DREAM 4 ILC

Evolution of the Dual-Readout Calorimeter

LCWS06 (Linear Collider Workshop 2006)

Indian Institute of Science, Bangalore - Sat. 11 March 2006

Aldo Penzo, Trieste-INFN

…on behalf of … DREAM 4 ILC

Vienna ECFA ILC Workshop 2005: DREAM Project

[Outline of project and test beam results]

LCWS06: Evolution of Dual-Readout Calorimeter

[New R&D studies, projects/plans for further beam tests]

- **Techniques to separate light from Cerenkov and scintillation:**
  - time structure and directionality of light.
- **Measuring MeV neutrons in showers:**
  - special SciFi (non-H, Boron-loaded)
  - time spectrum
  - Birk's parameter/PSD
- **Crystal EM section in front of triple-readout module**
- **Multi- anode PM or Multipixel Photon Counter/Si-PM for readout**

DREAM Collaboration:

Texas Tech University, Lubbock
Iowa State University, Ames
University of California, San Diego
Trieste - INFN, Trieste

[People, Publications, References and Website]

(2004-2005) 5 **DREAM**-related NIM articles: μ**,** **e-** **,** **h**adrons&”**j**ets”

(Since 1985) Several R&D and full production calorimeter projects

R&D: SICAPO , SPACAL, RD1, QFCAL, …

CDF plug&preshower upgrades, CMS HF,…

Website: www.phys.ttu.edu/dream

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Standard references in compensating hadronic calorimetry:

SICAPO: Si – U / W / Pb / Fe sampling calorimeter:

G.Barbiellini et al., N.I.M. A235 (1985) 55
E. Borchi et al., N.I.M. Phys.Res. A279 (1989) 57
F. Lemeilleur et al., Phys.Lett. B222 (1989) 518
A.L.S. Angelis et al., Phys.Lett. B242 (1990) 293
E. Borchi et al., Nucl.Phys. B, Proc.Supp. 23A (1991) 62
E. Borchi et al., Phys.Lett. B280 (1992)
E. Borchi et al., N.I.M. Phys.Res. A332 (1993) 85
M. Bosetti et al., N.I.M. Phys.Res. A345 (1994) 244
C. Furetta et al., N.I.M. Phys.Res. A368 (1996) 378

SPACAL: SciFi – Pb calorimeter:

D. Acosta et al., N.I.M. A294 (1990) 193
D. Acosta et al., N.I.M. A305 (1991) 55
D. Acosta et al., N.I.M. A308 (1991) 481
D. Acosta et al., N.I.M. A309 (1991) 143

Strongly non-compensating hadronic calorimeter:

HF (CMS): Quartz Fiber – Cu / Fe calorimeter:

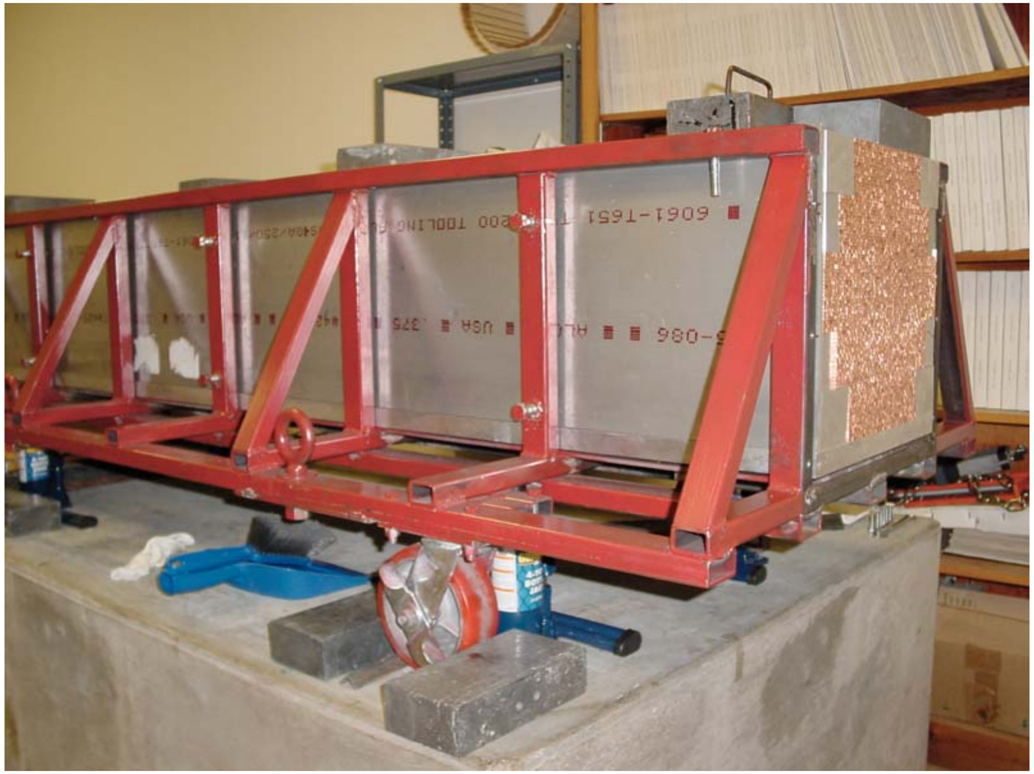
N. Akchurin et al., N.I.M. Phys.Res. A399 (1997) 202

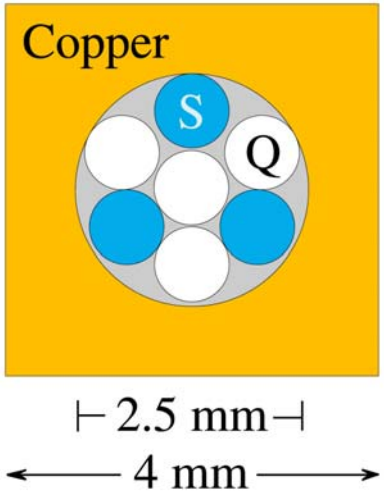
Main theme: multiple measurements of every shower to suppress fluctuations

•Spatial changes in density of local energy deposit	•fine spatial sampling with SciFi every 2mm	•Like SPACAL
•Fluctuations in EM fraction of total shower energy	•clear fibers measuring only EM component of shower via Cerenkov light from electrons (E_{th} = 0.25 MeV)	•Like HF
•Binding energy losses from nuclear break-up	•measure MeV neutron component of shower.	• Triple Readout

DREAM = SPACAL + HF

DREAM [Dual REAdout Module] prototype is 1.5 ton heavy





(S, Q fibers 0.8 mm ϕ)

Cell

[basic element of detector]

2m long extruded copper rod, [4 mm x 4 mm]; 2.5mm hole contains 7 fibers:3 scintillator & 4 quartz(or acrylic plastic).

In total, 5580 copper rods(1130Kg) and 90Km optical fibers.

Composition (volume) Cu: S : Q : air = 69.3 : 9.4 :12.6 : 8.7 (%)

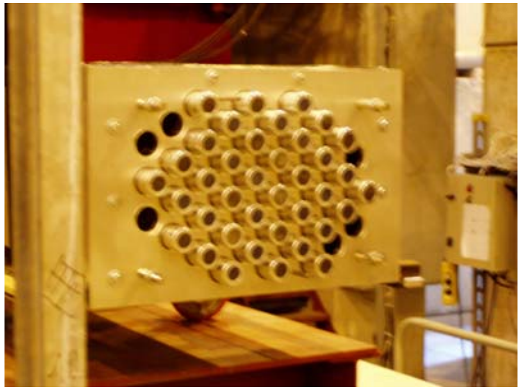
Effective Rad. length (X_0)=20.1mm;Moliere radius(r_M)=20.35mm

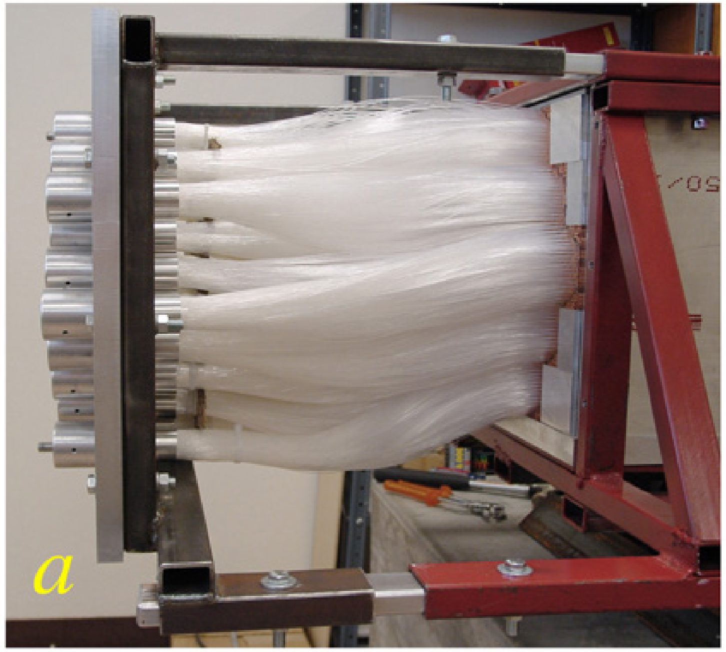
Nuclear Inter. length (λ_{int})=200mm;10 λ_{int} depth Cu.

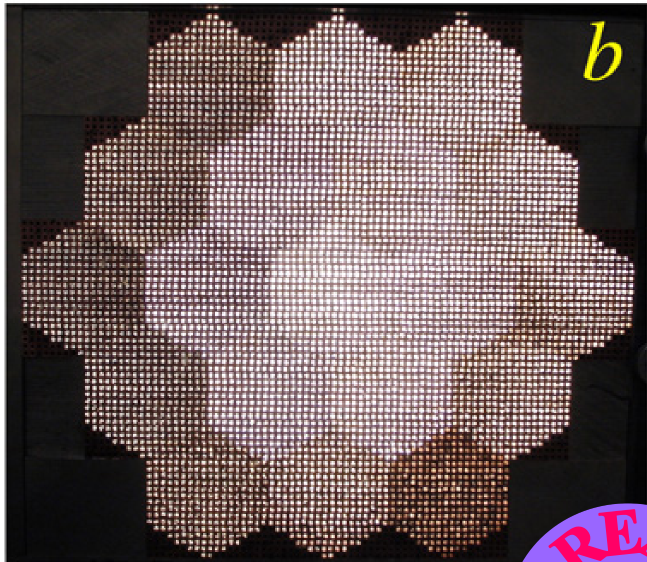
Filling fraction = 31.7%; Sampling fraction = 2.1%

- **Tower : readout unit**

Hexagonal shape with 270 cells (Fig. *b*); Readout 2 types of fibers to PMTs (PMT: Hamamatsu R580) (Fig. *a*)







- **Detector : 3 groups of towers (Fig. *b*)**

center(1), inner(6) & outer(12) rings; Signals of 19 towers routed to 38 PMT

Fig. ***a*** : fiber bundles for read-out PMT;
38 bundles of fibers

Fig ***b*** : front face of detector with rear end illuminated: shows 3 rings of honey-comb hexagonal structure..Effective radius 162 mm (0.8 λ_{int}, 8 r_M)

Test Beam: Experimental setup

- **H4 beam line of the Super Proton Synchrotron at CERN**(June 2003)
- **Two different angles of incident beam w.r.t the detector**

  2° in horizontal(ϕ) and 0.7° in vertical(θ) plane -> untilted data

  3° in ϕ and 2° in θ -> tilted data
- **TC : Trigger Counters**

  two scintillation counters (4 x 4 cm^2 each)

  coincidence of 2 counters provide main trigger signals
- **HOD : Hodoscopes**

  consist of ribbons of scintillating fibers oriented horizontally or vertically.

  provide x, y coordinate of beam spots (impact point on the detector).

  readout by position sensitive multi-anode PMTs.

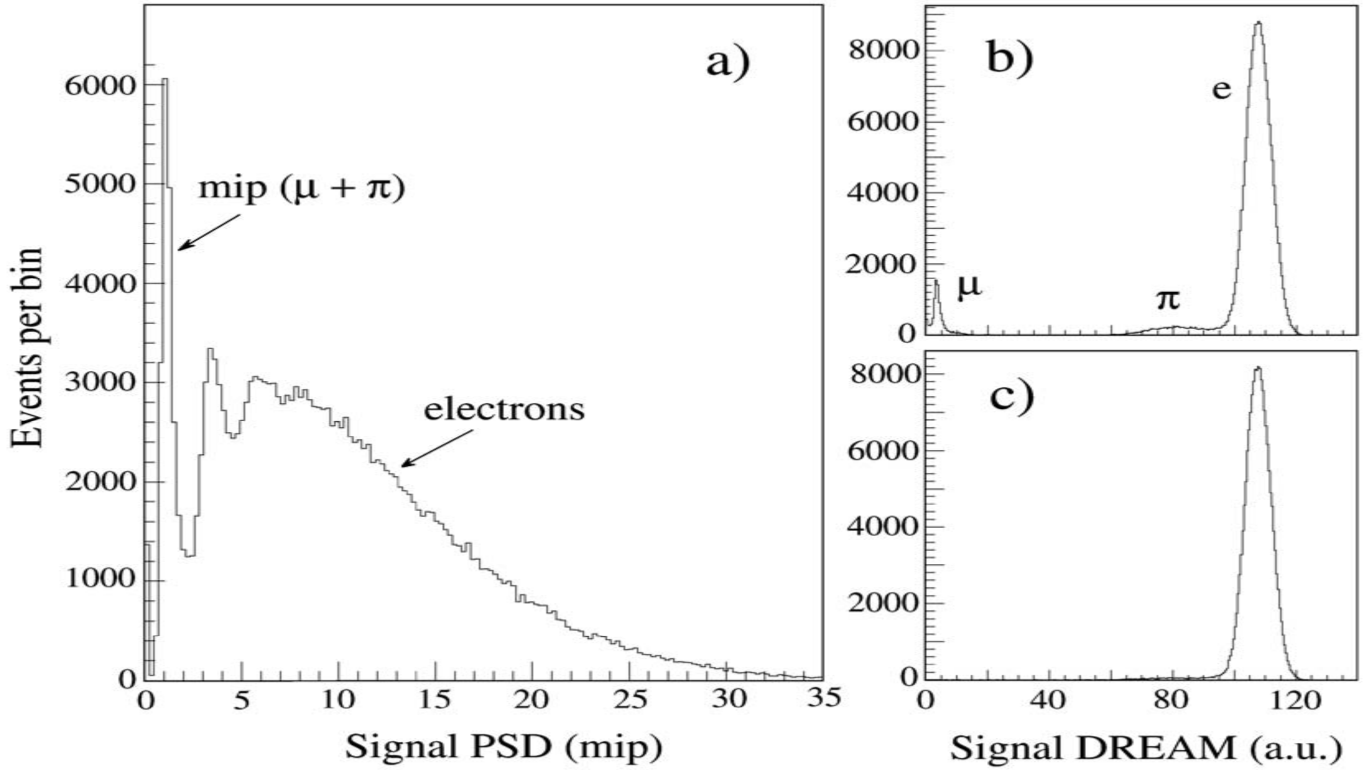
The module has been tested in dedicated runs at CERN SPS in June 2003 and July 2004.

- **MU :** **Muon detector**

  30 x 30 cm^2 scintillation counter behind 8 $\mathbf{l}_{int}$ absorber.
  to reject muon contaminated events.

- **PSD :** **Preshower detector**

  5mm thick (1 X_0) lead absorber with scintillation counter used to eliminate beam contamination.

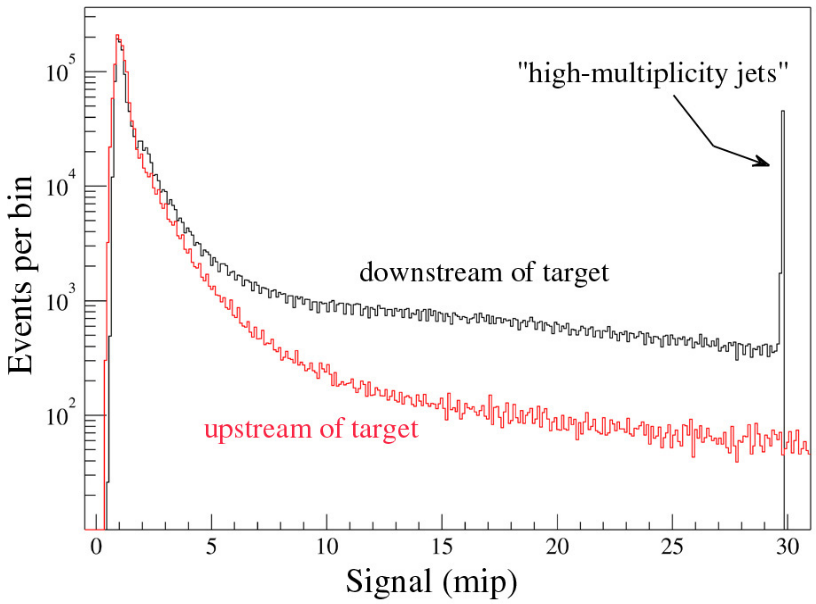


a) : PSD distribution for e^- beam. b) : energy distribution of e^-.
c) : MU information after removing contamination with PSD.

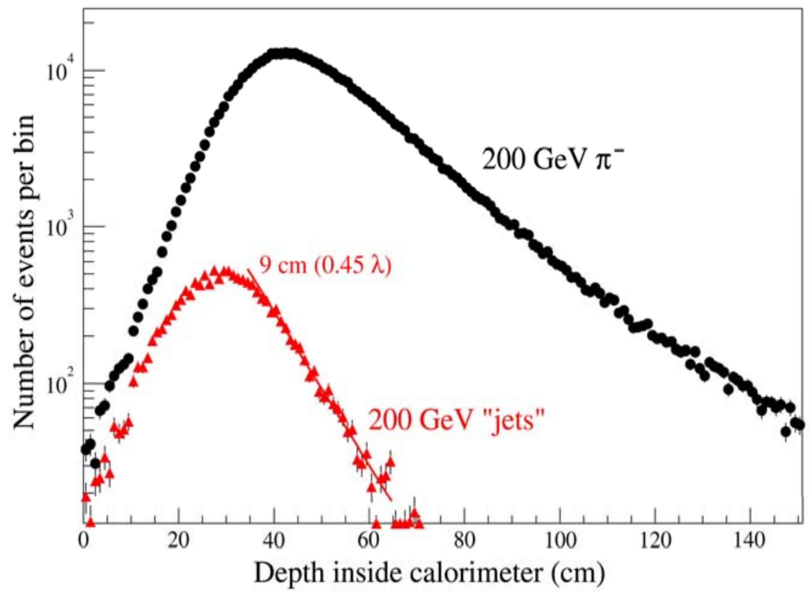
- **IT : Interaction target counter**

  10cm thick polyethylene target in front of detector…
  shows the multiplicity of the secondaries produced in the target.
  used to select high multiplicity events requiring a mip signal in PSD
  -> to mimic "jet" events in calorimeter.

IT & PSD distributions



Comparison of shower depth Zeff



Data & event selection

- **Data samples**

  20, 40, 80, 100, 150, 200, 250 & 300 GeV/c with $\phi = 2^o$, $\theta = 0.7^o$

  50, 100, 200 & 300 GeV/c with $\phi = 3^o$, $\theta = 2^o$.

  50, 100, 200 & 300 GeV/c "jet" mimicked by π

- **Event selection criteria**

  events with good (x, y) coordinate (~80% hodoscope efficiency)

  1cm radius beam spot

  MU < 0.25 (mip)

  0.5 < PSD < 2.0 (mip)

  28 < IT (for high multiplicity "jet" events)

- **Shower depth**

  Z_{eff} was calculated using beam impact point & center of gravity of shower profile [0. < Zeff < 100 (cm)]

- **Correction for light attenuation**

  attenuation length were measured 5 and 15m for scintillation and quartz fibers.

  (detector was rotated 24^O in ϕ for this measurements)

  S(attenuation corrected) = $S \times exp[-(Z_{eff}-30)/500]$

  shower depth for electron = 30cm is reference for correction.

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Results

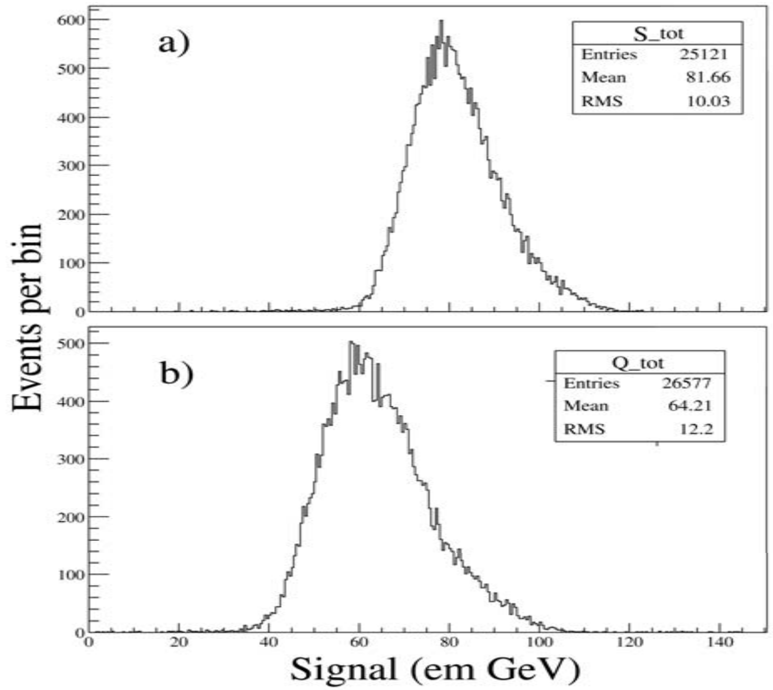
a), b) energy distributions from scintillating and Cerenkov fibers for 100GeV single π^-

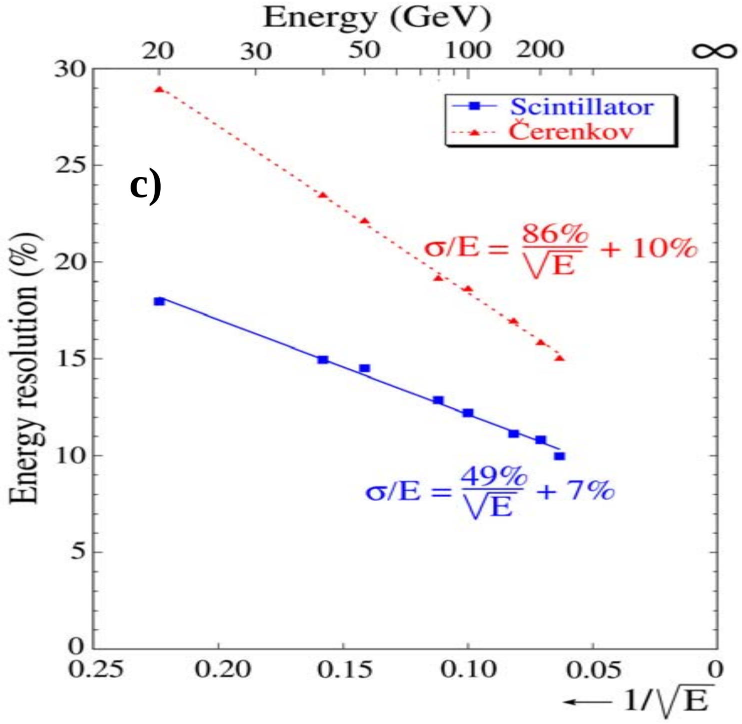
asymmetric, broad, smaller signal than *e*⁻

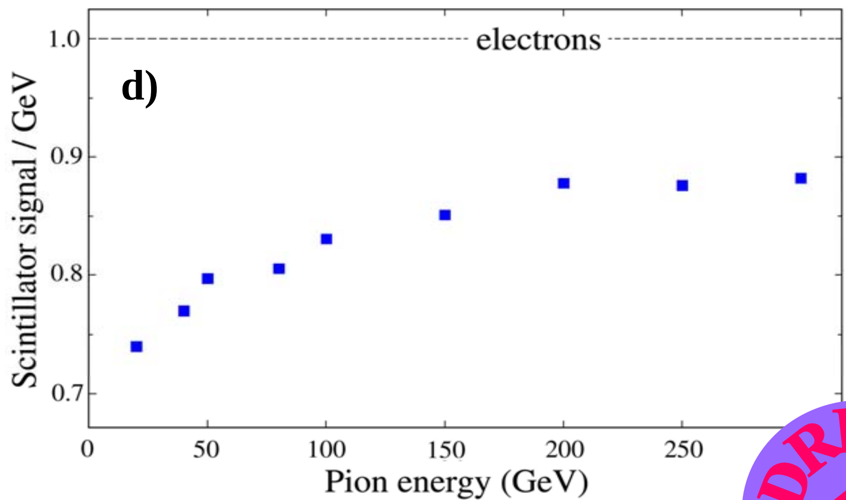
typical features of non-comp. calorimeter.

c) energy resolution (%) vs beam energy

d) Linearity of scintillation signal response







After (Q+S)/E correction,

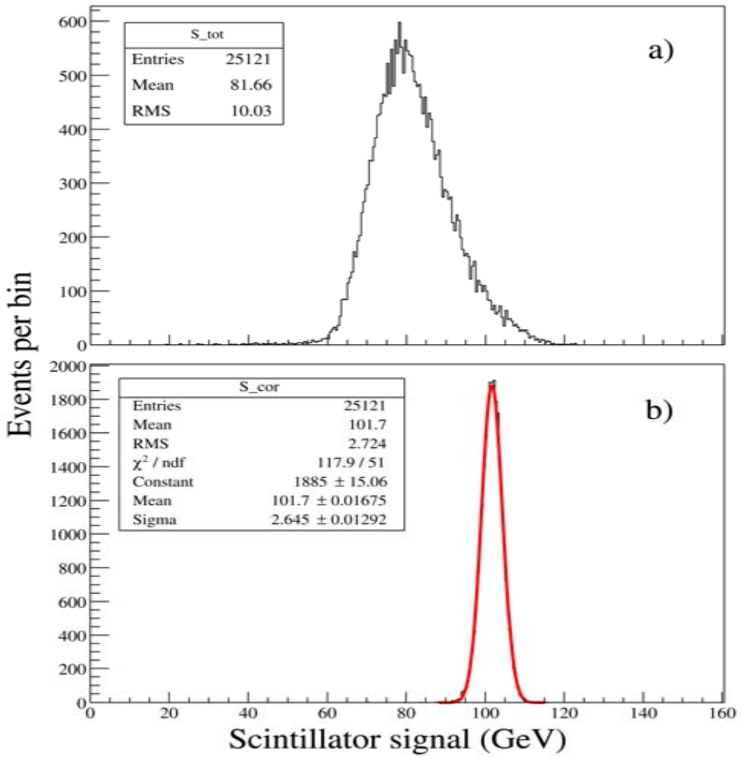
the signal distributions are described well by gaussian distribution and energy resolution was dramatically improved.

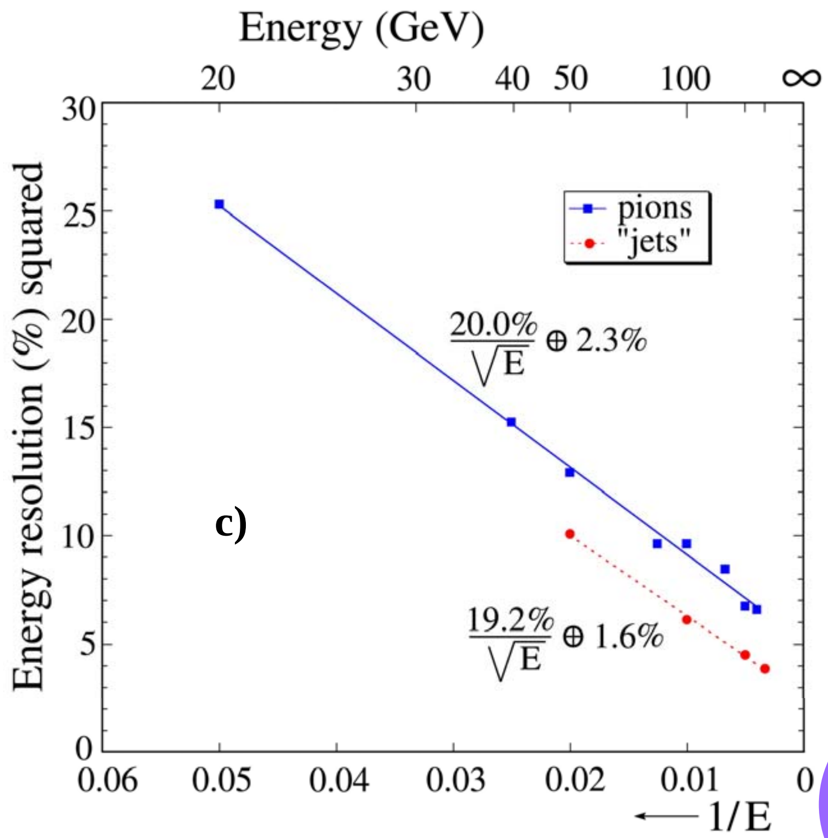
(12.3% resolution became 2.6% for 100GeV π beam). (**Fig. a & b**)

Energy resolution as a function of beam energy(**Fig. c**) are well described by

$$\frac{\sigma}{E} = \frac{a}{E^{1/2}} \oplus b$$

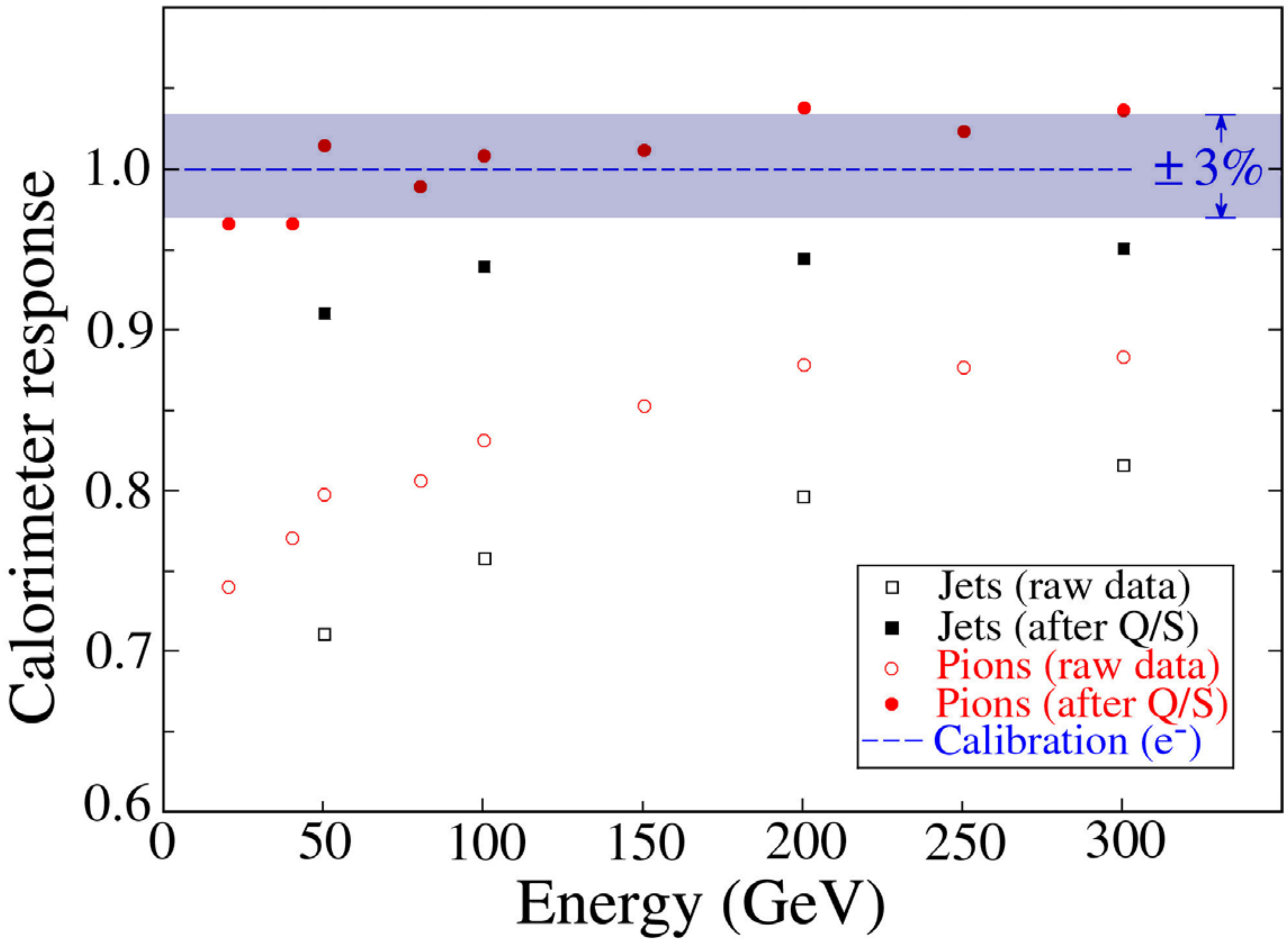
(b is related to sampling non-uniformity depending on impact point of the beam.)





DREAM calibrated with 40 GeV e^- into center of each tower,

recover linear hadronic response up to 300 GeV for π^- and "jets"



DREAM energy resolution (for jets):

40%/√E → 20%/√E

Q/S method → limit for zero leakage

Need to test larger calorimeter for full containment;

Test also effects of magnetic fields and finer sampling;

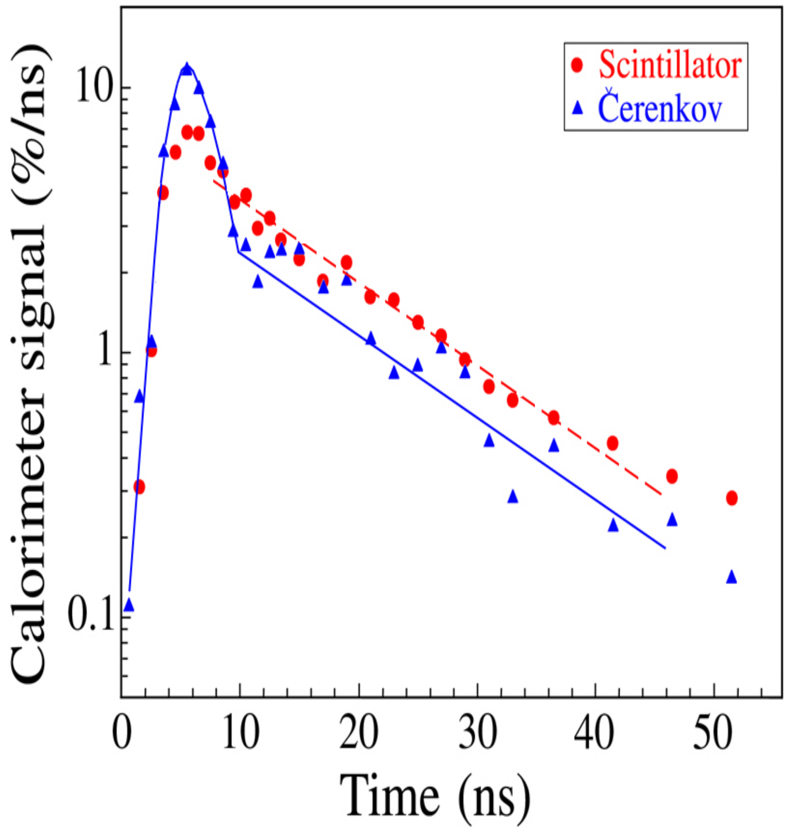
Simulation being tuned to the beam test data.

Suppose for time being we will end up in the range

20-25%/√E with finer sampling and BE fluctuations measured

Separation of Scintillation and Cerenkov Light with a single PMT

a. Method using the time structure



Time structure of light signals.

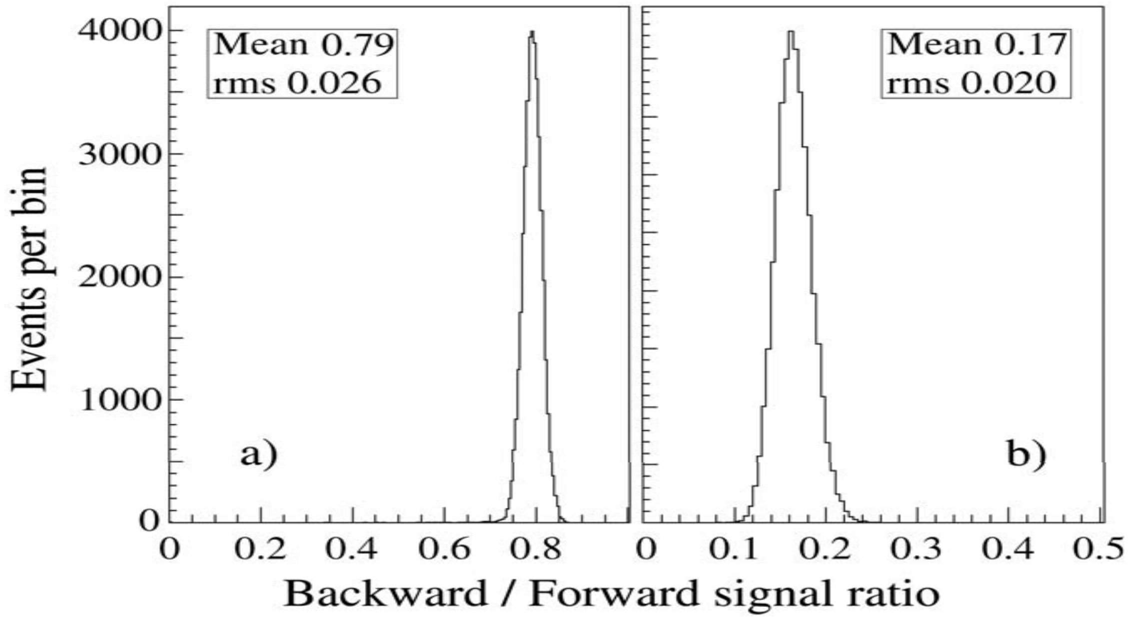
Scintillator and Cerenkov light pulses have distinctly different time spectra.

Applying Fast-Slow discrimination the two components can be selected;

This technique will be also useful for neutron selection as well.

b. Method using the directionality of Cerenkov light

- Measure the light from both ends of fibers (F and B).
- B/F = ratio of light emitted in the backward and forward.
- Clear difference was found in B/F ratio between Cerenkov and scintillation light.
- Scintillation light is generated isotropically and only 20% difference in backward and forward signals.
- Cerenkov light in forward direction is ~6 times larger than in backward direction.



B/F ratio for scintillator (a) and Cerenkov (b) signals generated by 80GeV electrons.

Measuring MeV neutrons:

- by time

Velocity is ~ 0.05 c: Scintillation light comes late;

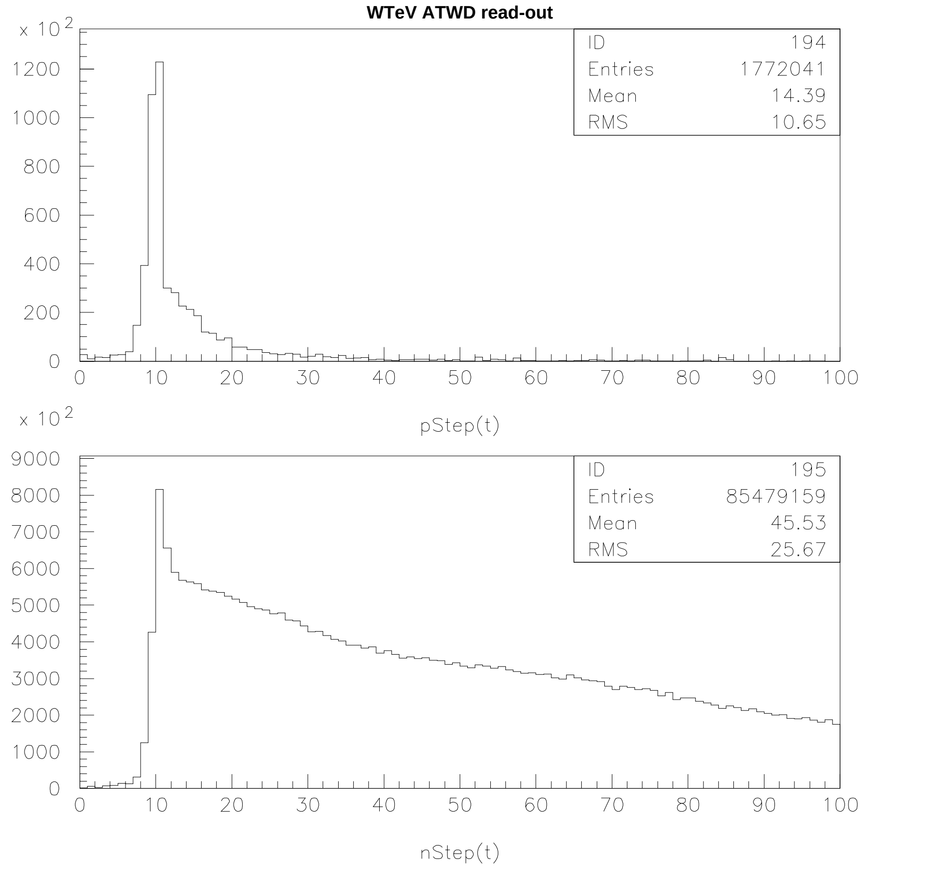
neutrons fill a larger volume.

- Scintillating non-hydrogenous fibers
- Lithium-loaded or Boron-loaded fibers
- Large Birk's parameter scintillators

DREAM → **TRUE** =**T**riple **R**eadout [**U**ltimat**E**] (Calorimeter)

Measuring MeV neutrons

by time



t(ns) →

Velocity of MeV n is ~ 0.05 c

(1) Scintillation light from np→np scatters comes late;

(2) neutrons fill a larger volume;

This method misses early neutrons

“hydrogen-rich” vs “hydrogen-poor” SciFi

•Hydrogenous scintillating fiber measures protons from np→np scatters;

•A second scintillating non-hydrogenous fiber measures all charged particles, but no protons from np scatters.

Lithium-loaded or Boron-loaded fibers

Pacific Northwest Laboratory works on these;

•**Birk’s constant:** parameterizes the reduction in detectable ionization from heavily ionizing particles (essentially due to recombination)

•Some of these materials are difficult liquids

Crystal ($PbWO_4$) EM section in front of triple-readout module

•Dual (scintillation+Cerenkov) readout: idea the dream group has tested at CERN, summer 2004. "Separation of Scintillation and Cerenkov Light in an Optical Calorimeter", *Nucl. Instr. Methods*, accepted (2005).

•Use multiple Multi-Pixel Photon Counters (MPPCs) probably four, two on each end of crystal, with filters.

•Physics gain: excellent EM energy resolution (statistical term very small), excellent spatial resolution with small transverse crystal size.

•Dual-readout yields correct hadronic energy deposited in EM section (1/2 of all hadrons interact in EM section).

Programme in 2006 (and later)

- Test beam at CERN summer 2006

After 2005 shutdown DREAM ready (and eager) to resume test beam

- Many ideas and techniques to explore, many suggestions/advices

- New collaborators are joining:

. . . .

-Korea

-Italy (Lecce, Messina, Pavia, Roma, Trieste / Udine)

. . . .

Gaining momentum, hopefully support also….