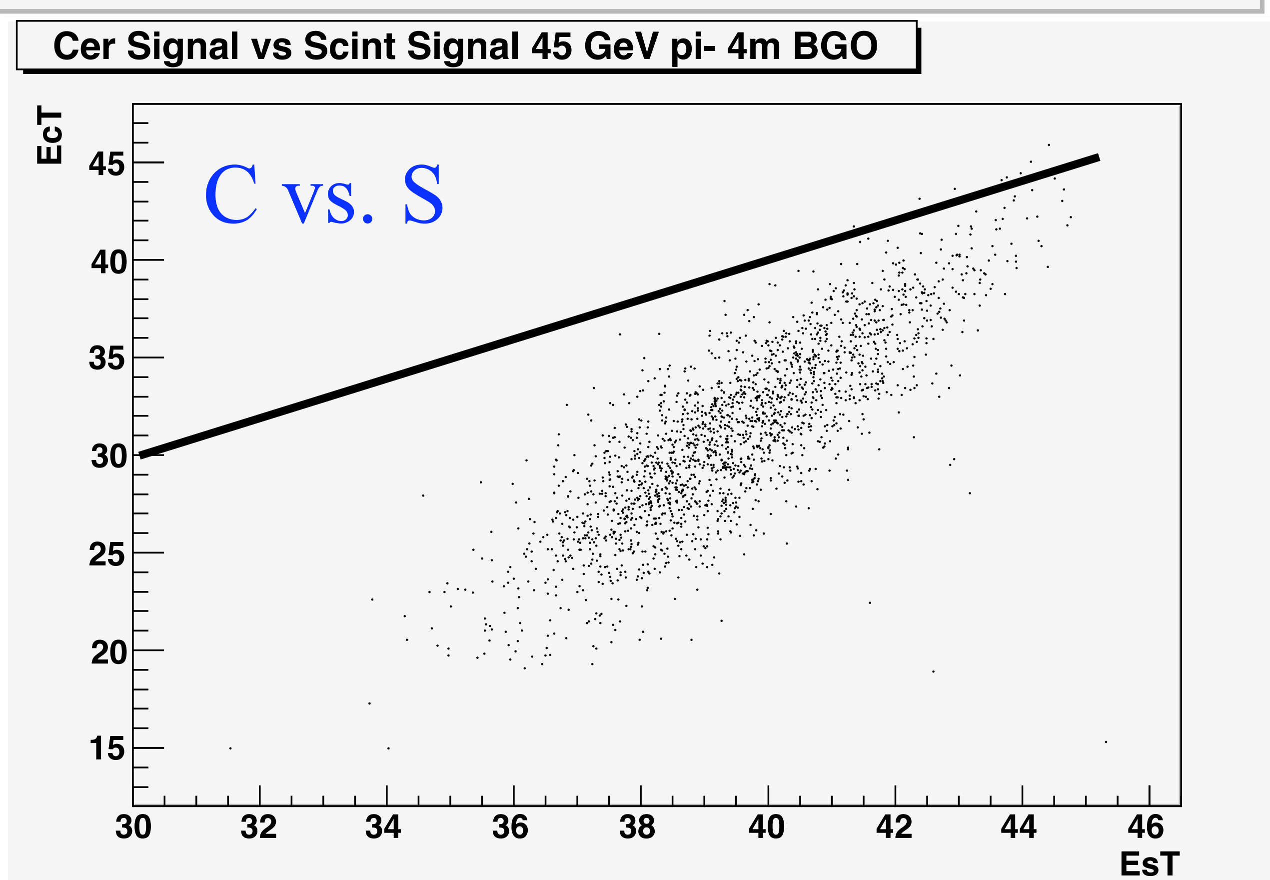
(4th calorimetry)

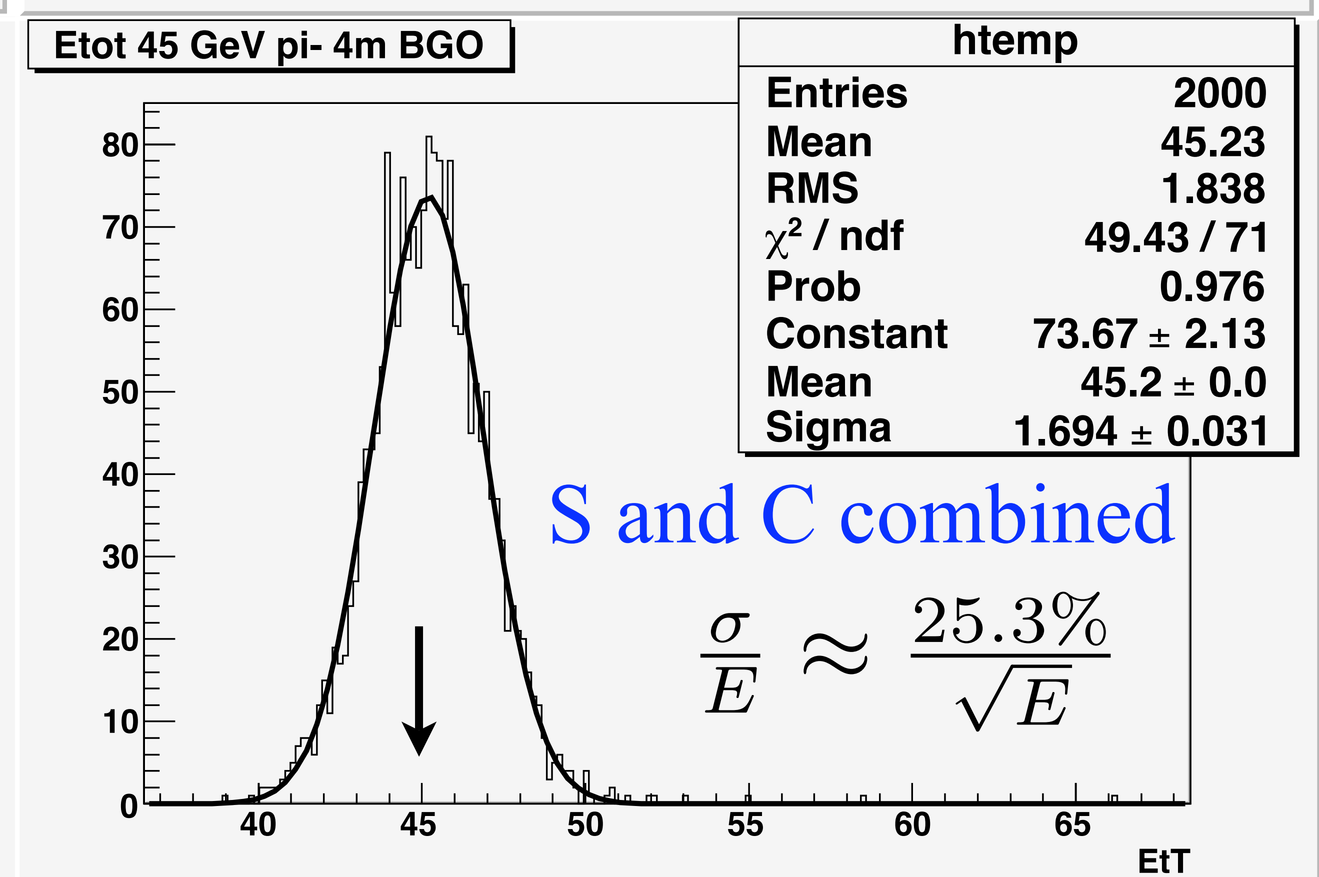
"BGO calorimeter" 45 GeV pions

Vito Di Benedetto



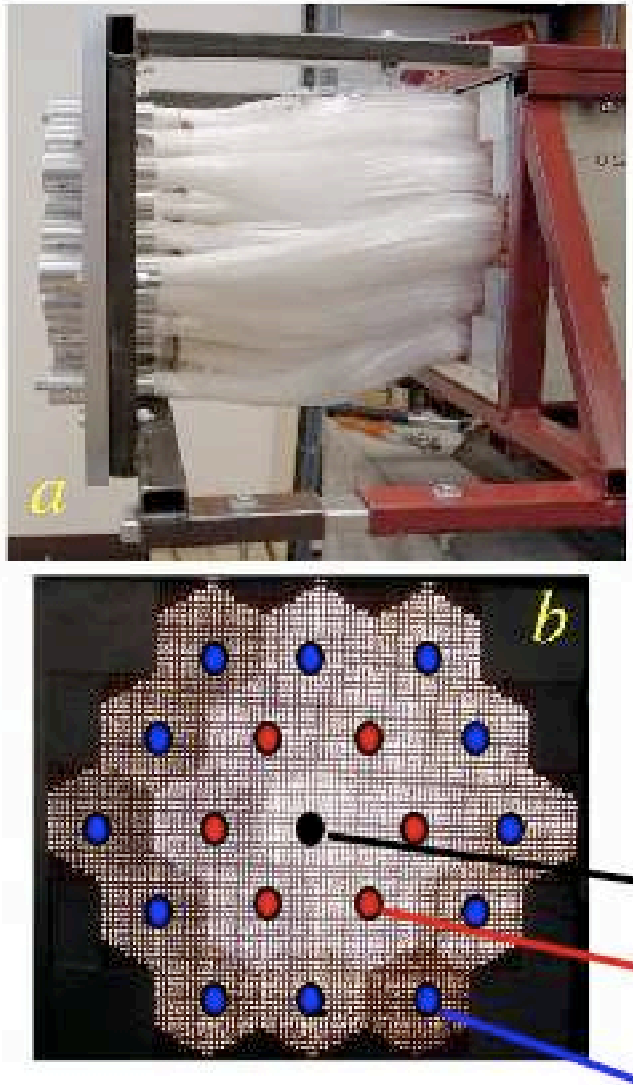






DREAM module neutron measurement

Reconfigure DREAM module to sum nearly the entire volume into three scintillation and one Cerenkov channel. Deliver these to a fast oscilloscope.



DAQ was 1 GHz 4-chan digital storage scope

transfer to counting house in fast air-core cables

Scintillating fibers

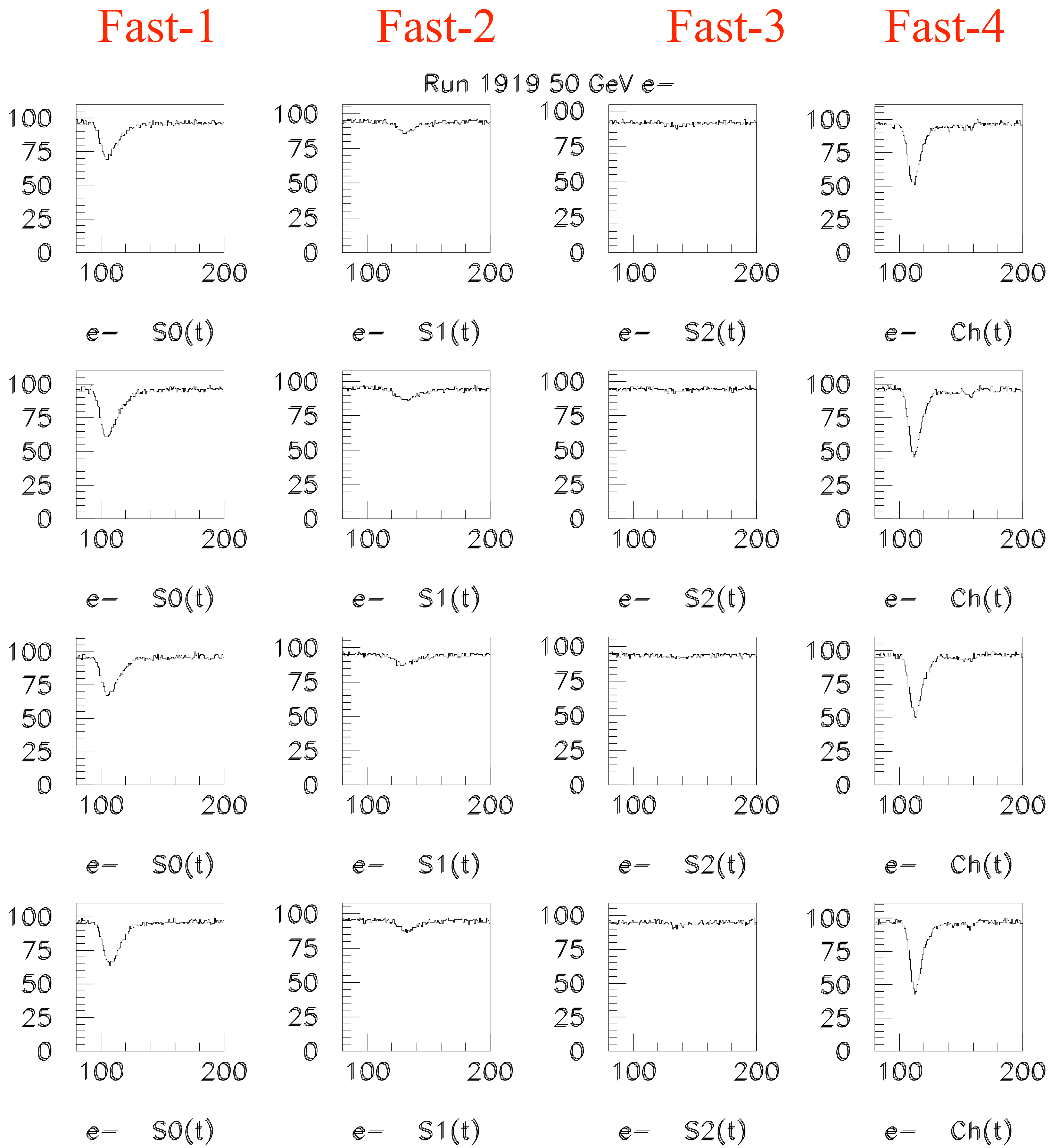
"Fast 1"

"Fast 2"

"Fast 3"

Cerenkov fibers

1● + 6● + 9● → "Fast 4"



50 GeV e-
data events

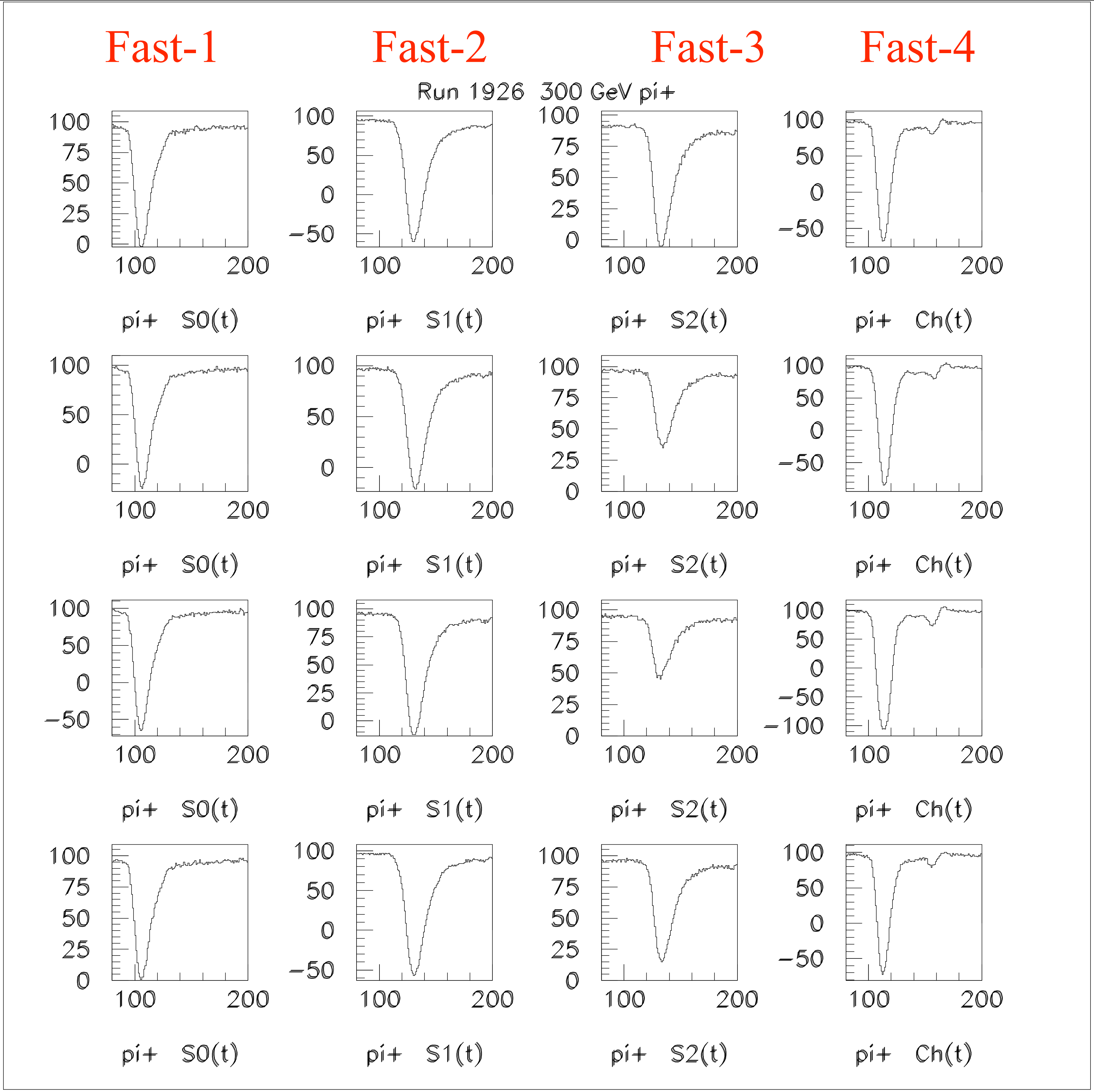
event #1

event #2

event #3

event #4

(clearly electrons)



300 GeV pi- data events

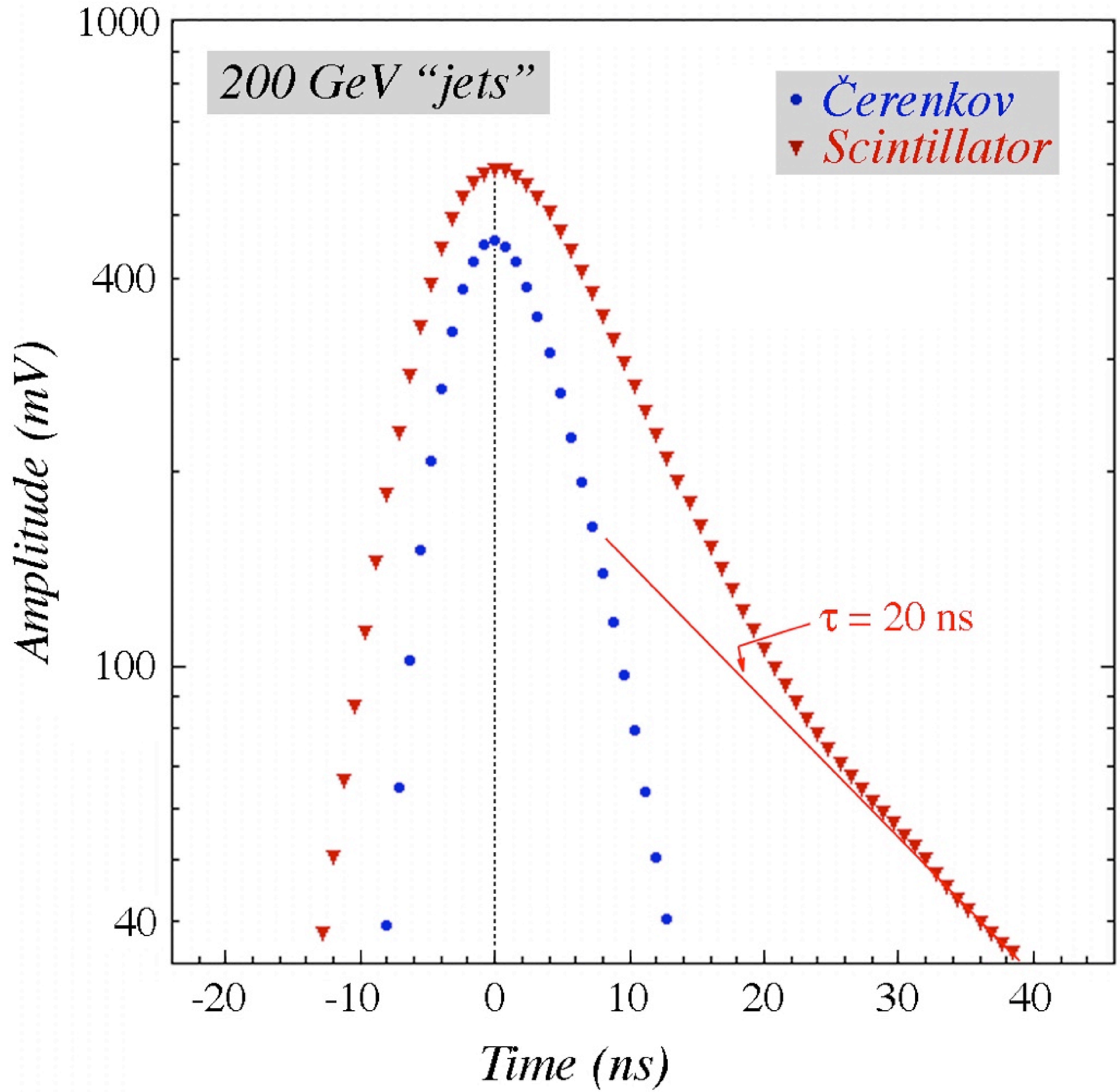
event #1

event #2

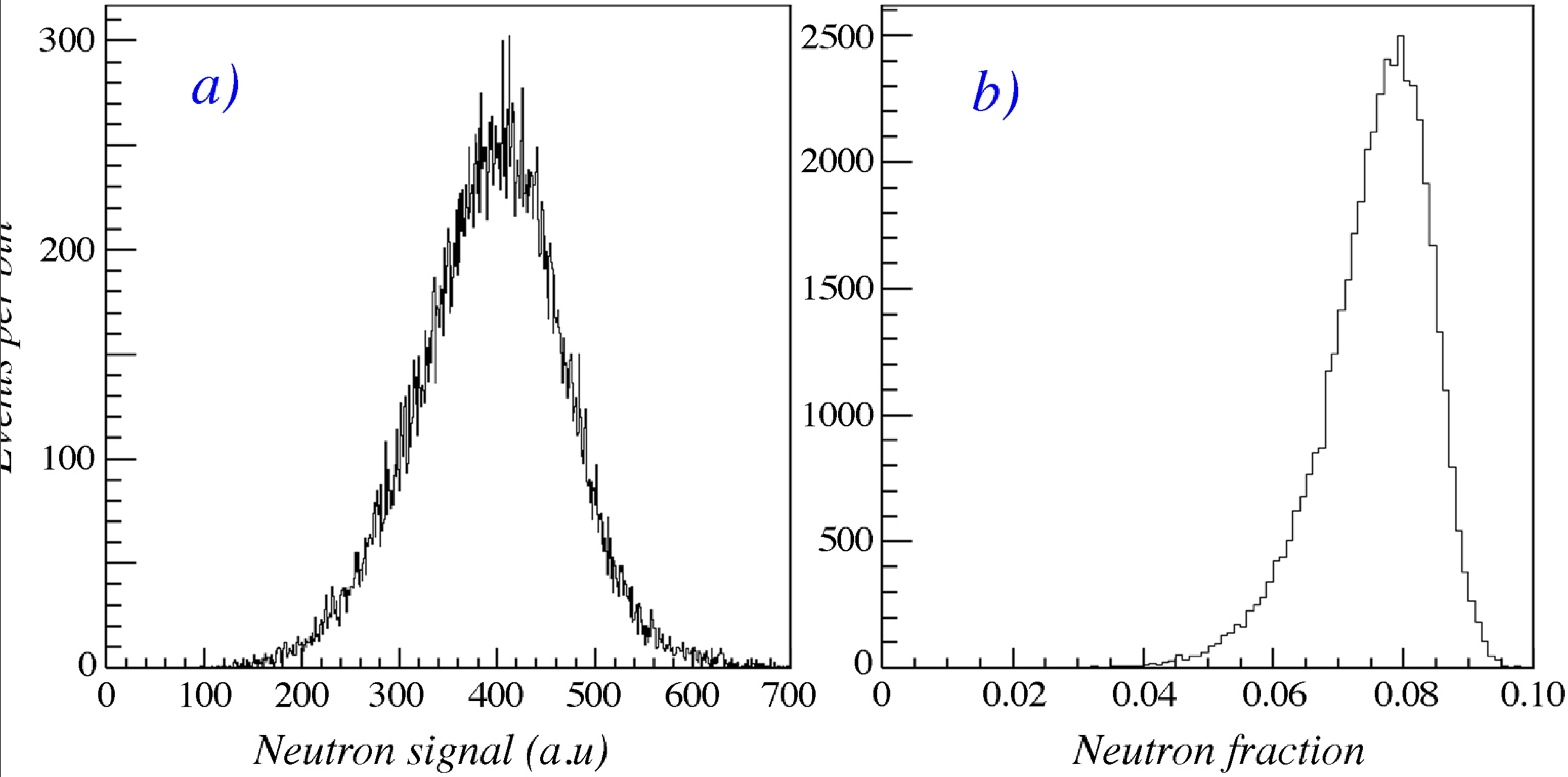
event #3

event #4

(clearly pions)



"neutron signal" defined simply as the integral of the Scintillation pulse over 20-40 ns

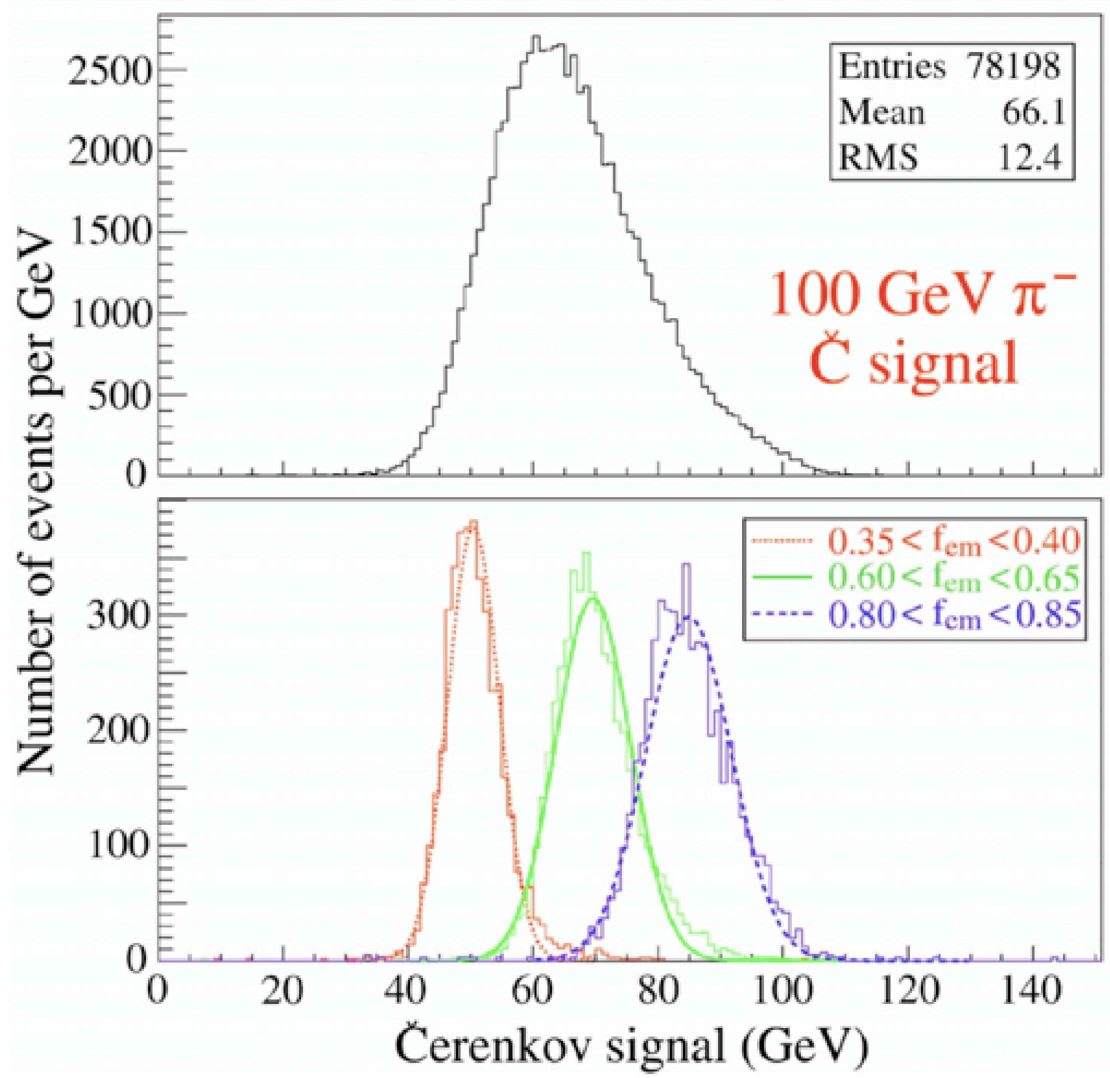


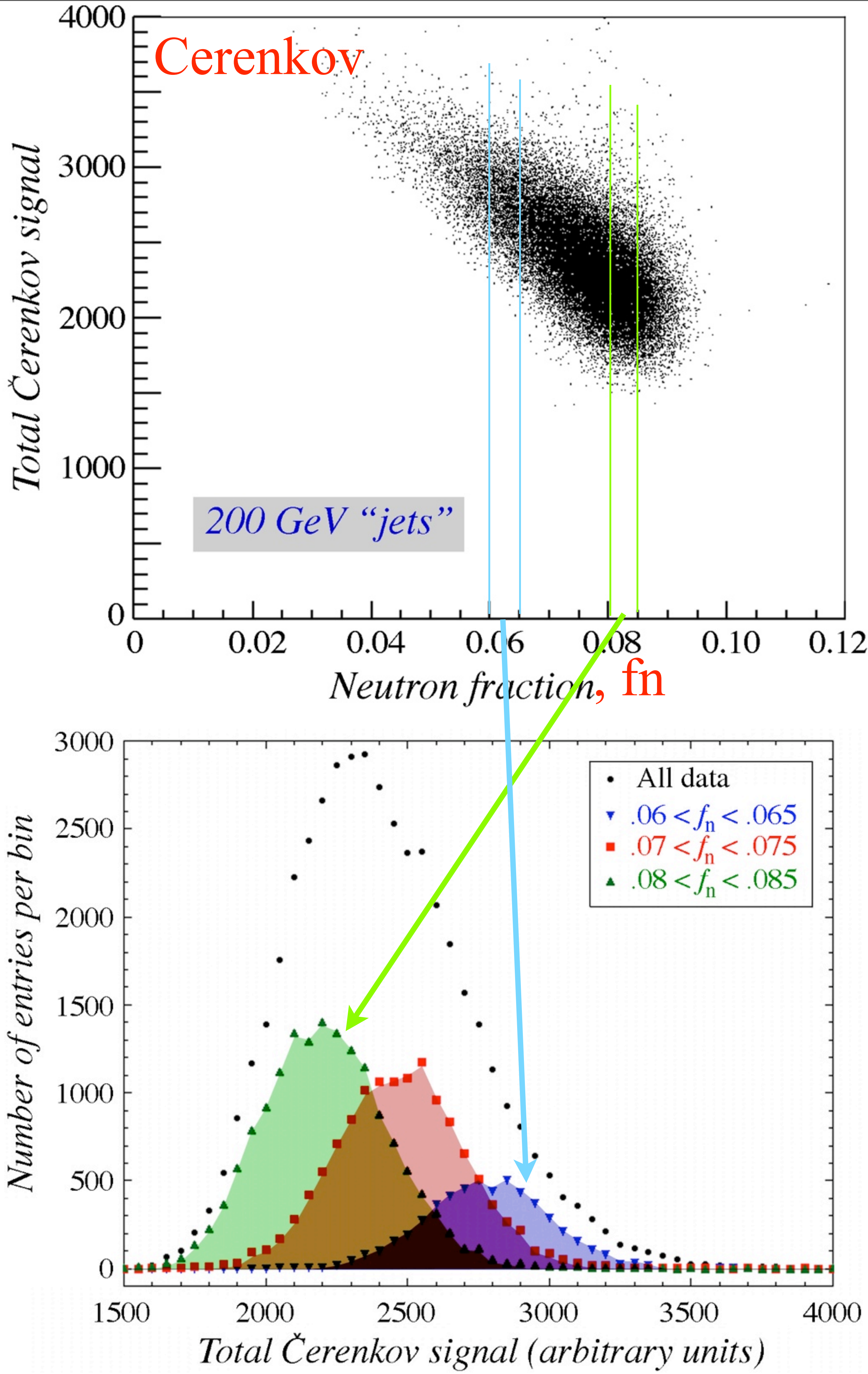
fn = En (EM energy units) / 200 GeV

The neutron fraction is anti-correlated with the Cerenkov signal, as expected

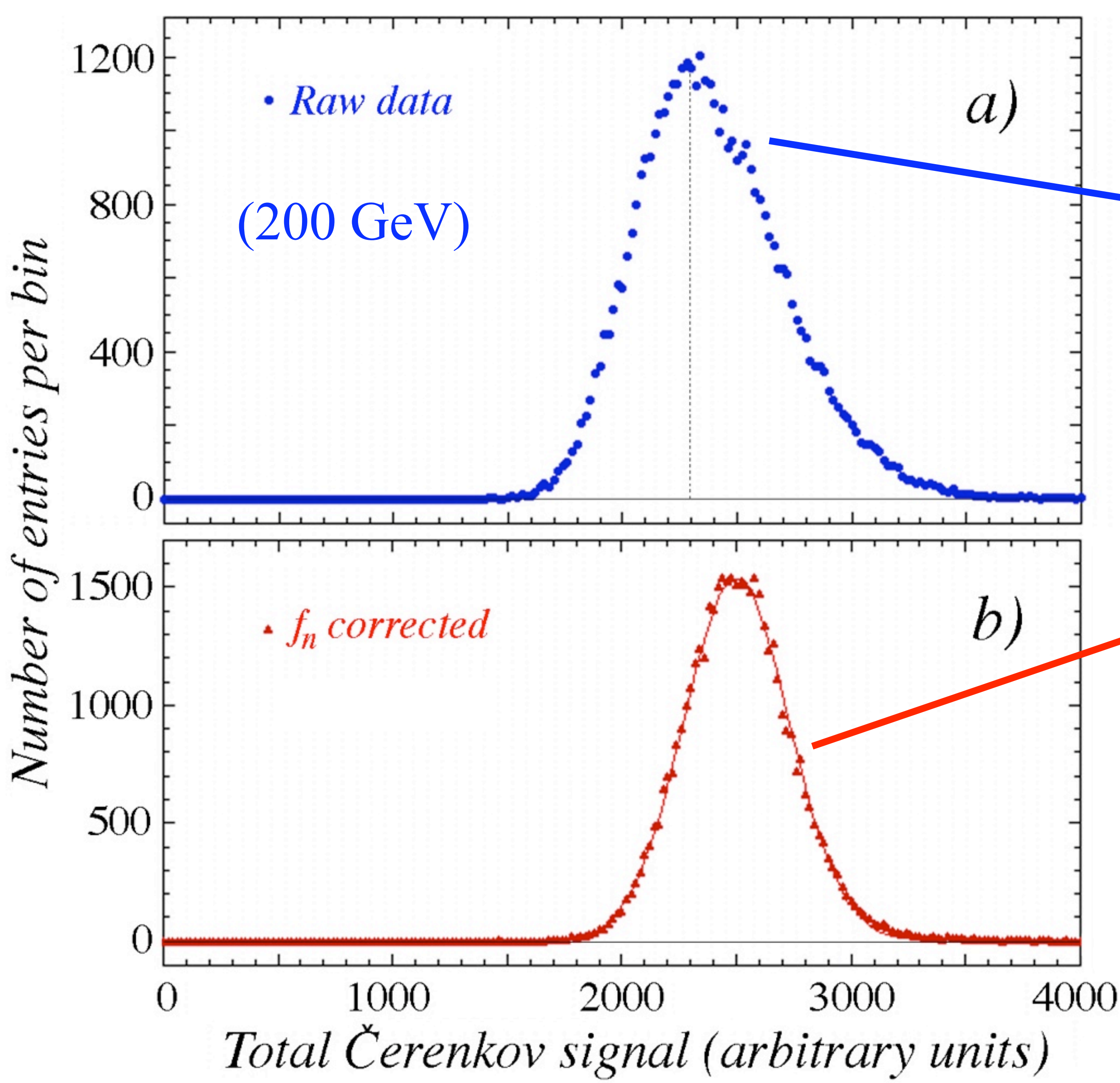
More interestingly, the Cerenkov distribution can be decomposed into its constituent parts as a function of the neutron fraction, fn.

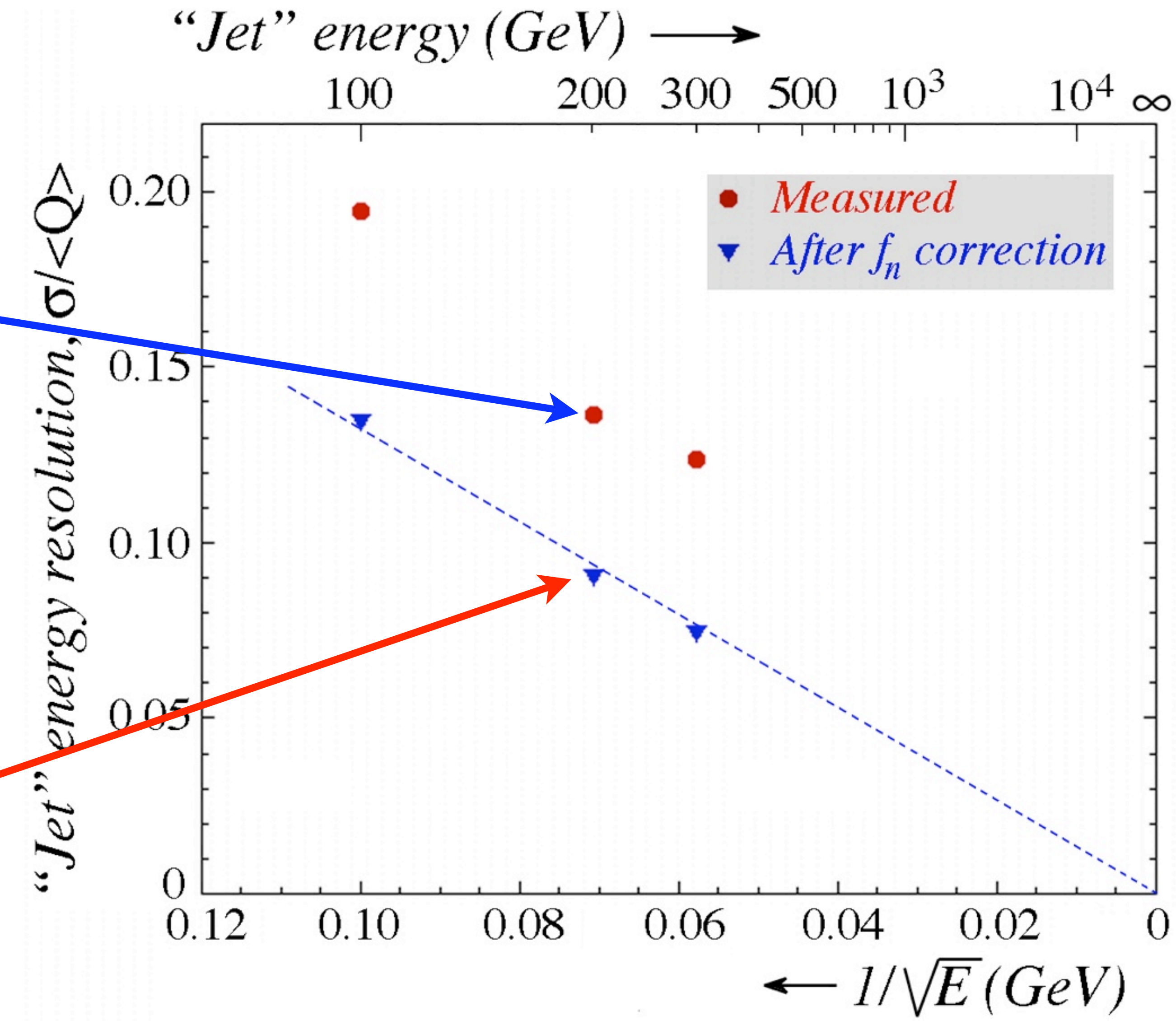
This is the analog to the fEM plot below.





Linearly correcting each Cerenkov distribution in an fn bin to fn=0.07 (arbitrary, middle value) results in the "fn corrected" distribution

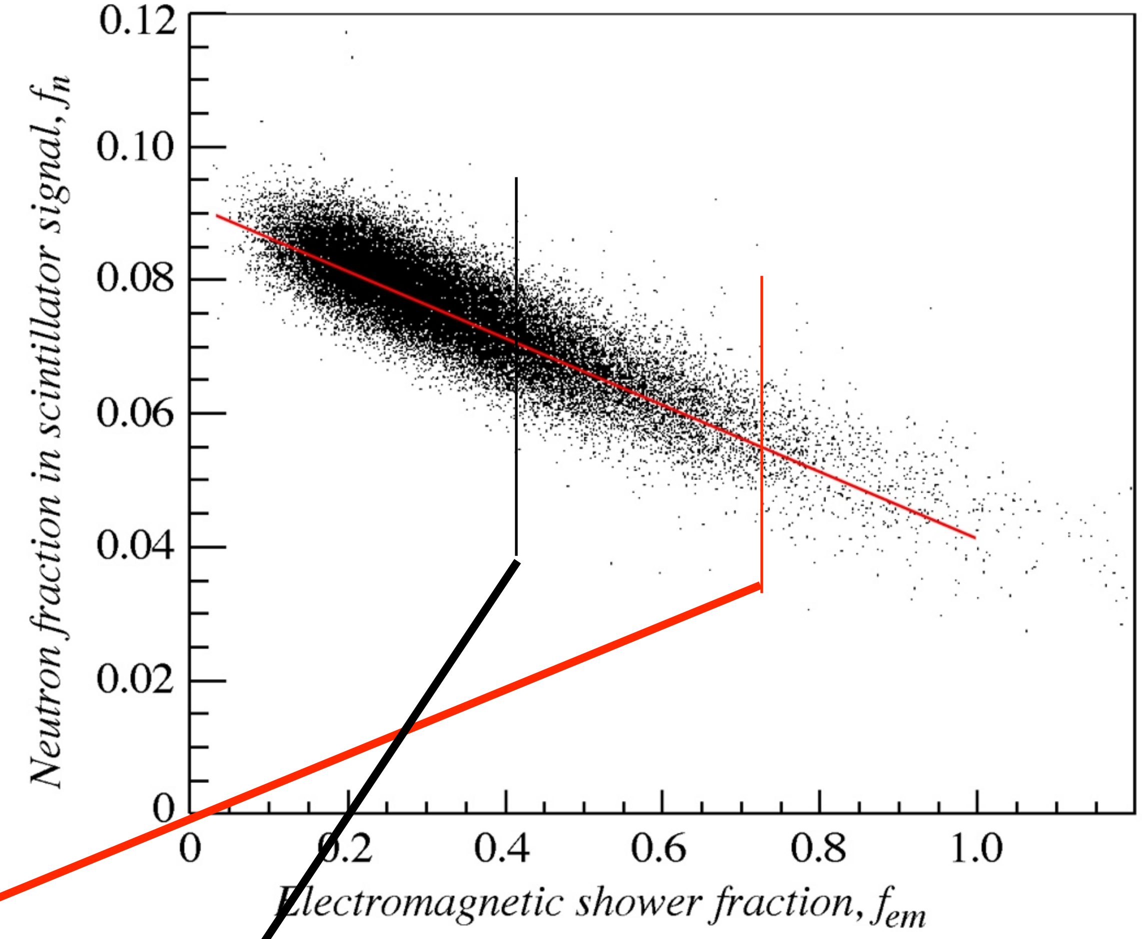


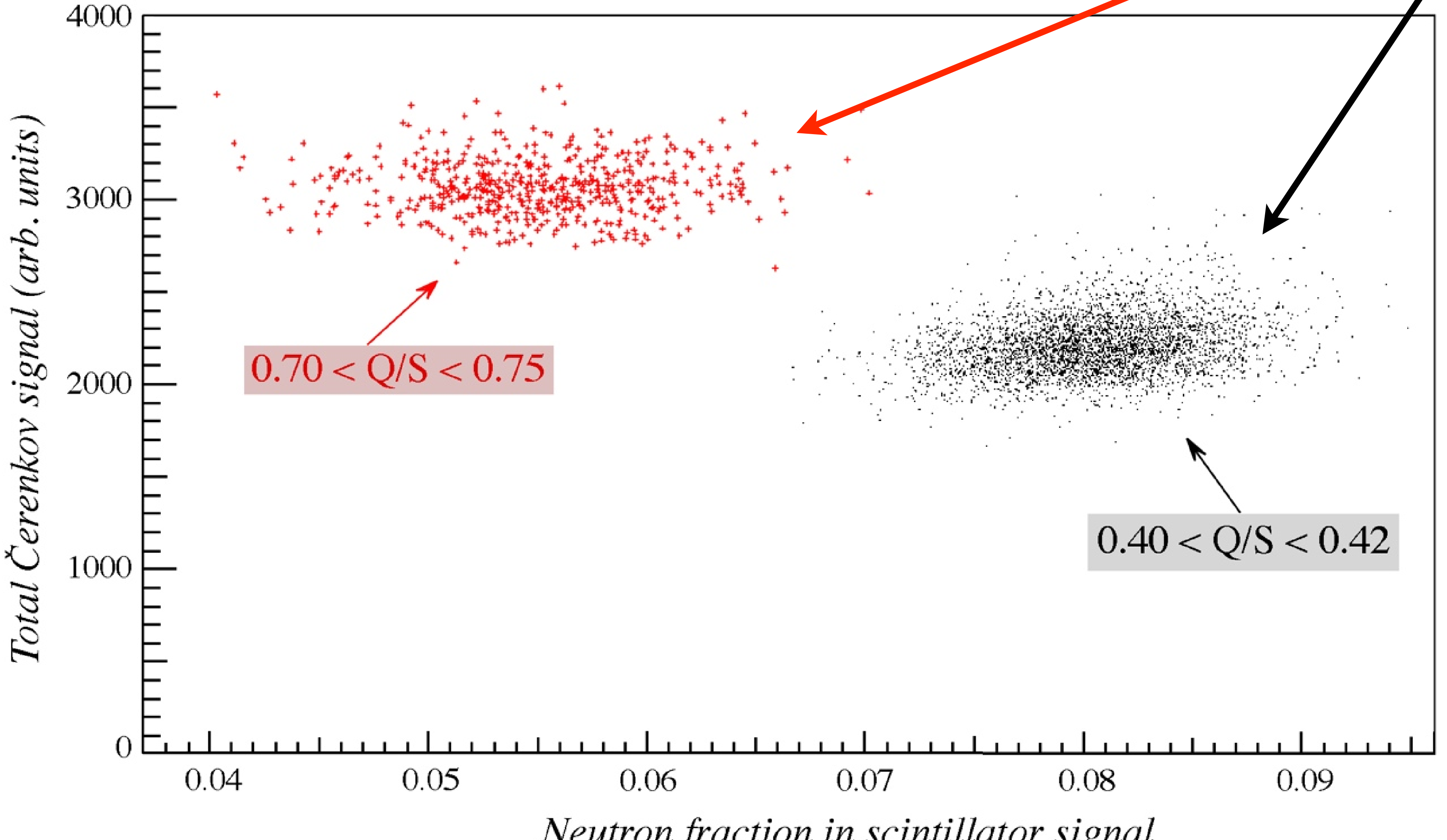


(1) fn-corrected Cerenkov resolution improves with shower energy ... AND ...

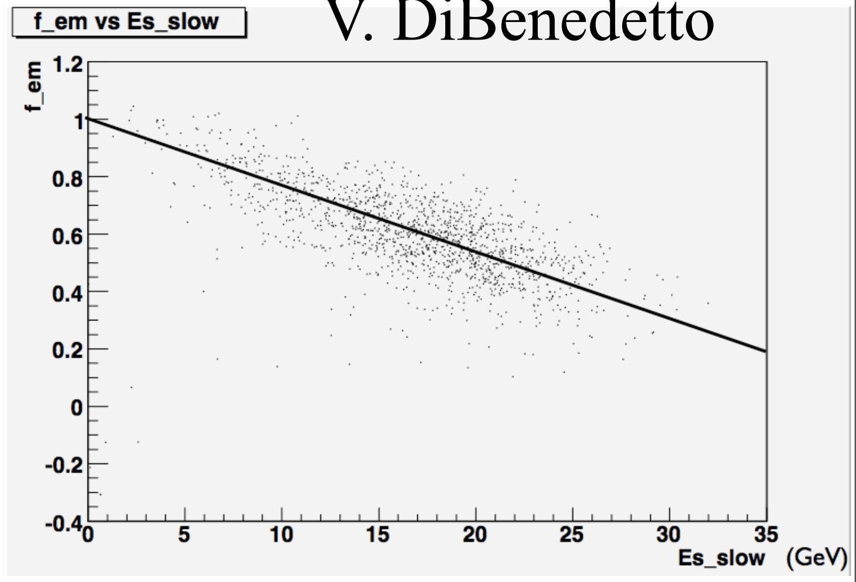
(2) Its dependence leaves no "constant term"

For fixed EM fractions, the neutron fraction varies by ~15% or more; these are the binding energy loss fluctuations on top of the EM fraction fluctuations.



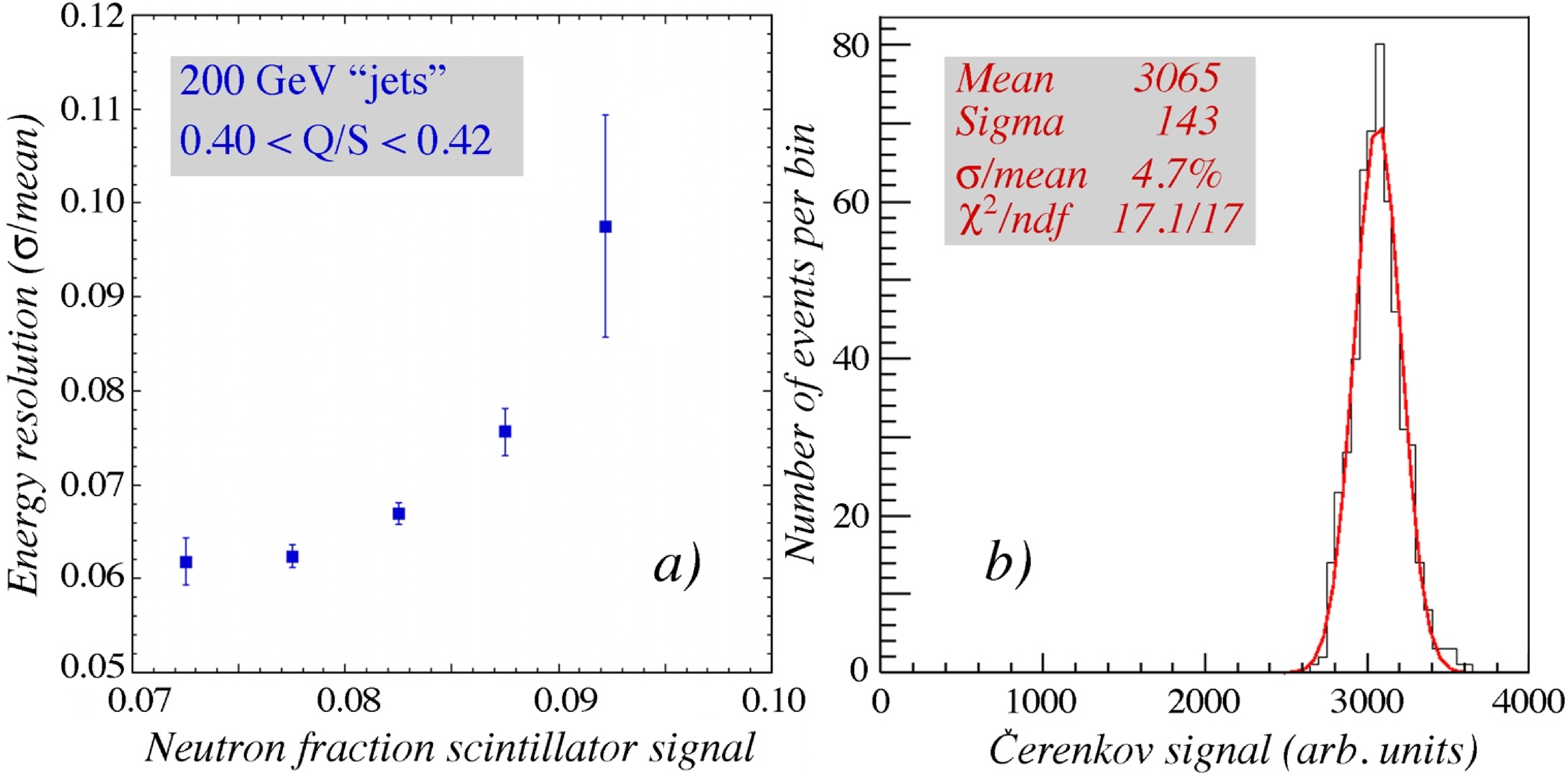


4th simulation,
V. DiBenedetto



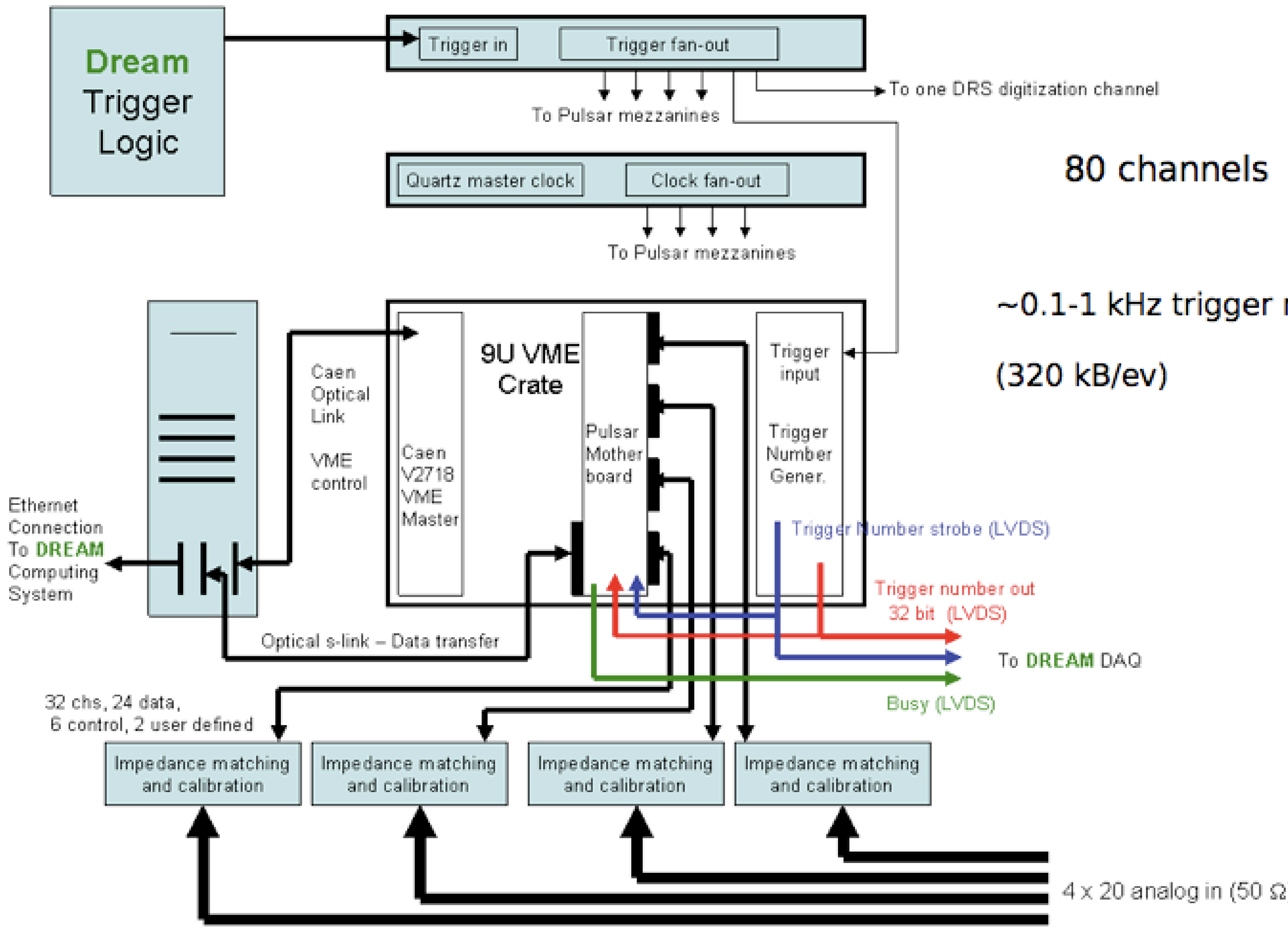
For fixed EM fraction, the resolution in the Cerenkov signal worsens as the neutron fraction grows larger, and its fluctuations grow larger.

Fix both EM fraction (~0.55) and neutron fraction (0.045<fn<0.065). The resolution in C signal is 4.7%. Neutron fraction (0.050<fn<0.055) tighter, the resolution is 4.4%.



Note bene: leakage fluctuations in DREAM are ~4%.

Setup for the DREAM test beam 2008



80 channels

~0.1-1 kHz trigger rate

(320 kB/ev)

Domino Ring Sampler, ~GHz digitizer.

R. Carosi, INFN, Pisa: CALOR08, Pavia

Summary and plans for dual-readout work

- The DREAM collaboration continues to explore multiple manifestations and effects of dual-readout calorimetry.
- Record time history of every channel with the Domino Ring Sampler (DRS) for neutron fraction and particle ID.
- Attempt to measure side leakage in DREAM module.
- Complete design of 4th calorimetry for the LoI.
- It will be *a pleasure* to be limited in a collider experiment by jet-finding, reconstruction, and other confusions and systematics ... but not the hadronic calorimeter energy resolution or the jet energy scale!