Dual readout calorimetry in 4th Concept

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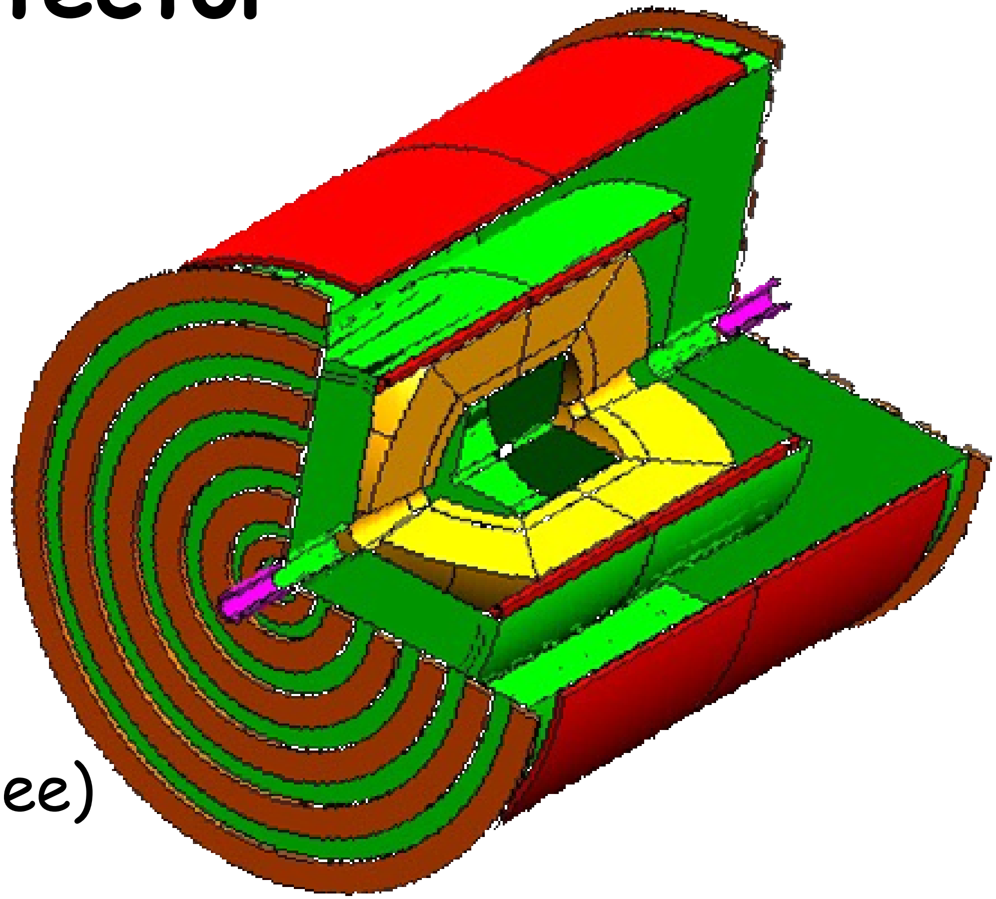
Outline

- The 4th Concept
- ILCroot Offline Framework
- Hadronic Calorimeter geometry
- Calibration studies
- Conclusion

The 4th Concept detector



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

Subject of this talk

ILCRoot: summary of features

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

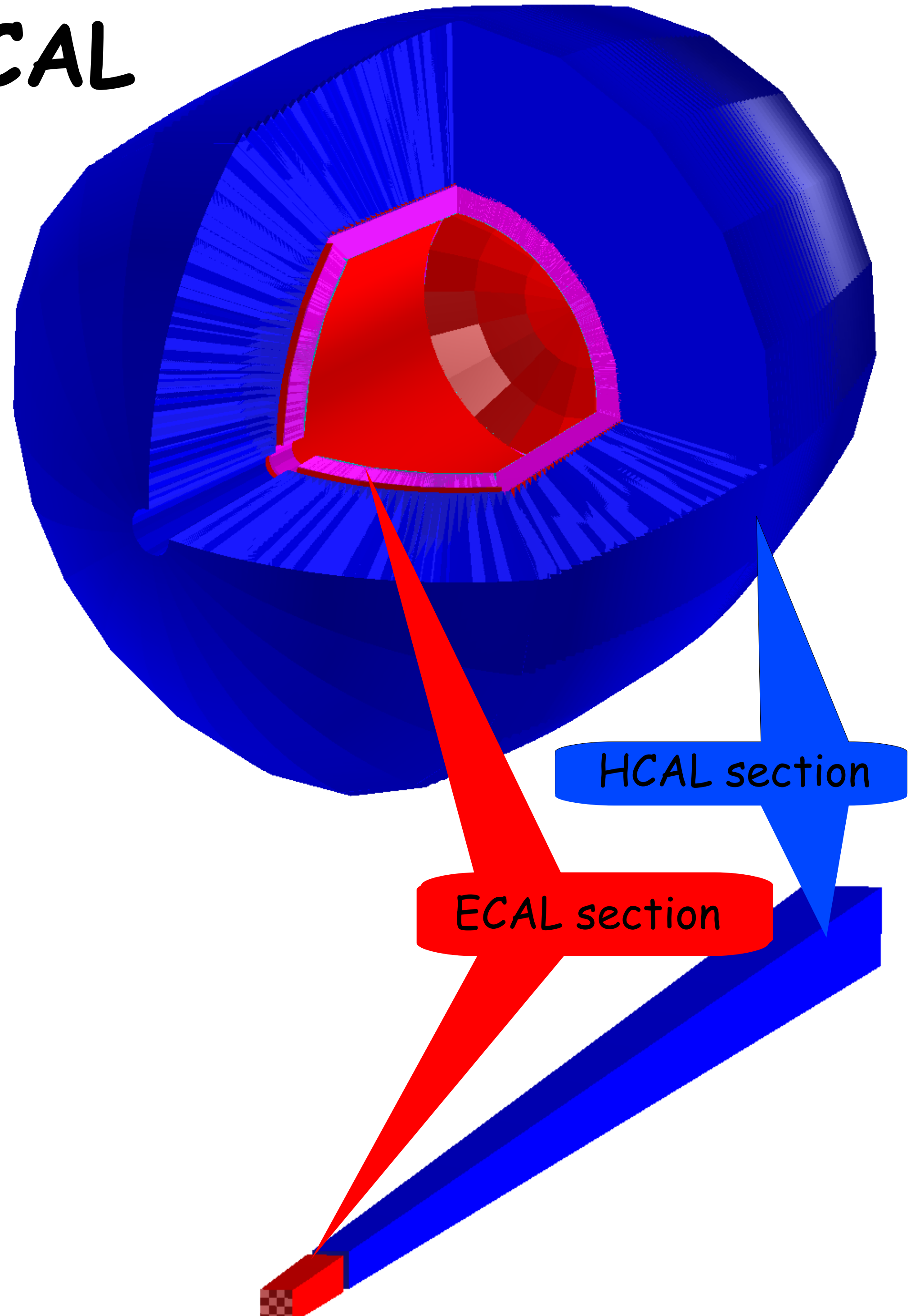
  All ROOT tools are available (I/O, graphics, PROOF, data structure, etc)

  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!!!

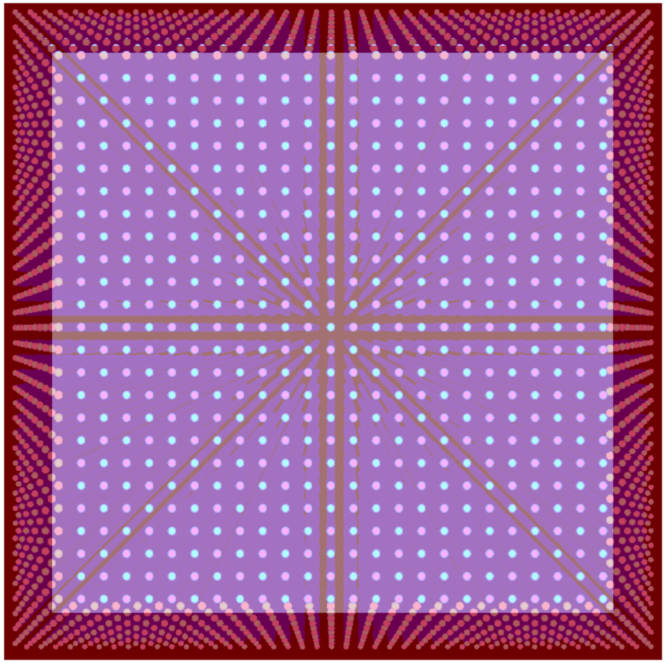
All the studies presented are performed by ILCRoot

The 4th Concept HCAL

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

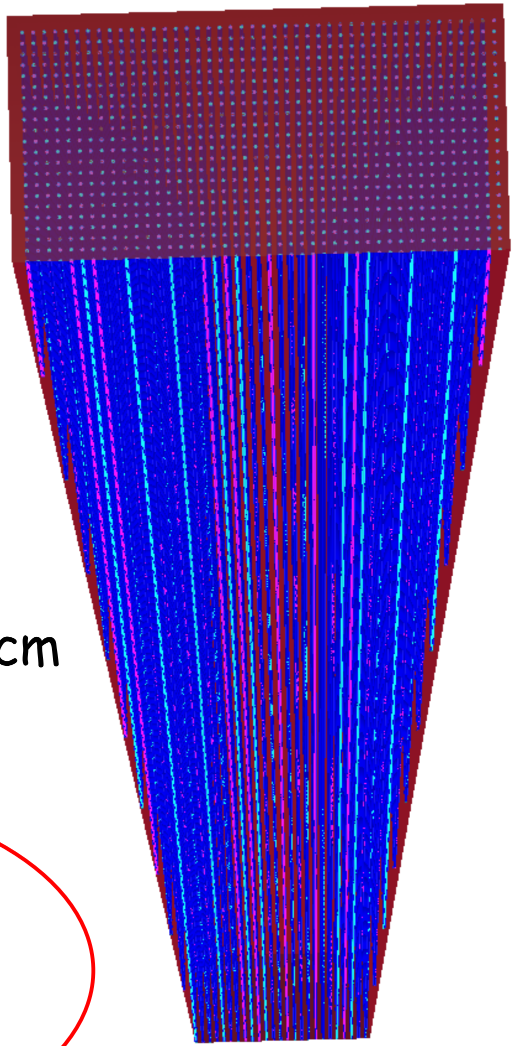


Hadronic Calorimeter Towers



Bottom view of single tower

Top tower size:
~ 8.1 × 8.1 cm^2



Prospective view of clipped tower

Quite the same absorber/fiber ratio as DREAM

Tower length: 150 cm

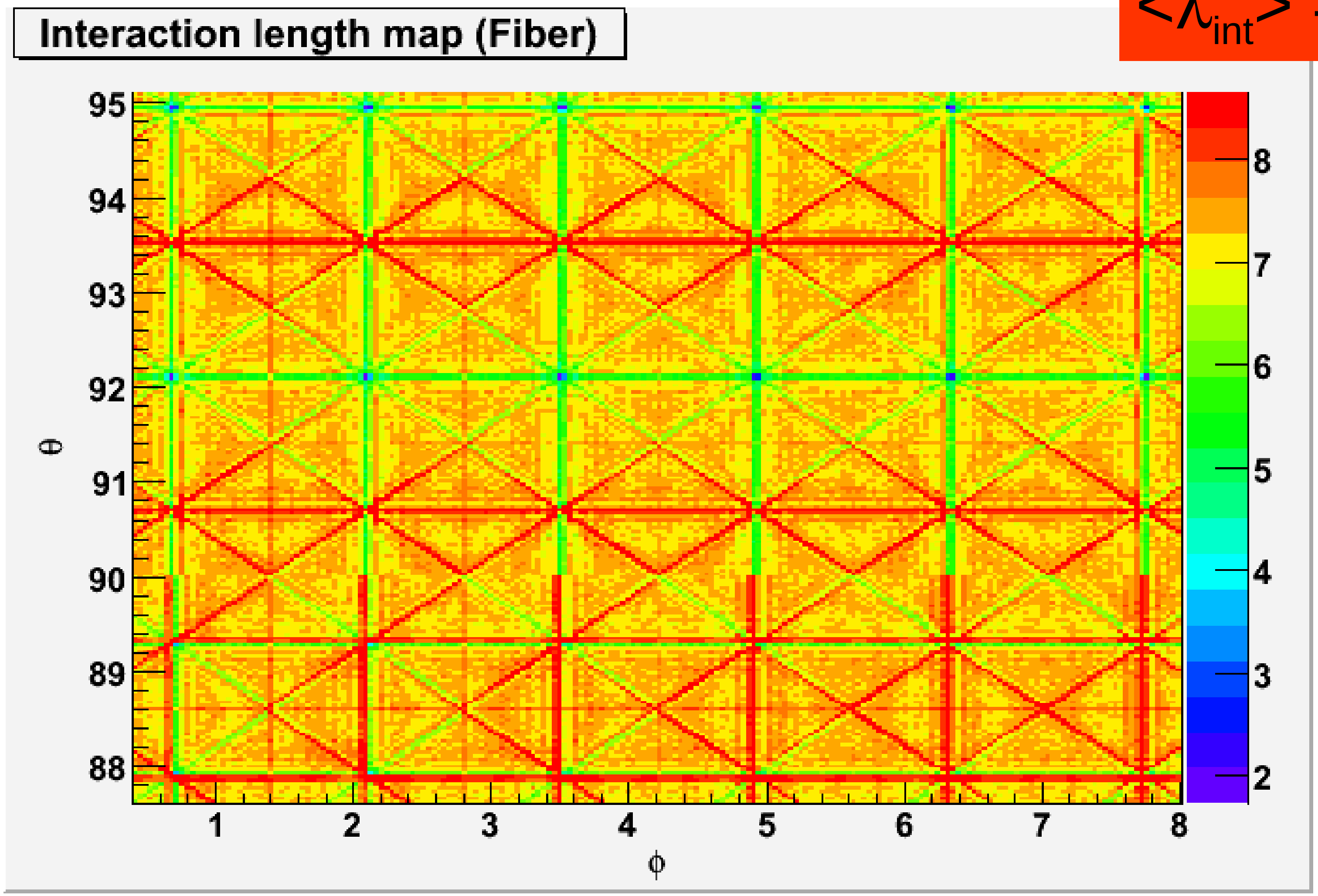
Bottom tower size:
~4.4 × 4.4 cm^2

- 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

Dual Readout Fibers Calorimeter

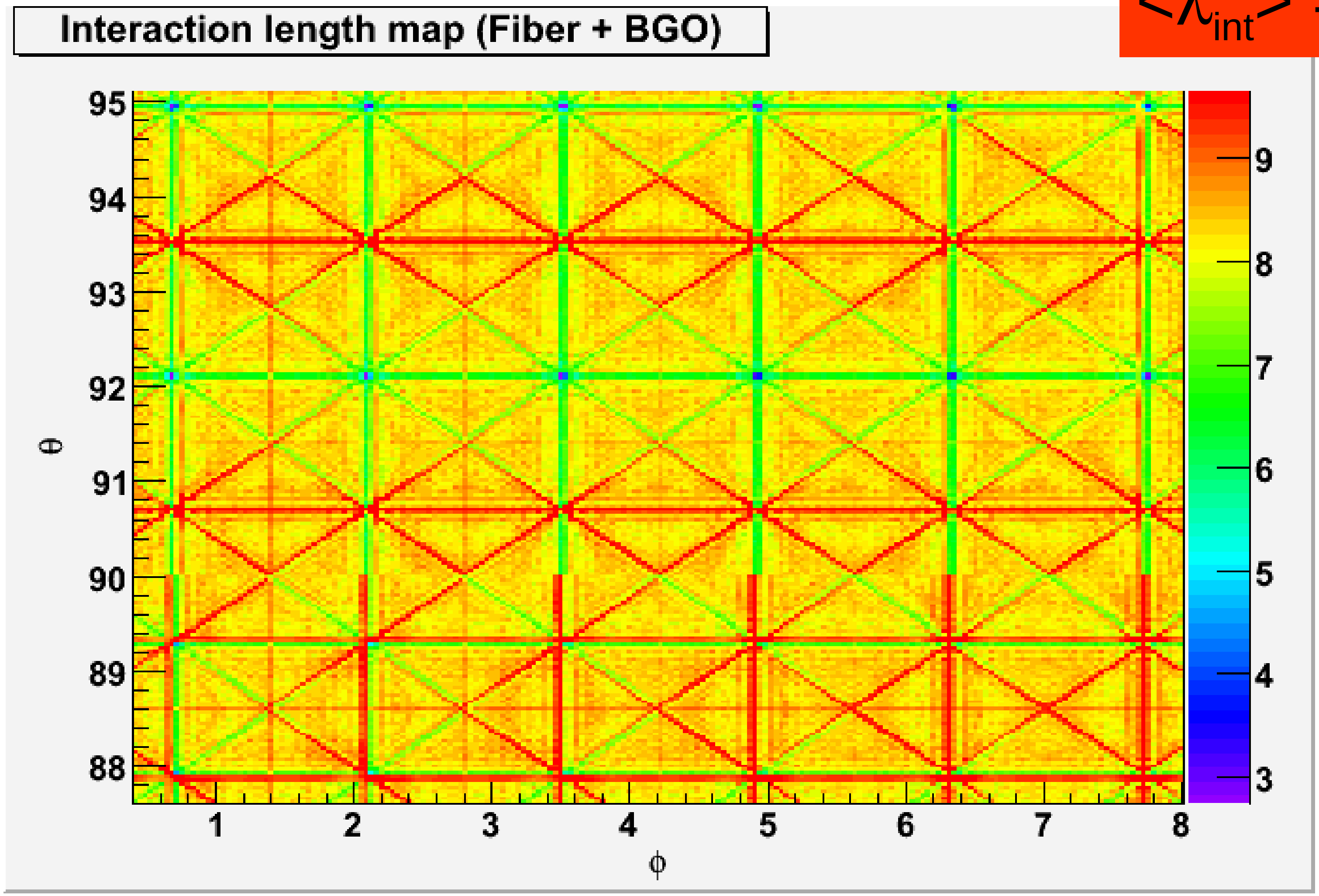
Material Budget Map (Fibers)

$<\lambda_{int}> = 7.3$



Material Budget Map (Crystal+Fibers)

$\langle\lambda_{int}\rangle = 8.3$



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:

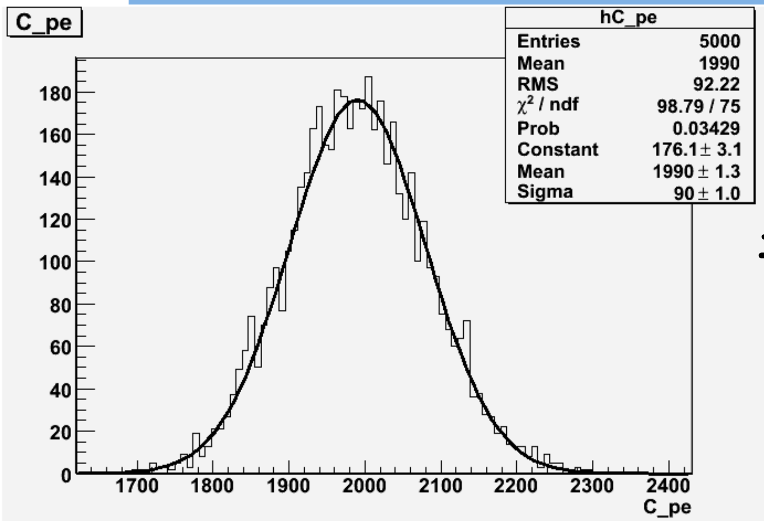
- Calibrate with single 45 GeV e^-
  - ➡ raw E_c and E_s
- Calibrate with single 45 GeV π^- and/or di-jet @ 91.2 GeV
  - ➡ η_c , η_s and η_n

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

η_n is for neutrons

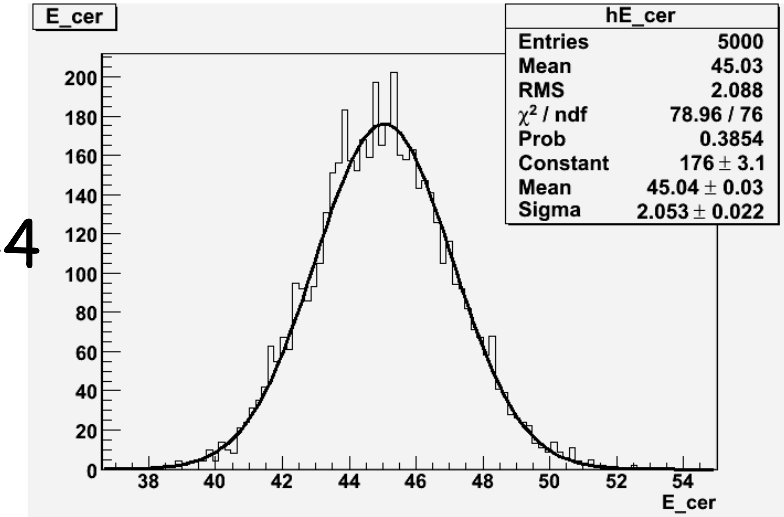
First step calibration

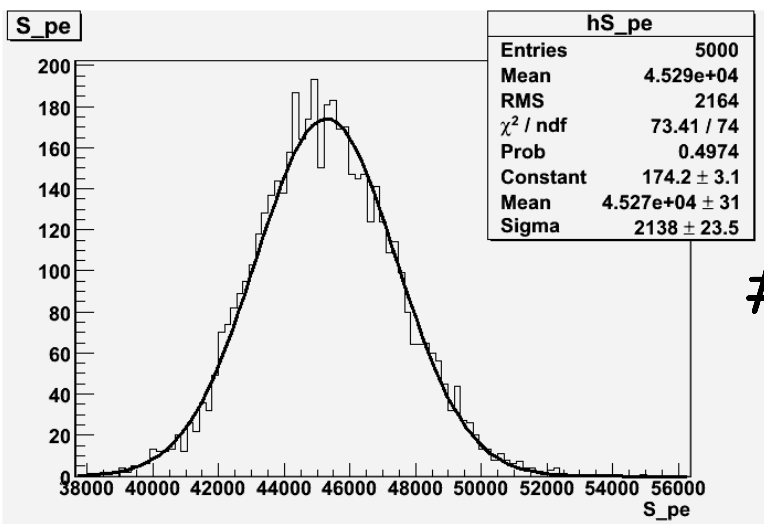
Beam of 45 GeV e^-



Cer

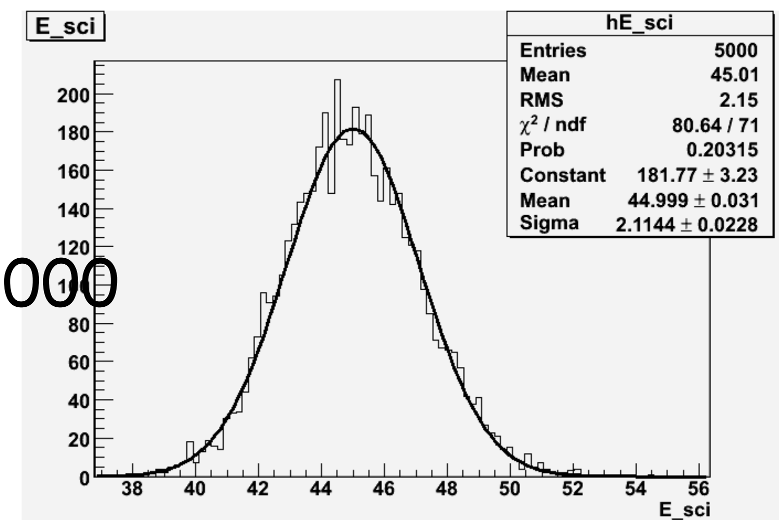
#pe/GeV ≈ 44





Scint

#pe/GeV ≈ 1000



Second step calibration

π^- @ 45 GeV

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

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

f_{em} = em fraction of the hadronic shower

η = em fraction in the fibers

hadronic energy:

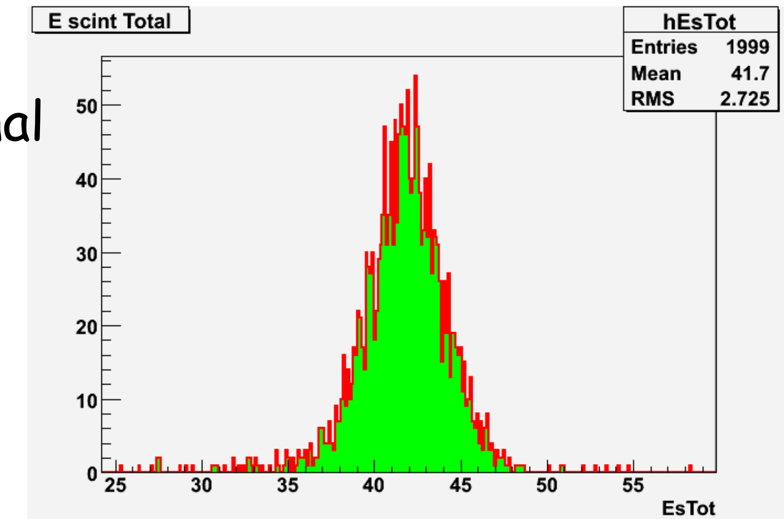
$$E_{Beam} = \frac{\eta_S E_S (\eta_C - 1) - \eta_C E_C (\eta_S - 1)}{\eta_C - \eta_S} + \eta_n E_n$$

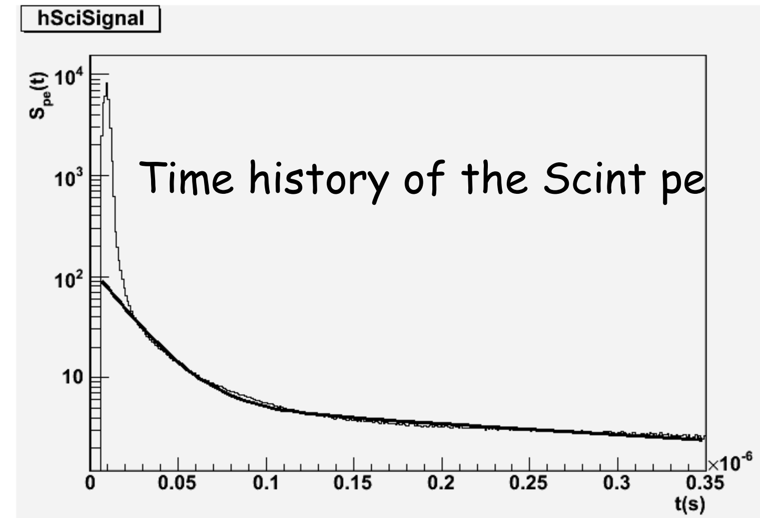
Dual Readout

Triple Readout with time history

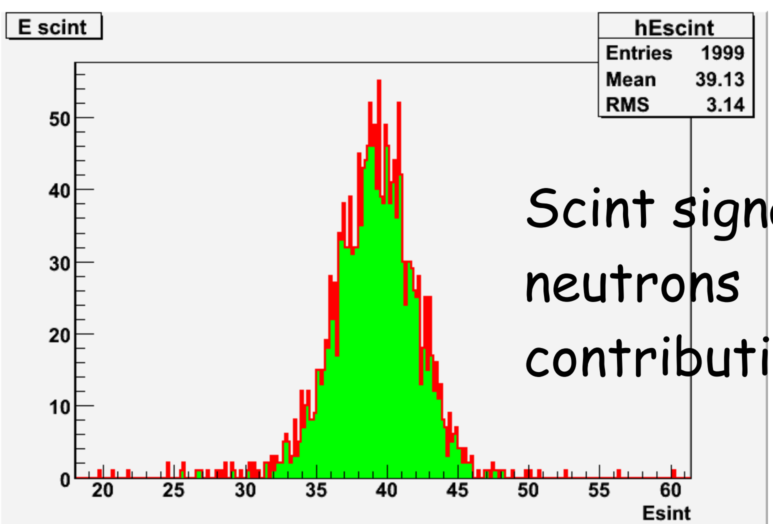
Separation of the neutron component in the scintillation signal

Full Scint signal

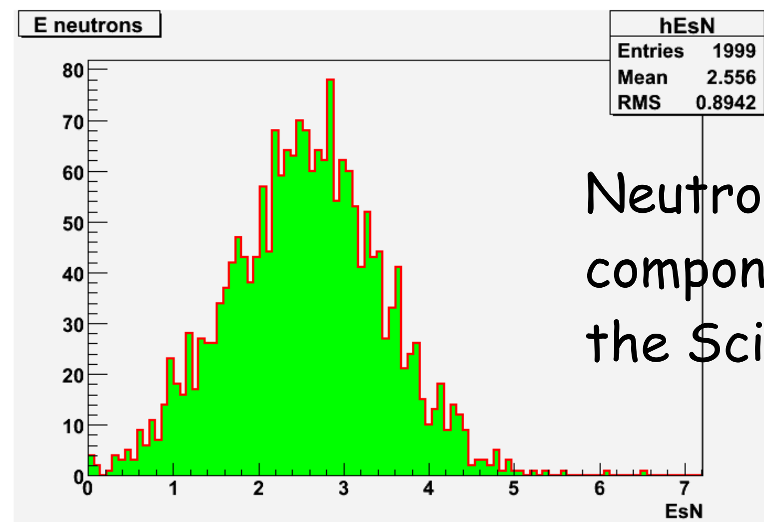




Time history of the Scint pe



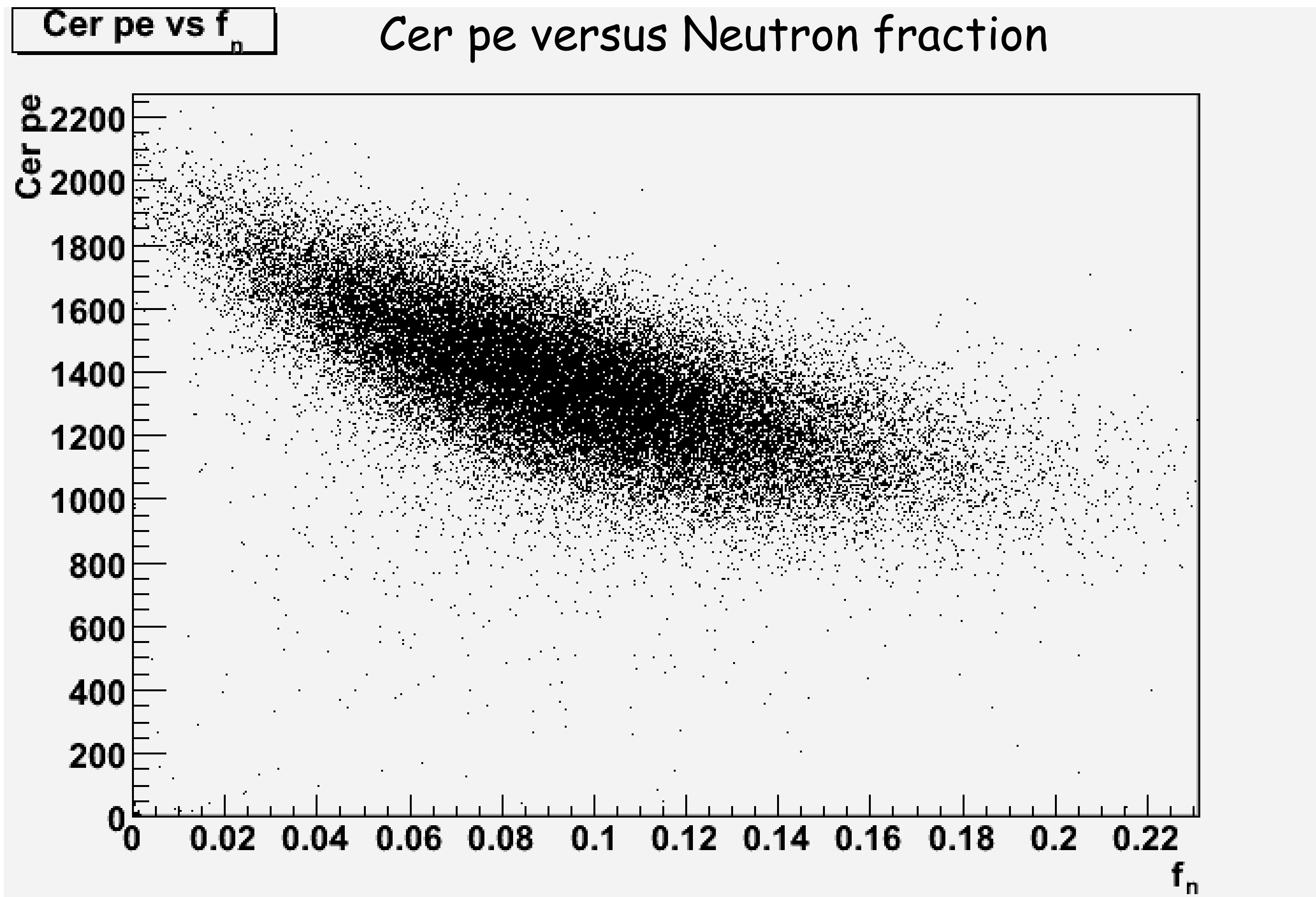
Scint signal w/o neutrons contribution

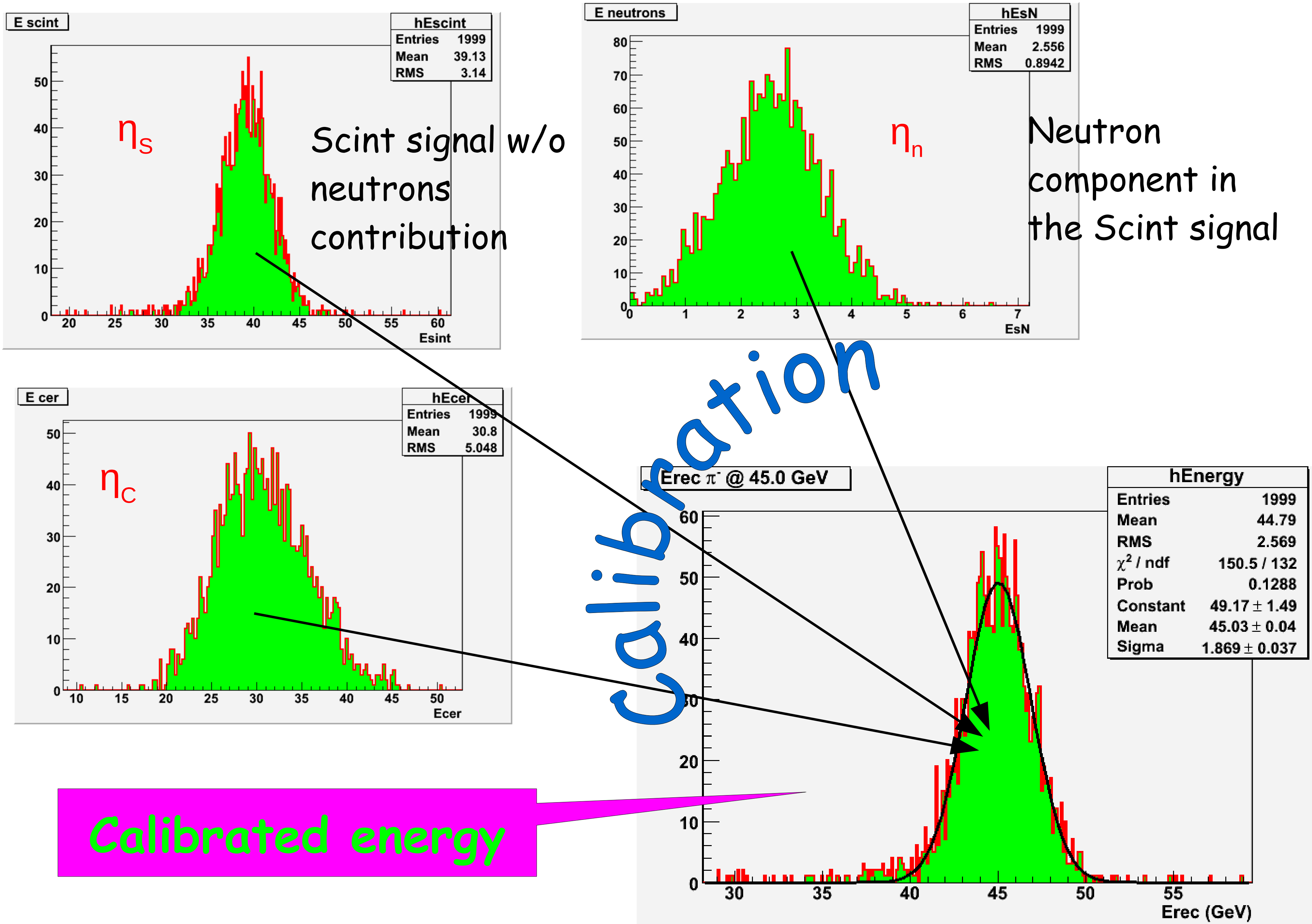


Neutron component in the Scint signal

Correlation between neutron signal and Čerenkov signal

π^- @ 45 GeV



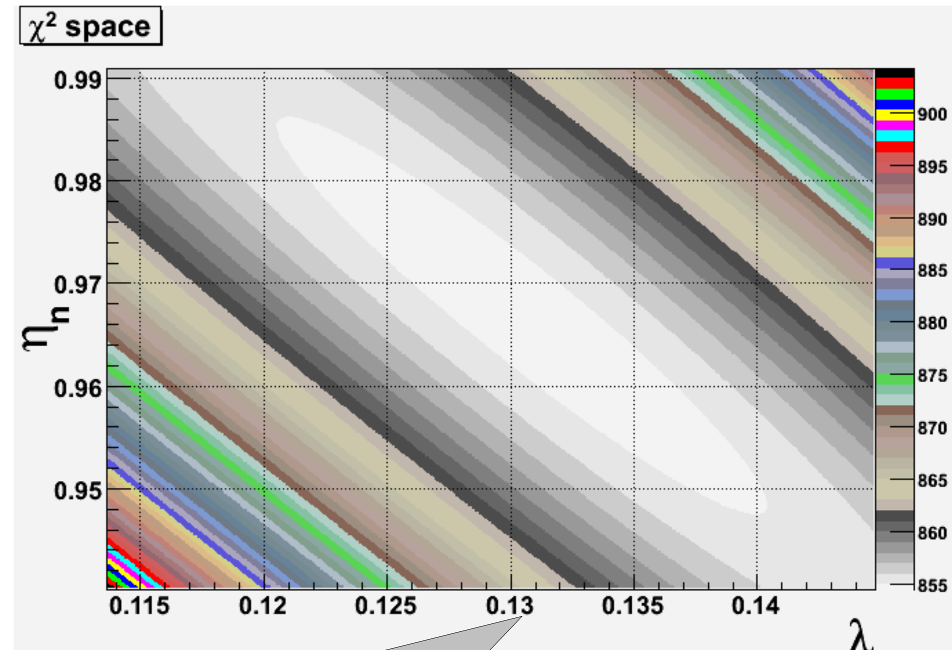


E scint
hEscint
Entries 1999
Mean 39.13
RMS 3.14
Esint
η_S
Scint signal w/o neutrons contribution
E neutrons
hEsN
Entries 1999
Mean 2.556
RMS 0.8942
EsN
η_n
Neutron component in the Scint signal
E cer
hEcer
Entries 1999
Mean 30.8
RMS 5.048
Ecer
η_C
Calibration
Erec π⁻ @ 45.0 GeV
hEnergy
Entries 1999
Mean 44.79
RMS 2.569
χ² / 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

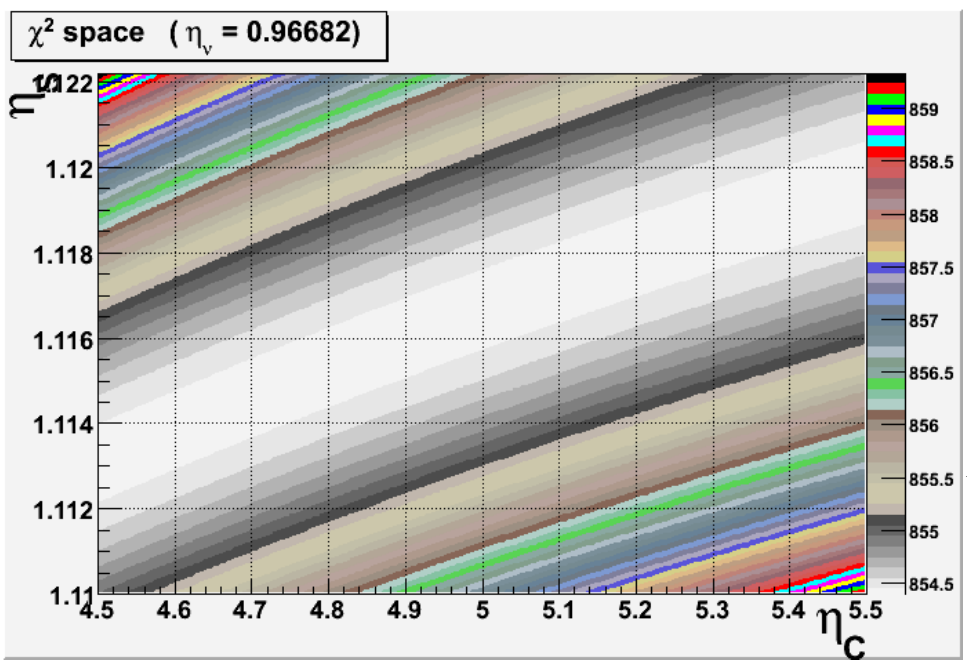
Second step calibration   di-jet @ 91.2 GeV case

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

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



η_n = 0.967 λ = 0.130



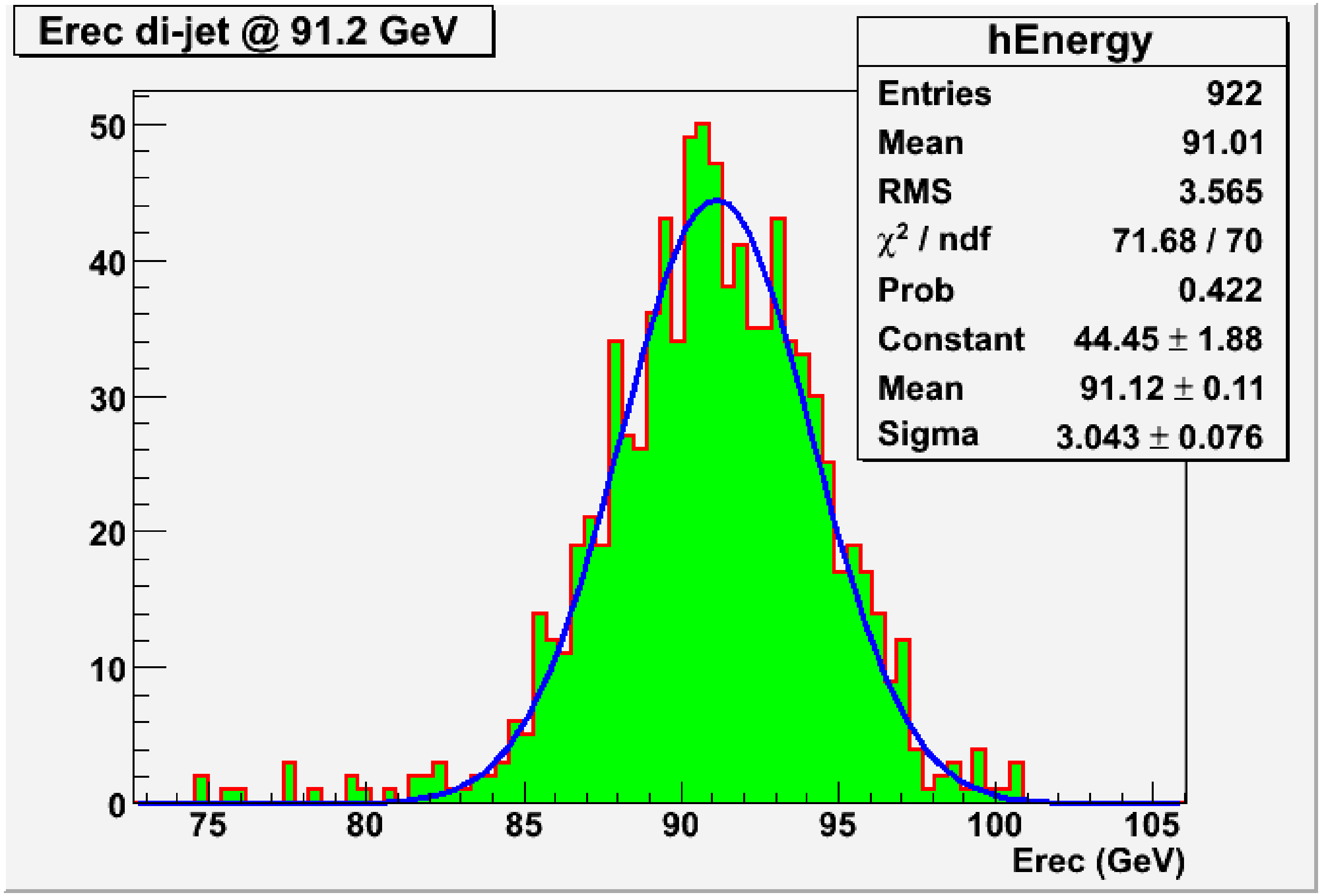
#events = 744
χ^2 = 854.39

χ^2/ndf = 1.15

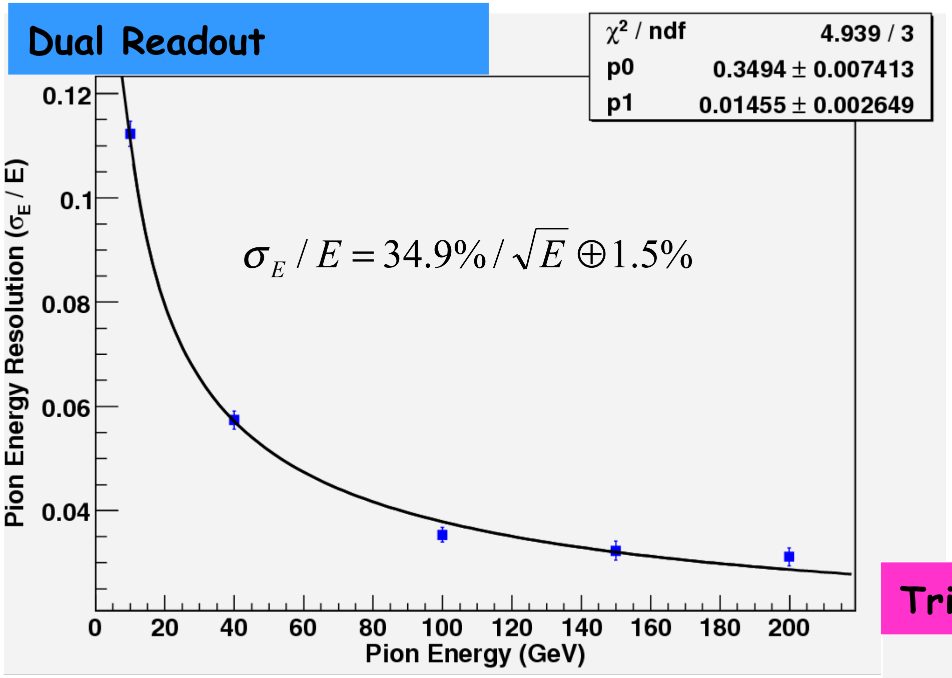
η_c = 4.665 η_S = 1.114

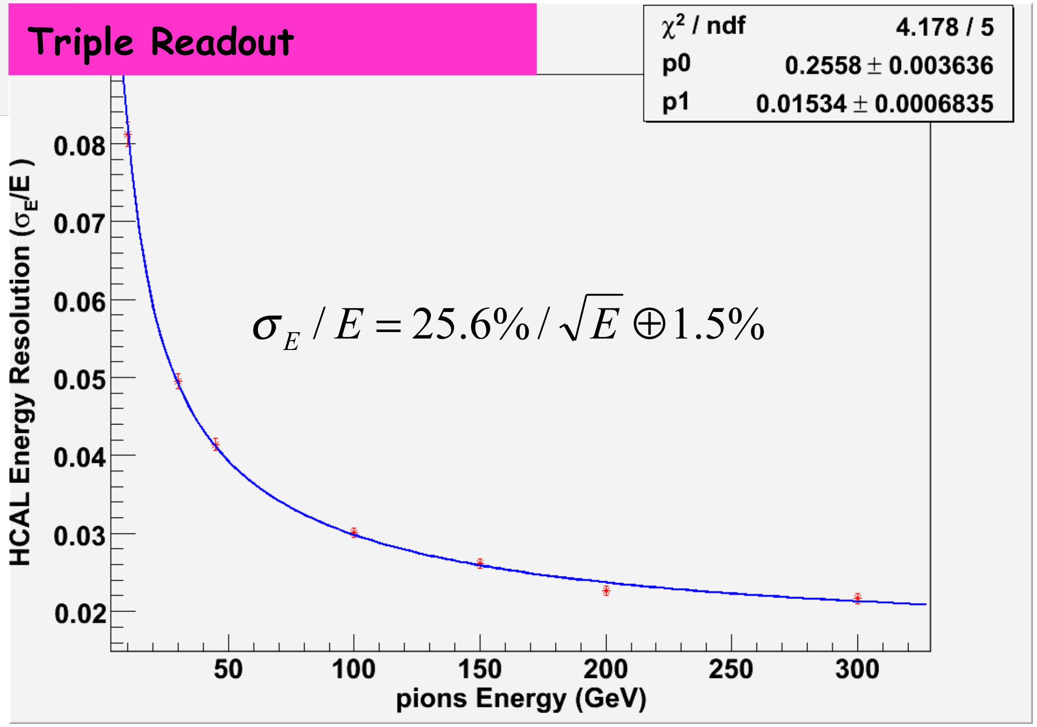
Calibrated energy: di-jet @ 91.2 GeV case using Triple Readout

$$E_{HCAL} = \frac{\eta_S E_S(\eta_C - 1) - \eta_C E_C(\eta_S - 1)}{\eta_C - \eta_S} + \eta_n E_n$$



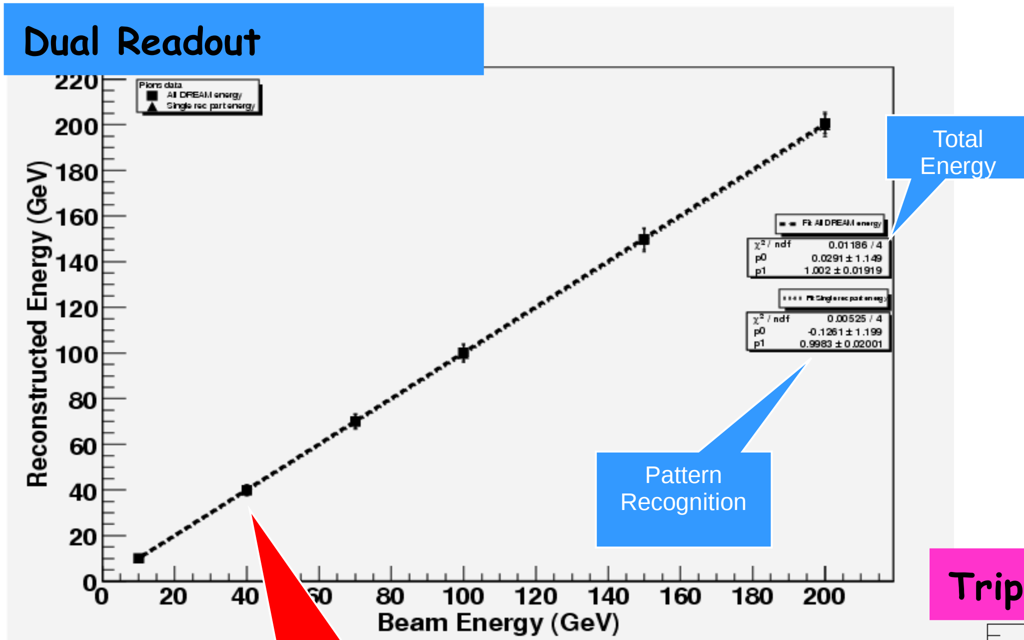
HCAL resolution with single π⁻





Reconstructed vs Beam Energy

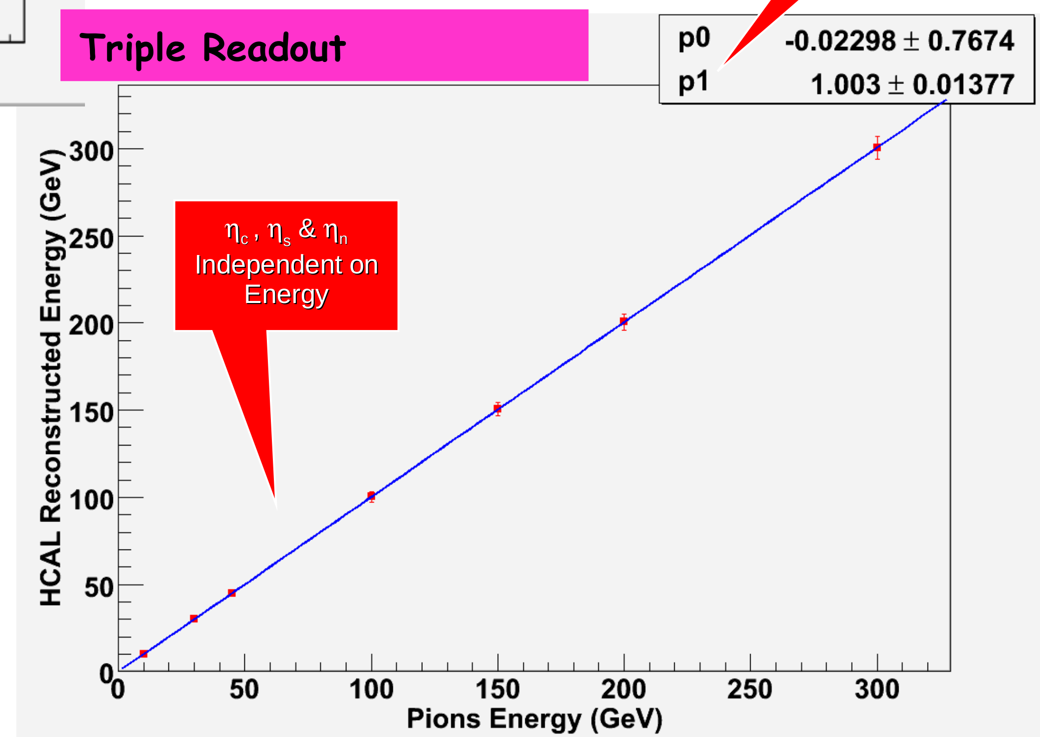
Dual Readout



η_c & η_s Independent on Energy

Visible energy fully measured

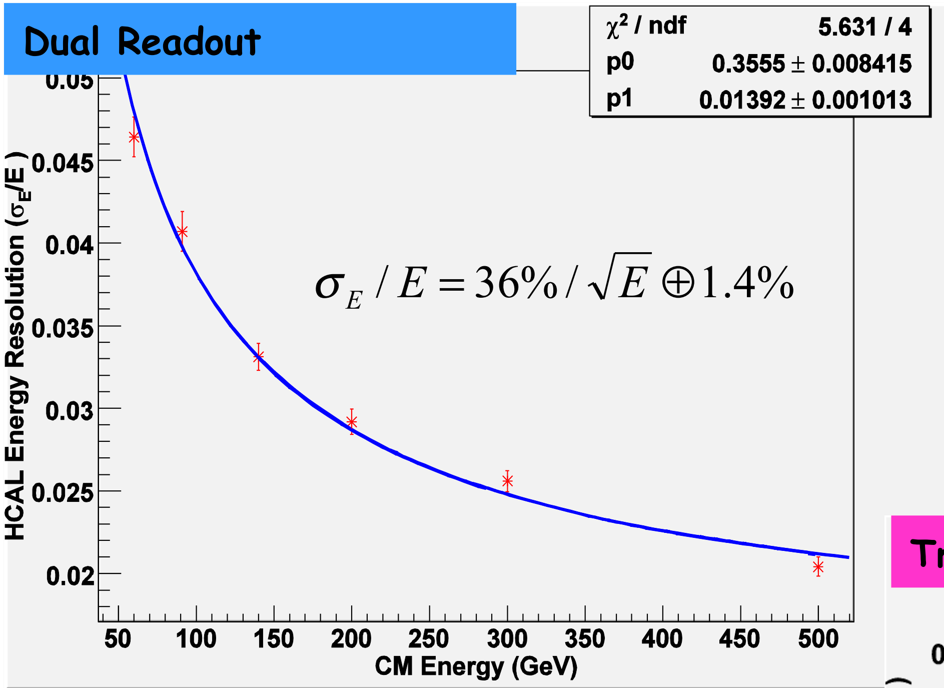
Triple Readout

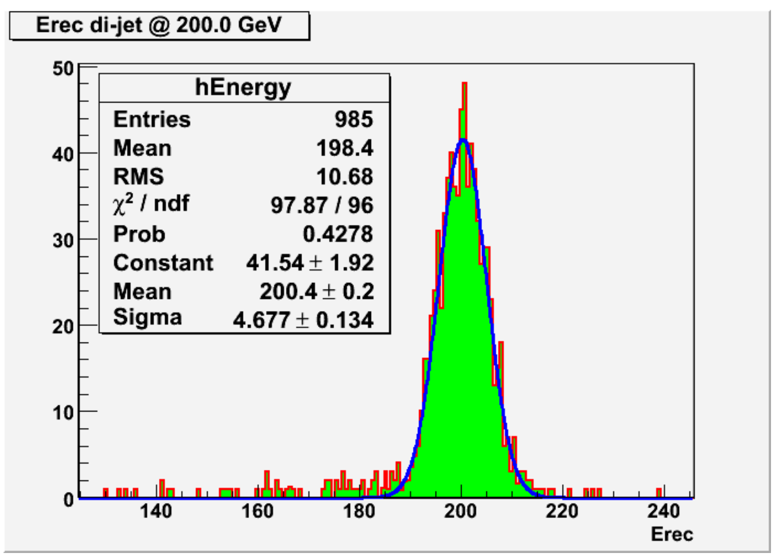


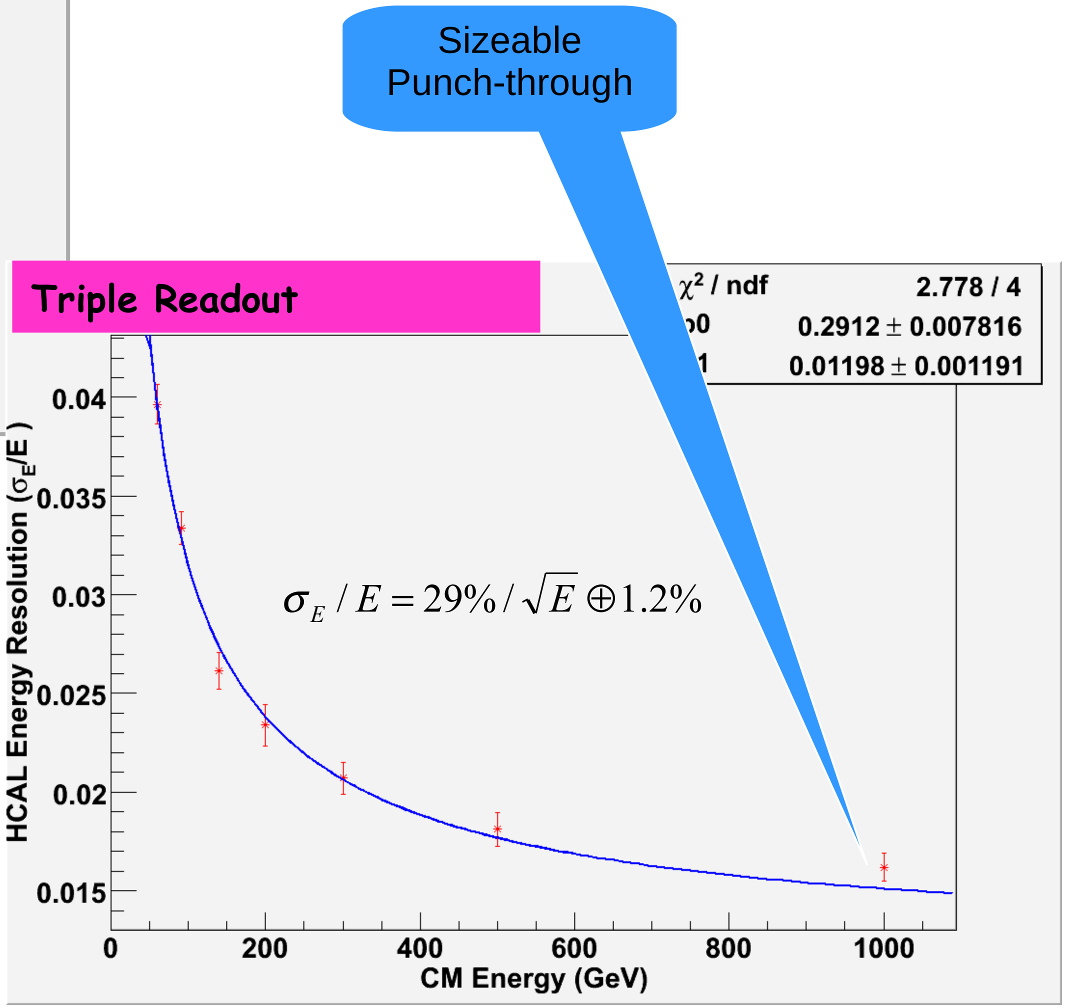
η_c , η_s & η_n Independent on Energy

Total Energy Resolution for di-jets

Di-jets events



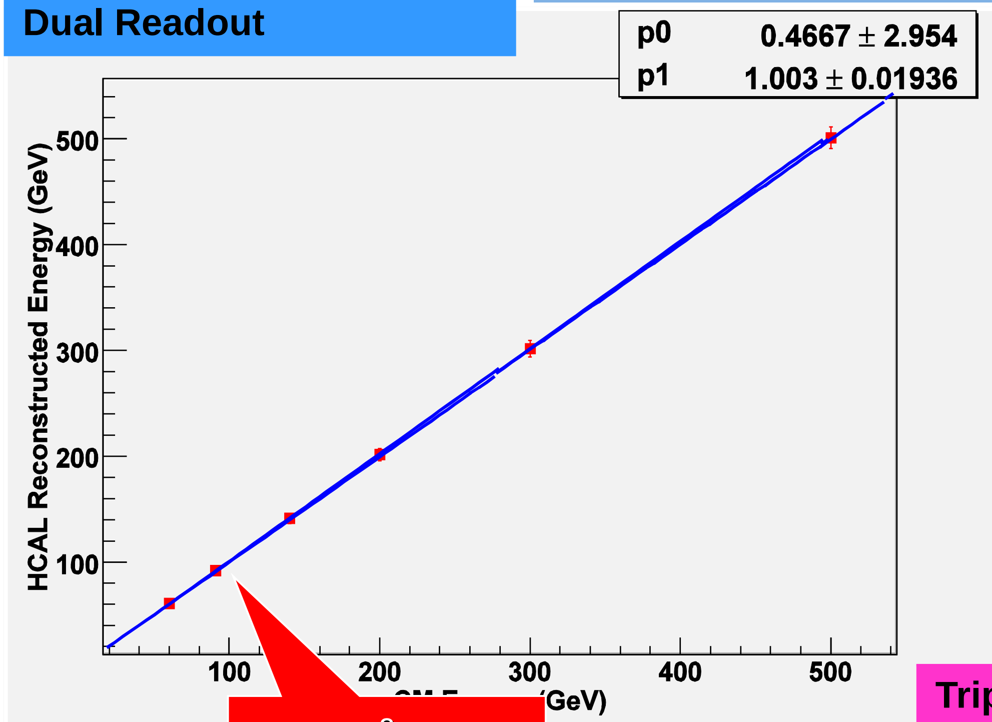




Energy Response

Di-jets events

Dual Readout



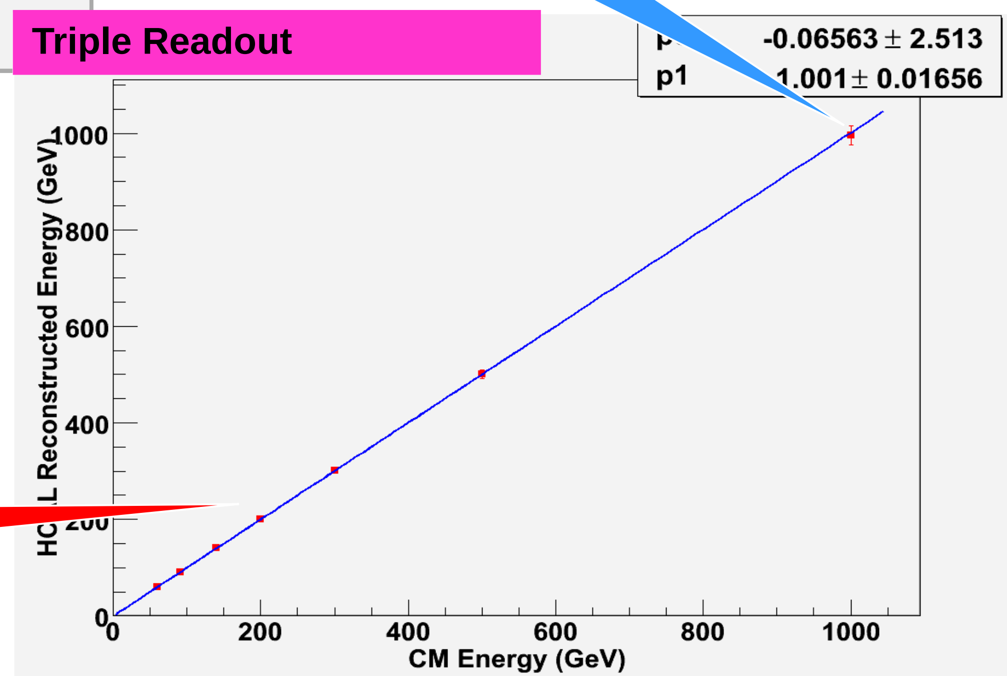
η_c & η_s Independent on Energy

Sigma from Gaussian fit on the Total Energy Distribution

Mean from Gaussian fit on the Total Energy Distribution

Skewed distribution:
Sizeable
Punch-through

Triple Readout

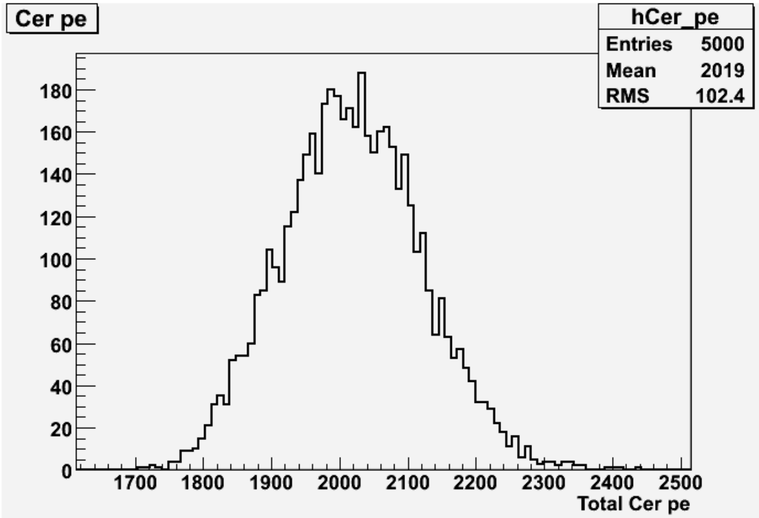


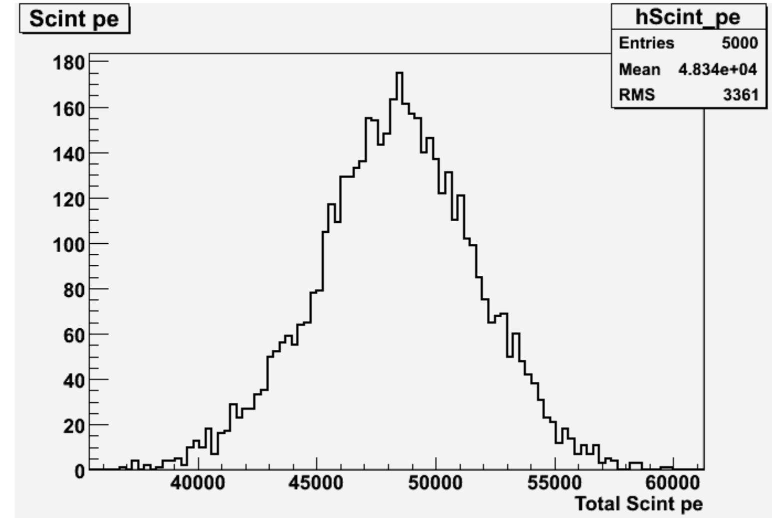
η_c , η_n & η_s Independent on Energy

Small not uniform response

Beam of 45 GeV e^-

boundary

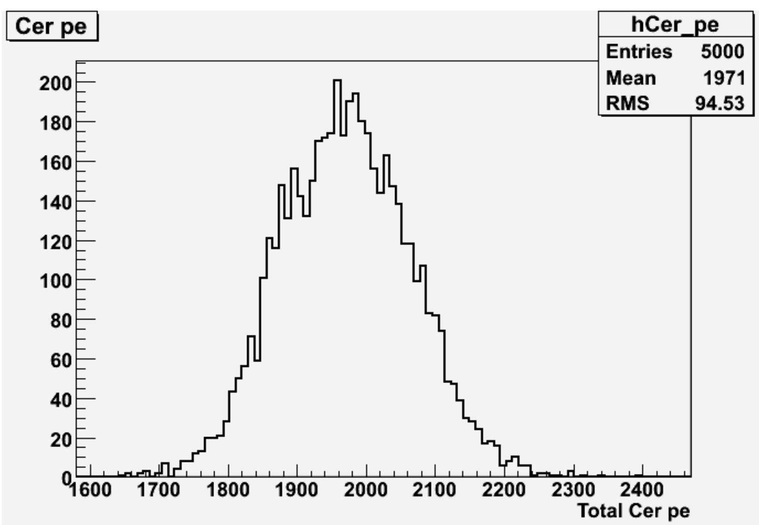


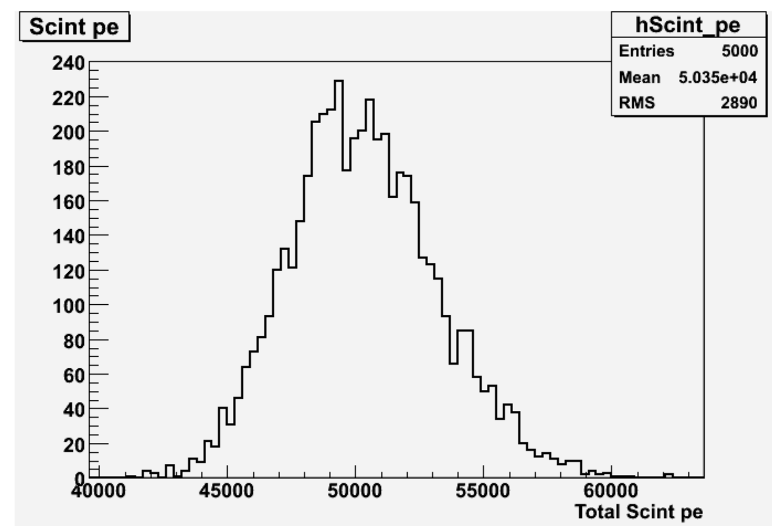


Cer #pe/GeV = 44.9

Scint #pe/GeV = 1074.2

core

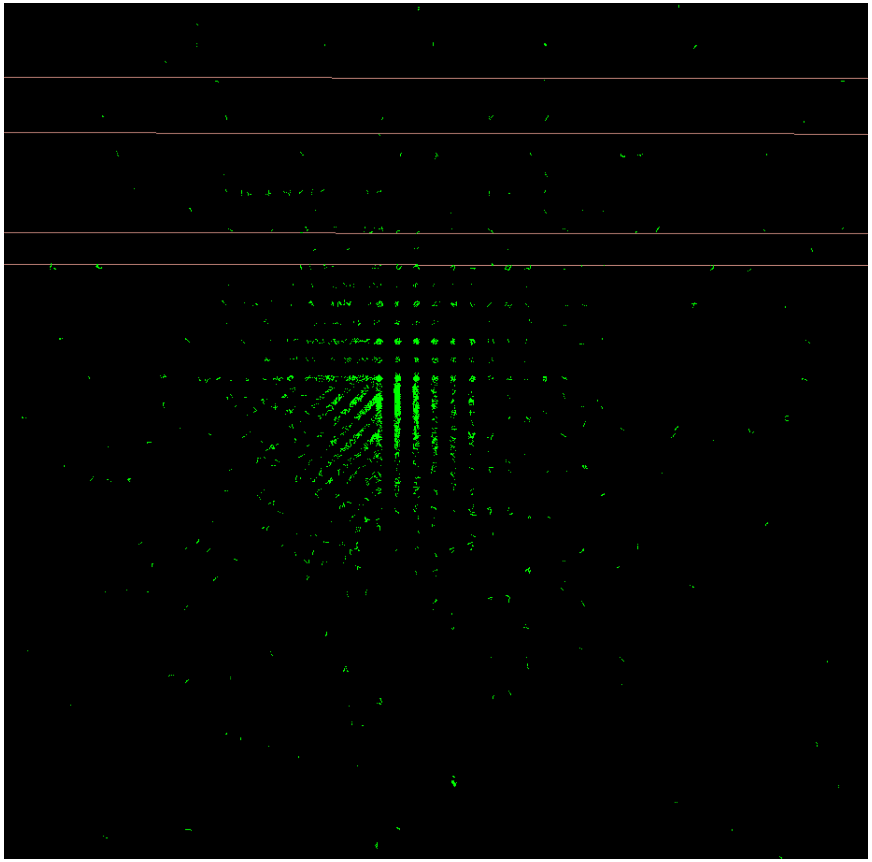




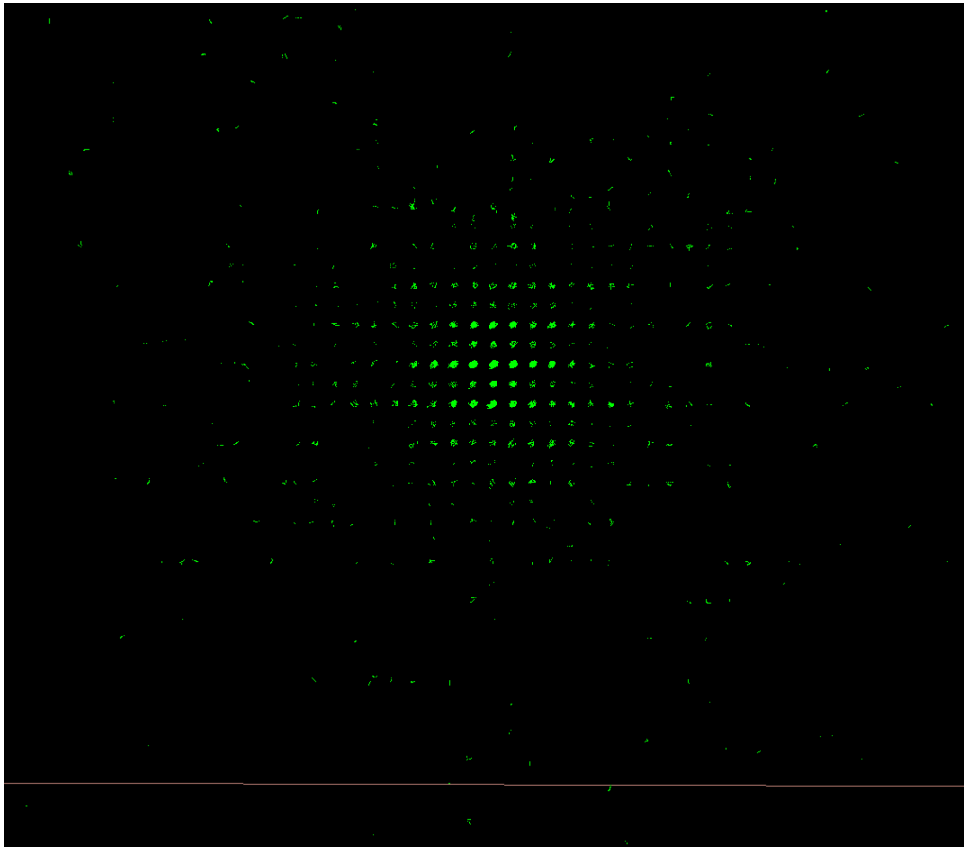
Cer #pe/GeV = 43.8

Scint #pe/GeV = 1118.9

Top view of the shower of a 45 GeV e^-

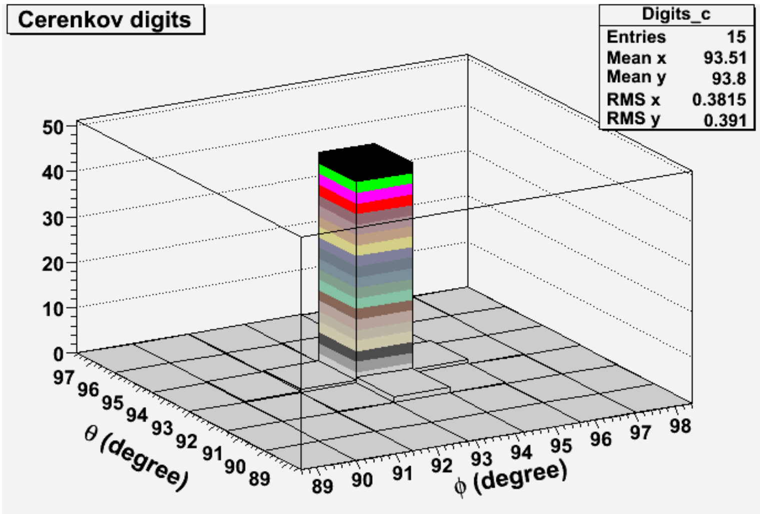


boundary

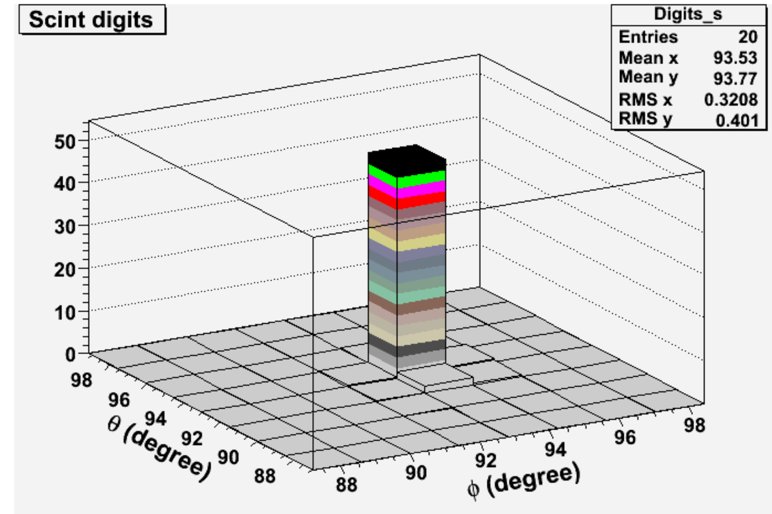


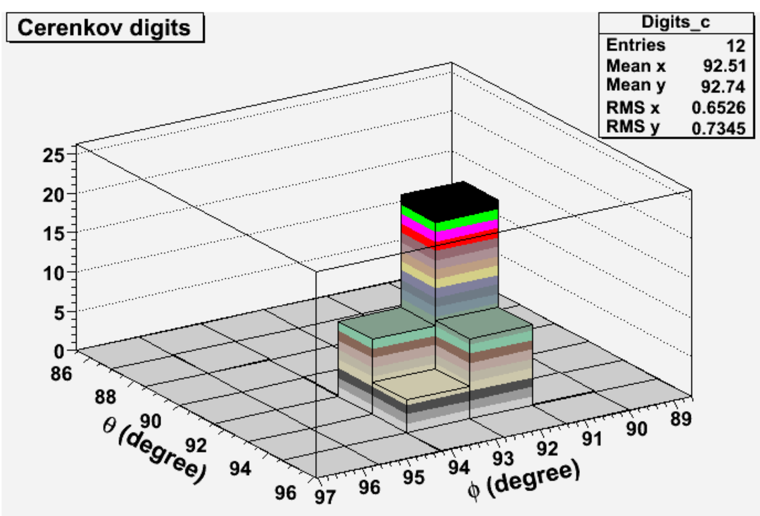
core

Calorimeter response for 45 GeV e$^-$

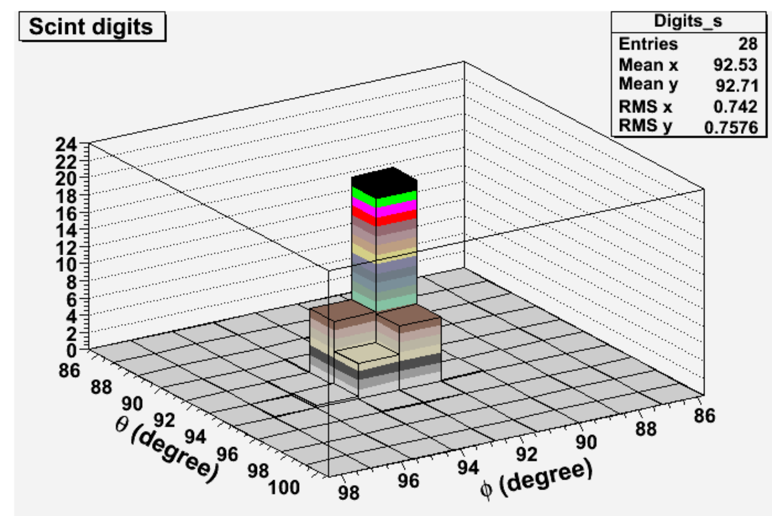


core

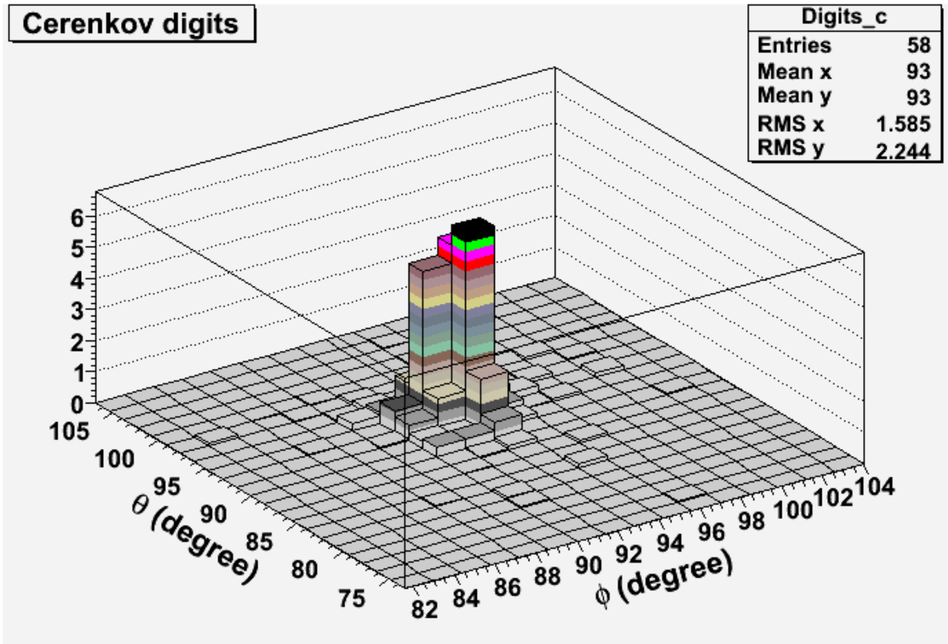


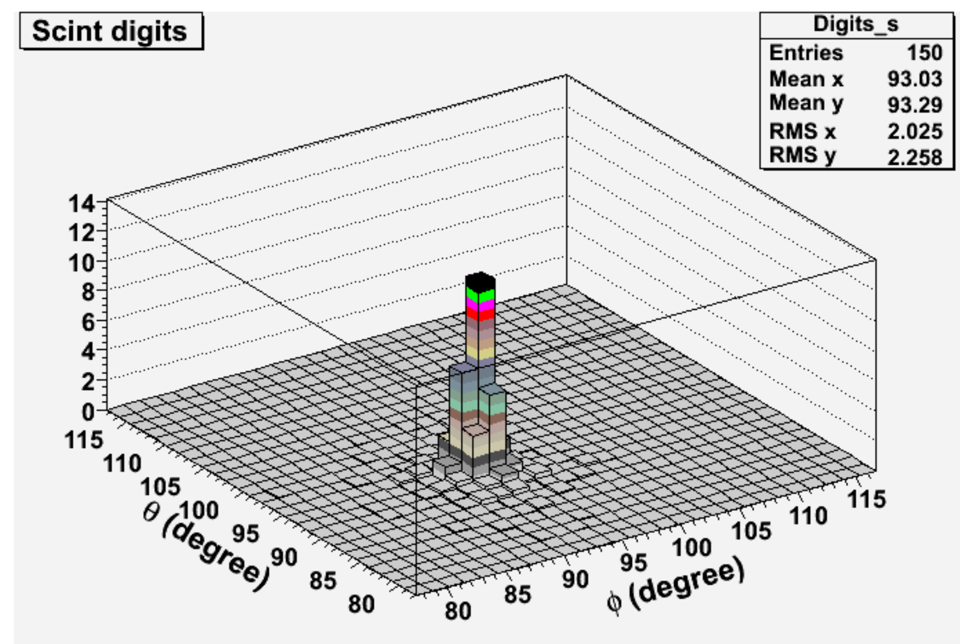


boundary



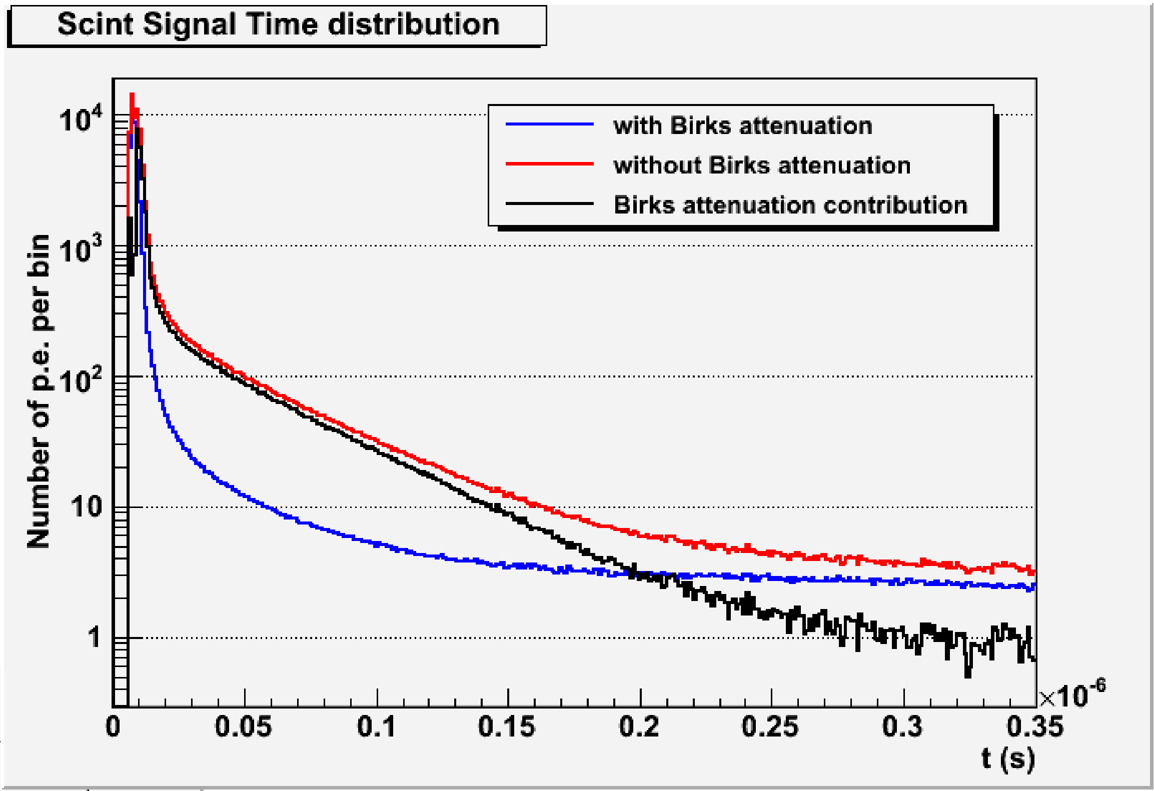
Calorimeter response for 45 GeV π^-

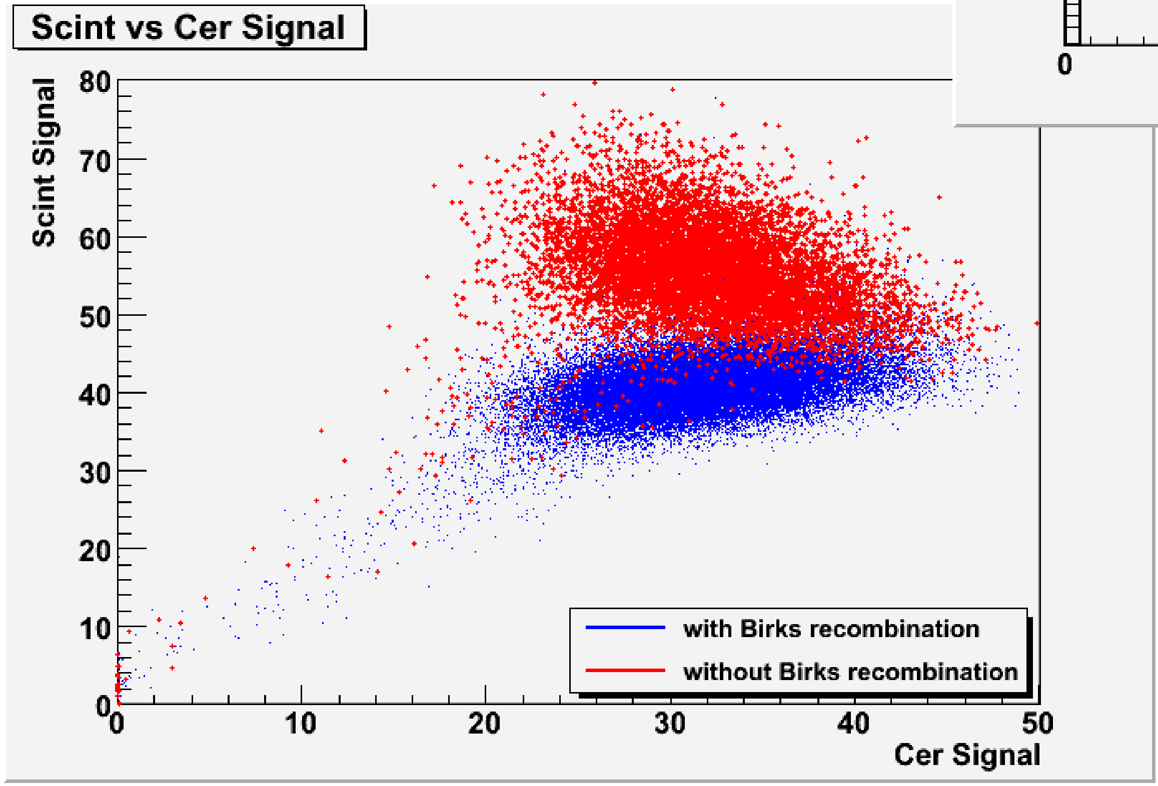




Beam of 45 GeV π^-

Birks recombination effect

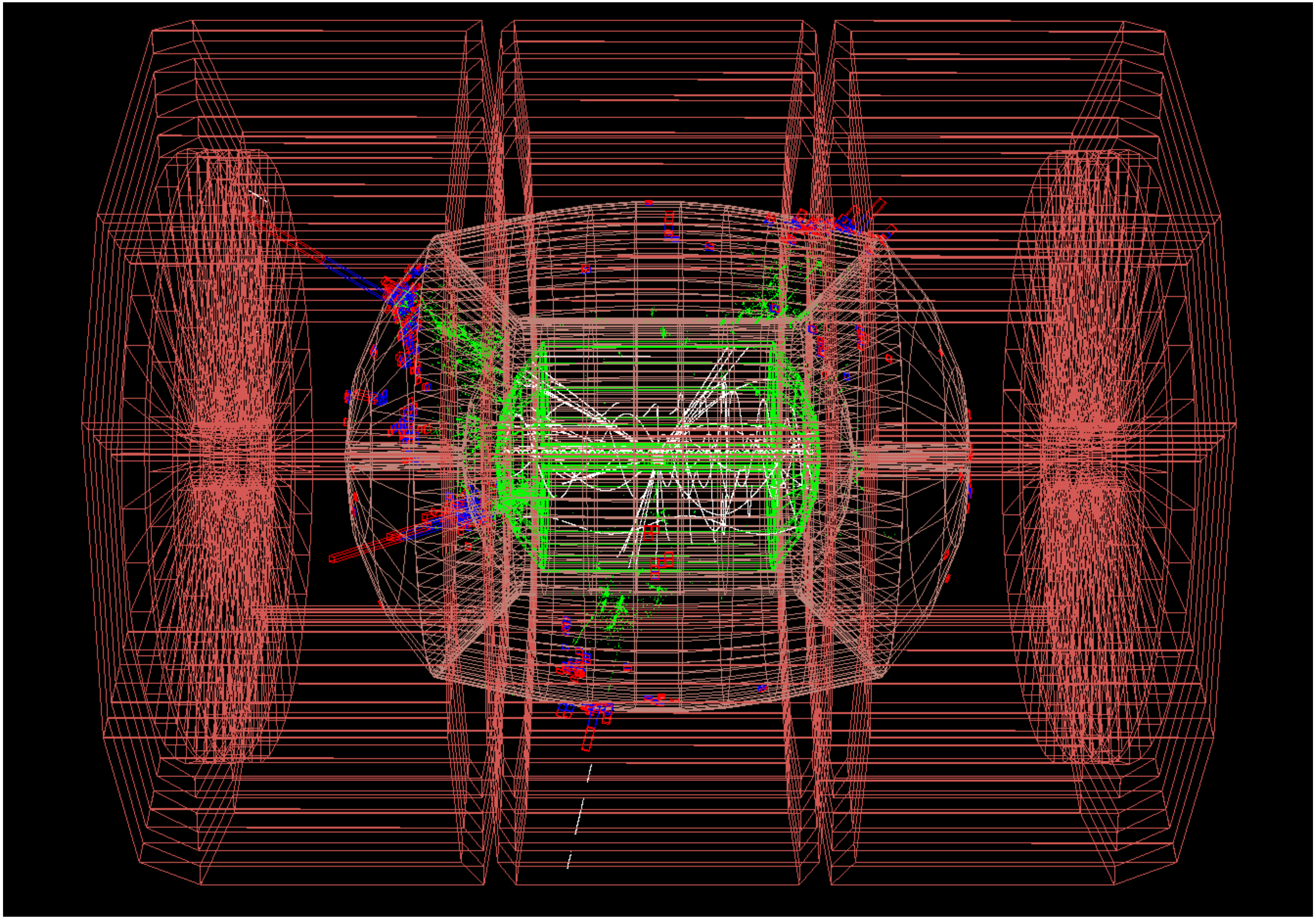




Conclusion

- 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
- It is ready to do good Physics: see *A. Mazzacane talk on Wednsday afternoon on Jet Reconstruction and Physics Performance with the 4th Concept*
- Now it is time to understand the dual readout in the crystals, looking at DREAM results and working with FermiLab

Thank you!



ZZνν event in ILCRoot