DREAM data: 20-300 GeV

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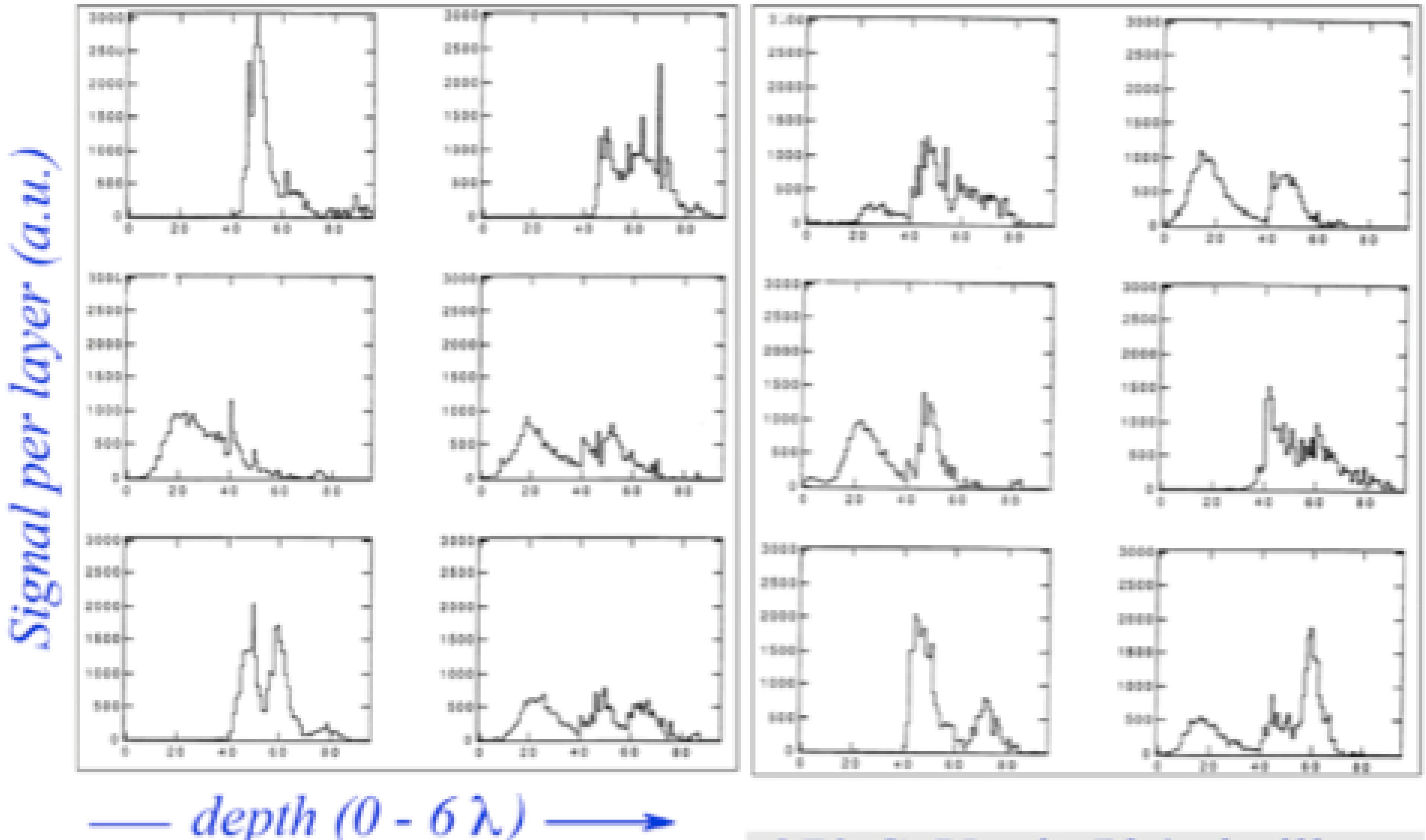
DESY LCWS07 19-20 May 2007

With few exceptions, all you see will be data. Five extensive papers published, three more on dual readout of crystals and measurements of MeV neutrons, done by a small group of 5-6 people. Another beam test scheduled in CERN H4 beam 18 June - 4 July 2007. Colleagues welcome.

We know exactly what to do for a calorimeter EDR in 2010.

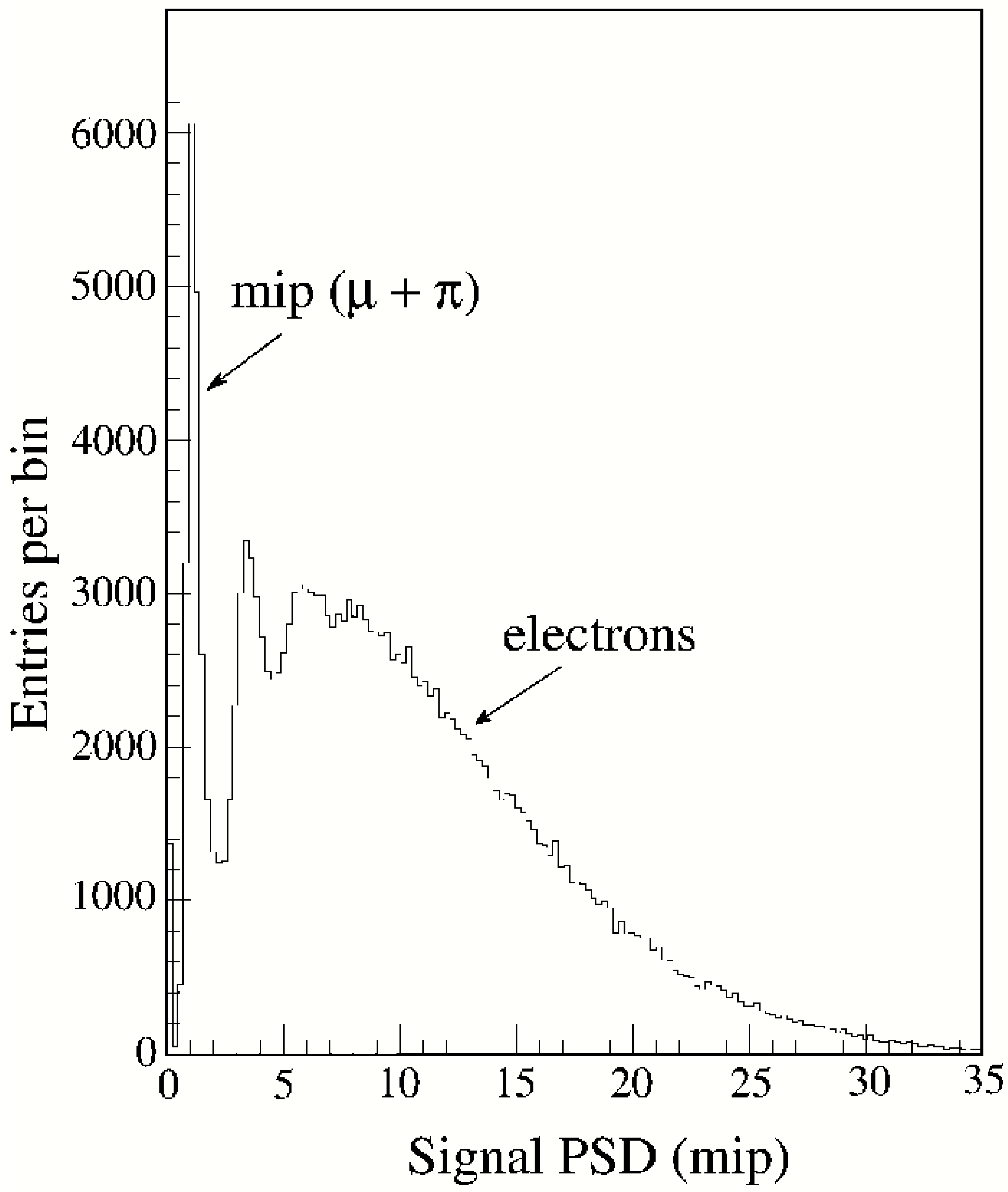
Depth development of 12 hadronic showers, or why dual-readout is easy and PFA is hard.

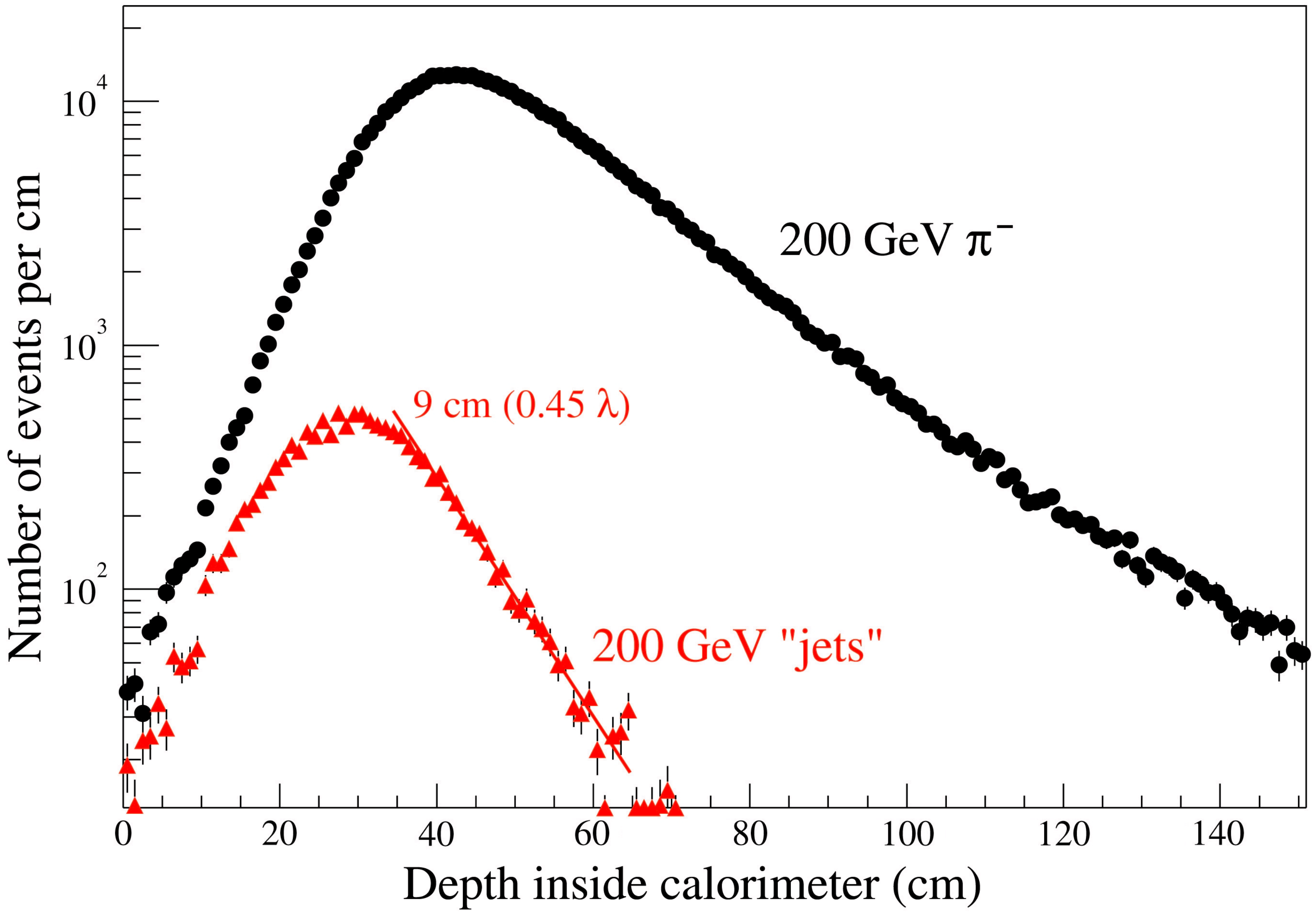


270 GeV π in Pb/scintillator
(hanging-file experiment)

H4 beam

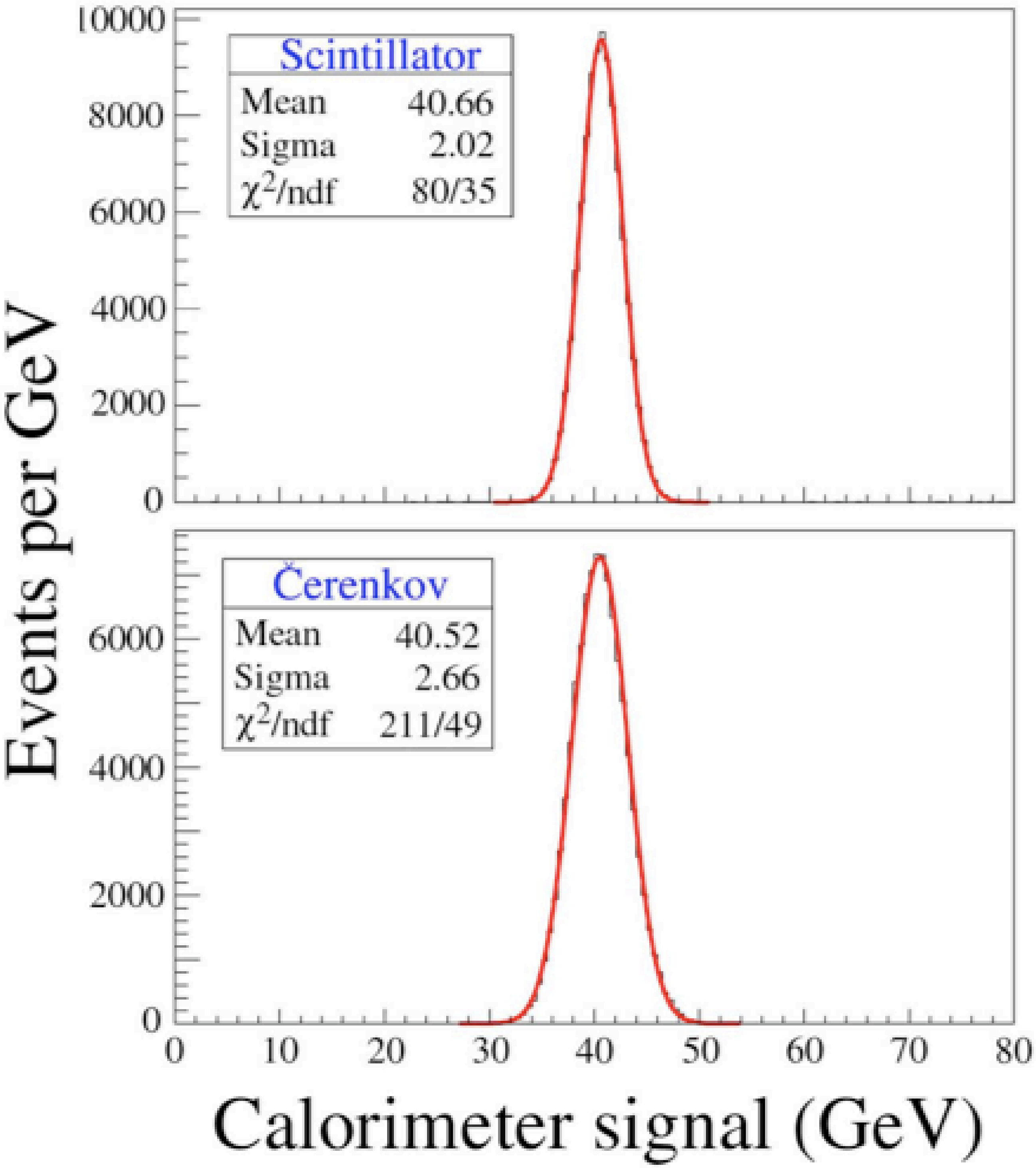
- TC: Trigger Counters
- HOD: fiber xy hodoscope
- PSD: pre-shower detector, 5mm Pb+scintillator
- ITC: Interaction Trigger Counter, 10cm lucite+scintillator (“jets”)
- MU: Muon tagger, scintillator



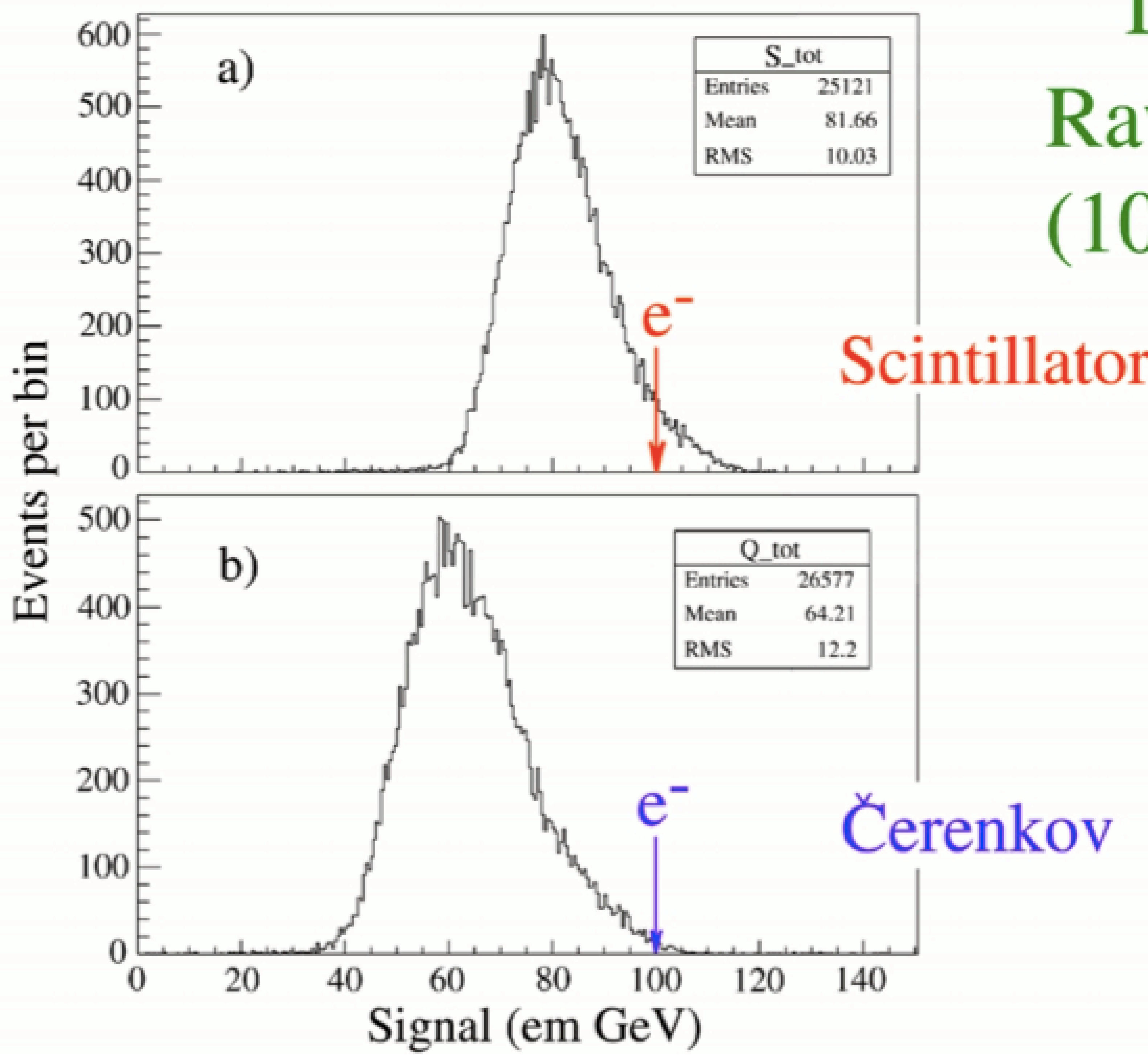


Depth distribution of “center of light” of pions and “jets”

Calibration with 40 GeV electrons (tilt 2°)

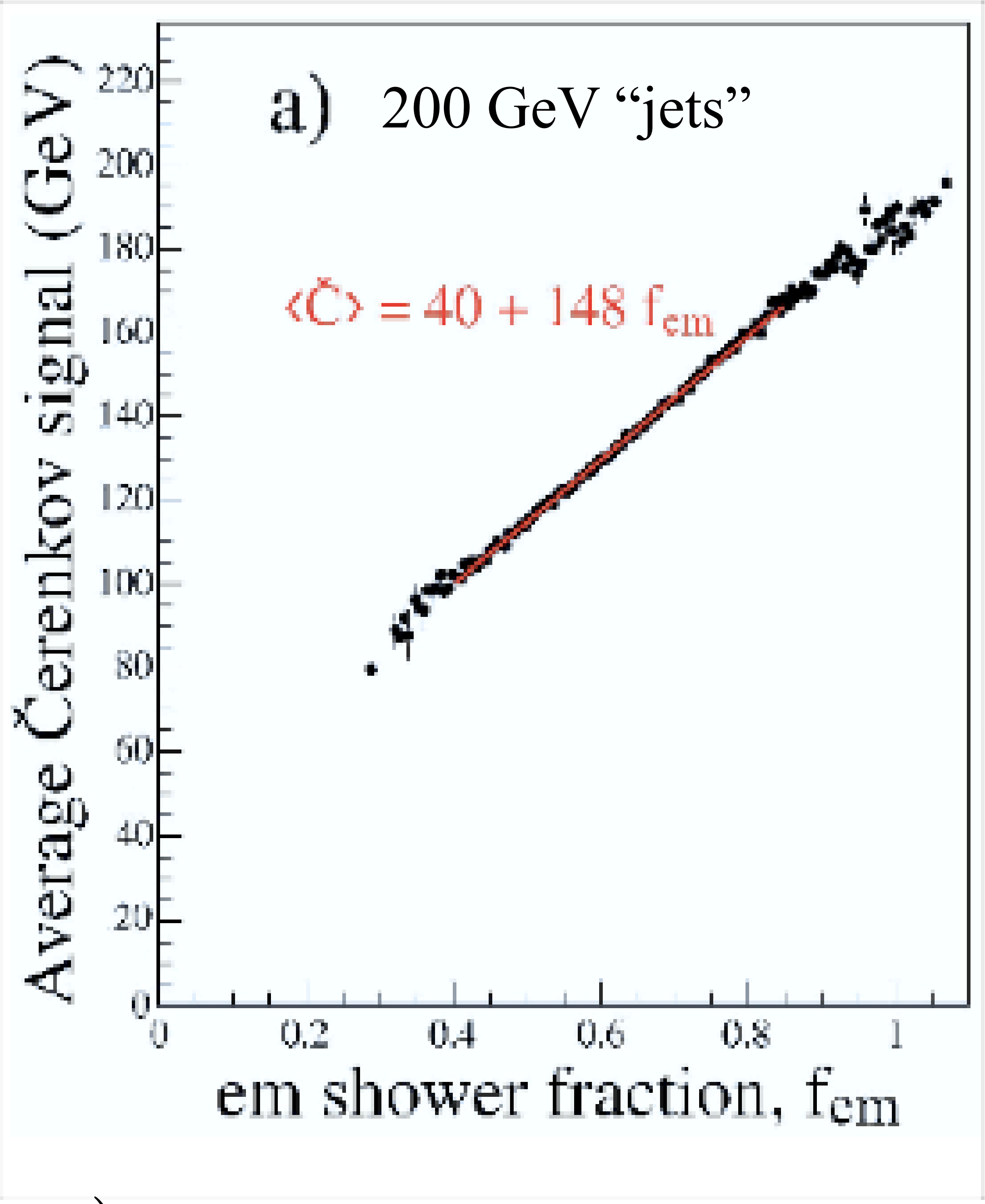


DREAM Raw signals (100 GeV π^-)



EM fraction in hadronic showers ...

... nicely and linearly correlated with the Cerenkov signal. The simplest possible description of the calorimeter "response" to hadronic energy, E, is ...



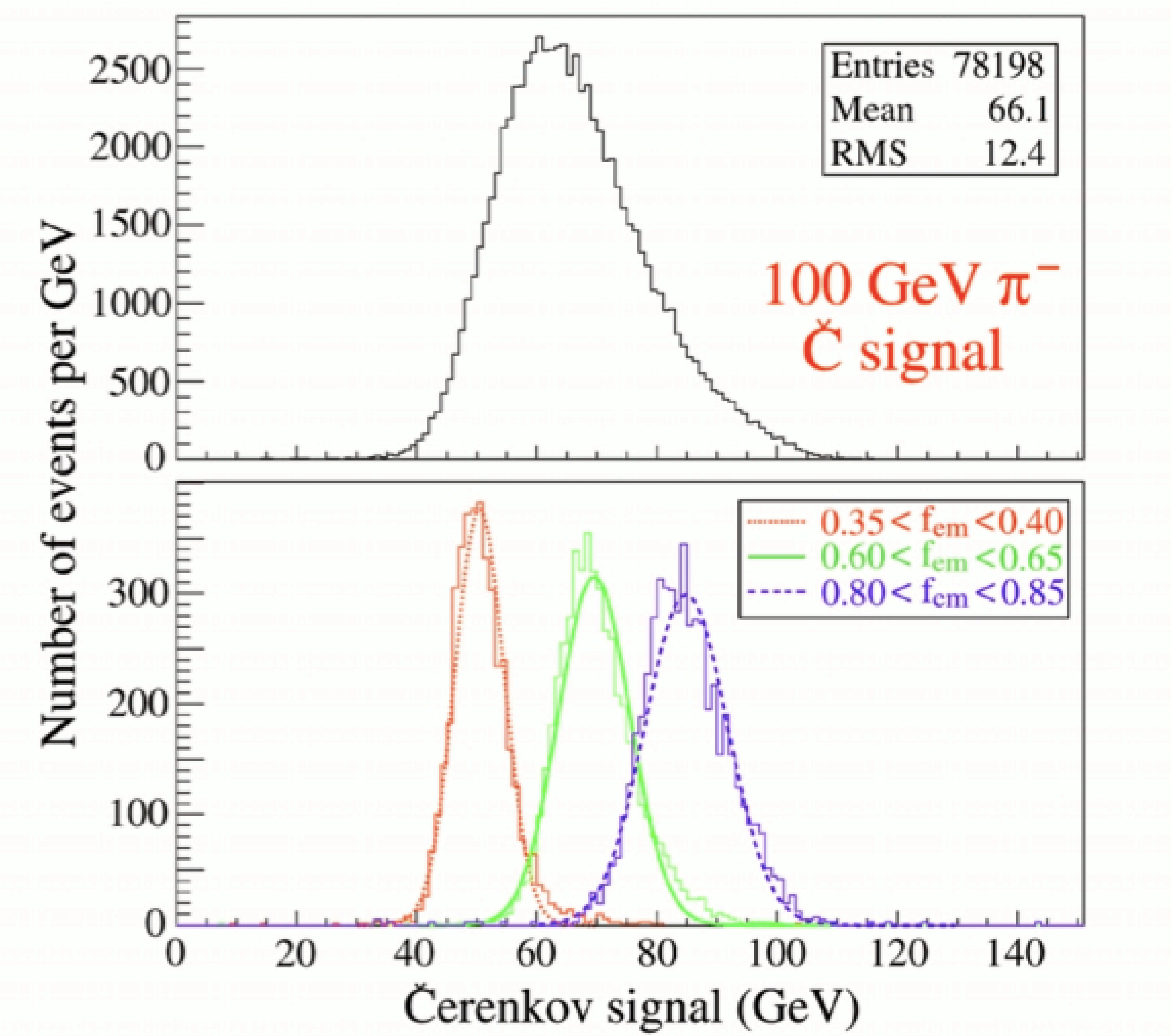
$$(e/h)_C = \eta_C \approx 5$$
$$(e/h)_S = \eta_S \approx 1.4$$

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

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

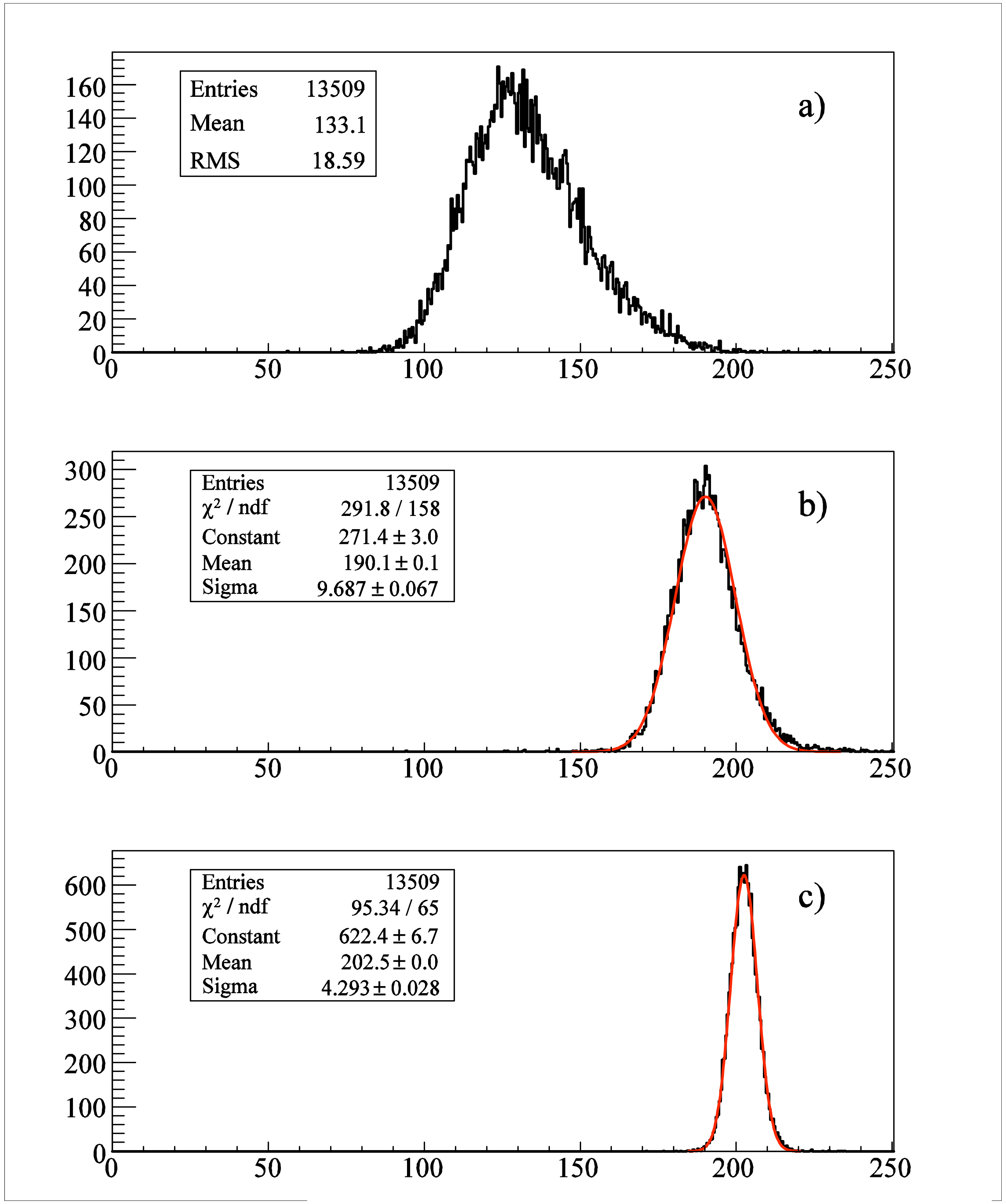
Data NIM A537 (2005) 537.

DREAM: Effect of event selection based on f_{em}



Calculate fem from C/S.

DREAM data 200 GeV π^-: Energy response



Scintillating fibers

Scint + Cerenkov

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

(4% leakage fluctuations)

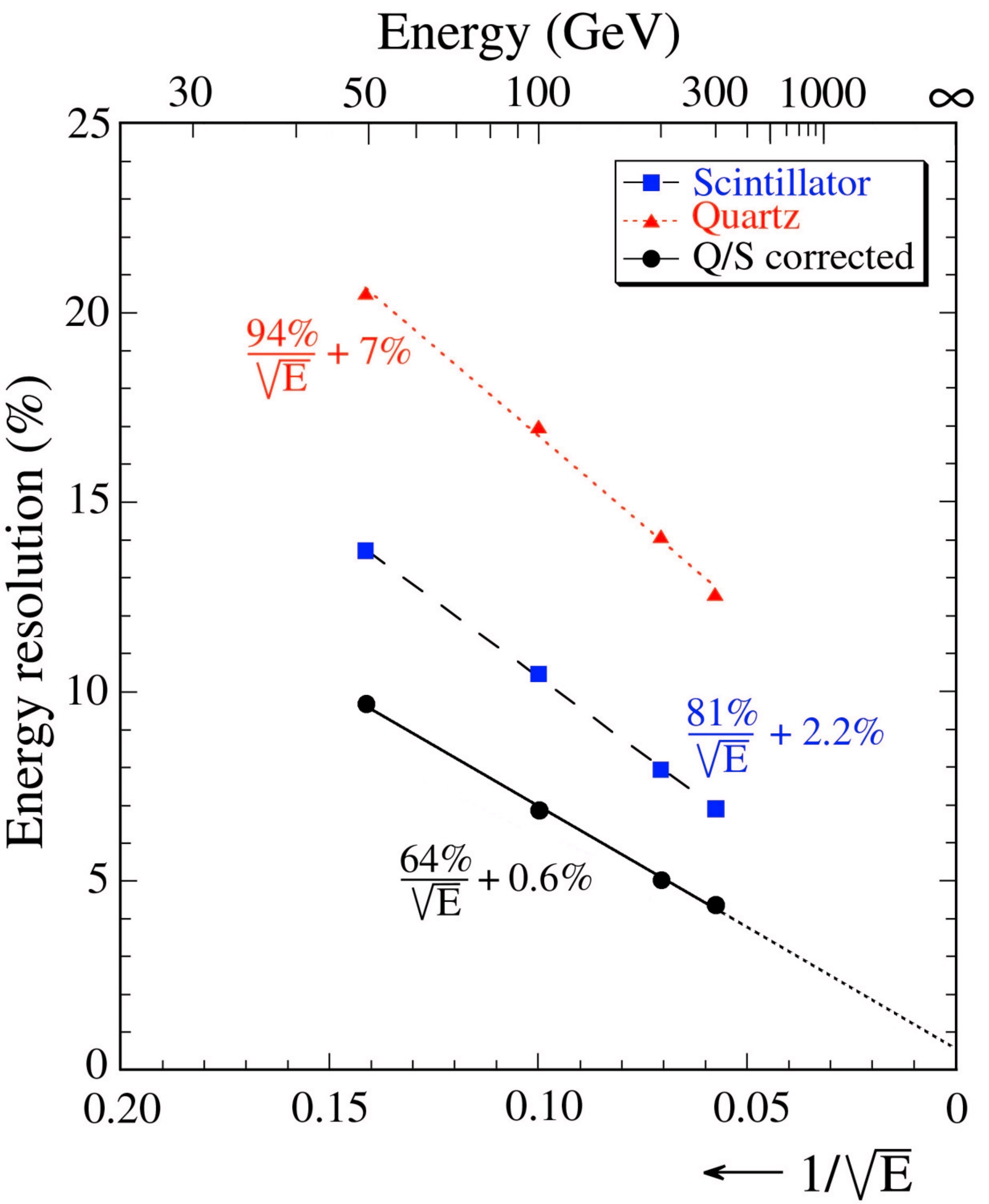
Scint + Cerenkov

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

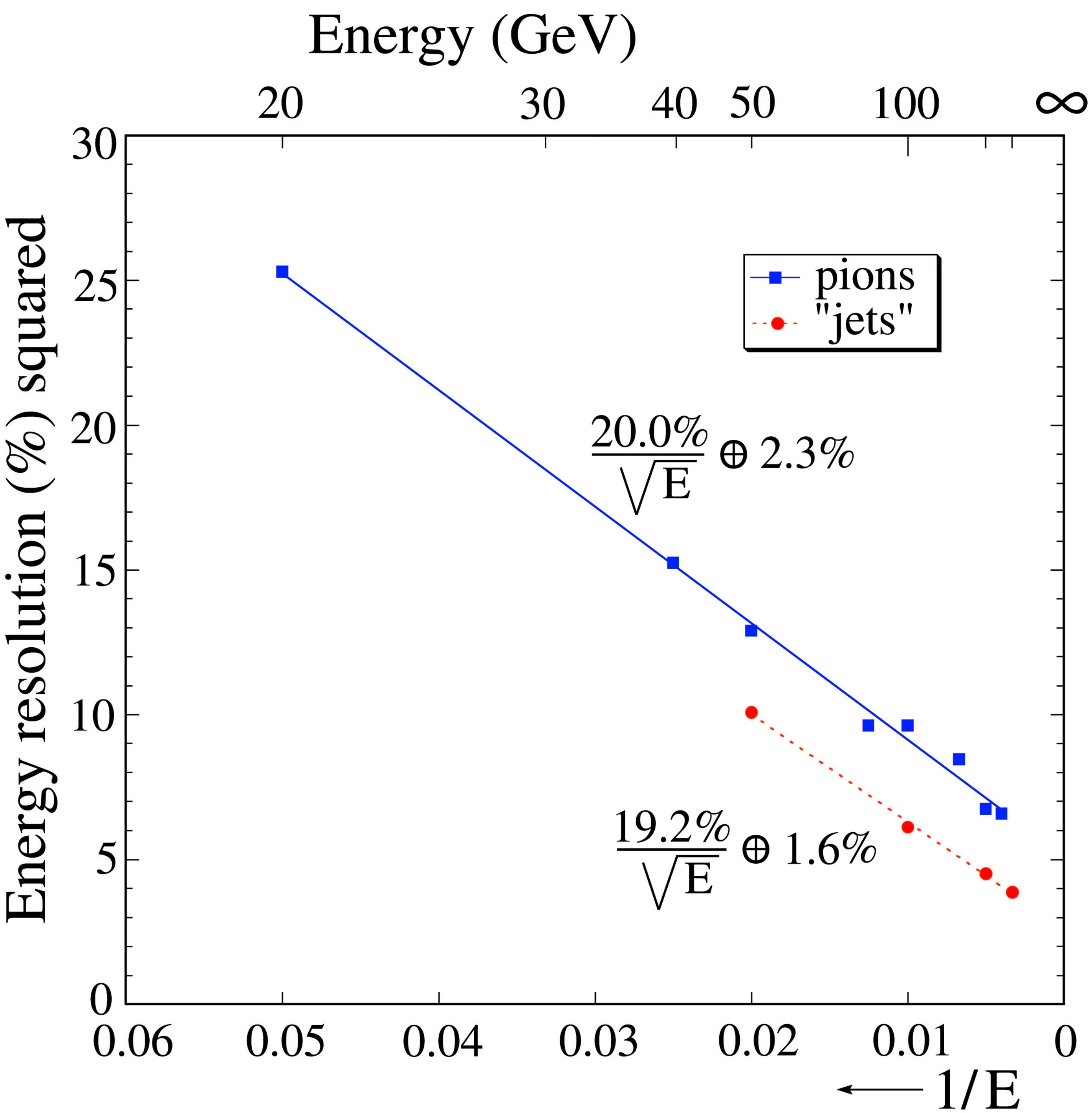
(suppresses leakage)

Data NIM A537 (2005) 537.

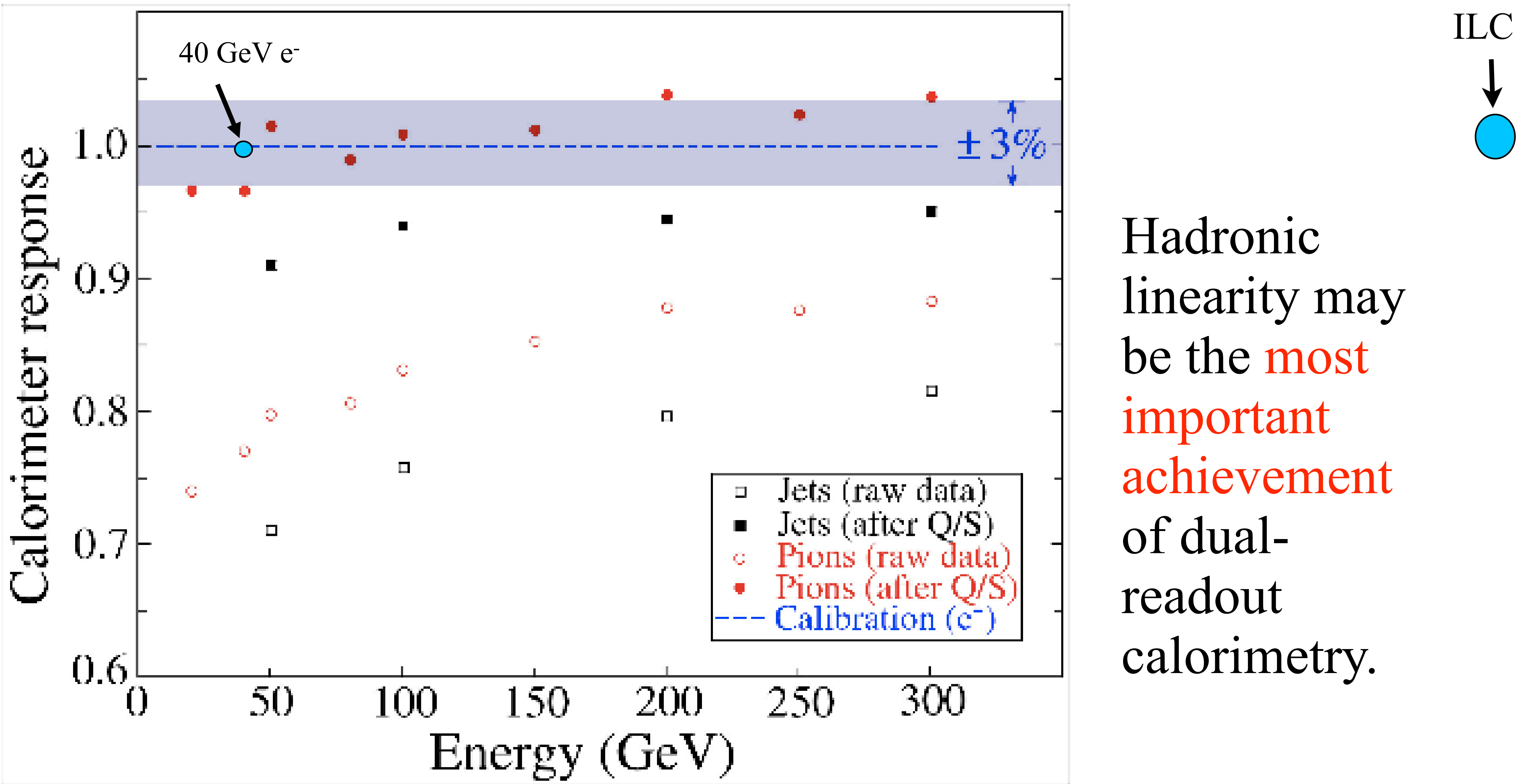
“Worst” for dual-readout



“Best” for dual-readout



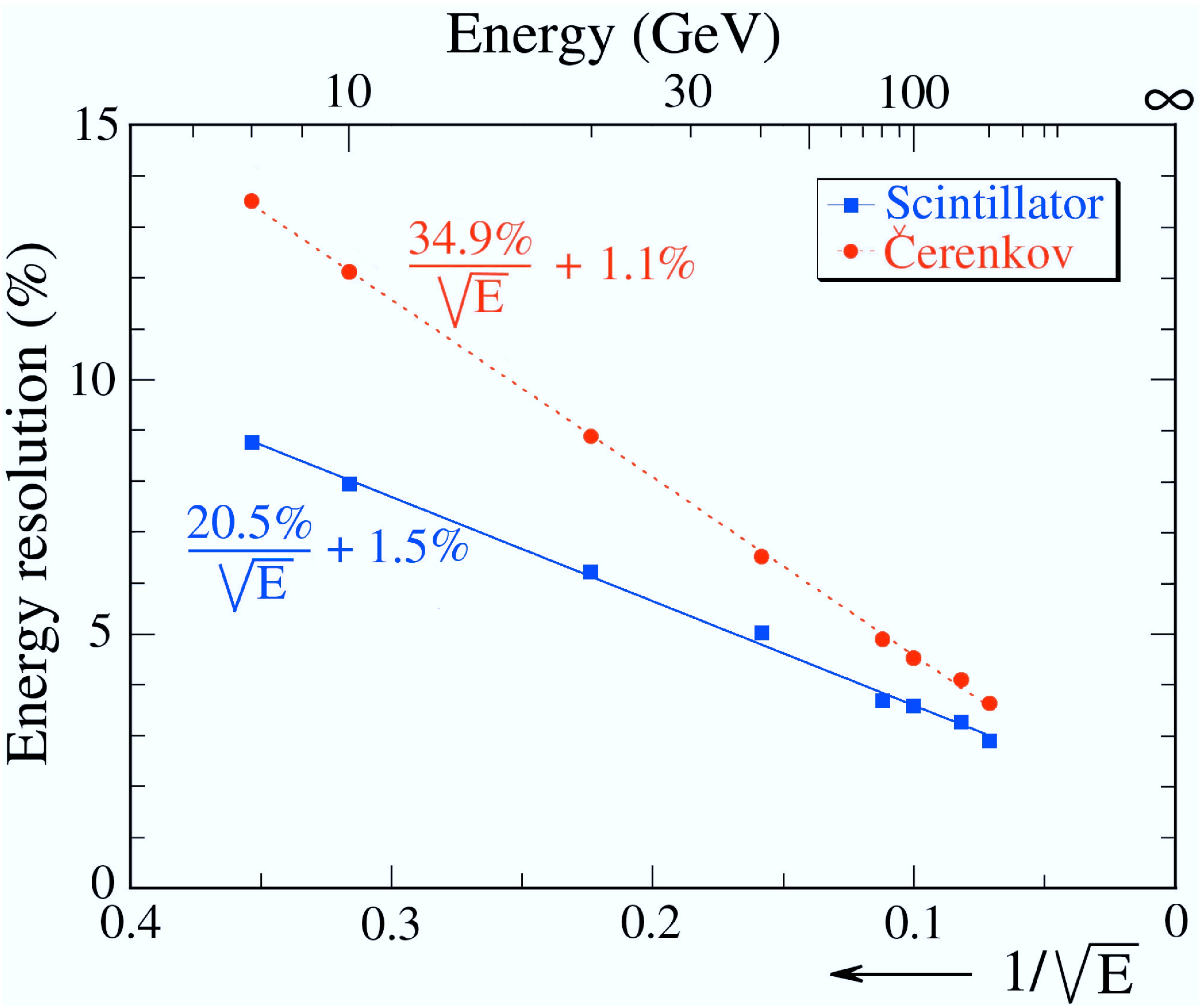
DREAM module calibrated with 40 GeV e^- into the centers of each tower responds linearly to π^- and "jets" from 20 to 300 GeV.



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

Data NIM A537 (2005) 537.

What limits DREAM module: *DREAM was a proof-of-principle module, never intended to be the "best" at anything; for example, EM resolution.*



electrons 8-200 GeV

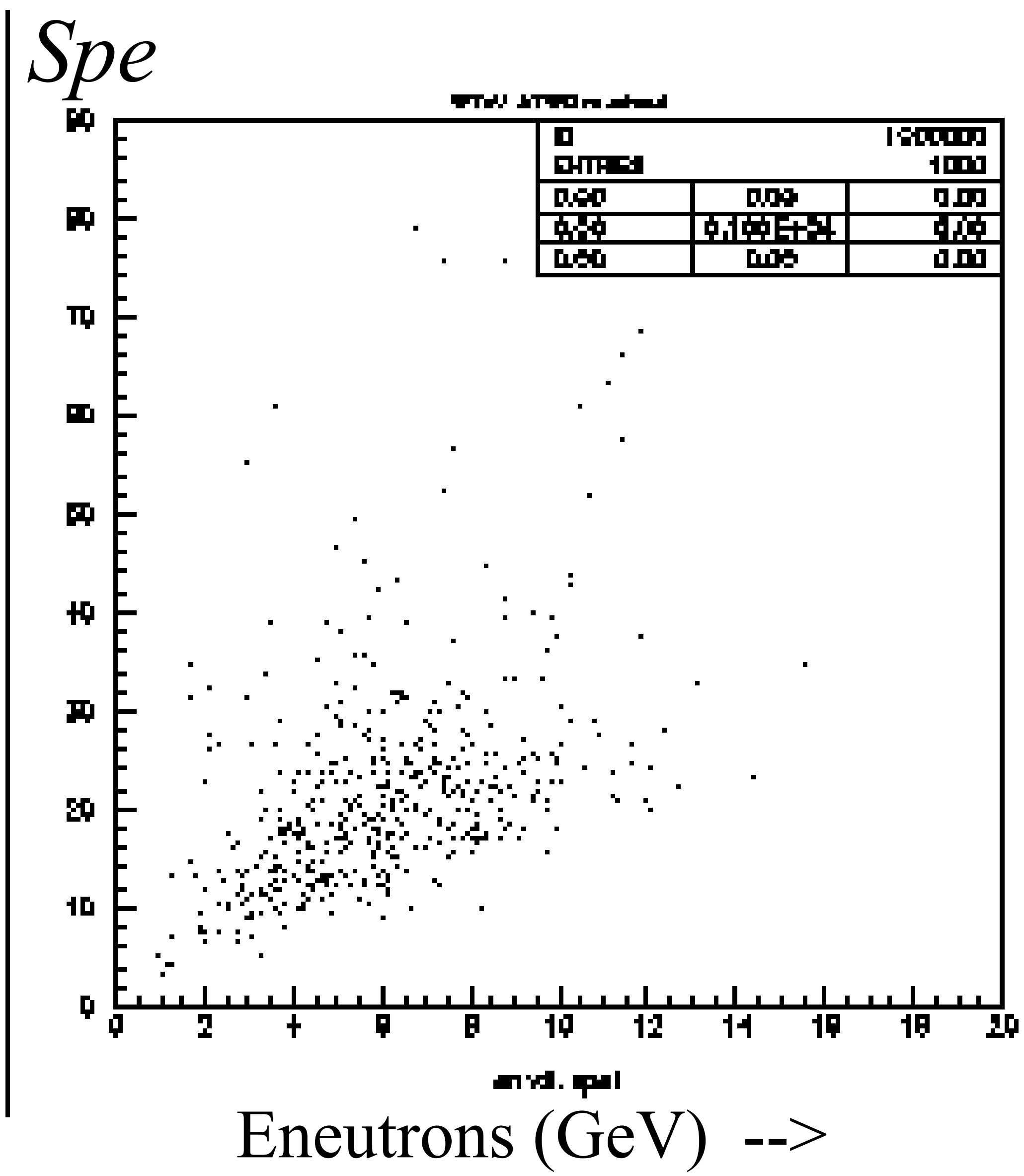
- Electron energy resolution independently in Cerenkov and Scintillator fibers:
- Cerenkov limited by photoelectron statistics: ~8pe/GeV gives resolution of only 35%/√E
- Limits EM fraction resolution
- Limits hadronic resolution

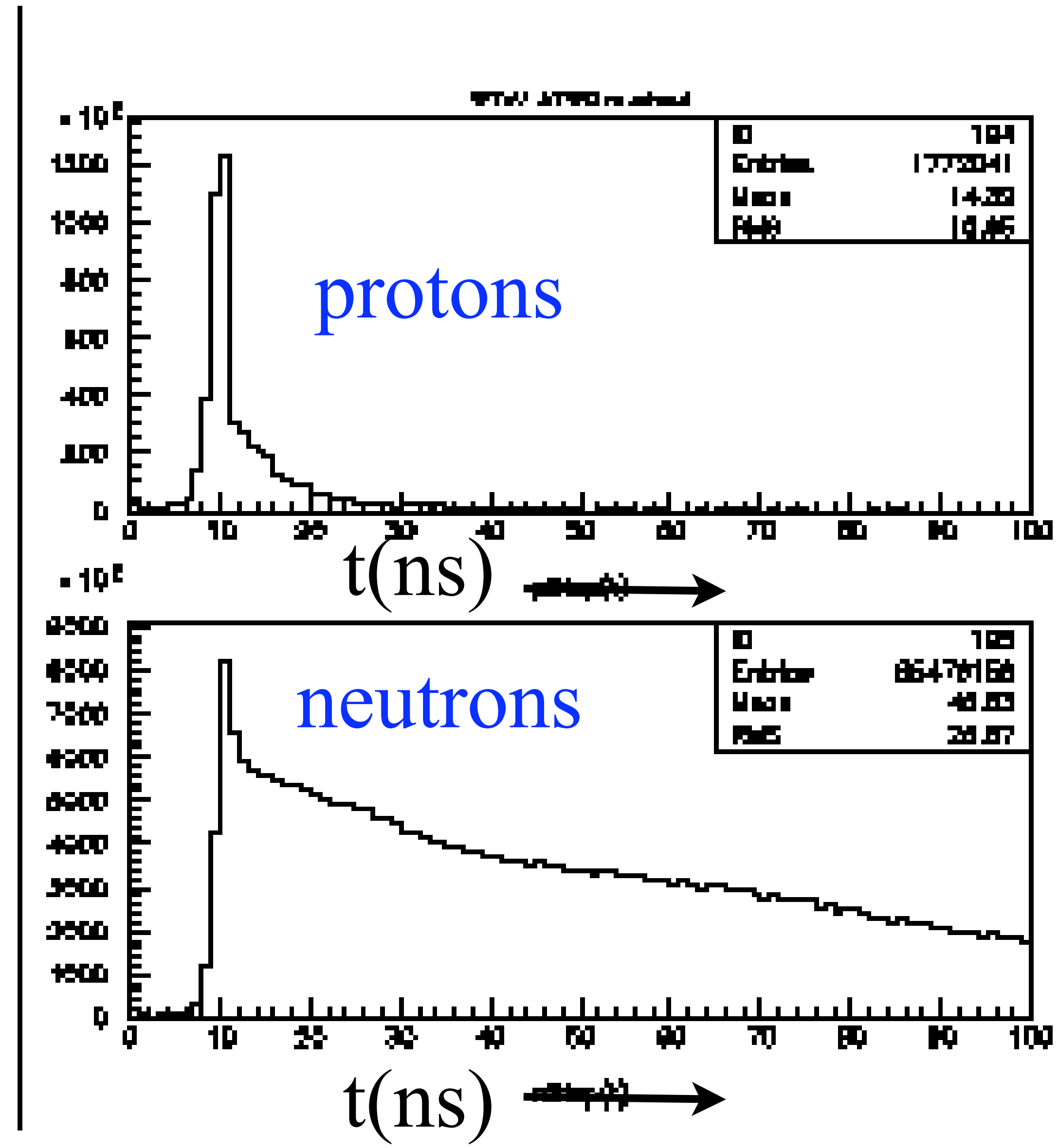
Energy resolutions of compensating and dual-readout calorimeters

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 $E_{\rm shower}$ fluctuations (30%/$\sqrt{E}$?)*	*36*	-
$f_{EM} \propto$ *(C/Ebeam - 1/η_C)*	*19.2*	*1.6*

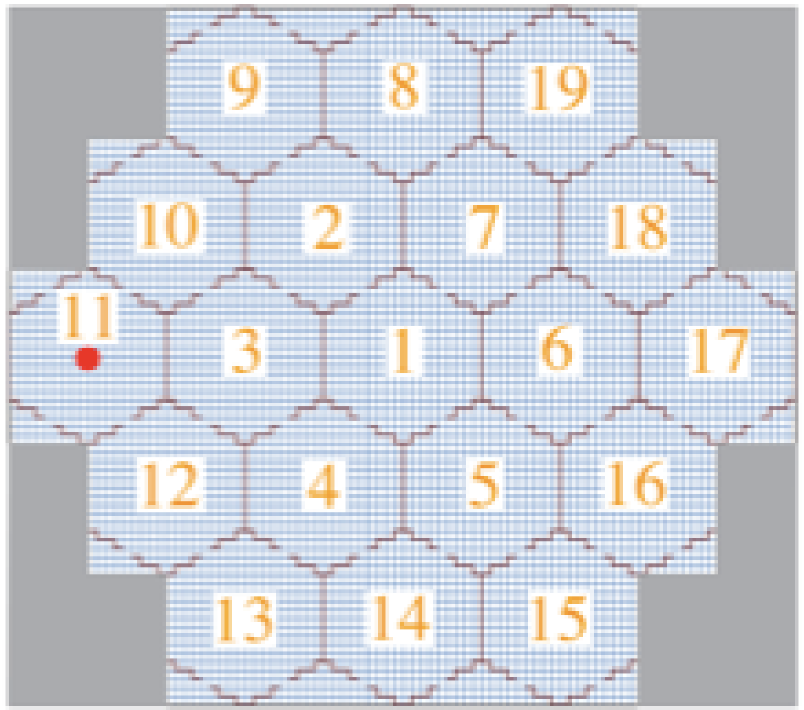
Table 1: Measurements (**boldface**) and estimates (*italics*) of the stochastic and the constant terms in the energy resolution of the DREAM dual readout calorimeter. These are all derived from the beam test data of the DREAM module and described in the DREAM papers (1-3). The overall resolution is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

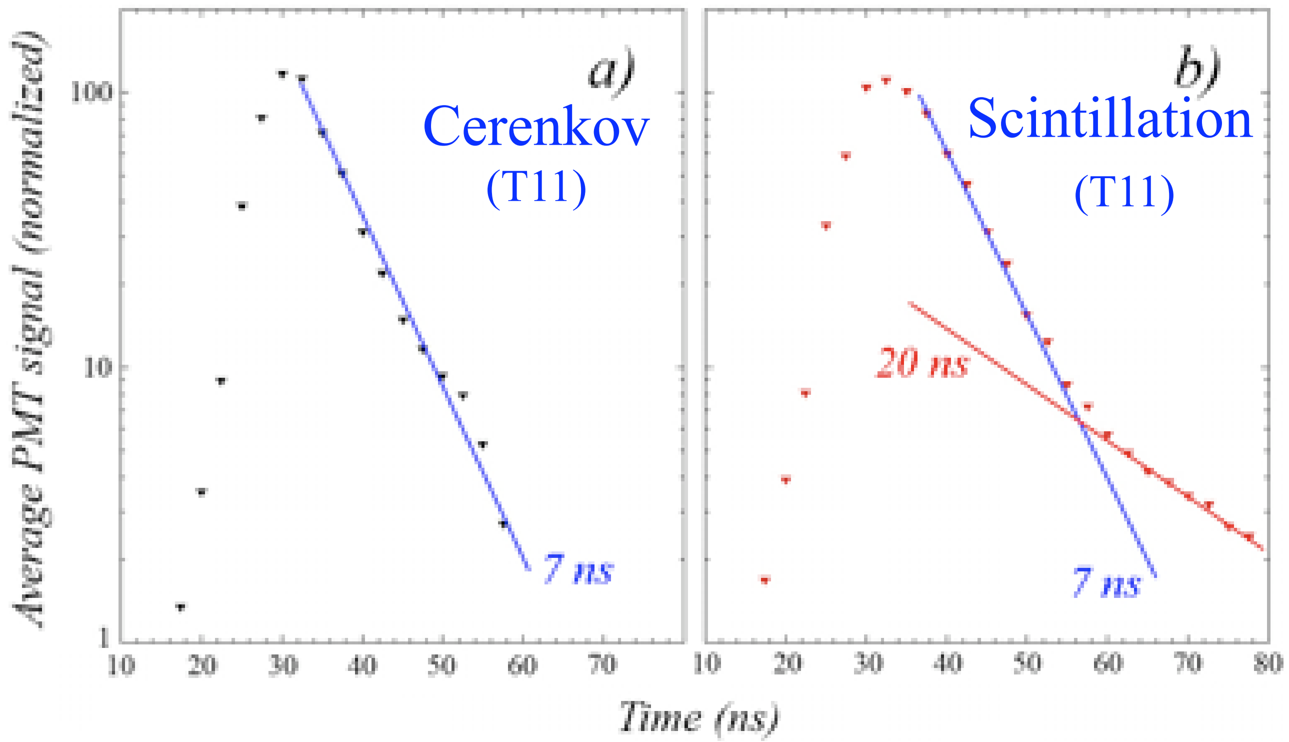
Next, go after the neutrons: 100 GeV pions (GEANT3 calc.)



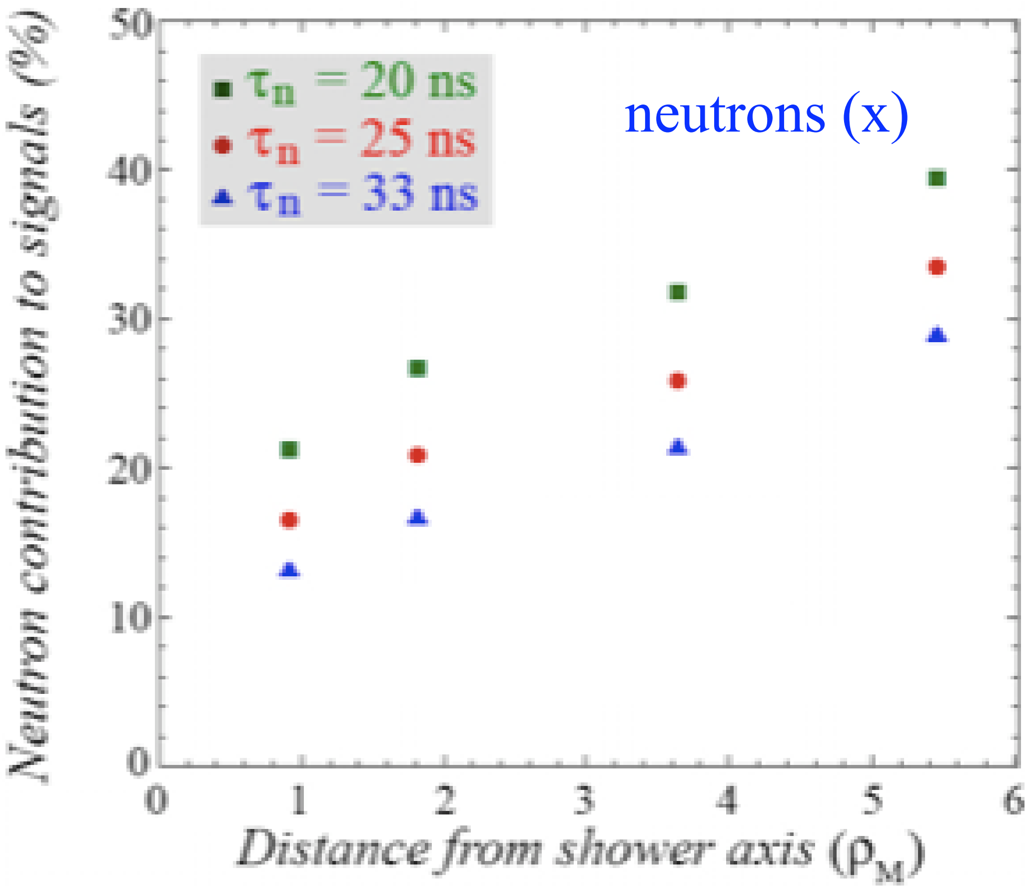


Neutrons measured in the DREAM module, Nov-Dec 2006





Send pion beam into center of channel 11, clock out scintillator/PMT signals in channels 3, 1, 6 and 17.



Ingredients for a new "scalable" dual-readout fiber module:

1. Cerenkov (clear) fibers, double clad, square, NA ~ 0.7 and with a larger fiber volume to increase photoelectron yield to 100 pe/GeV.

2. Scintillating fibers, double clad, square, NA ~ 0.7, more strongly filtered to increase attenuation length to above 5m.

3. Fiber geometry that is easier for a truncated pyramid module, and scalable for negligible inter-module dead volume. A dual-readout calorimeter like DREAM has all its readout at the rear, not the sides, and therefore has the possibility to be perfectly hermetic.

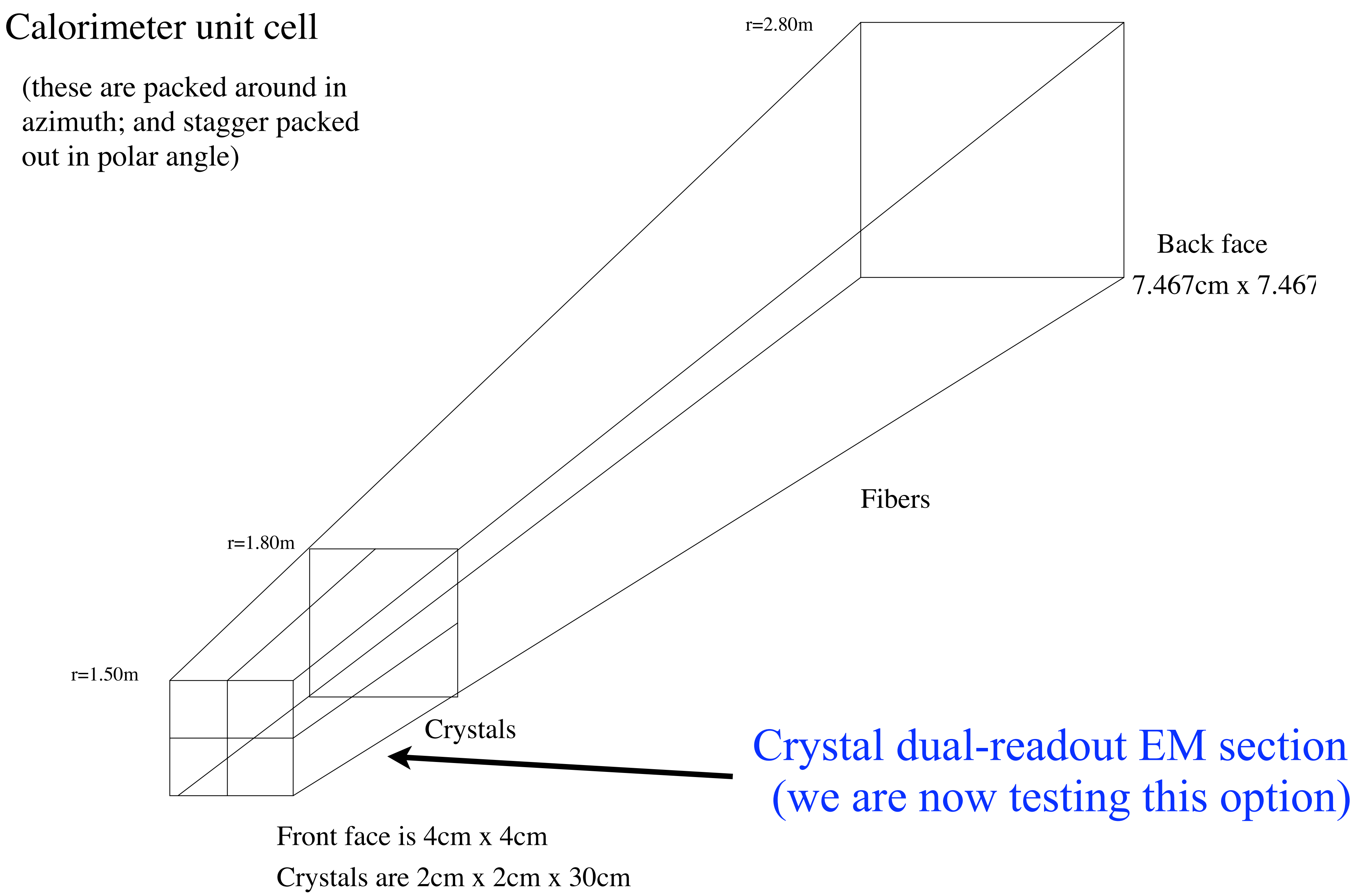
4. Photo-converter for B = 3.5 T. The usual suspects: SiPM, HPD, special B-resistant PMTs, microchannel plate PMs.

5. Readout both scintillation and Cerenkov fibers in 2-5ns buckets to measure neutrons and to monitor the volume for EM activity.

6. FLUKA for "system" simulation

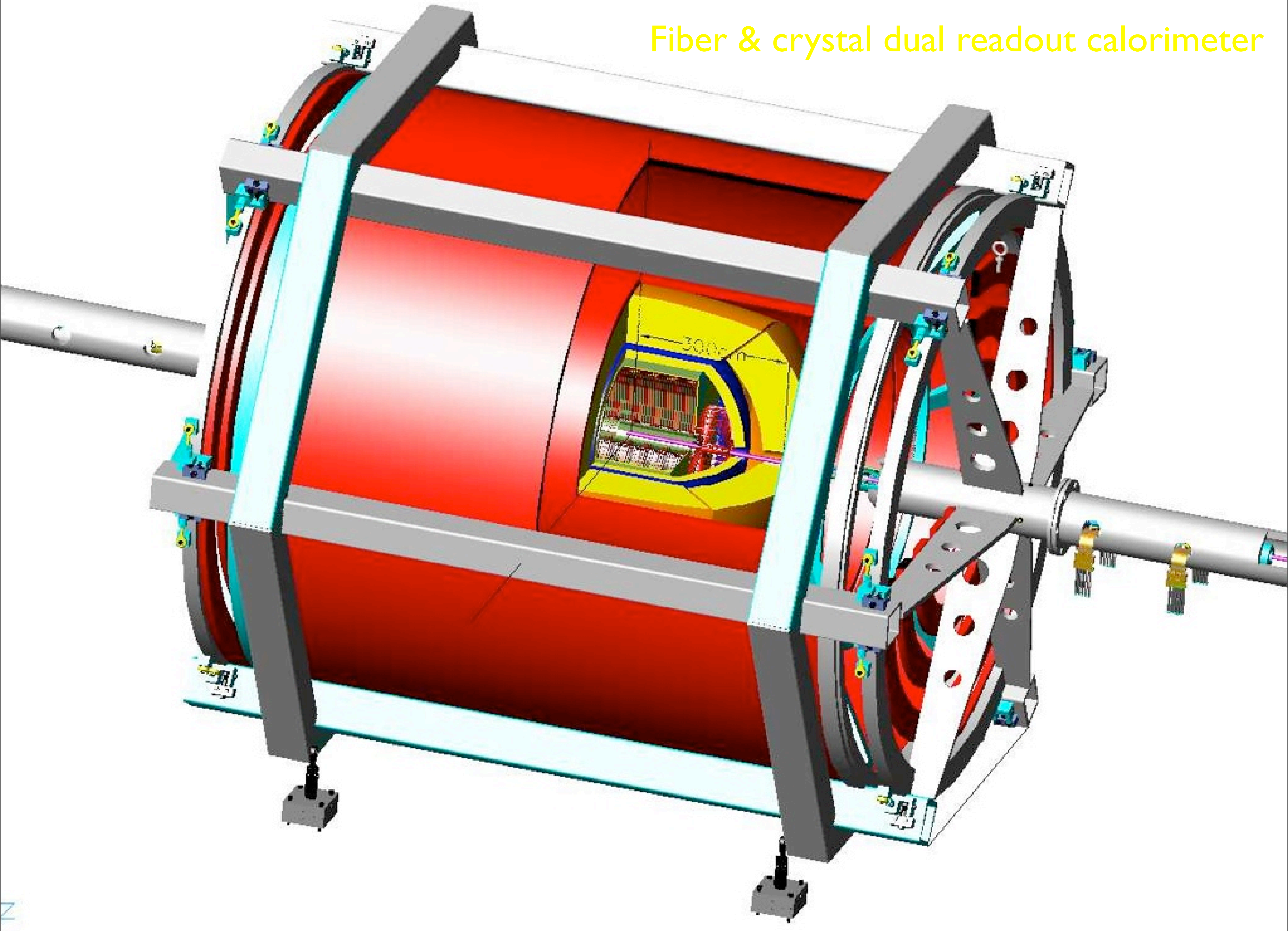
This is the next step for 4th.

4th calorimeter configuration



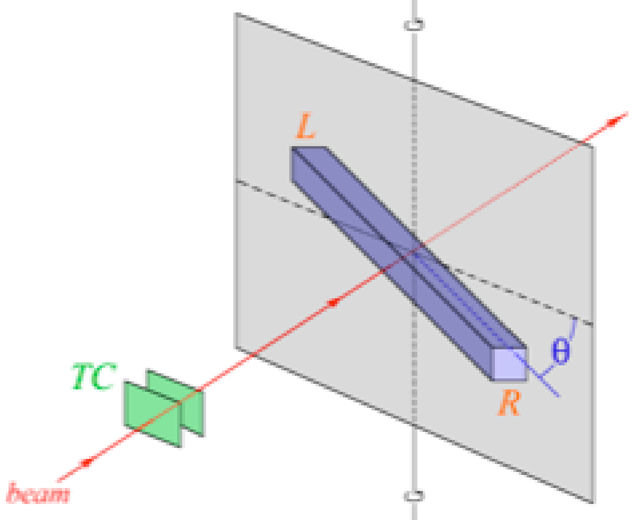
A "scalable" module; excellent electron & photon measurement; excellent hadron measurement.

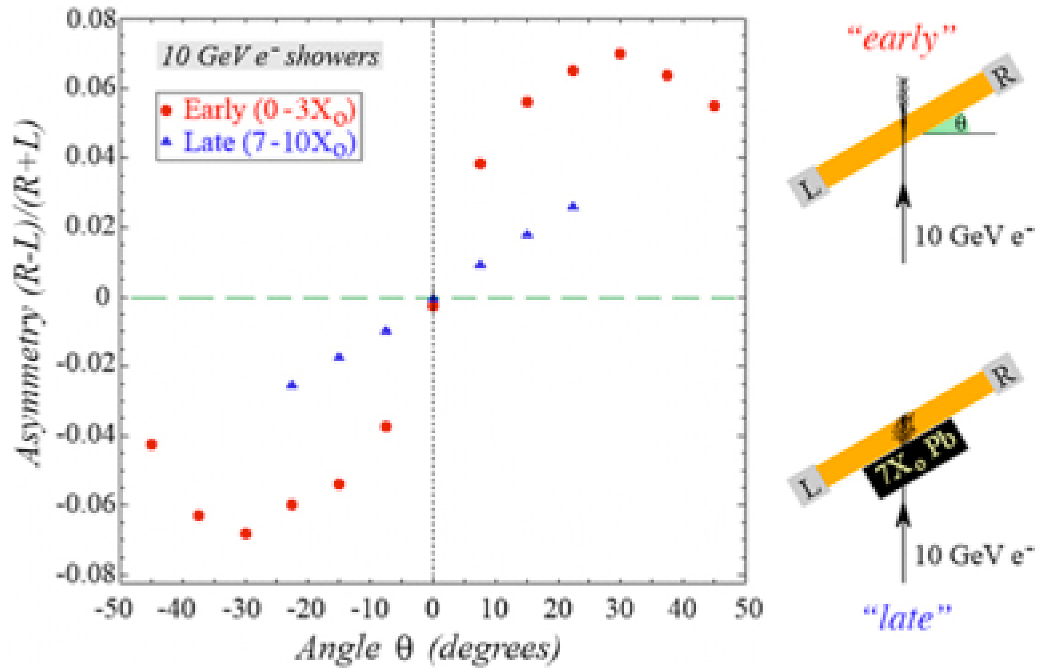
Fiber & crystal dual readout calorimeter

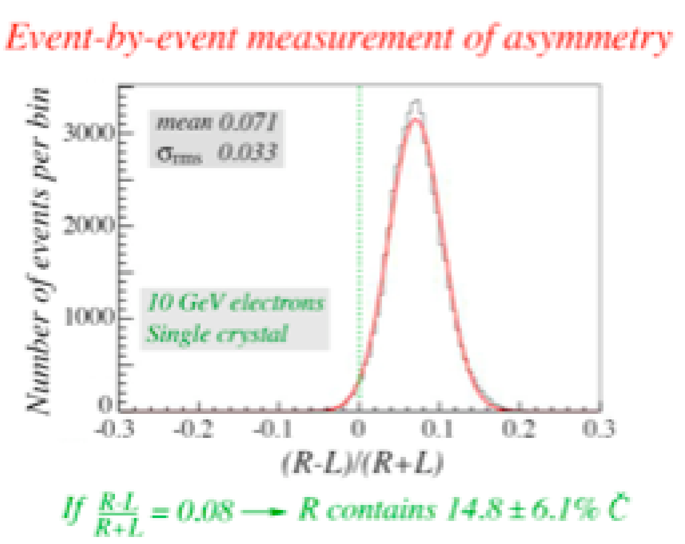


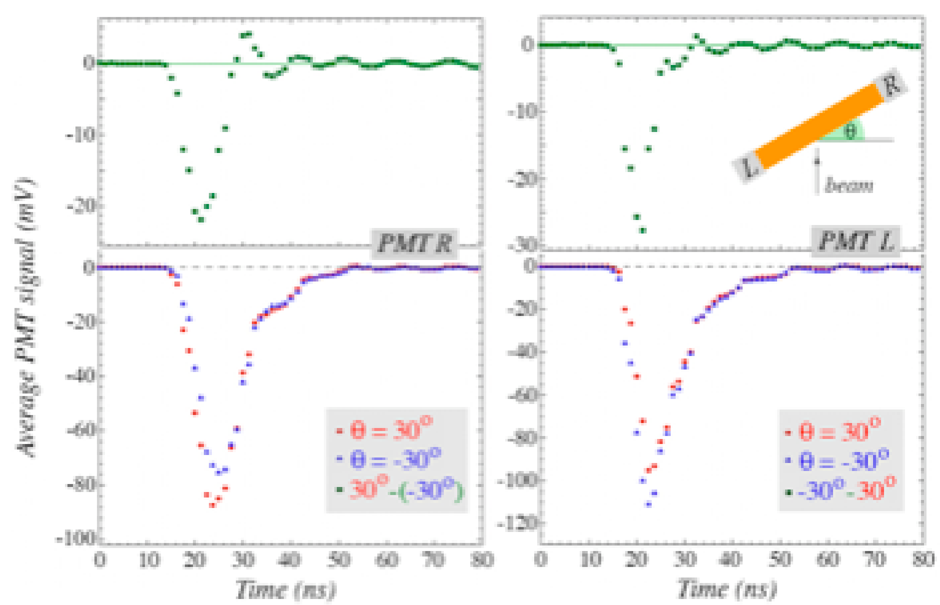
Dual readout of a single $PbWO_4$ crystal

(CERN test beam, Nov-Dec 2006)



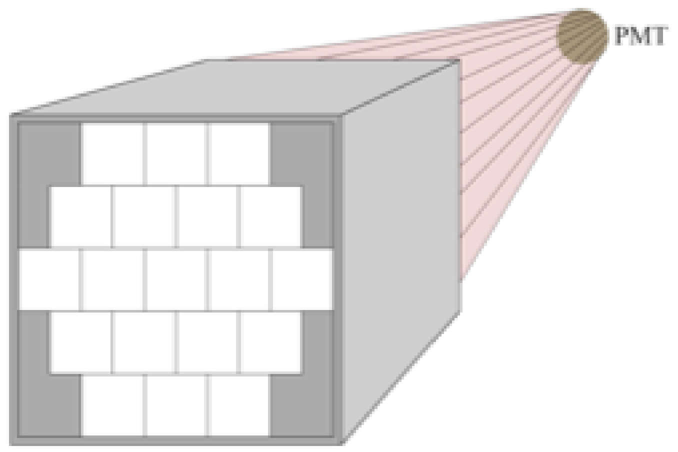


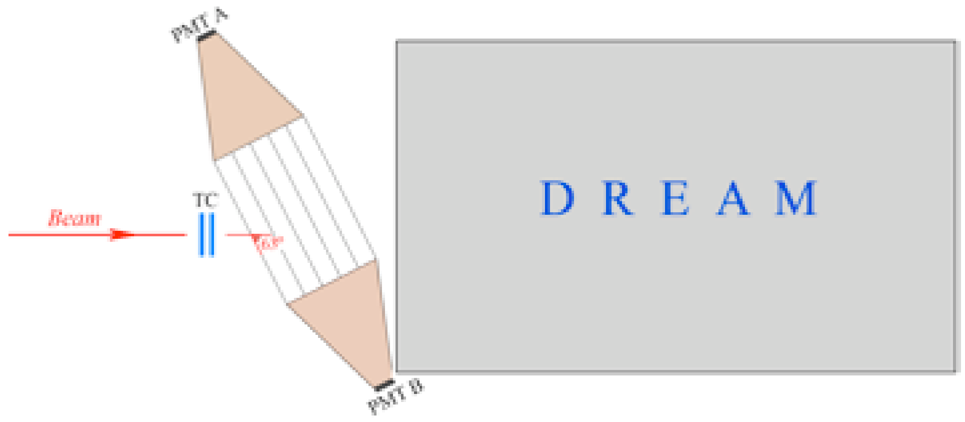


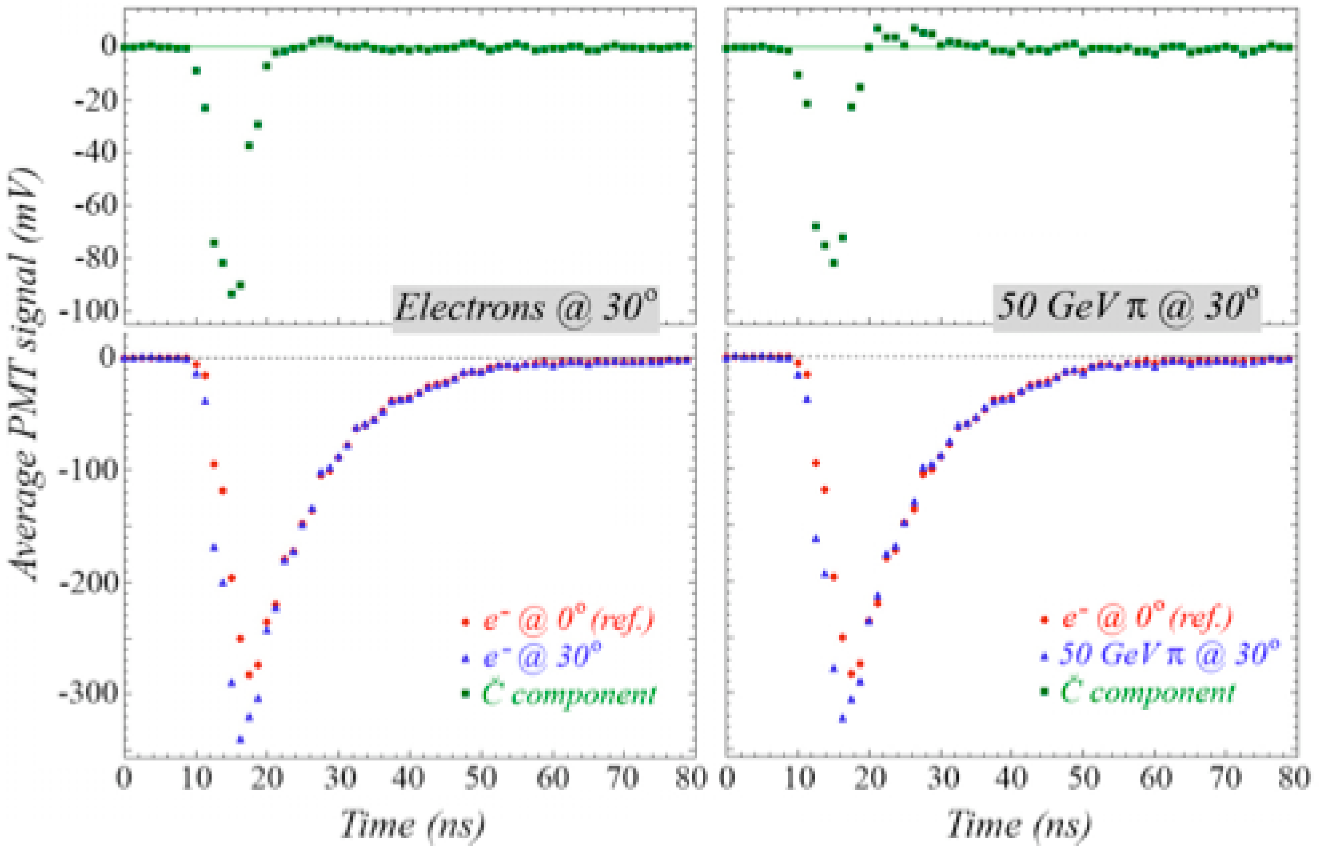


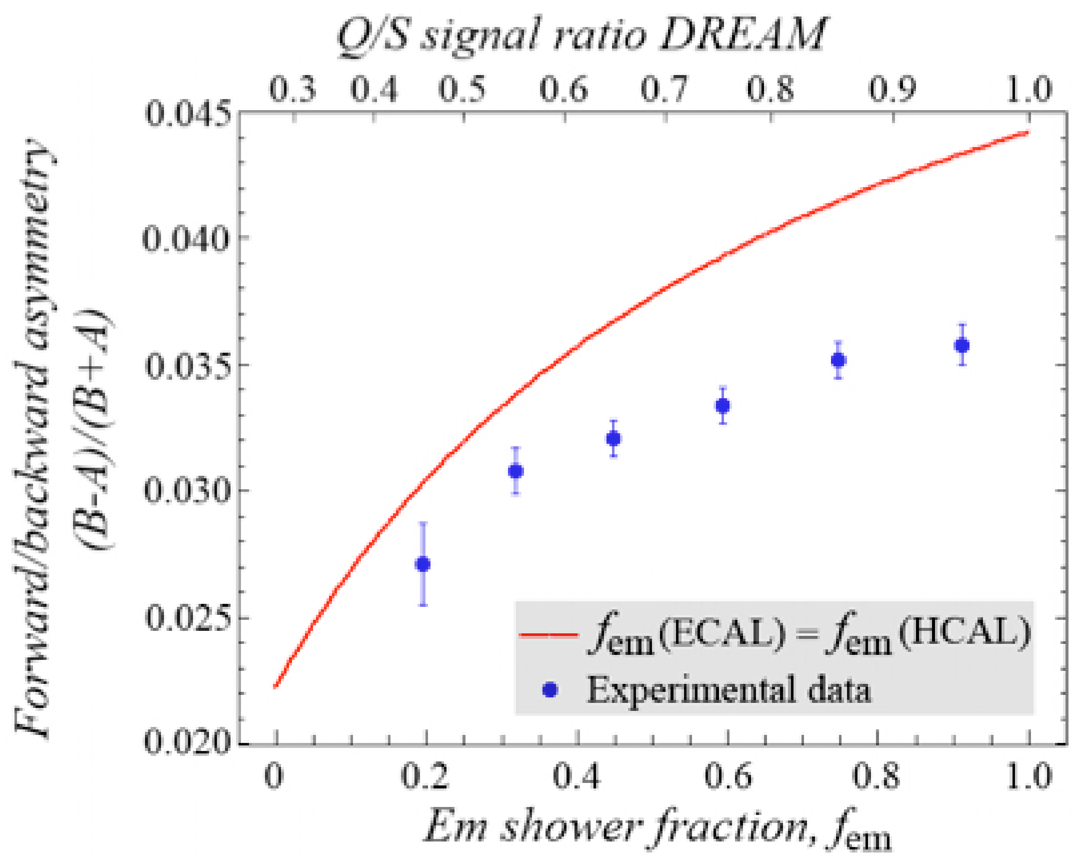
Dual readout of an array of 19 PbWO4 crystals

(CERN test beam, Nov-Dec 2006)









We are going after everything ...

- energy resolution for jets and hadrons: fiber dual readout
- energy resolution for electrons and photons: crystal dual readout
- lateral segmentation for pi-zero decays: crystal dual readout
- S-C for unique muon ID
- S, C, n: covers all known particles
- “other” ID
- calorimeter essentially empty of light in 300 ns
- robust, simple construction, direct energy measurement

Some objections to dual-readout fiber calorimeters:

a. particles can “channel” down a fiber: No, not likely, and in a B=3.5T field, it will never be a problem. The crystals in front convert all photons.

b. only one depth section? Yes, absolutely. Hadronic depth development fluctuations are best summed over, not measured. (“Depth segmentation is asking for trouble”-Wigmans). Dual readout provides at least three physical measurements per shower that discriminate between jets, photons, electrons, single hadrons, and muons.

c. can’t measure $\tau^{\pm} \rightarrow \rho^{\pm}\nu \rightarrow \pi^{\pm}\pi^{0}\nu \rightarrow \pi^{\pm}\gamma\gamma\nu$? I think we can [“Can the decay $\tau^{\pm} \rightarrow \rho^{\pm}\nu$ be measured directly?”, J. Hauptman, SLC-37, Aug. 25, 1981.] with the 2cm x 2cm dual readout crystals in front.

d. can’t measure some odd object not from the origin: I am not sure, but the crystal and fiber channels are small, so we can do some “tracking”.

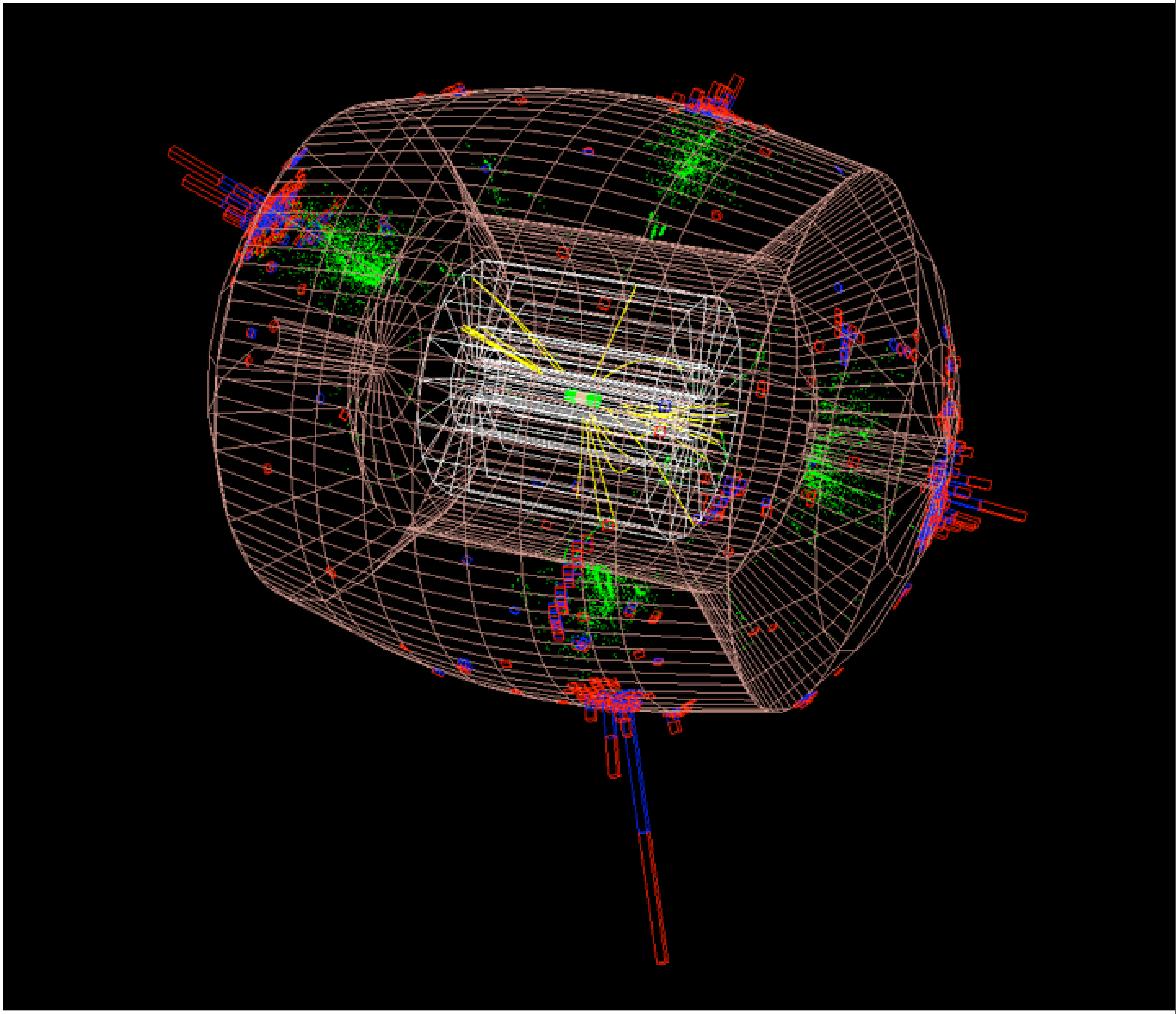
e. you’re too small a group: no problem so far, but many are interested.

f. FE electronics, DAQ: all at back of modules, PM, FADC.

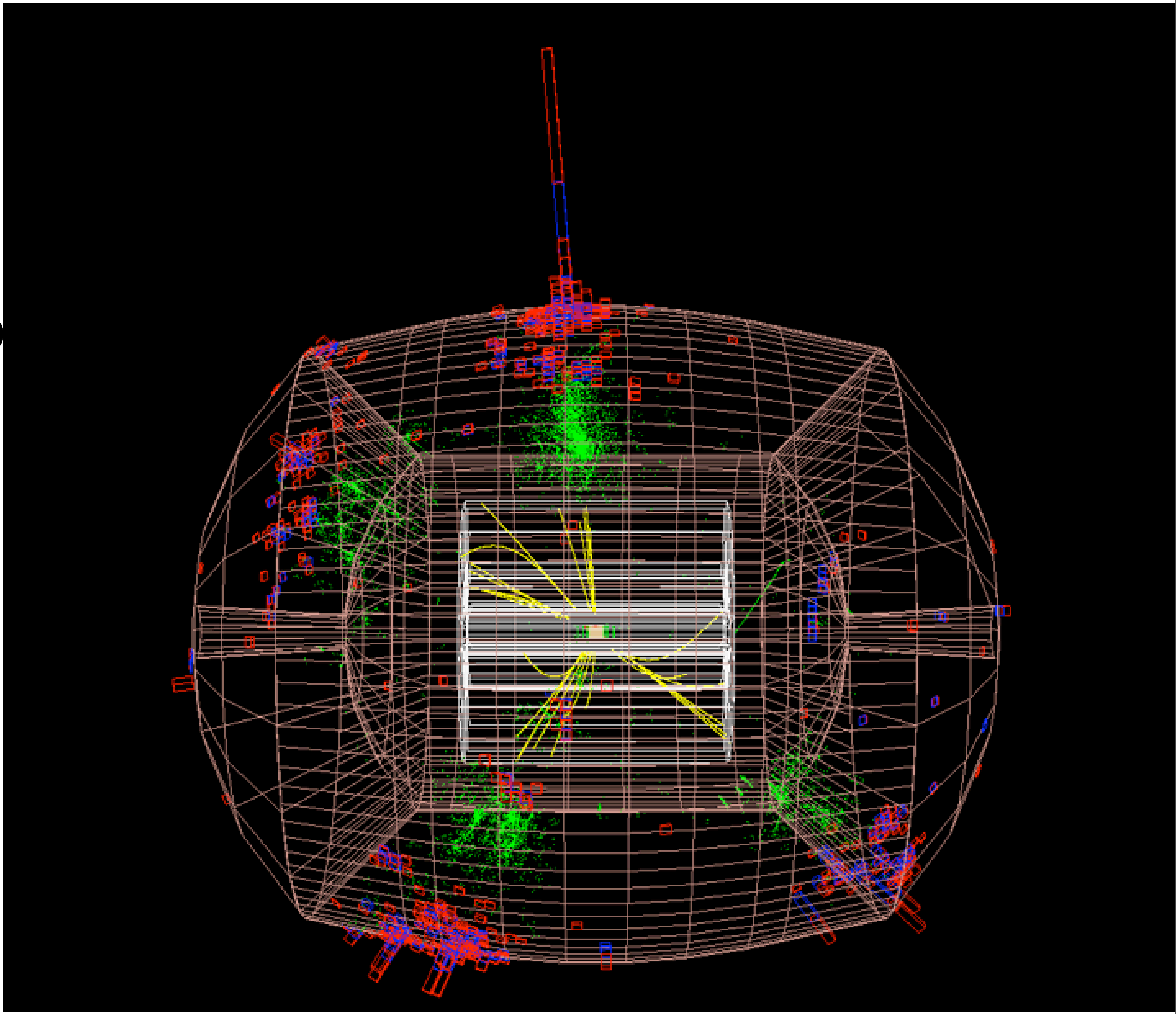
g. mechanical support: we have an engineering model to support the wedges like a Roman arch.

h. EMI, flyers, beam losses: complicated, but we have 10 int. lengths and time history of Cerenkov fiber volume.

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



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



“Calorimeter EDR” in 2010:

1. We understand dual readout;
2. We understand how to build the “best possible” fiber calorimeter;
3. We are developing dual-readout in single crystals to achieve the best-of-the-best: dual readout with huge photostatistics;
4. We have done engineering studies (see Report);
5. Very interesting particle (and parton) identifications in dual-readout;
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.