Implementing Dual Readout in ILCroot

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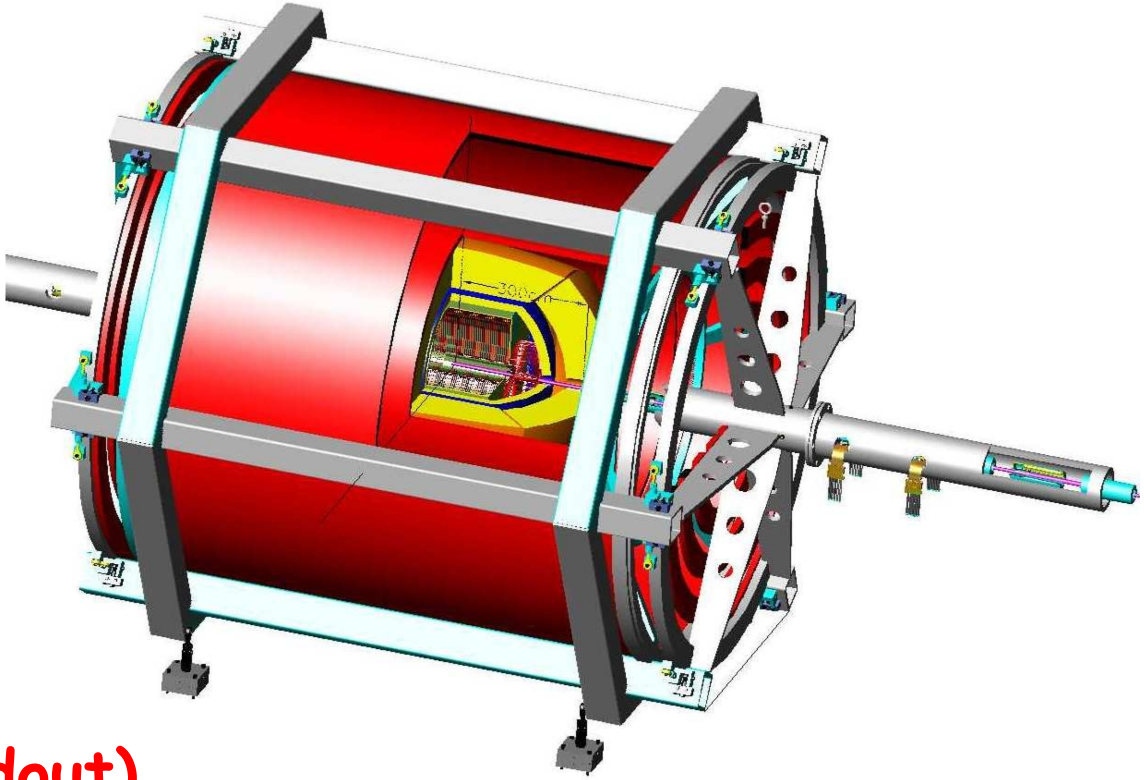
Outline

- The 4th Concept
- ILCroot Offline Framework
- Calorimeter layout
- Calibration studies and calorimeter performances
- Comparison of DREAM data with ILCroot simulation
- Conclusion

"The 4th Concept" detector



- VXD (SiD Vertex)
- DCH (Clu Cou)
- ECAL (BGO Dual Readout)
- HCAL (Fiber Multiple Readout)
- MUDET (Dual Solenoid, Iron Free, Drift Tubes)

ILCRoot: summary of features

- CERN architecture (based on Alice's Aliroot)
- Full support provided by Brun, Carminati, Ferrari, et al.
- Uses ROOT as infrastructure

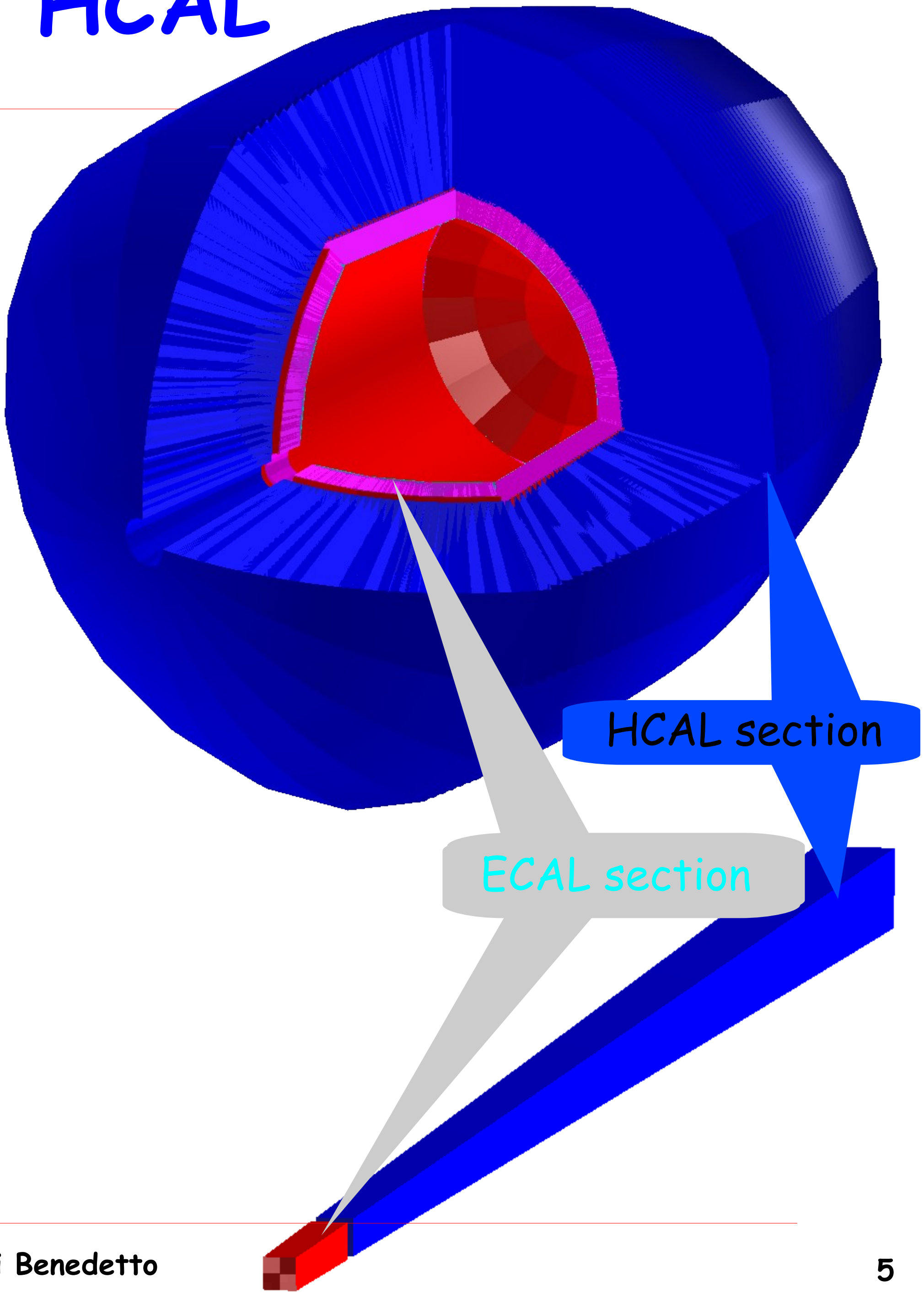
  All ROOT tools are available (I/O, graphics, PROOF, data structure, etc)

  Extremely large community of users/developers
- Six MDC have proven robustness, reliability and portability
- Single framework, from generation to reconstruction through simulation. Don't forget analysis!!!

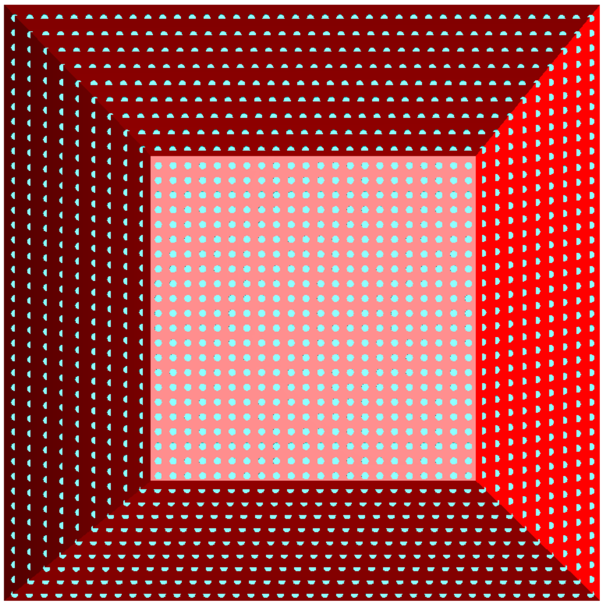
All the studies presented are performed by ILCRoot

The 4th Concept HCAL

- Cu + scintillating fibers
  + Čerenkov fibers
- ~1.4° tower aperture angle
- 150 cm depth
- ~ 7.3 λ_{int} depth
- Fully projective geometry
- Azimuth coverage
  down to ~2.8°
- Barrel: 16384 towers
- Endcaps: 7450 towers



Hadronic Calorimeter Towers

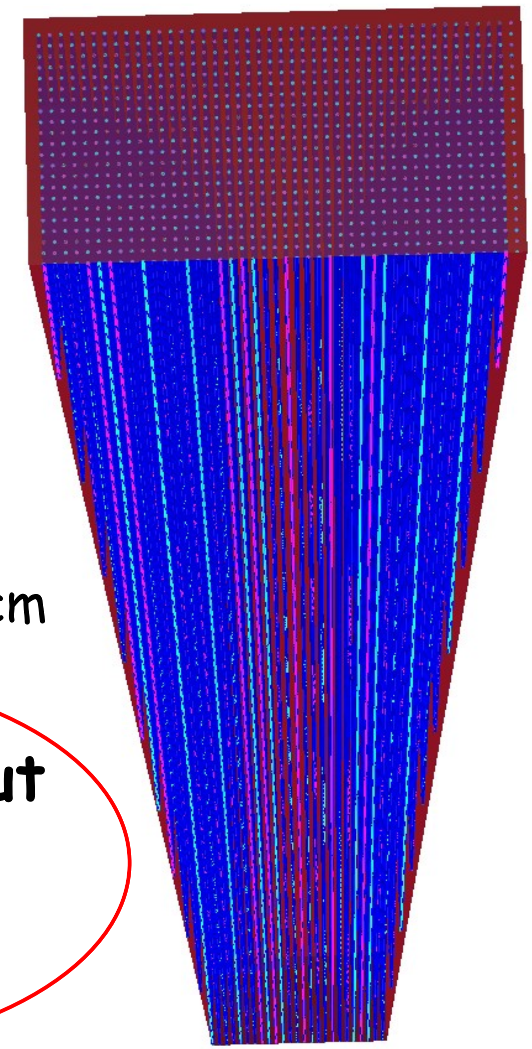


Bottom view of single tower

Top tower size: ~ 8.1 × 8.1 cm^2

Bottom tower size: ~ 4.4 × 4.4 cm^2

Prospective view of clipped tower



Quite the same absorber/fiber ratio as DREAM

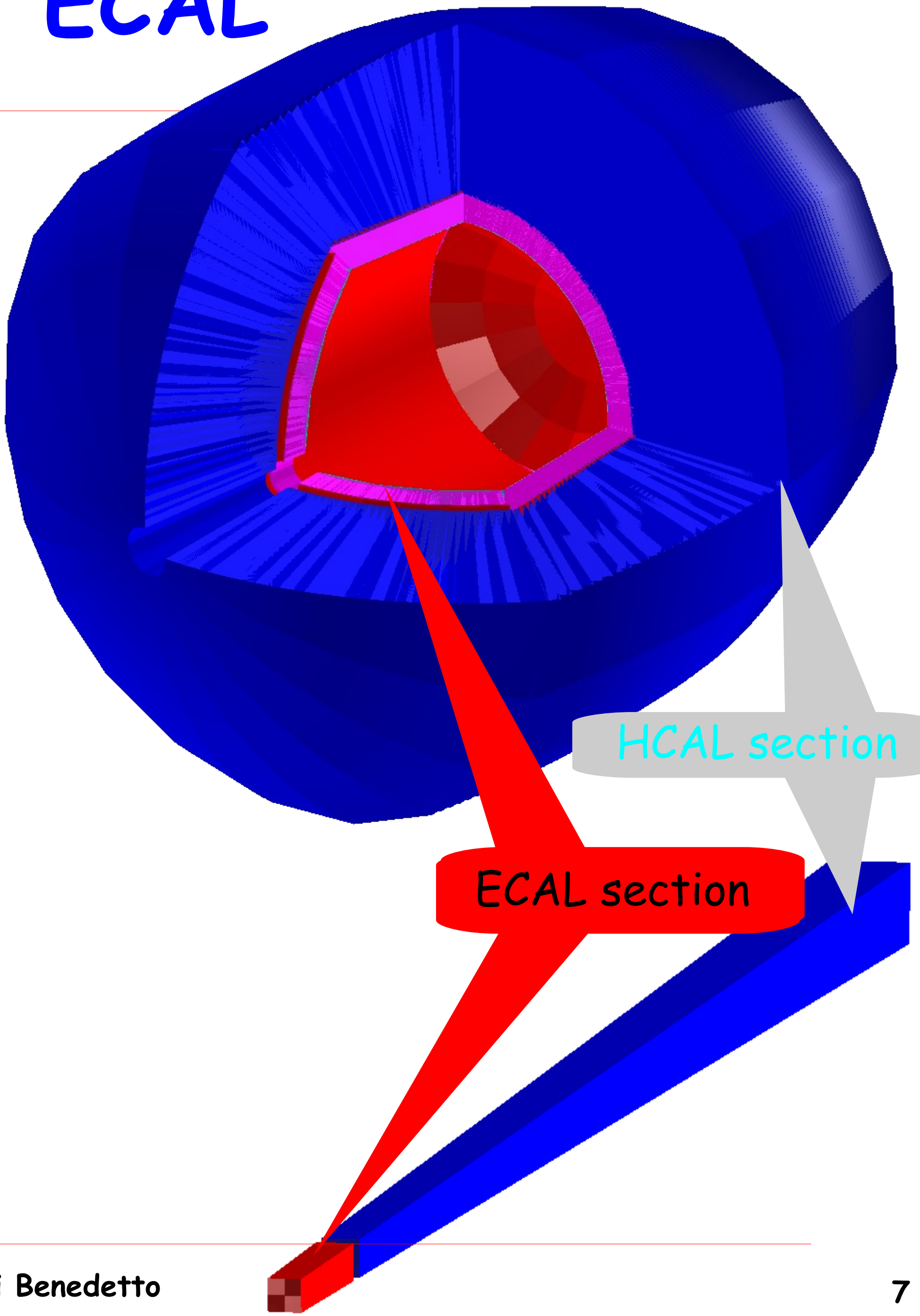
- 500 μm radius plastic fibers
- Fiber stepping ~2 mm
- Number of fibers inside each tower: ~1600 equally subdivided between Scintillating and Čerenkov
- Each tower works as two independent towers in the same volume

Tower length: 150 cm

Multiple Readout Fibers Calorimeter

The 4th Concept ECAL

- BGO crystals for scintillating and Čerenkov light
- 25 cm depth
- ~22.7 X_0 depth and ~ 1 λ_{int} depth
- 2x2 crystals for each HCAL tower
- Fully projective geometry
- Azimuth coverage down to ~2.8°
- Barrel: 65536 crystals
- Endcaps: 29800 crystals



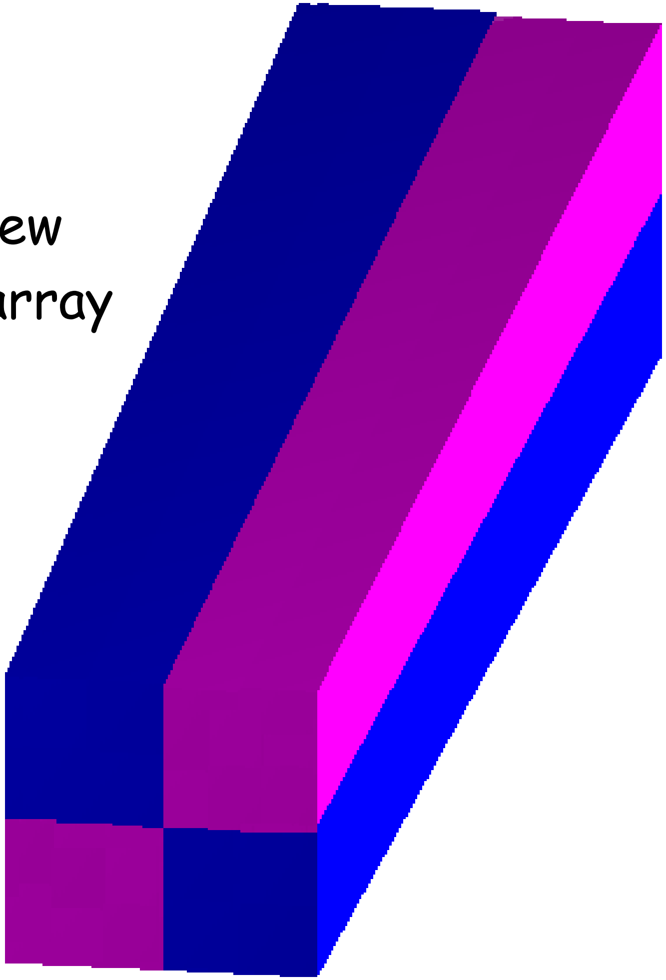
Electromagnetic Calorimeter Cells

Top cell size: ~ 4.3 × 4.3 cm^2
Bottom cell size: ~ 3.7 × 3.7 cm^2

- Array of 2x2 crystal
- Crystal size ~ 2x2x25 cm^3
- Each crystal is used to read scintillating and Čerenkov light
- Each crystal works as two independent cells in the same volume

Prospective view of BGO cells array

crystal length: 25 cm



Dual Readout BGO Calorimeter

MonteCarlo

- ROOT provides the Virtual MonteCarlo (VMC) interface
- VMC allows to use several MonteCarlo (Geant3, Geant4, Fluka)
- The user can select at run time the MonteCarlo to perform the simulations without changing any line of the code

The results presented here have been simulated using Fluka

Calibration

The energy of HCAL is calibrated in 2 steps:

- Calibrate with single 45 GeV e^-

  ➡ raw S_e and C_e

- Calibrate with single 45 GeV π^- and/or di-jet @ 91.2 GeV

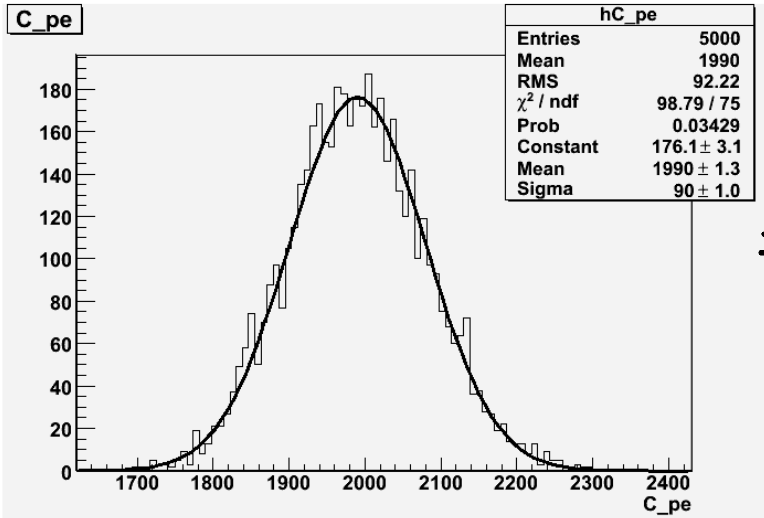
  ➡ η_c , η_s and η_n

$$\eta_C = \left(\frac{e}{h}\right)_C \qquad \eta_S = \left(\frac{e}{h}\right)_S$$

η_n is for neutrons

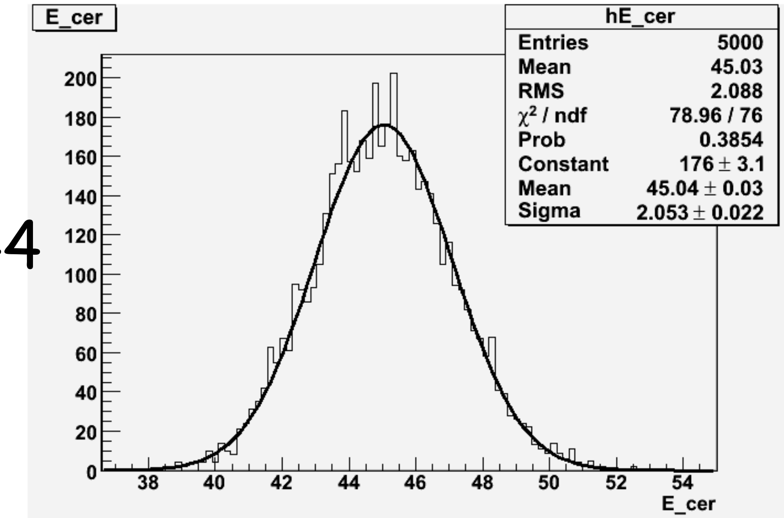
First step calibration

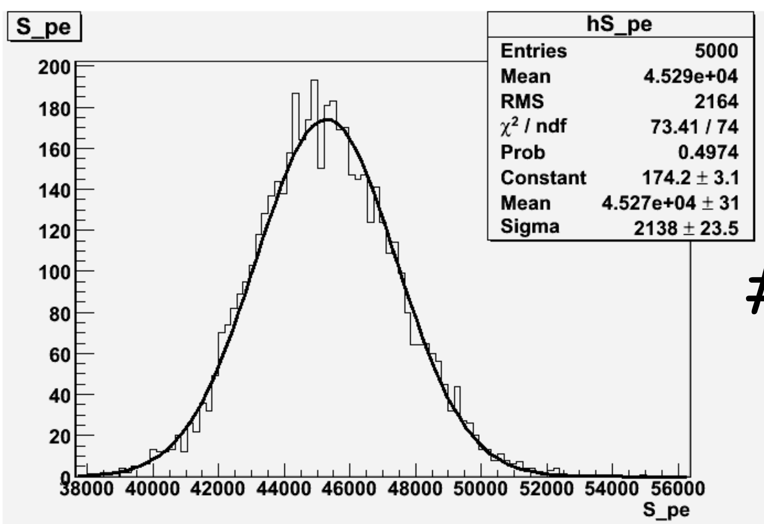
Beam of 45 GeV e^-



Cer

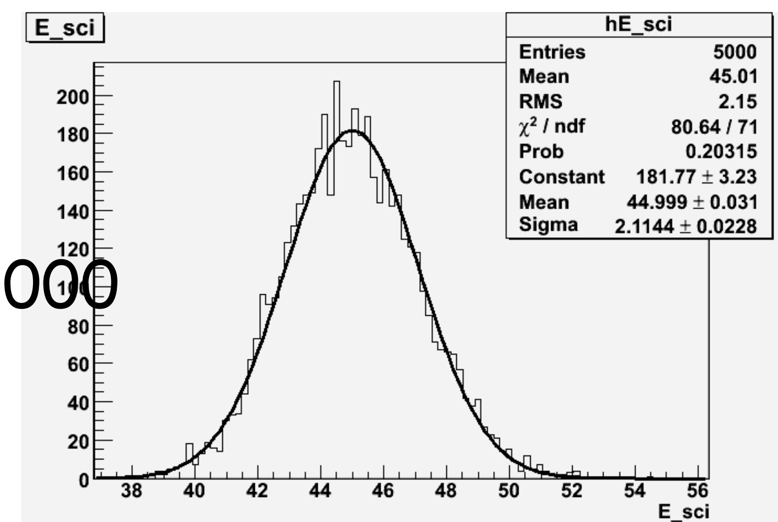
#pe/GeV ≈ 44





Scint

#pe/GeV ≈ 1000



How Dual Read-out works

$$R(f_{em}) = f_{em} + \frac{1}{\eta}(1 - f_{em})$$

$$R = \frac{E_{RAW}}{E}$$

f_{em} = em fraction of the hadronic shower

η = em fraction in the fibers

hadronic energy:

$$E_{Cal} = \frac{S_e - \lambda C_e}{1 - \lambda} + \eta_n Sn_e$$

$$\lambda = \frac{1 - 1/\eta_S}{1 - 1/\eta_C}$$

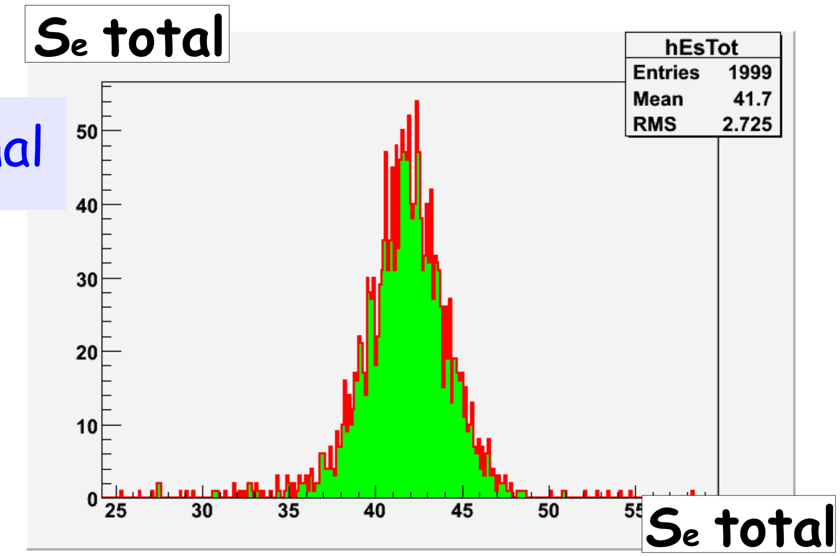
Dual Readout

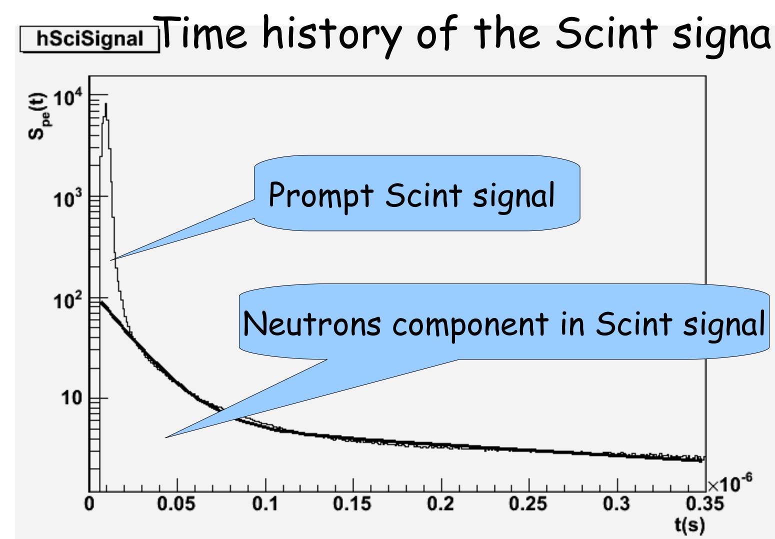
Triple Readout with time history

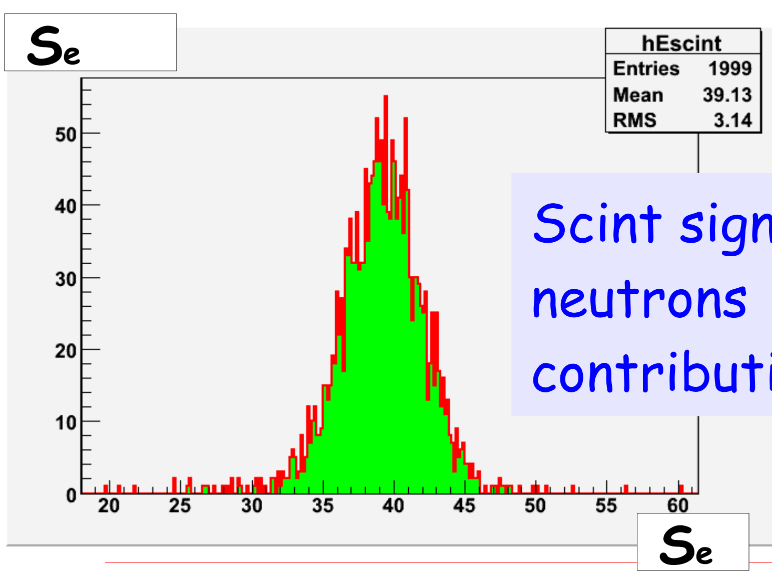
How Dual Read-out works

Separation of the neutron component in the scintillation signal

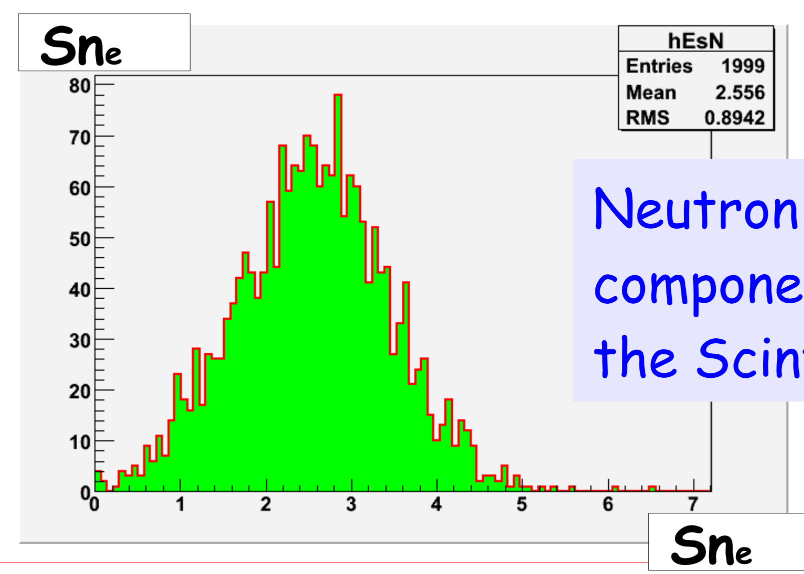
Full Scint signal





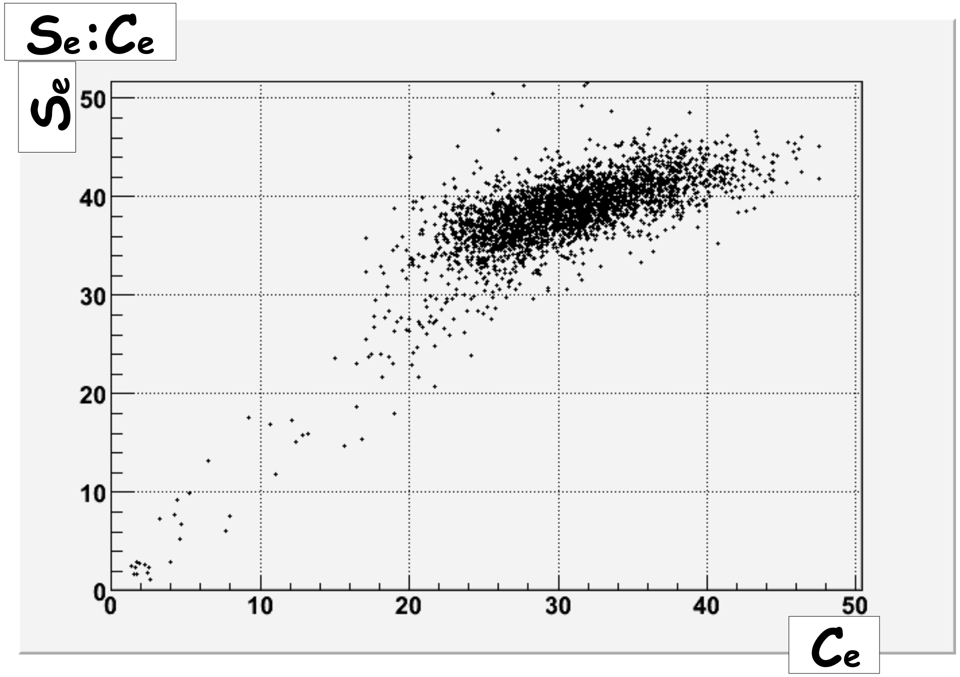


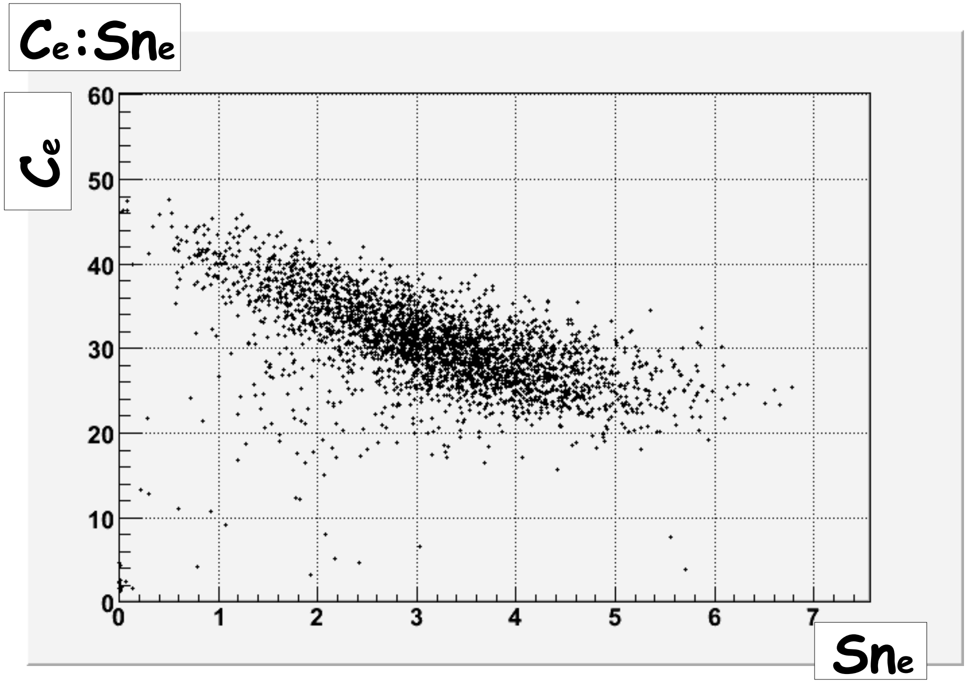
Scint signal w/o neutrons contribution

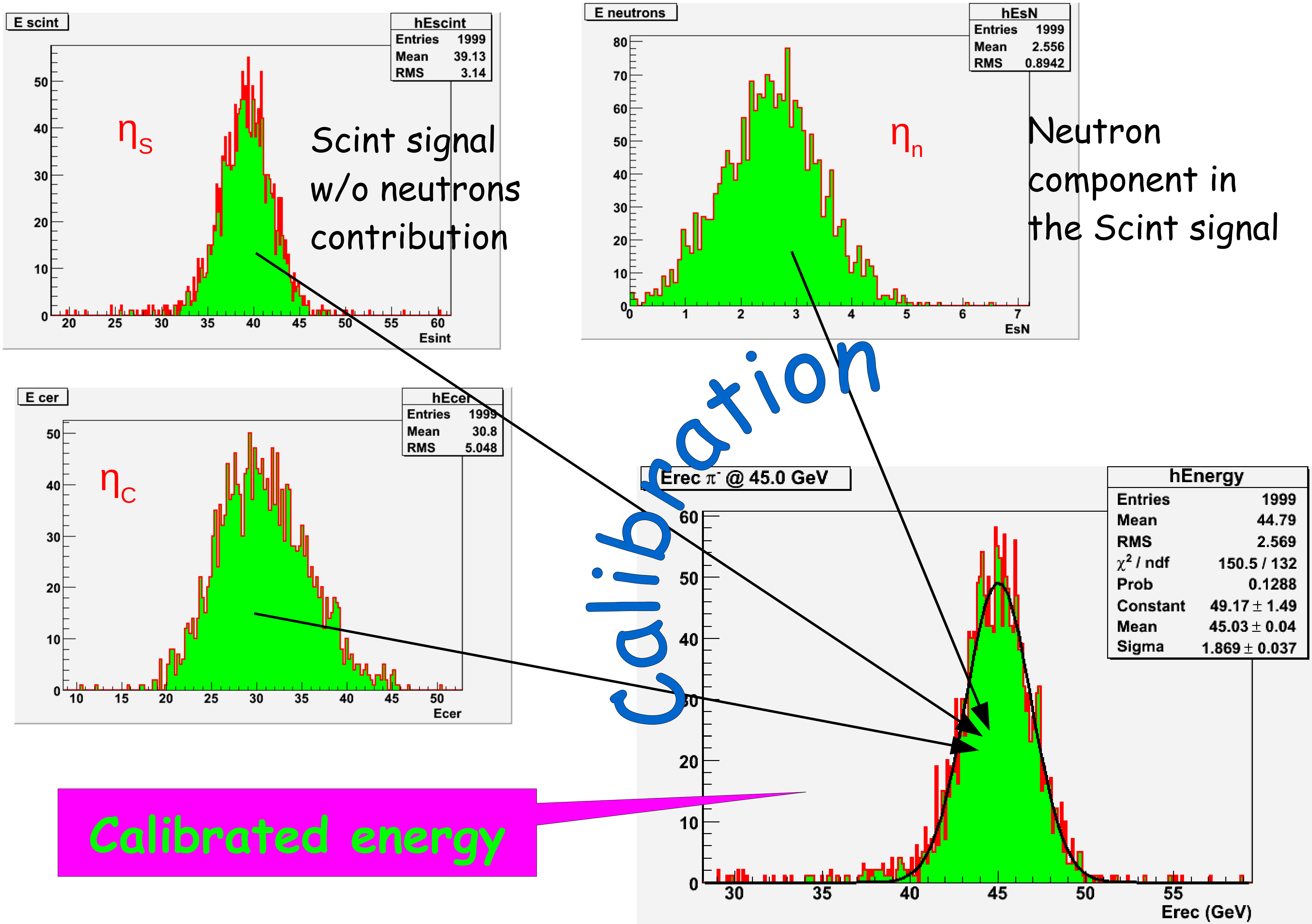


Neutron component in the Scint signal

Correlation between calorimeter signals



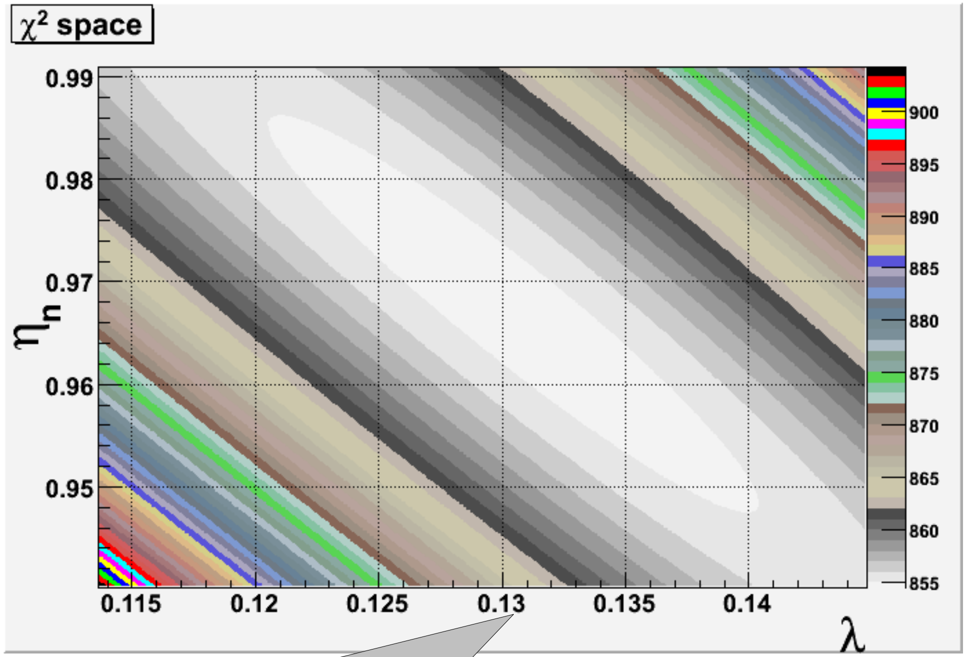



E scint
hEscint
Entries 1999
Mean 39.13
RMS 3.14
Esint
η_S
Scint signal w/o neutrons contribution
E neutrons
hEsN
Entries 1999
Mean 2.556
RMS 0.8942
EsN
η_n
Neutron component in the Scint signal
E cer
hEcer
Entries 1999
Mean 30.8
RMS 5.048
Ecer
η_C
Calibration
Erec π^- @ 45.0 GeV
hEnergy
Entries 1999
Mean 44.79
RMS 2.569
χ^2 / ndf 150.5 / 132
Prob 0.1288
Constant 49.17 ± 1.49
Mean 45.03 ± 0.04
Sigma 1.869 ± 0.037
Erec (GeV)
Calibrated energy

Second step calibration di-jet @ 91.2 GeV case

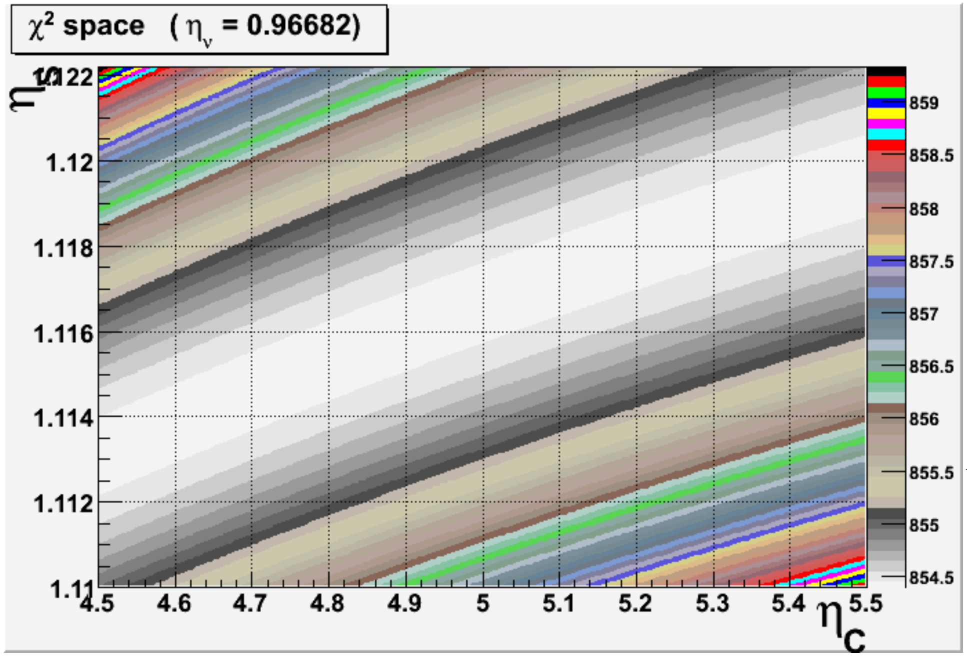
$$E_{Beam}=\frac{E_S-\lambda E_C}{1-\lambda}+\eta_n E_n$$

$$\lambda=\frac{1-1/\eta_S}{1-1/\eta_C}$$



η_n = 0.967 λ = 0.130

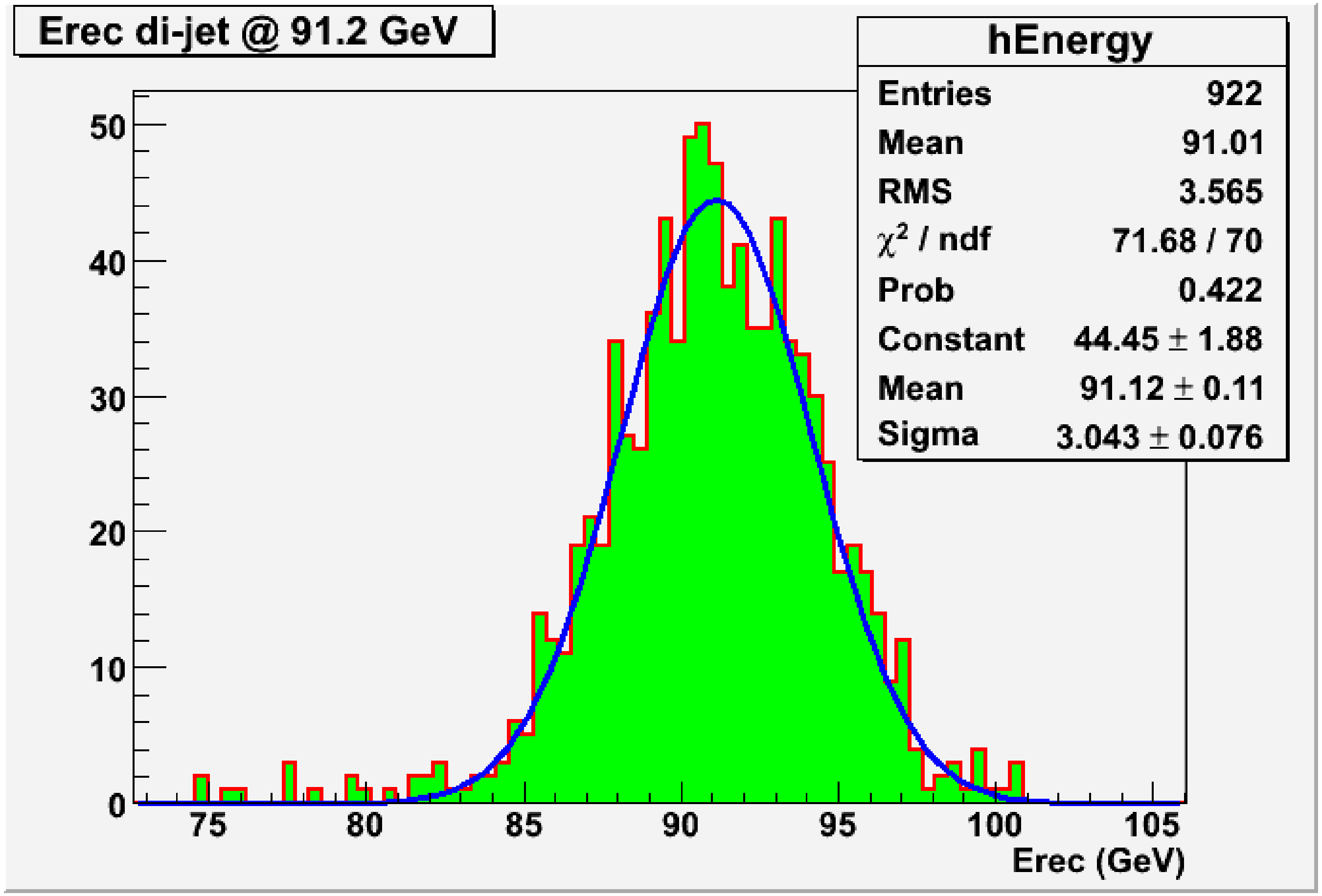
#events = 744
χ^2 = 854.39
χ^2/ndf = 1.15



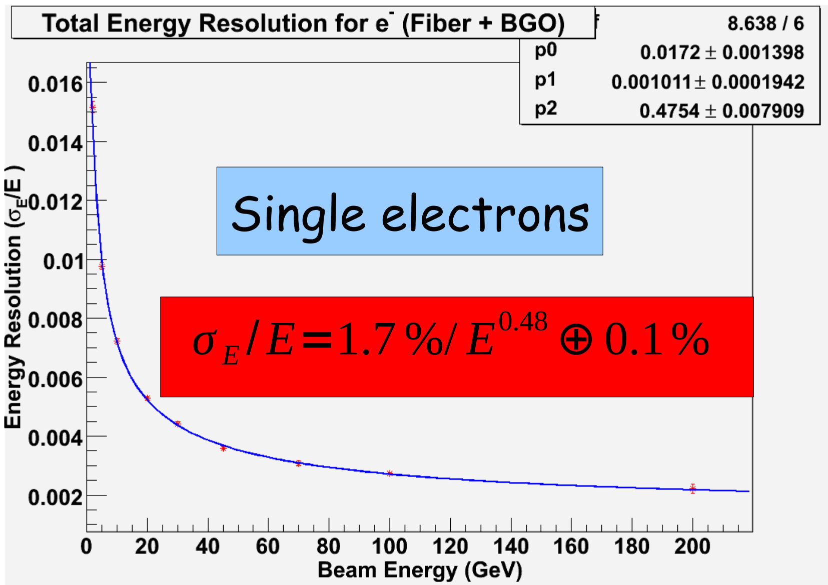
η_c = 4.665 η_S = 1.114

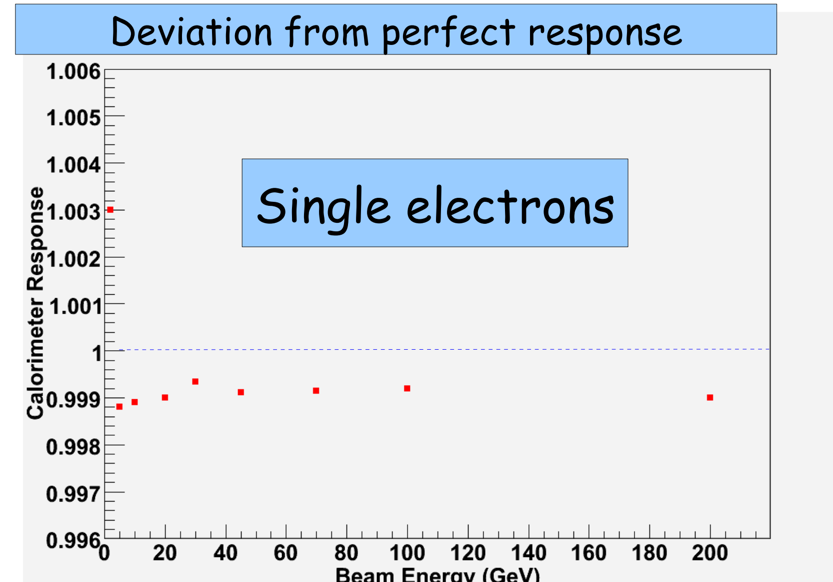
Calibrated energy: di-jet @ 91.2 GeV case using Triple Readout

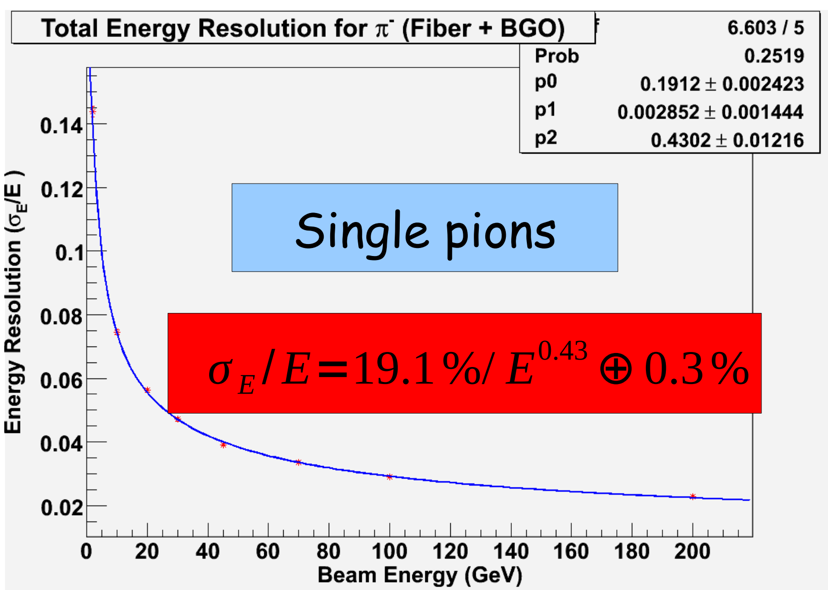
$$E_{HCAL} = \frac{E_S - \lambda E_C}{1 - \lambda} + \eta_n E_n$$

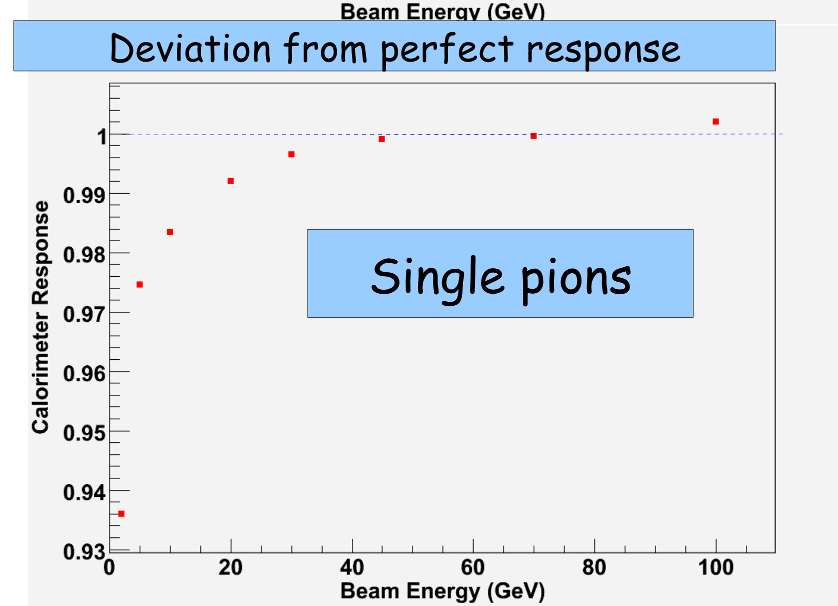


HCAL + ECAL resolution (single particles)

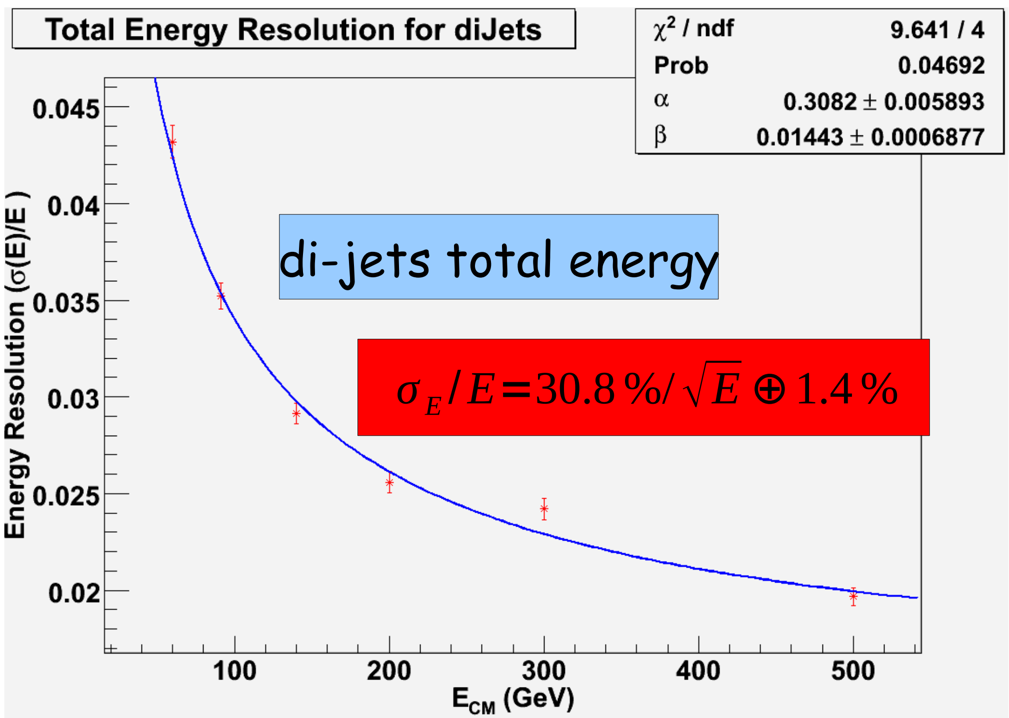


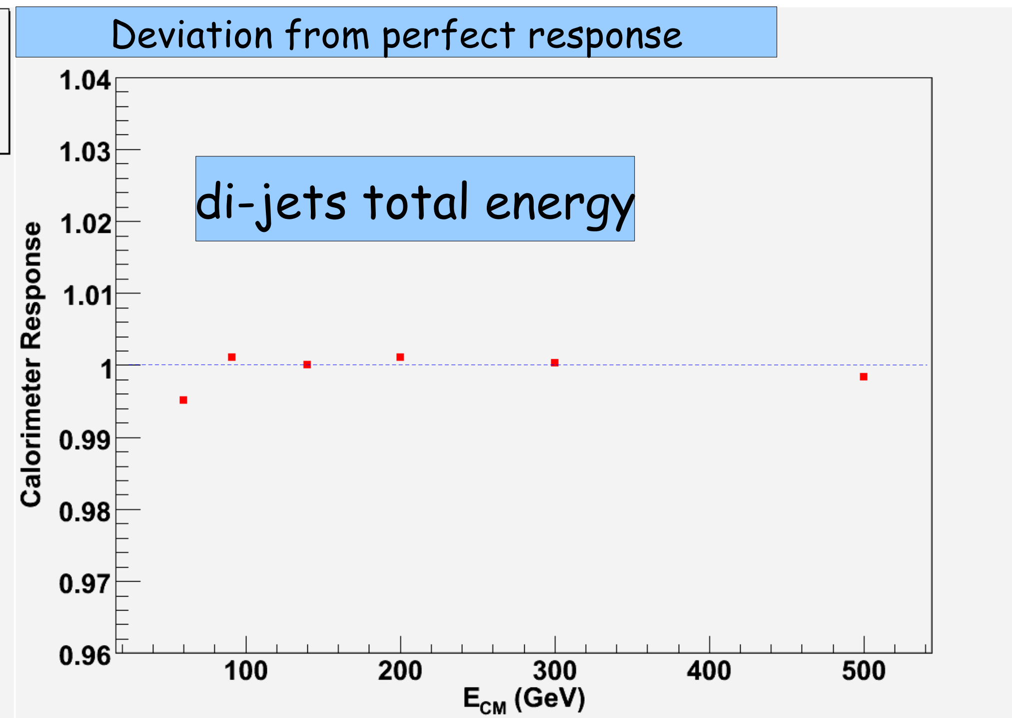






HCAL + ECAL resolution (di-jets)





HCAL + ECAL resolution: summary

Triple readout HCAL	Gaussian resolution stocastic term	constant term
π^-	25.6%/√E	1.5%
di-jet	29%/√E	1.2%

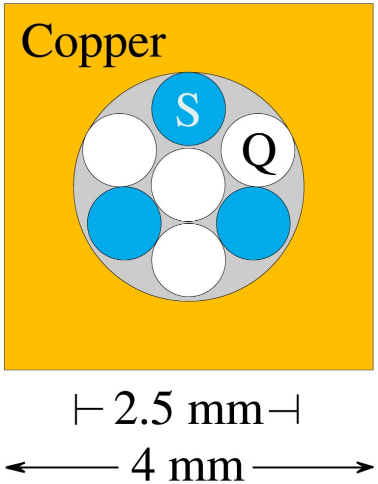
Triple readout ECAL + HCAL	Gaussian resolution stocastic term	constant term
e^-	$1.7\%/E^{0.48}$	0.1%
π^-	$19.1\%/E^{0.43}$	0.3%
di-jet	30.8%/√E	1.4%

How the mass reconstructions of Physics particles is affected by the calorimeter performances?

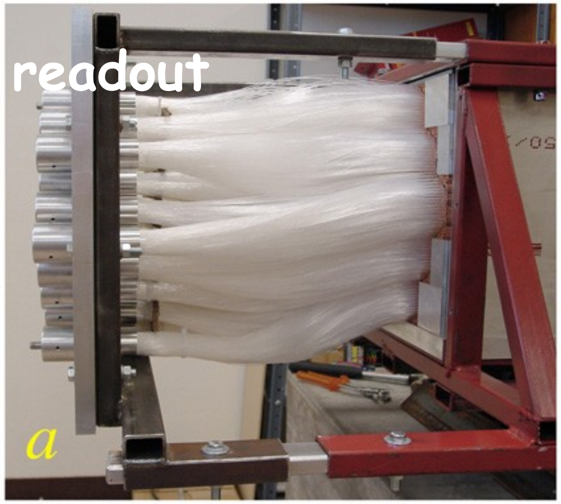
2 jets	$e^+e^- \rightarrow Z^0H^0$; $Z \rightarrow \nu\bar{\nu}$; $H \rightarrow q\bar{q}$	$M_{Higgs} = 119.60 \pm 0.07$ GeV/c^2 $\sigma_{Higgs} = 3.83 \pm 0.07$ GeV/c^2	**35%/√E**	HCAL
4 jets	$e^+e^- \rightarrow Z^0H^0$; $Z \rightarrow u\bar{u}$; $H \rightarrow c\bar{c}$	$M_{Higgs} = 117.9 \pm 1.2$ GeV/c^2 $\sigma_{Higgs} = 4.48 \pm 1.6$ GeV/c^2	**41%/√E**	HCAL
4 jets	$e^+e^- \rightarrow \chi_1^+\chi_1^- \rightarrow \chi_1^0\chi_1^0 W^+W^-$	$M_W = 79.40 \pm 0.06$ GeV/c^2 $\sigma_W = 2.84 \pm 0.06$ GeV/c^2	**31%/√E**	HCAL + ECAL
4 jets	$e^+e^- \rightarrow \chi_2^0\chi_2^0 \rightarrow \chi_1^0\chi_1^0 Z^0Z^0$	$M_Z = 89.55 \pm 0.20$ GeV/c^2 $\sigma_Z = 2.77 \pm 0.21$ GeV/c^2	**29%/√E**	HCAL + ECAL
6 jets	$e^+e^- \rightarrow t\bar{t} \rightarrow W^+bW^-b \rightarrow qqbqqb$	$M_{top} = 174.21 \pm 0.06$ GeV/c^2 $\sigma_{top} = 4.65 \pm 0.06$ GeV/c^2	**35%/√E**	HCAL

Look at the Corrado Gatto talk on the benchmark Physics studies

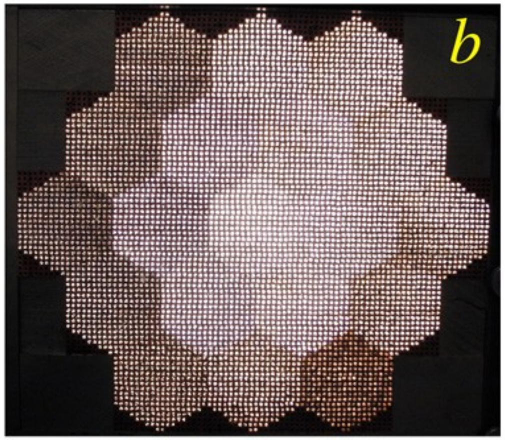
DREAM beam test setup



Unit cell

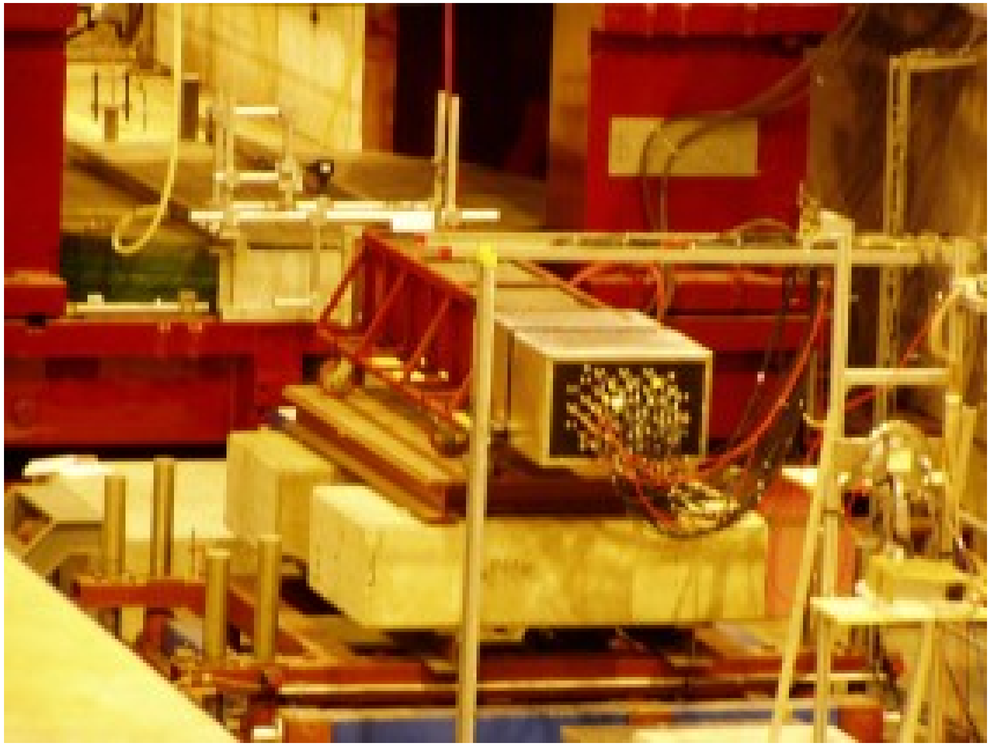


Channels structure



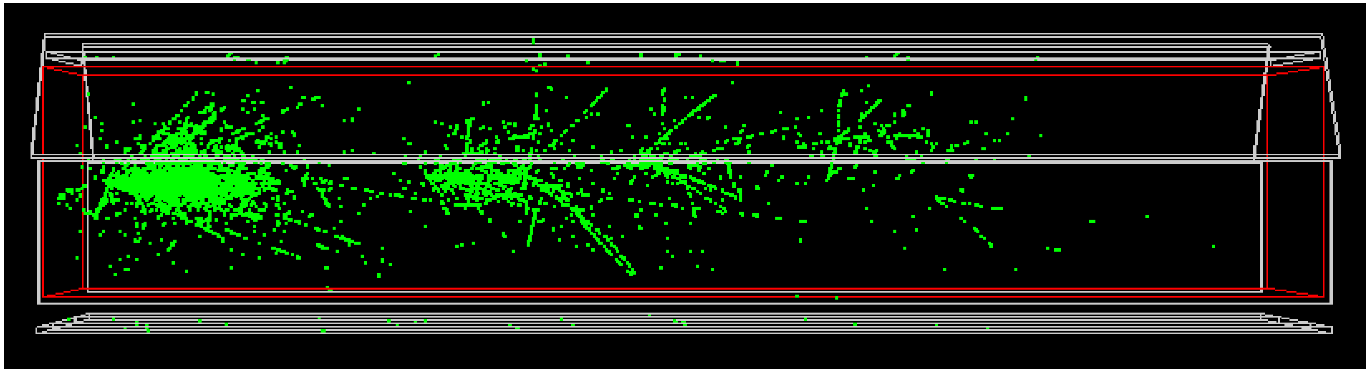
Look at the John Hauptman and Nural Akchurin talks in the Calorimetry session

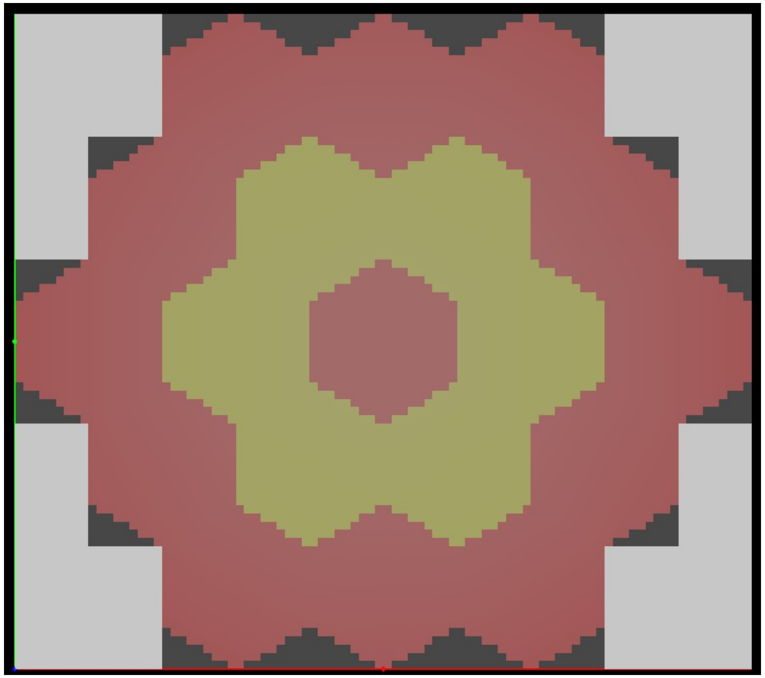
DREAM



DREAM simulated in ILCroot

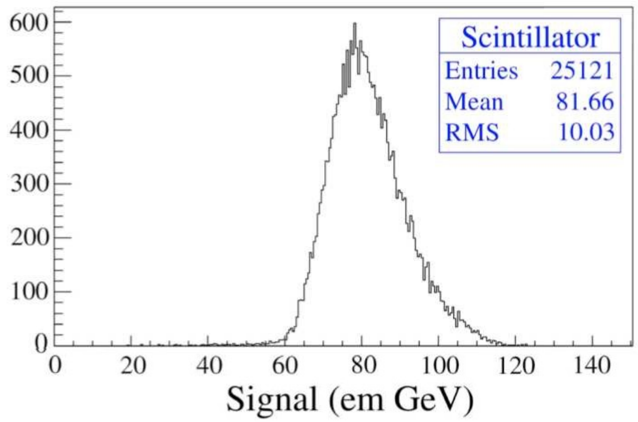
100 GeV π^- shower

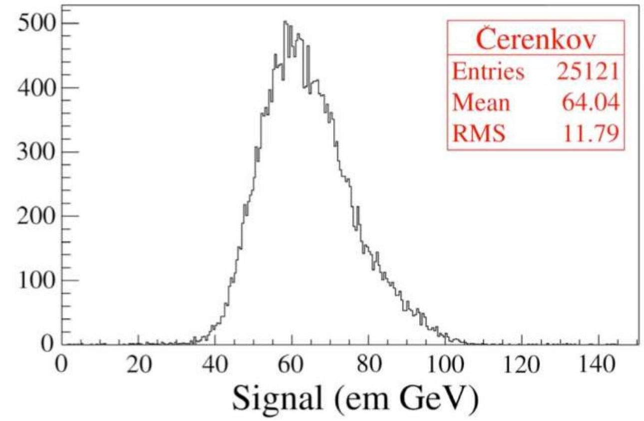




Front view of the DREAM module in the simulation

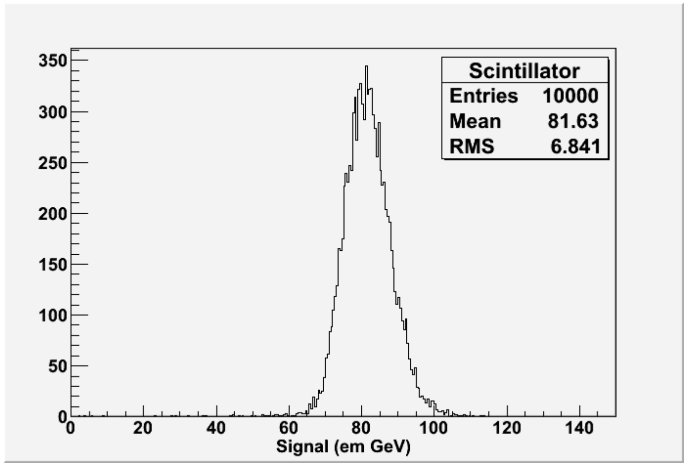
Scintillation and Cerenkov signal distributions for 100 GeV pions

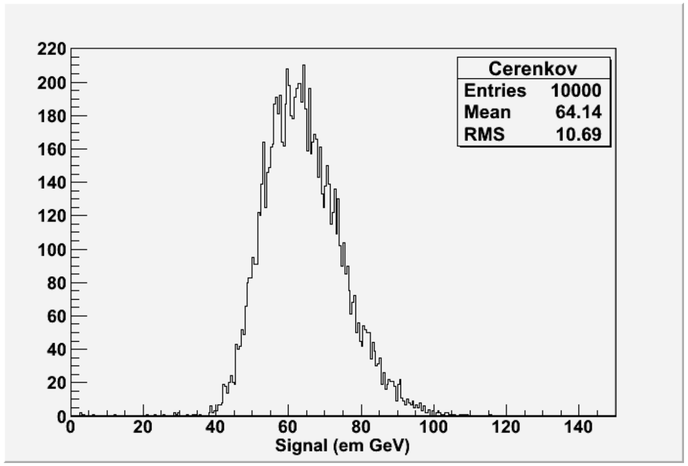




DREAM data

(raw signals)

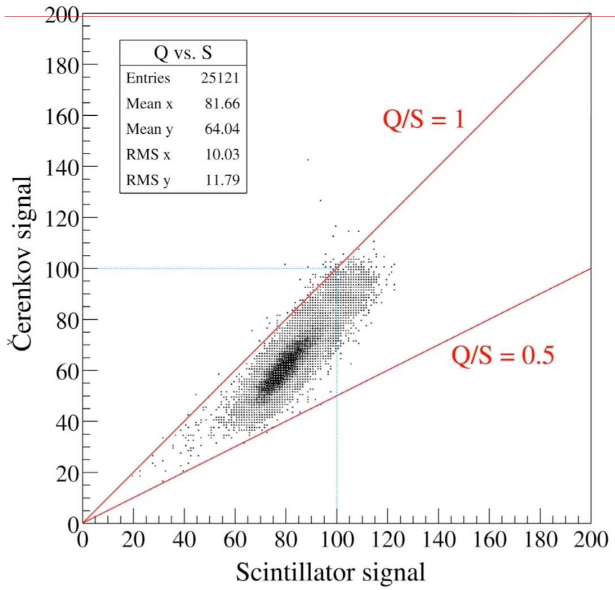


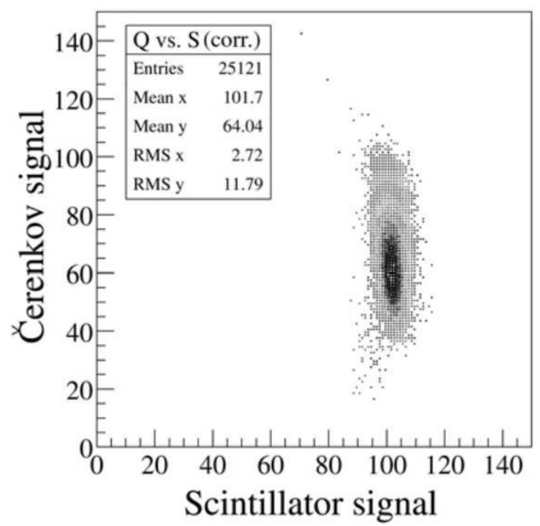


ILCroot simulation

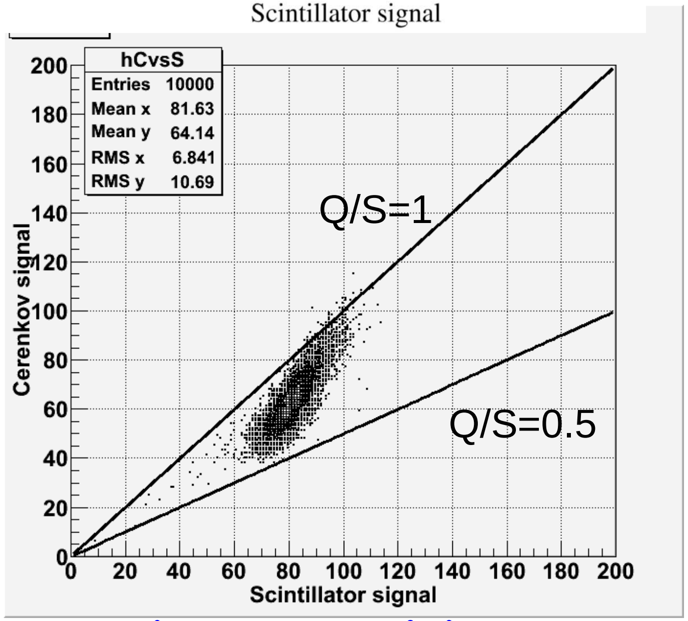
Note: DREAM integrate the signal in 80 ns, in the ILCroot simulation I integrate the signal in 350 ns

Scintillation signal vs. Cerenkov signal for 100 GeV pions

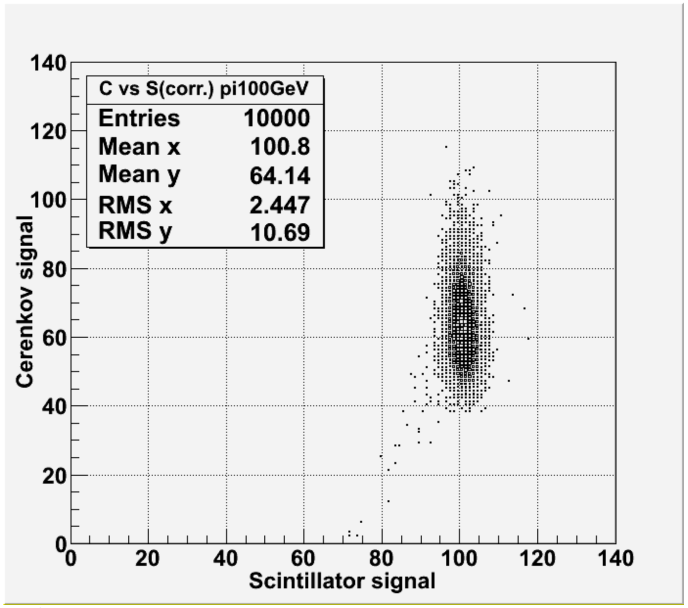




DREAM data



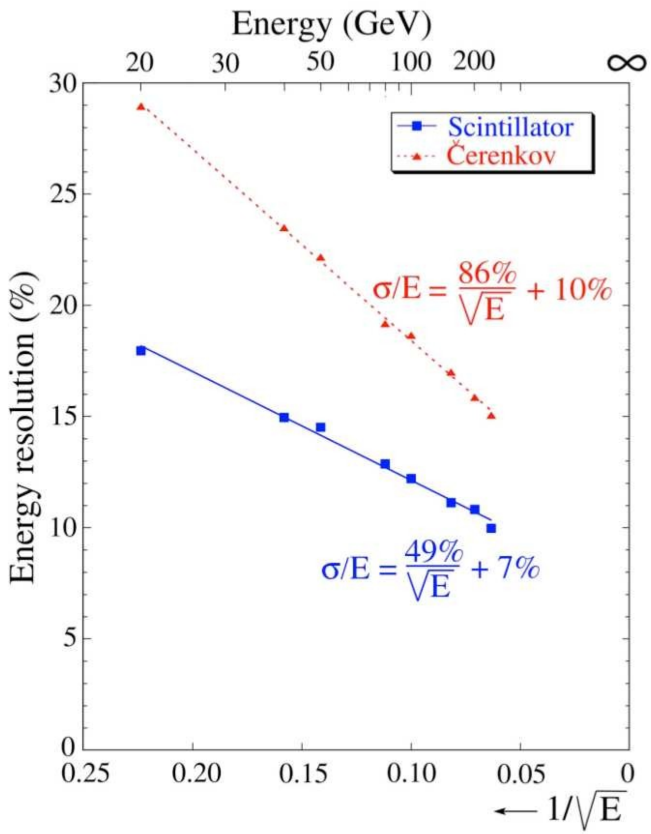
(raw signals)

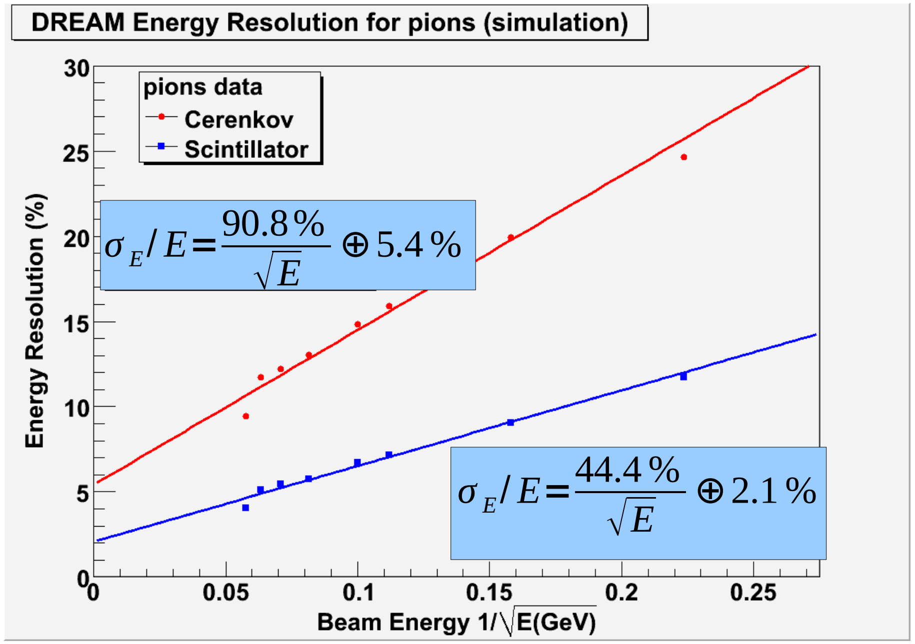


(raw Cer, corrected Scint)

ILCroot simulation

Individual resolutions for pions in the scintillation and Cerenkov signals



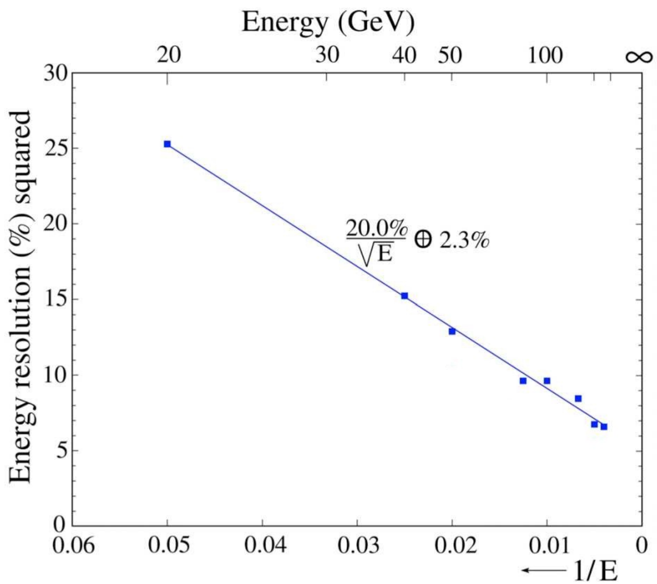


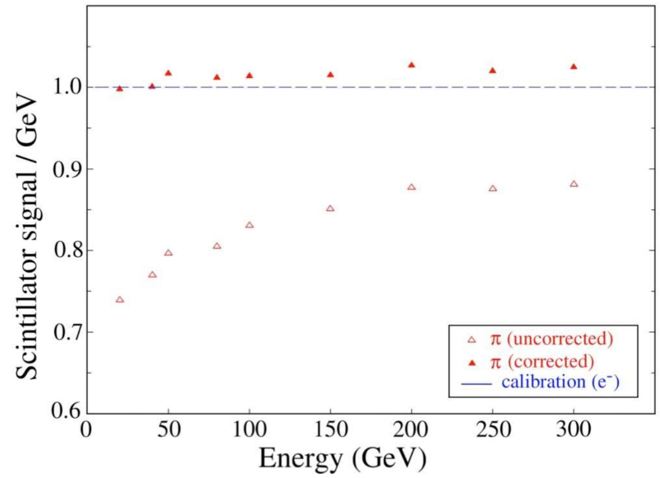
DREAM data

(raw signals)

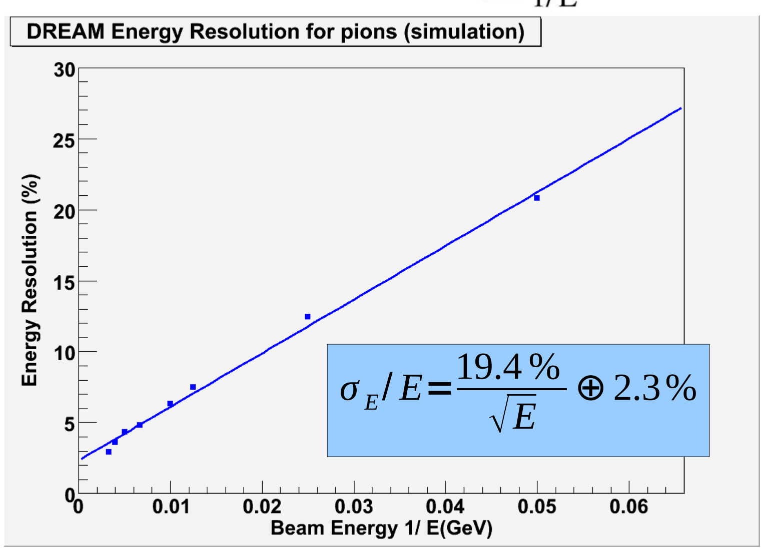
ILCroot simulation

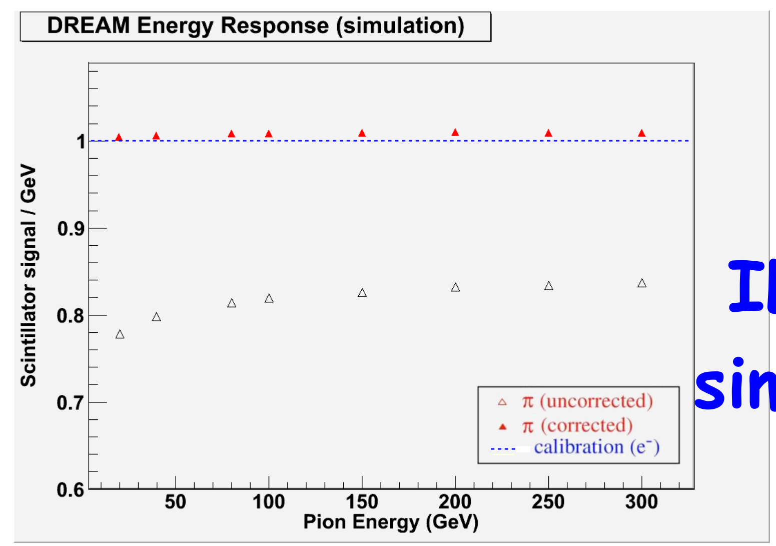
Energy resolutions for pions (calibrated energy)





DREAM data





ILCroot simulation

The algorithm used for the reconstructed energies are not the same but equivalent

Conclusion

- The Dual/Triple Readout calorimetry is performing very well with data and simulations
- Need to work to understand the constant term in the energy resolution and make it more realistic
- Effect on the Physics is well understood
- Comparison of ILCroot simulations with DREAM test beam is exellent
- **All the machinery is ready to perform a very large number of Physics and performances studies**