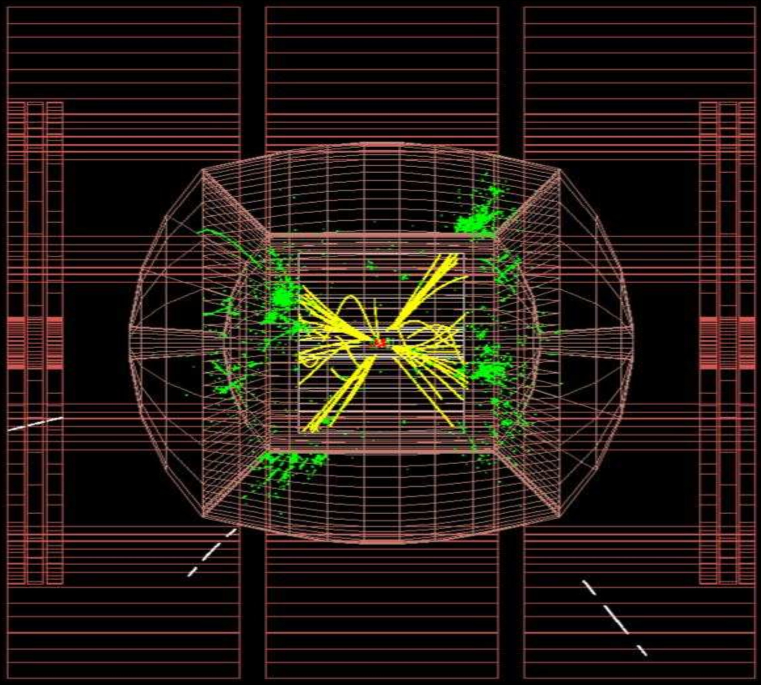
W and Z Boson reconstruction at CLIC



Corrado Gatto
INFN Napoli/Lecce
On behalf of the
4th Concept Collaboration

The 4th Concept Collaboration

4th Letter of Intent

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Started @ Snowmass
8 / 2005

140 Members
33 Institutions
15 Countries

www.4thconcept.org

Detector Design Guidelines for studies at CLIC

- Alternative design
  - No PFA for Calorimetry
  - No TPC for Central Tracking
  - No range-based Muon Detector
- Low material budget in front of the Calorimeter at small angles
- Light -> no iron
  - Easier push-pull operation
  - Probabaly the only way to go for future, high field magnets (iron saturate)
- Open mind toward the choice of technology
  - Define a baseline configuration
  - Work in parallel over (reasonable) alternatives
- Most of the work presented is transitional from ILC activities

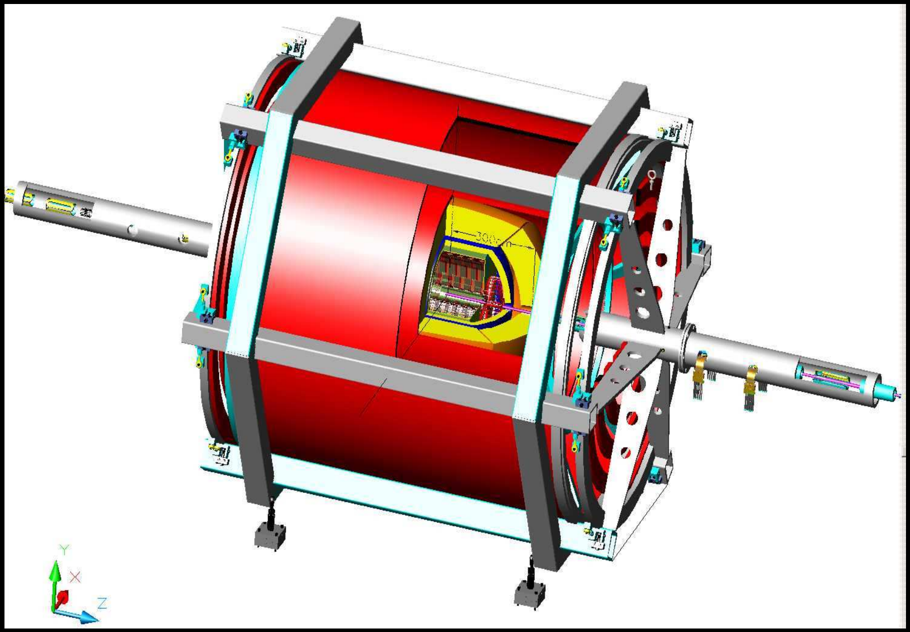
Motivations for Baseline Configuration

- **Silicon Pixel Tracker (à la Damerell) with Forward Tracking Disks (modified SiLC design)**
  - Fast timing
  - Lowest material budget for θ < 45°
  - High performance at small angles (for γ–γ separation)

Temporary version: talks with SiLC for R&D collaboration

- **Dual readout with time history of all channels**
  - Resolution scales as 1/sqrt(E) at all energies
  - $\mathcal{O}(10^4)$ channels
  - Cost
- **Dual Solenoid Muon Spectrometer**
  - No iron
  - Precise determination of particle momentum
  - Tail catcher
  - Independent calibration for the calorimeter (i.e. via μ->μγ)

An Alternative Detector for Physics Studies at CLIC

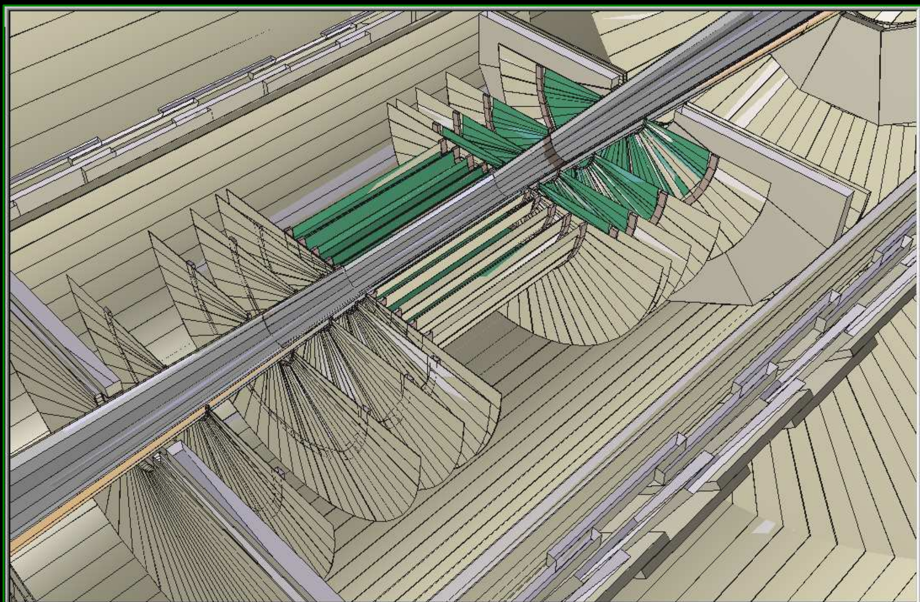


Modification of 4th Concept Detector for 3 TeV Physiscs

1. Vertex Detector 20-micron pixels
2. Silicon Tracker (preliminary version)
3. Forward Tracker Disks (preliminary version)
4. Double-readout calorimeter (specific implementation for CLIC)
5. Dual-solenoid with Muon Spectrometer

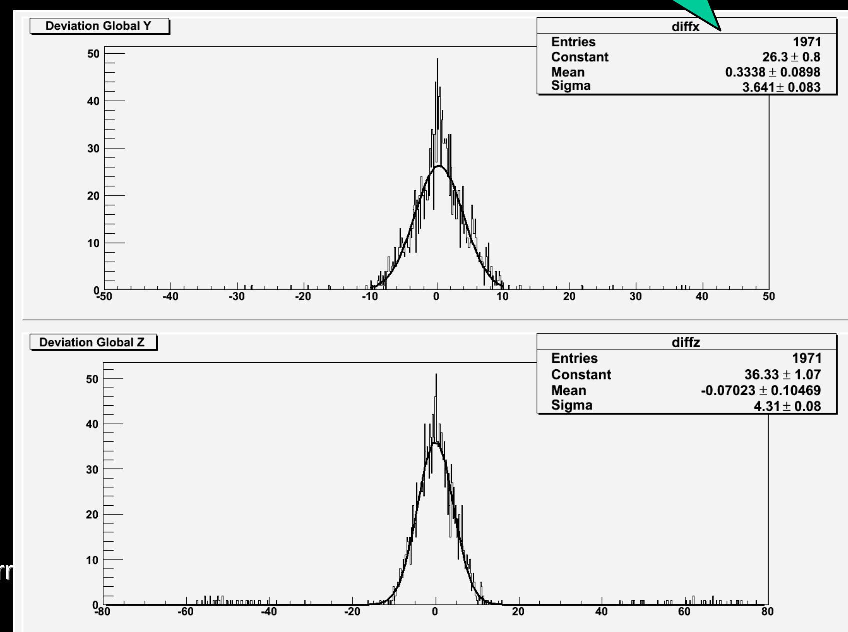
} **Replaces a Drift Chamber**

Beam Pipe and VXD layout



Includes:

1. Diffusion in Si
2. Cross talk
3. Gaussian noise
4. Electronic thresholds
5. Clusterization

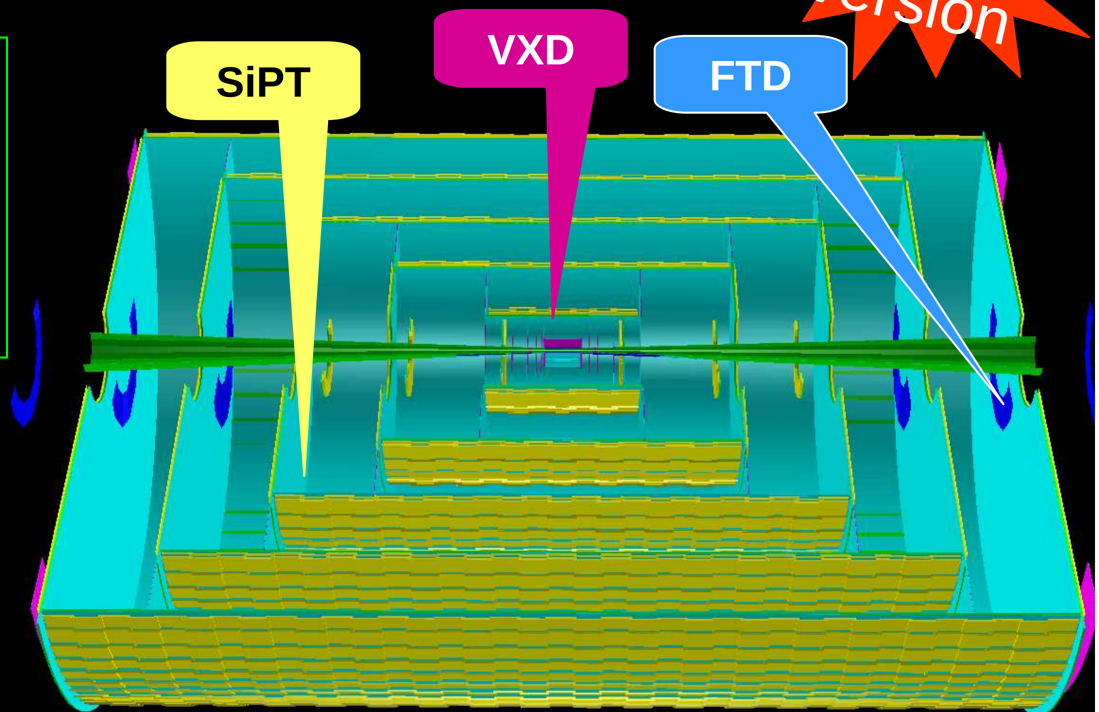


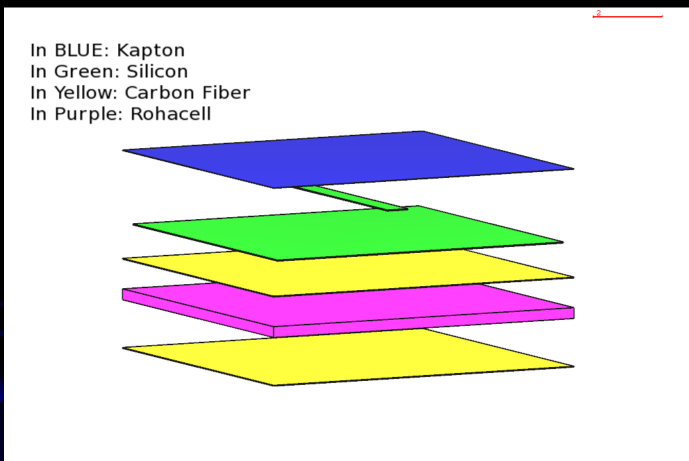
ILCRoot simulation

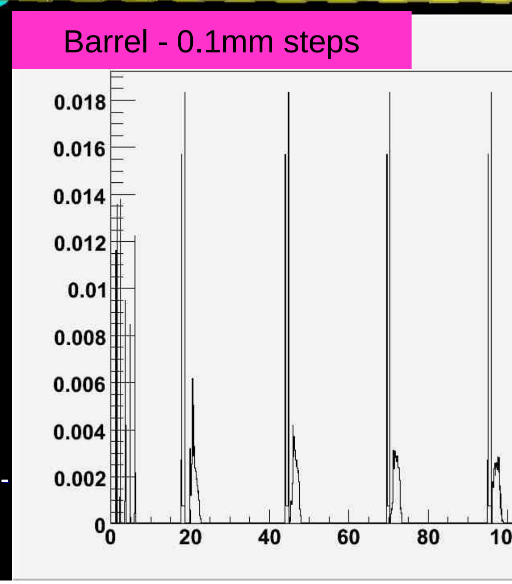
Si-Pixel Tracker + FTD

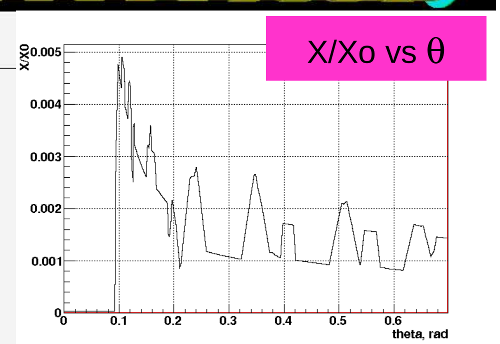
Preliminary version

- Same layout as Si Strip
- 100µm thikness Si detectors
- 50µm x 50µm pixels
- $\mathcal{O}(5\times10^{10})$ channels







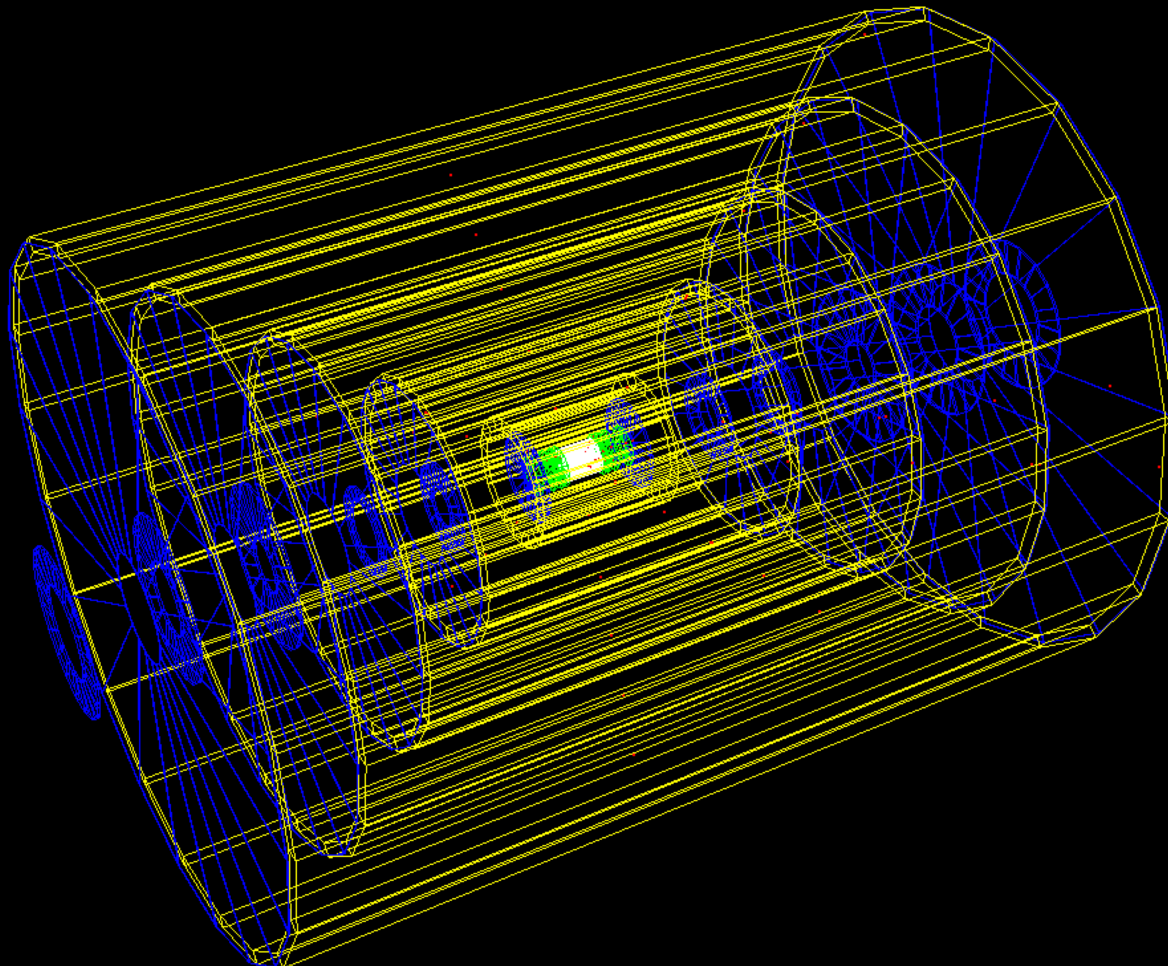


Si Pixel Tracker

- Barrel : 4.8% (Si=2.6% + Support=2.2%)
- Endcap Inner Disks: 2.22 % X/Xo
- Endcap Outer Disks: 3.78-4.28% (with supports) X/Xo

Event Display in ILCroot Tracking Systems

e^+e^- -> 10 muons
E_{CM} = 3 TeV
in Tracking System



The 4th Concept Calorimeter

Hadronic Calorimeter

Cu + scintillating fibers + Ĉerenkov fibers

Fully projective layout

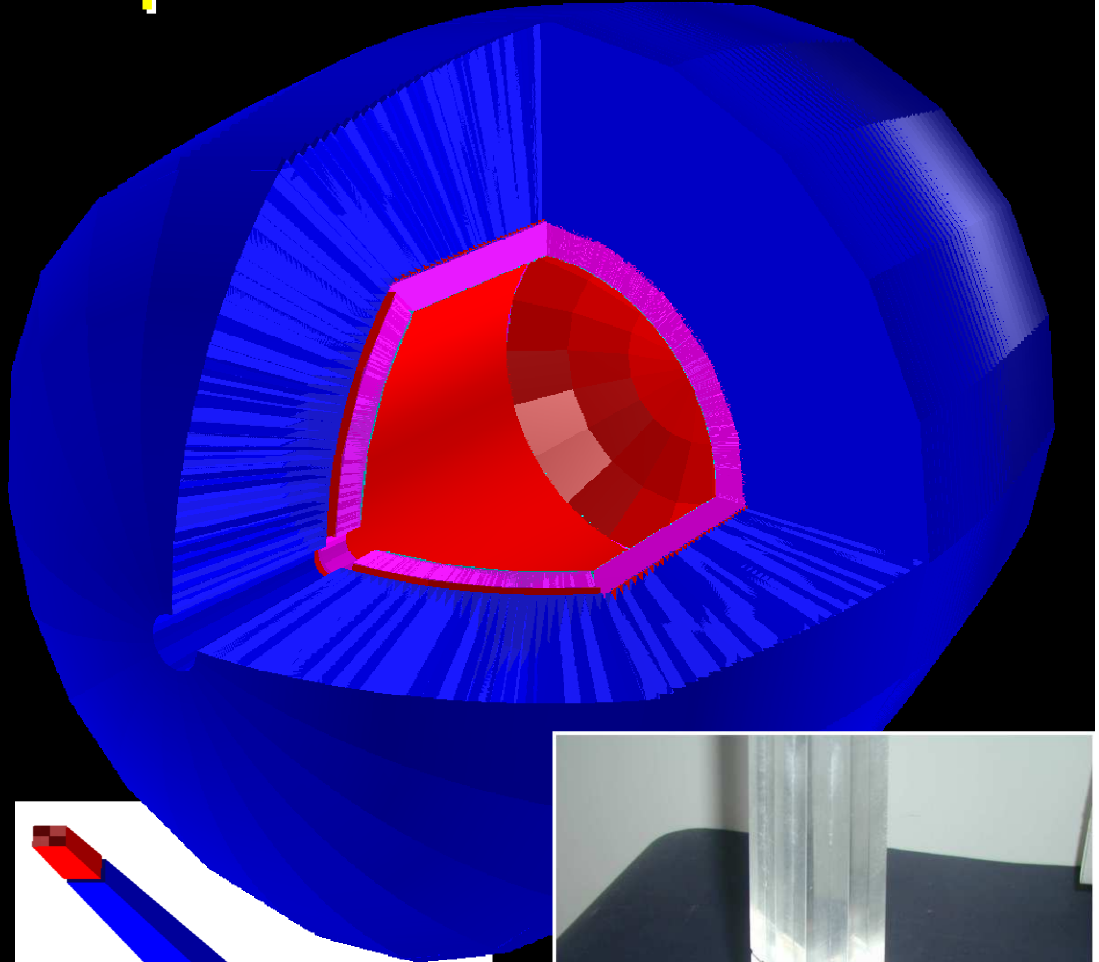
~1.4° aperture angle

~ 7.3 <λ_{int}> (Fibers)

Azimuth to 2.8°

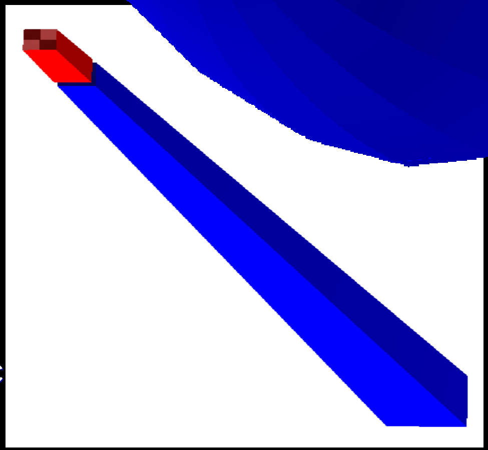
Barrel: 16384 cells

Endcaps: 7450 cells

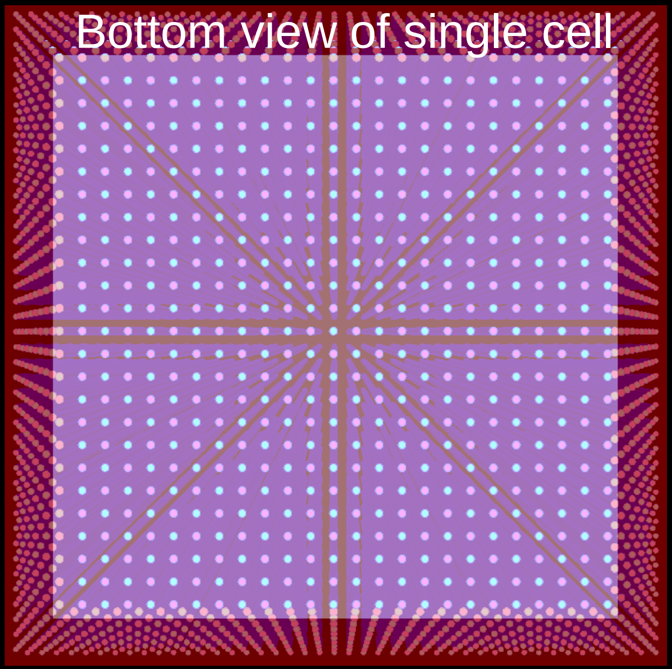


Electromagnetic Calorimeter

- BGO crystals for scintillating
- and Čerenkov light
- 2x2 crystals for each HCAL tower
- ~25 cm/22.7 Xo depth and ~ 1 λ_{int} depth
- Barrel: 65536 cells
- Endcaps: 29800 cells

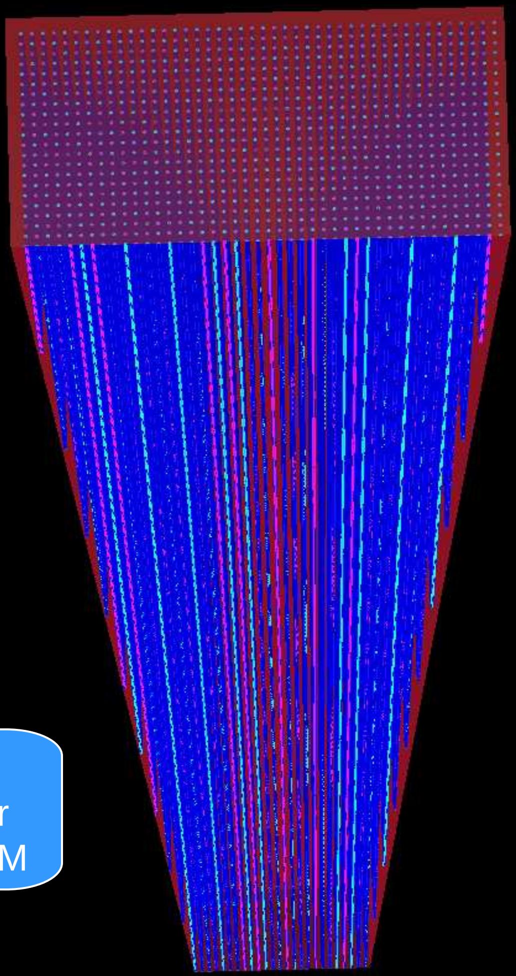


Hadronic Calorimeter Cells



Prospective view of clipped cell

Top cell size:~ 8.1 × 8.1 cm^2



Bottom cell size: ~ 4.4 × 4.4 cm^2

1 mm diameter

Plastic/Quartz fibers

Aperture Number=0.50

(C fibers)

Same absorber/fiber ratio as DREAM

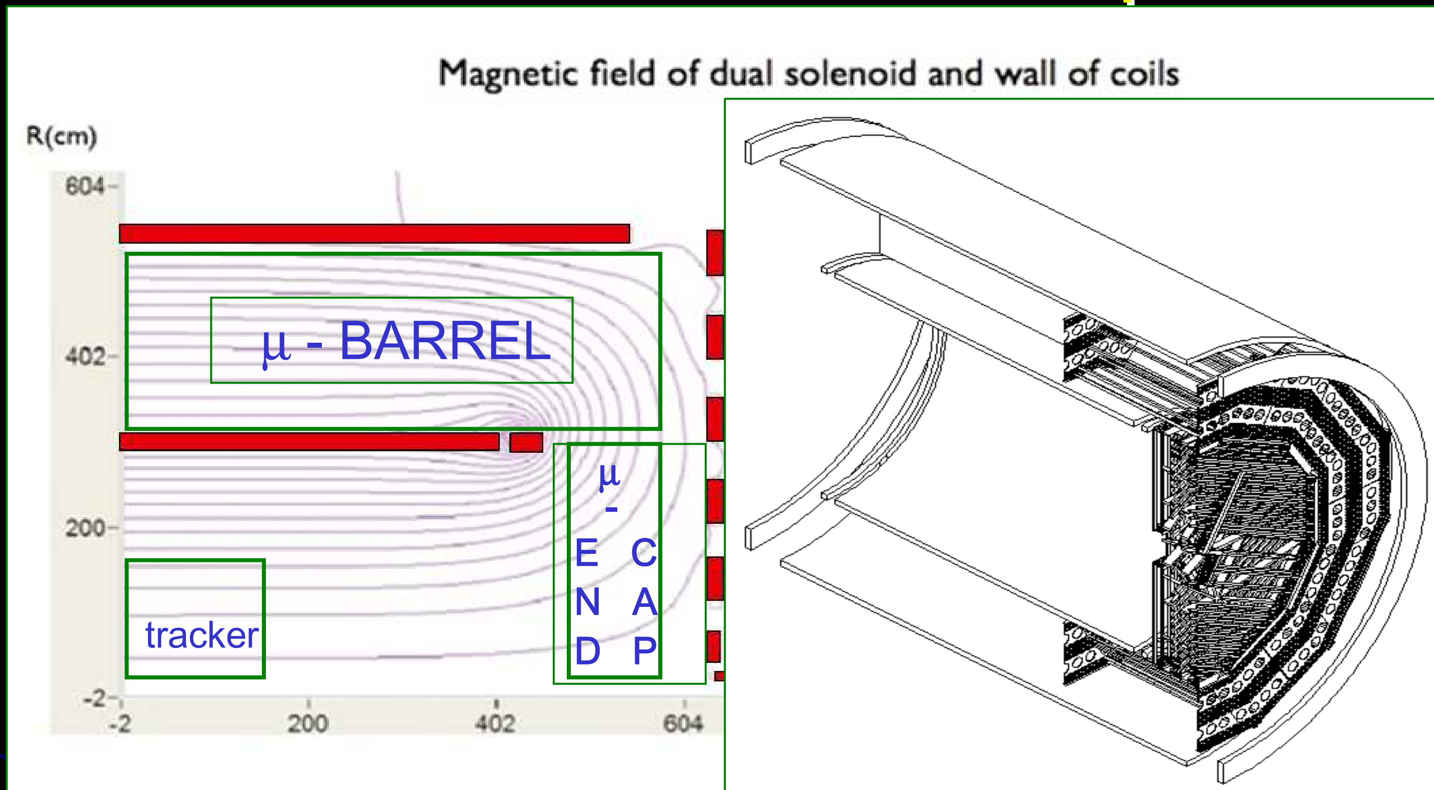
Number of fibers inside each cell: ~1600 equally subdivided between Scintillating and Cerenkov

Fiber stepping ~2 mm

Cell length: 150 cm

Each tower works as two independent towers in the same volume

Dual Solenoid B-field & Muon Spectrometer



radius 2.3 cm
filled with 90% He – 10% iC_4H_{10} @ NTP
gas gain few × 10^5
total drift time 2 μs
primary ionization 13 cluster/cm ⇒ ≈ 20 electrons/cm total
both ends instrumented with:

- > 1.5 GHz bandwith
- 8 bit fADC
- > 2 Gsa/s sampling rate
- free running memory

for a

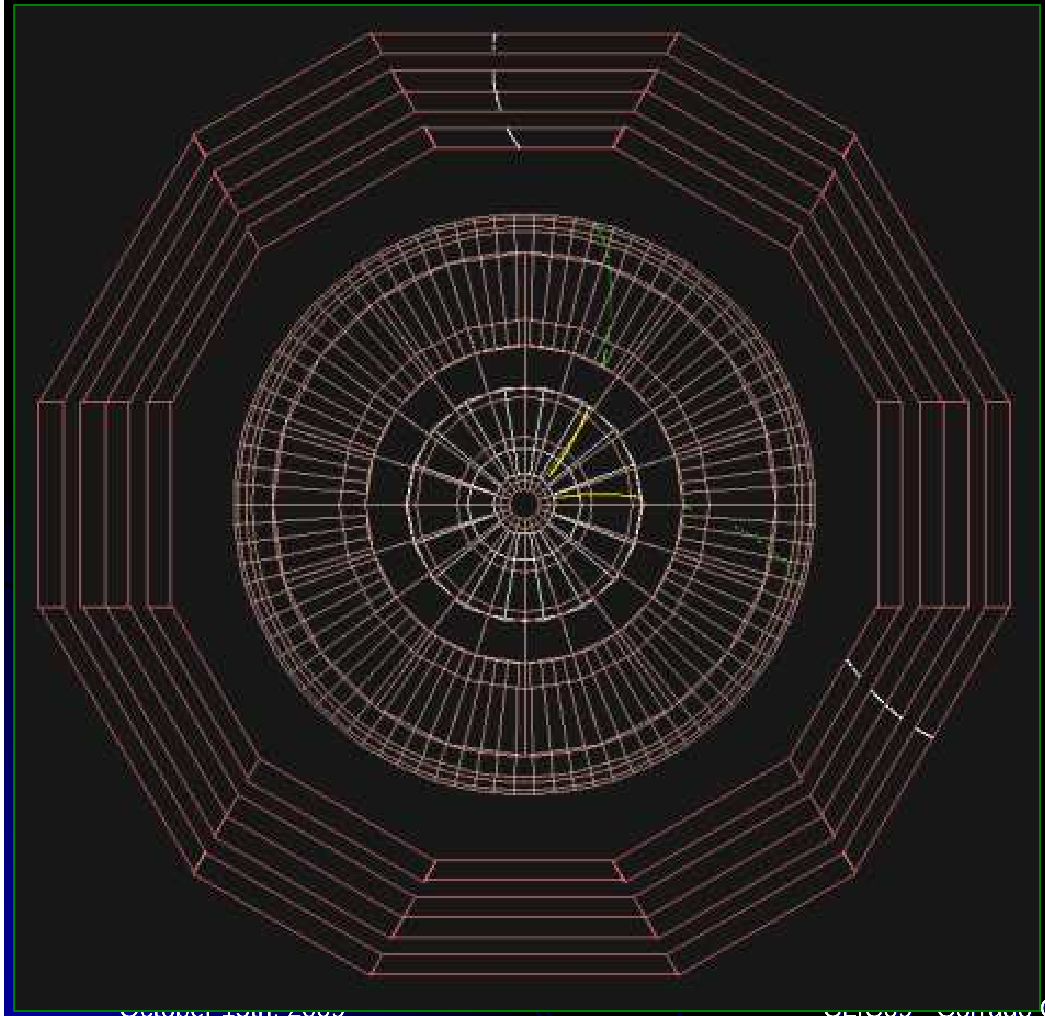
- fully efficient timing of primary ionization: cluster counting
- accurate measurement of longitudinal position with charge division
- particle identification with dN_{cl}/dx

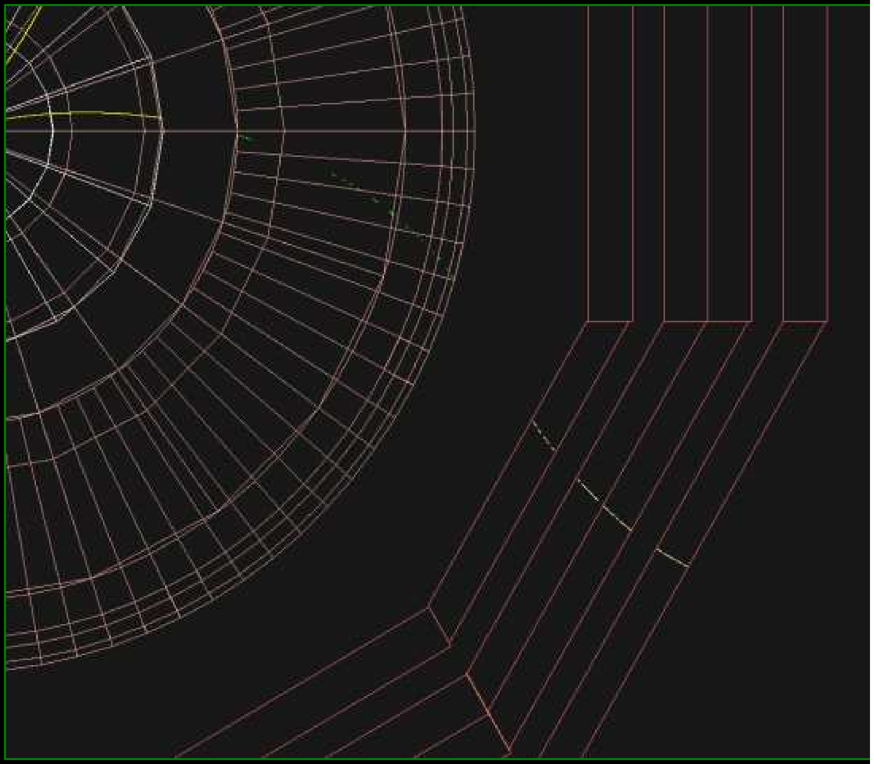
Barel:
31500 tubes
21000 channels
840 cards

End caps:
8640 tubes
9792 channels
456 cards

Total:
40140 tubes
30792 channels
1296 cards

$\mu^+ \mu^-$ at 3.5 GeV/c

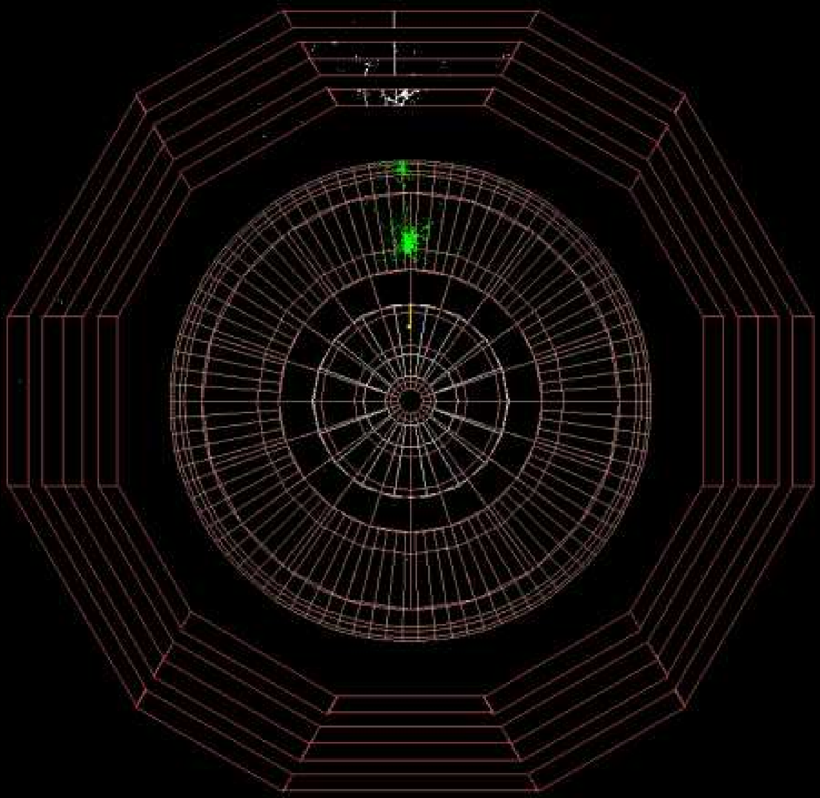


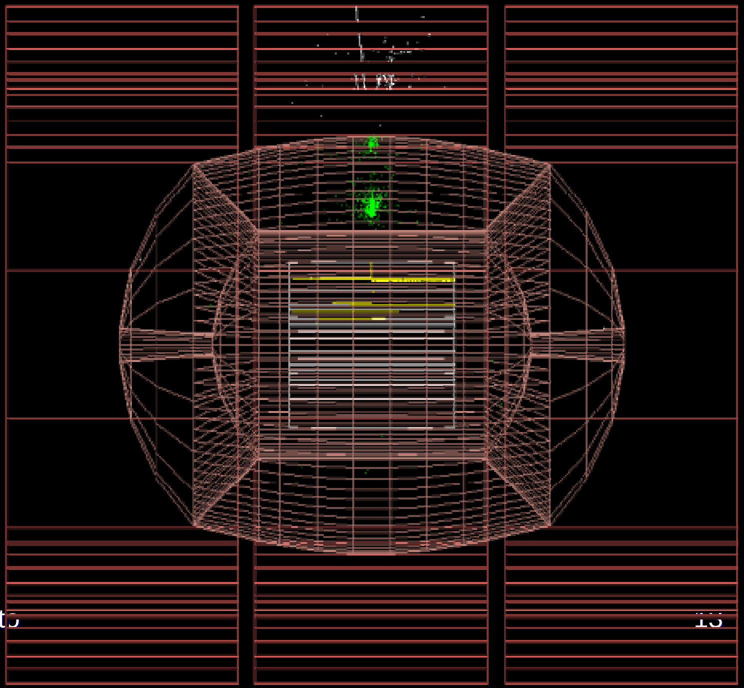


ILCRoot simulation

80 GeV jet with escaping particles

ILCRoot simulation



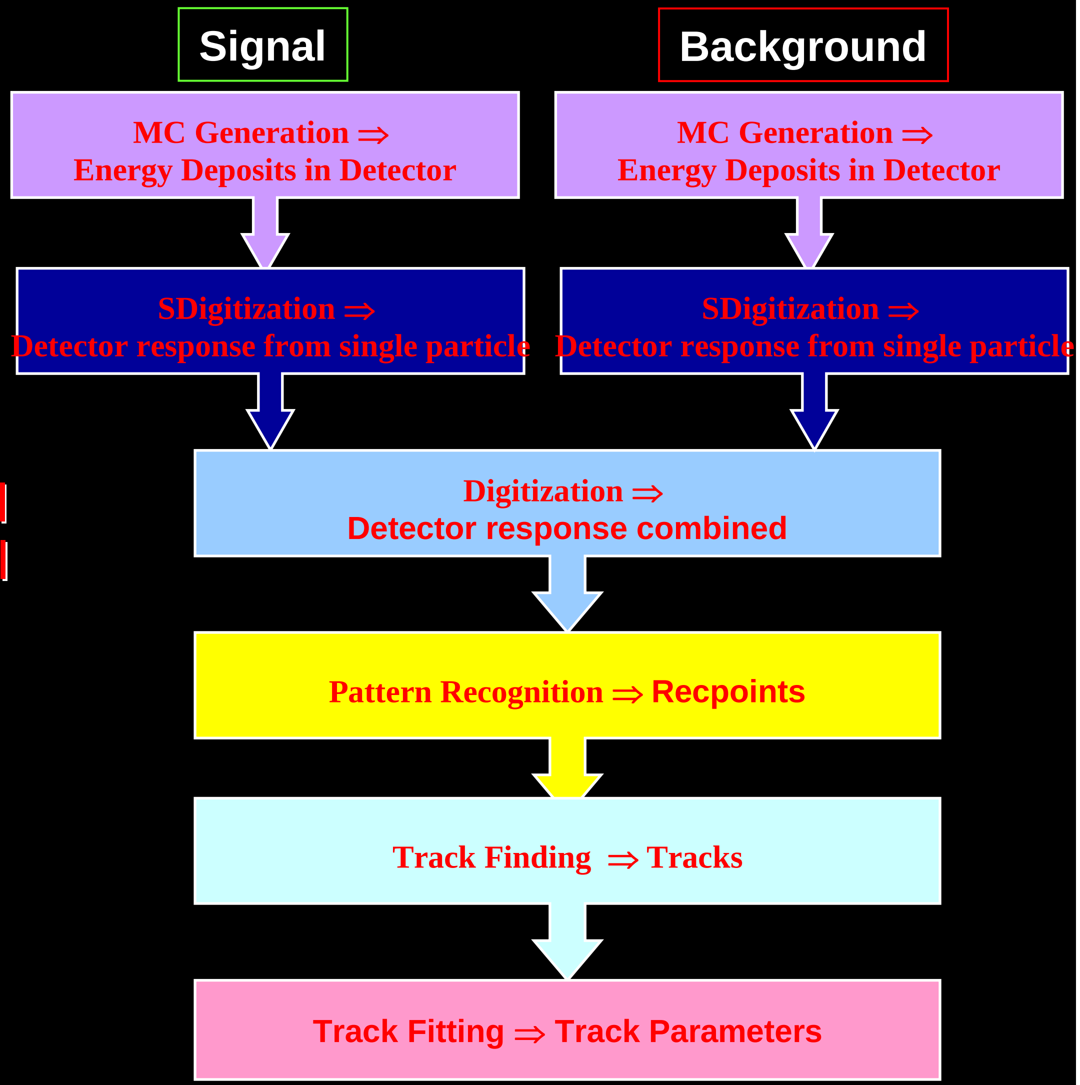


ILCroot: root Infrastructure for Large Colliders

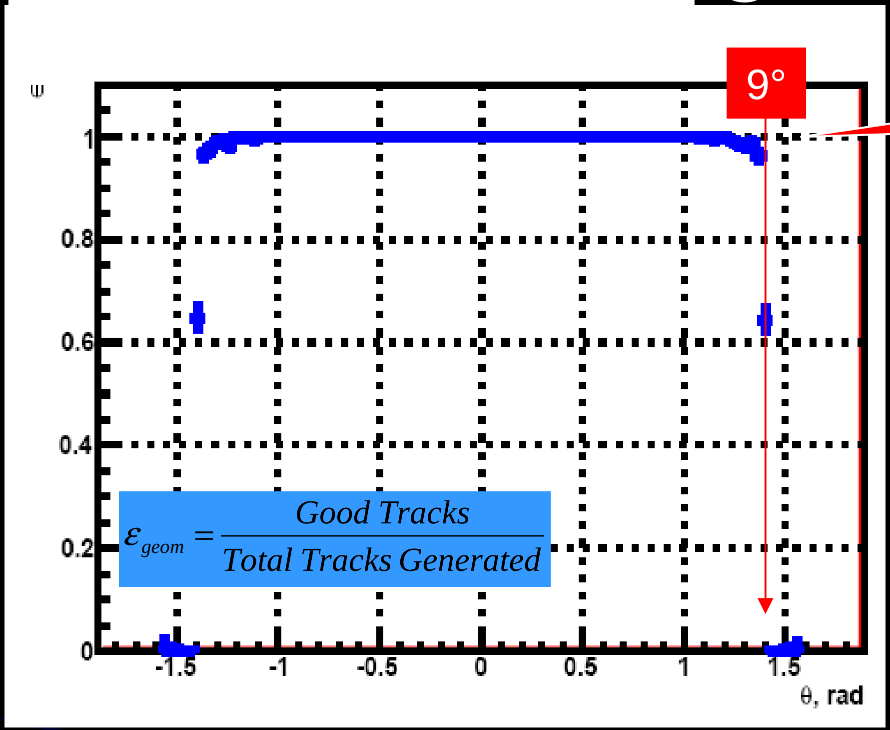
- **CERN architecture based on root, VMC and Aliroot**
  - All ROOT tools are available (I/O, graphics, PROOF, data structure, etc)
  - Extremely large community of users/developers
- **Re-allignement with latest Aliroot version every 1-2 years (v4.17 release)**
- **It is a simulation framework and an Offline Systems:**
  - **Single framework, from generation to reconstruction through simulation. Don't forget analysis!!!**
  - It naturally evolves into the offline systems of your experiment
  - It is immediatly usable for test beams
  - Six MDC have proven robustness, reliability and portability
- **Main add-ons Aliroot:**
  1. Interface to external files in various format (STDHEP, text, etc.)
  2. Standalone VTX track fitter
  3. Pattern recognition from VTX (for si central trackers)
  4. Parametric beam background (# integrated bunch crossing chosen at run time
- Growing number of experiments have adopted it: Alice (LHC), Opera (LNGS), (Meg), CMB (GSI), Panda(GSI), 4th Concept and **LHeC**

Simulation: full digitization + reconstruction

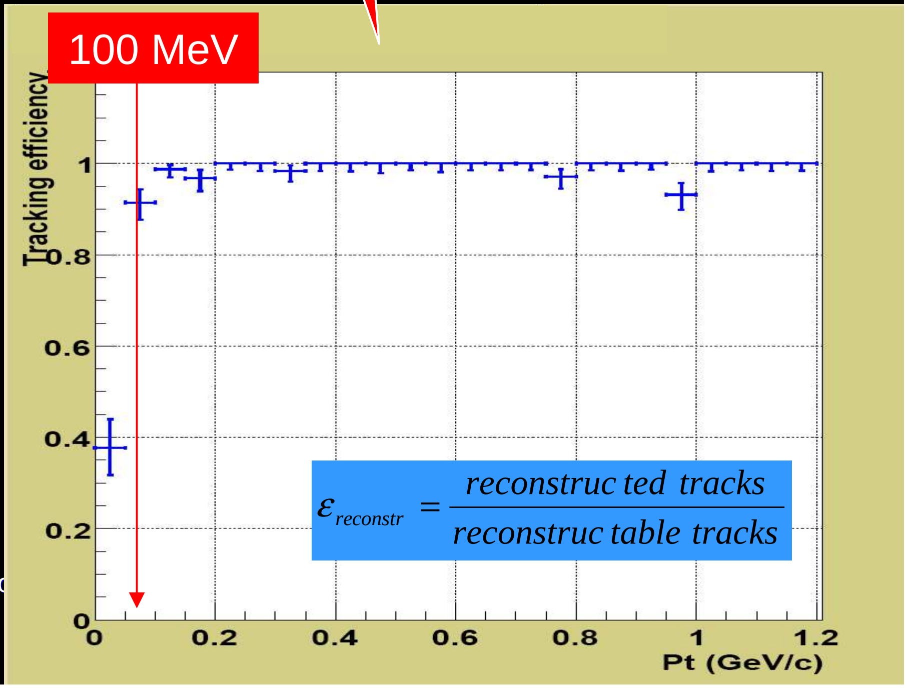
- Hits: produced by MC (G3,G4,Fluka)
- SDigits: simulate detector response for each hit
- Digits: merge digit from several files of SDigits (example Signal + Beam Bkgnd)
- Recpoints: Clusterize nearby Digits
- Pattern recognition + track fit through full Parallel Kalman Filter



Tracking Performance



$$\varepsilon_{geom} = \frac{Good\ Tracks}{Total\ Tracks\ Generated}$$



$$\varepsilon_{reconstr} = \frac{reconstructed\ tracks}{reconstructable\ tracks}$$

Defining "reconstructable tracks"

I. DCA(true) < 3.5 cm

AND

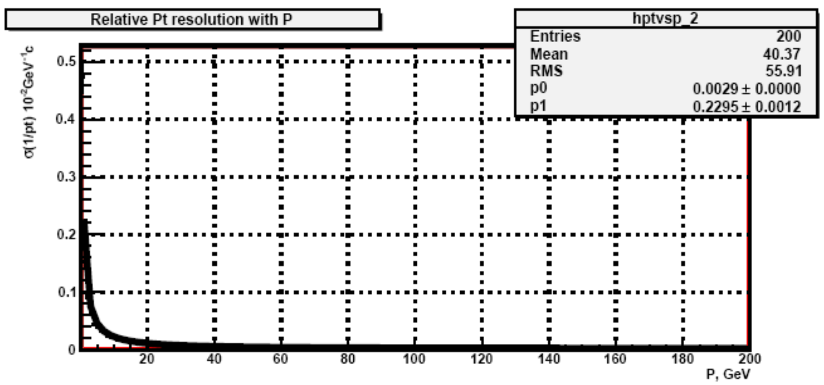
II. At least 4 hits in VTX)

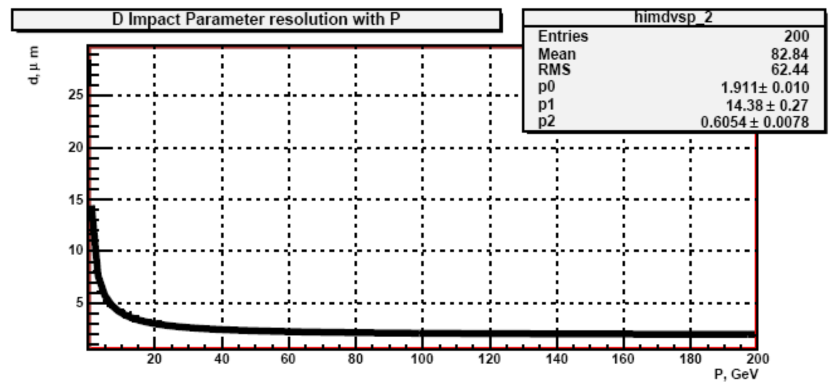
M. Peccarisi

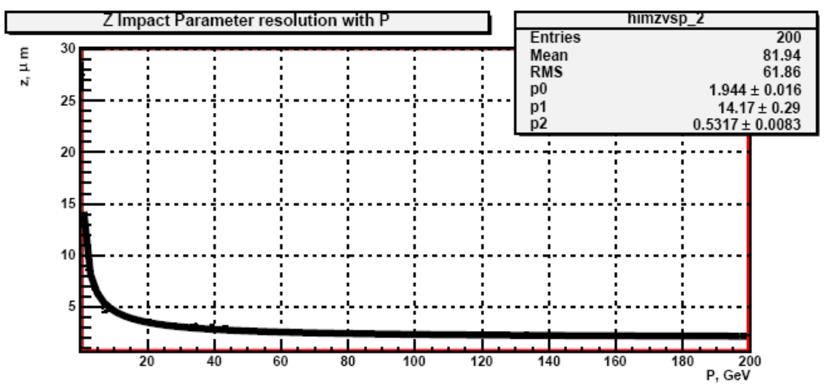
Single muons
No beam bkg

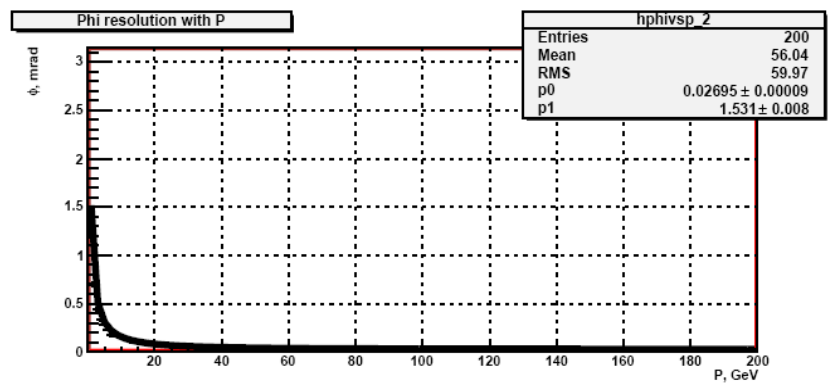
M. Peccarisi

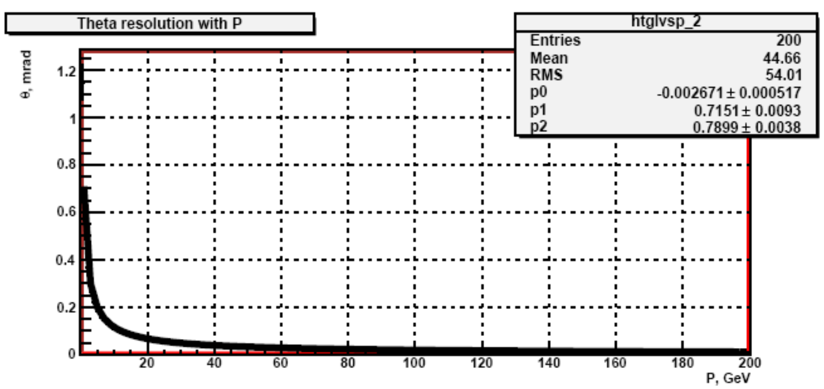
Tracking resolution vs P











$$\sigma(P_t^{-1}) = 23 / P \oplus 0.29 \times 10^{-4}\, GeV^{-1} c$$

$$\sigma(\vartheta) = 0.72 / P^{0.79} \oplus 0.002 \;\; mrad$$

$$\sigma(\varphi) = 1.53 / P \oplus 0.027 \;\; mrad$$

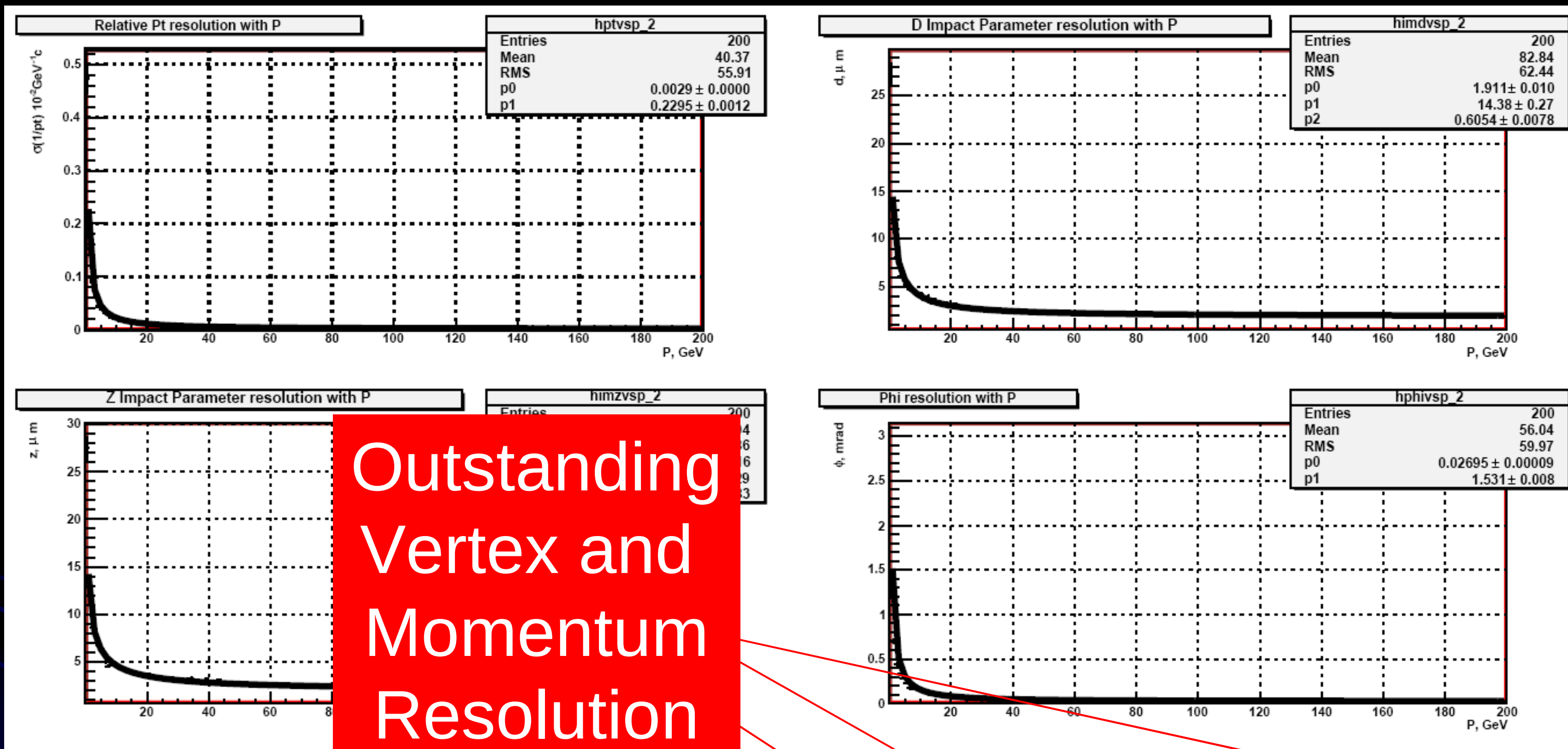
$$\sigma(D_o) = 14.4 / P^{0.61} \oplus 1.9 \;\; \mu m$$

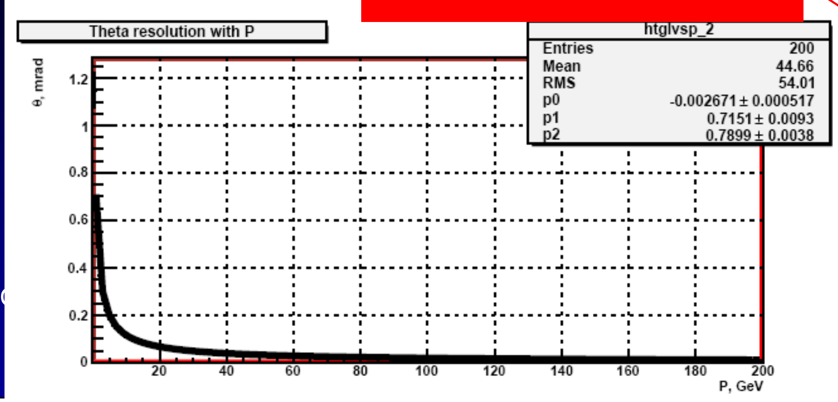
$$\sigma(Z_o) = 14.2 / P^{0.53} \oplus 1.9 \;\; \mu m$$

Single muons
No beam bkg

M. Peccarisi

Tracking resolution vs P





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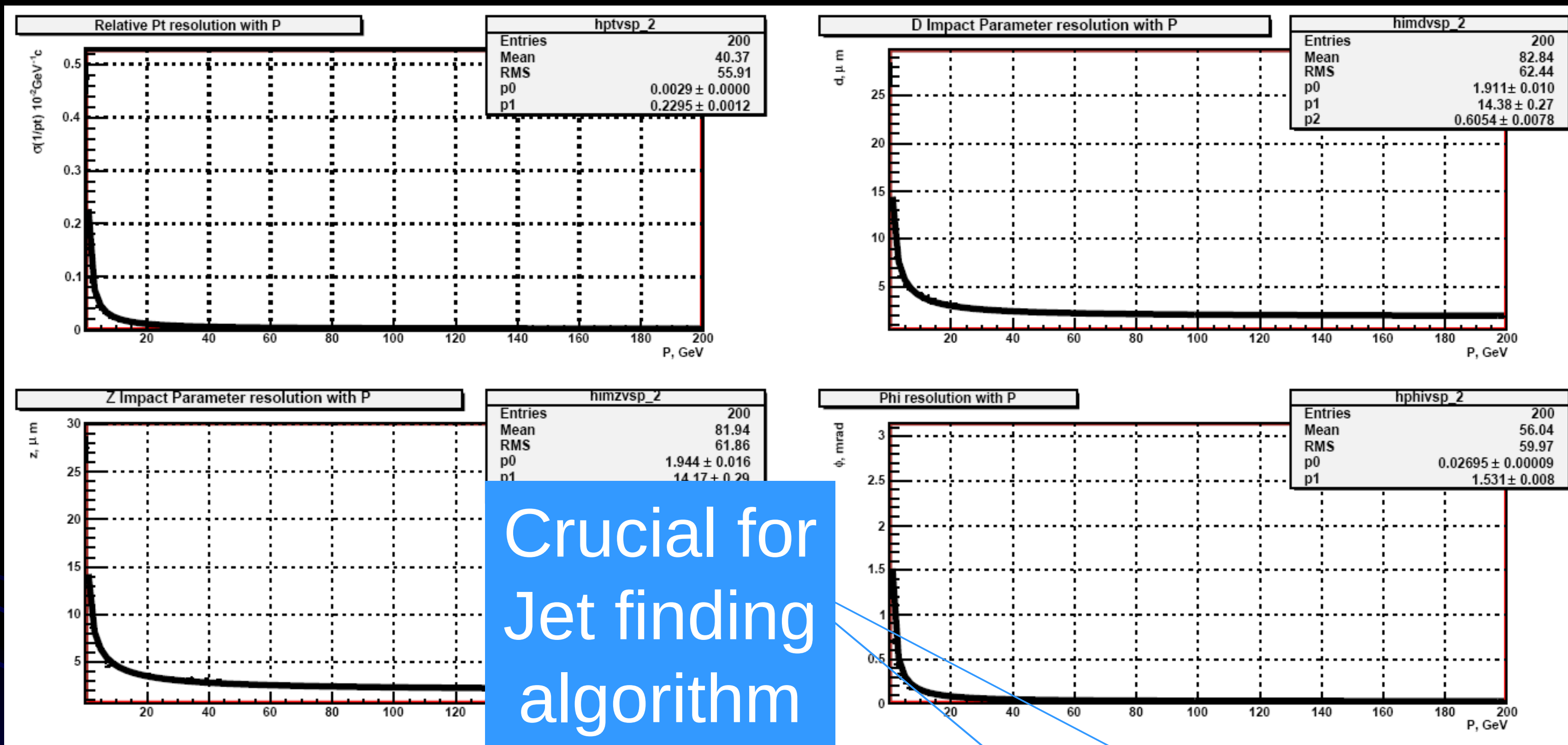
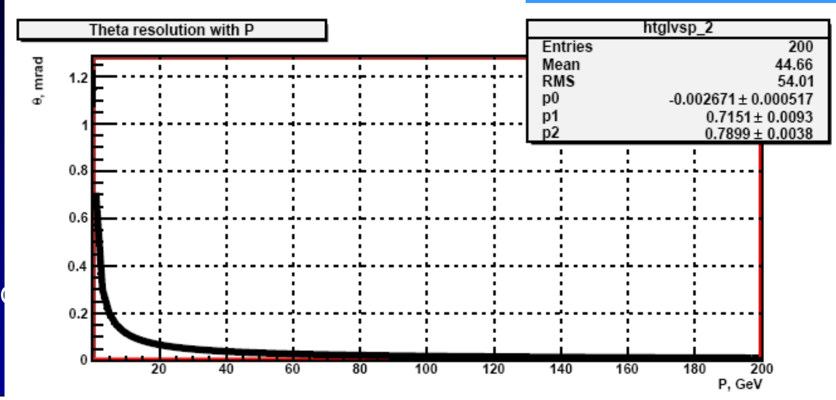


Crucial for Jet finding algorithm



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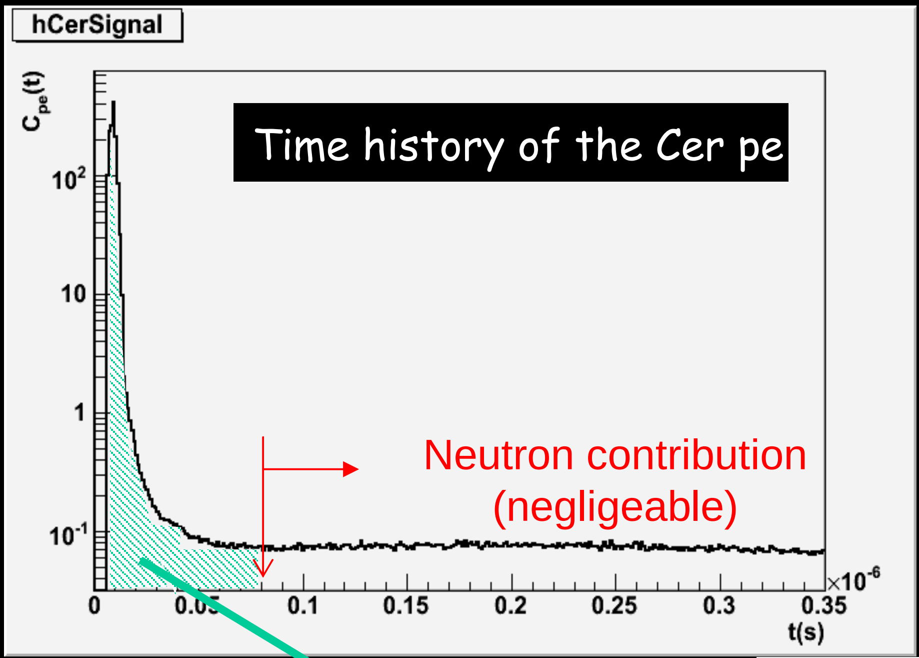
$$\sigma(Z_o) = 14.2 / P^{0.53} \oplus 1.9 \; \mu m$$

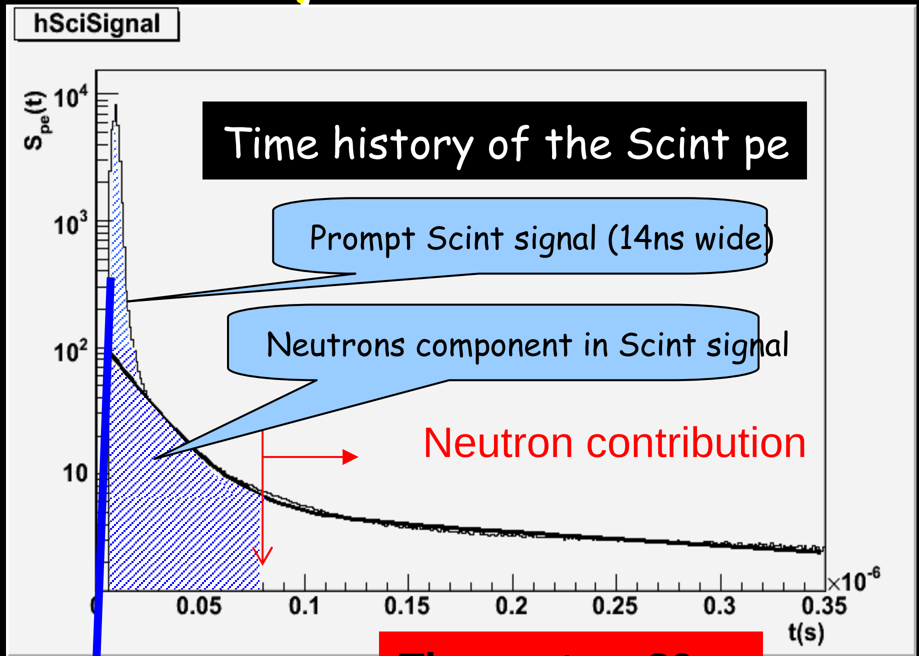
Dual Readout Calorimetry for CLIC:

A conservative approach

- Main difference between ILC/μCollider is that at CLIC the neutron contribution may not be related to the shower being measured
- Because of intense γ–γ contamination, the time gate should be of the order of 20 nsec

Dual Readout in ILC/μCollider





Time gate > 80ns

45 GeV π^-

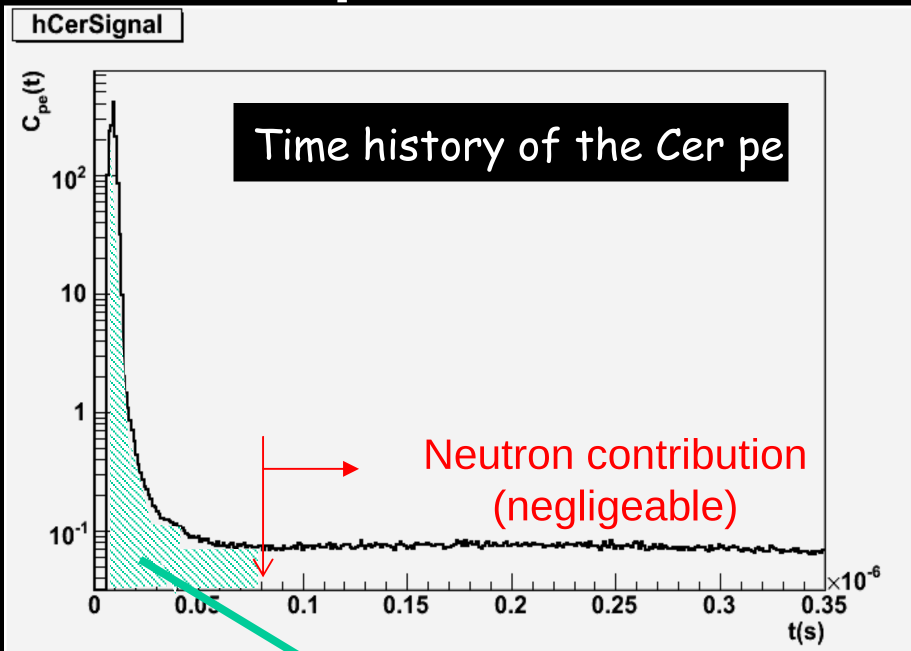
$$E_{HCAL} = \frac{\eta_C \cdot E_C \cdot (\eta_S - 1) - \eta_S \cdot E_S \cdot (\eta_C - 1)}{\eta_S - \eta_C}$$

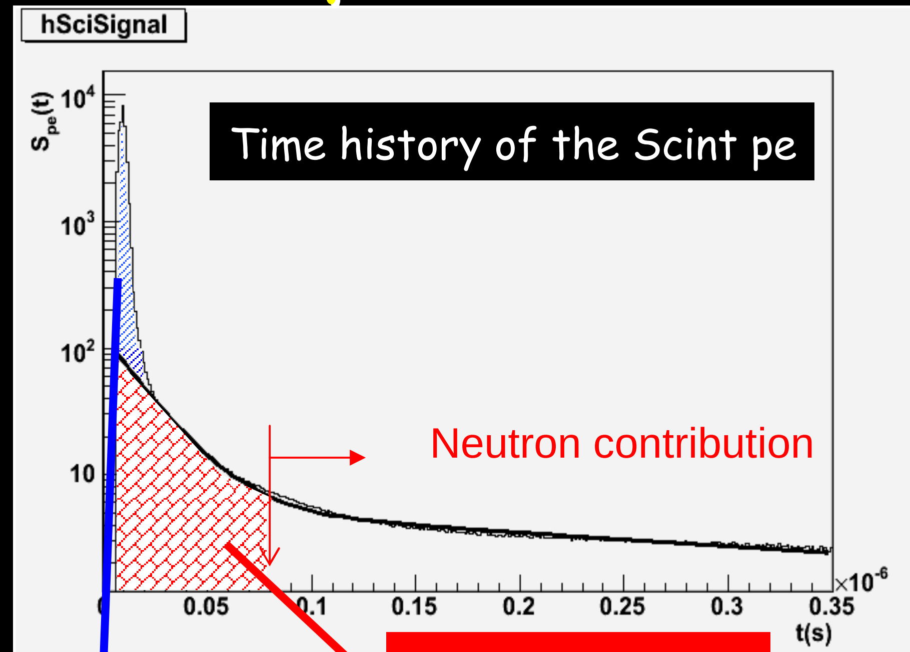
In DualReadout the signals from Cerenkov and Scintillation fibers is integrated
Neutron contribution cannot be disentangled

V. Di Benedetto

ILCRoot simulation

Triple Readout in ILC/μCollider





Time gate > 80ns

45 GeV π^-

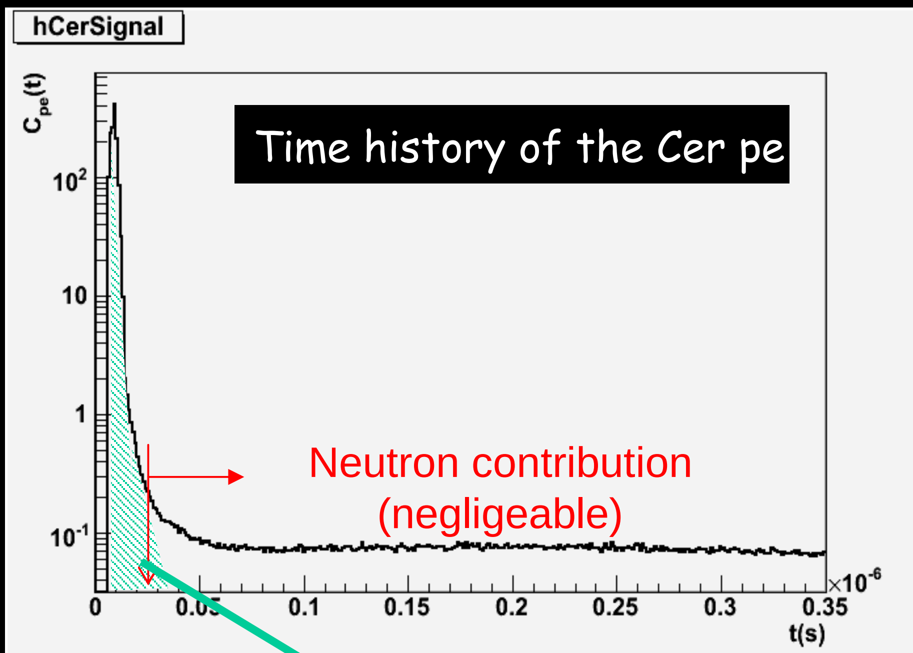
$$E_{HCAL} = \frac{\eta'_C E_C \cdot (\eta'_S - 1) - \eta'_S \cdot E_S \cdot (\eta'_C - 1)}{\eta'_S - \eta'_C} + \eta_n \cdot E_{neutrons}$$

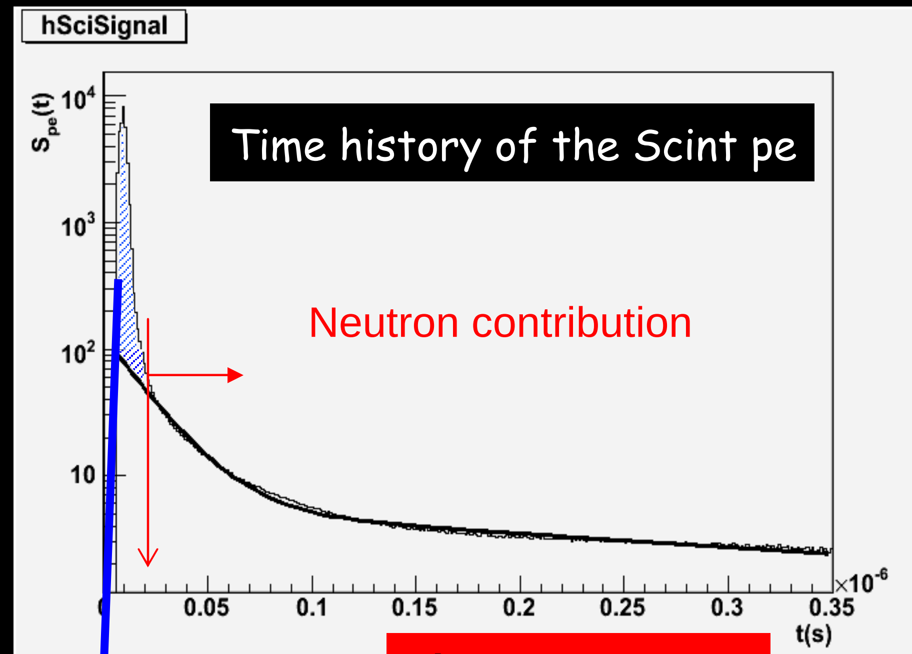
Triple readout add the contribution from the neutrons
It is a Dual Readout with time history readout
Neutron contribution is extracted from fit and used in the formula

V. Di Benedetto

ILCRoot simulation

Dual Readout at CLIC: worst case





Time gate = 20ns

45 GeV π⁻

$$E_{HCAL} = \frac{\eta''_C \cdot E_C \cdot (\eta''_S - 1) - \eta''_S \cdot E_S \cdot (\eta''_C - 1)}{\eta''_S - \eta''_C}$$

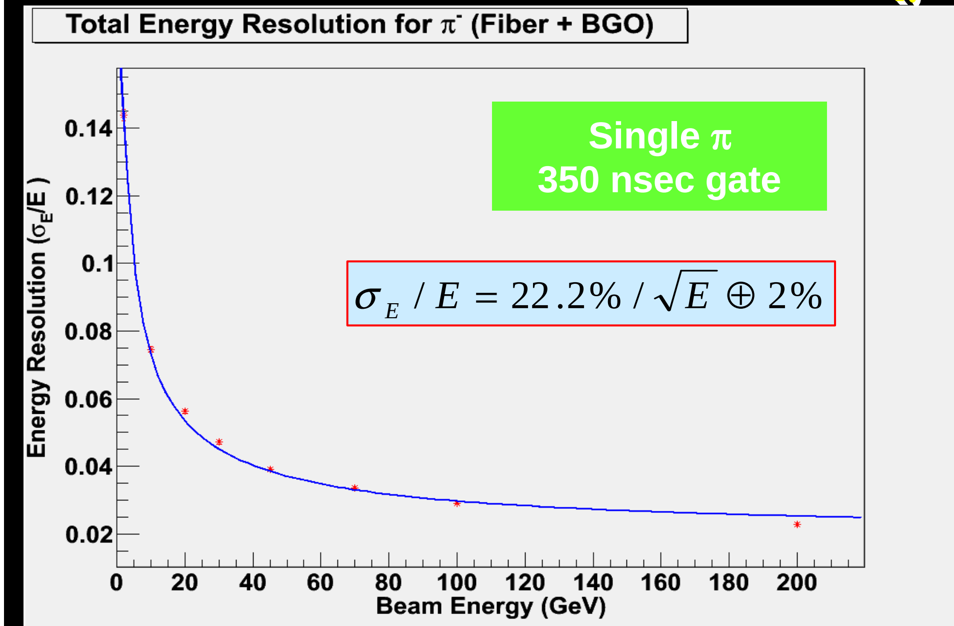
Neutron signal is disregarded
Scintillation contribution is extracted from fit and used in the formula

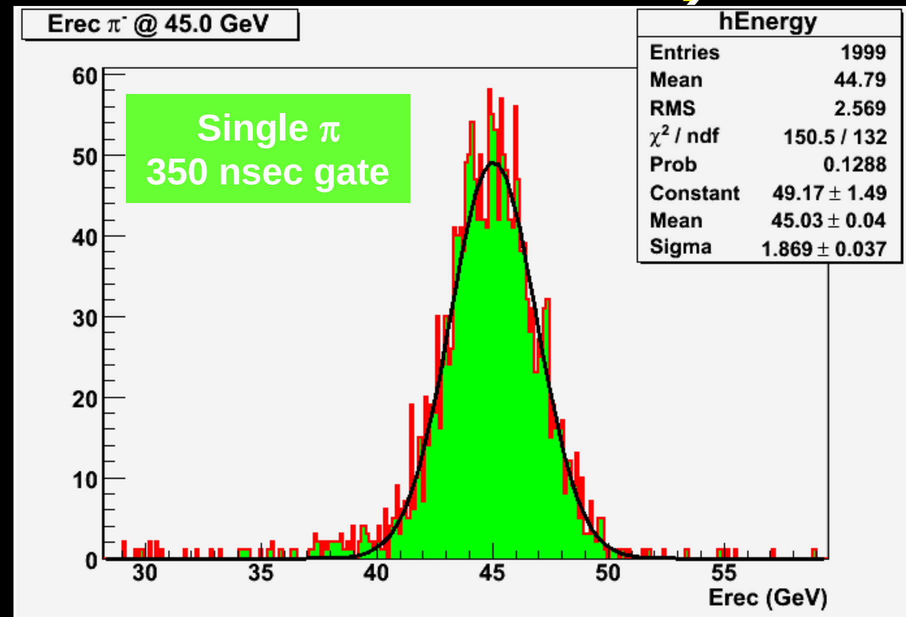
V. Di Benedetto

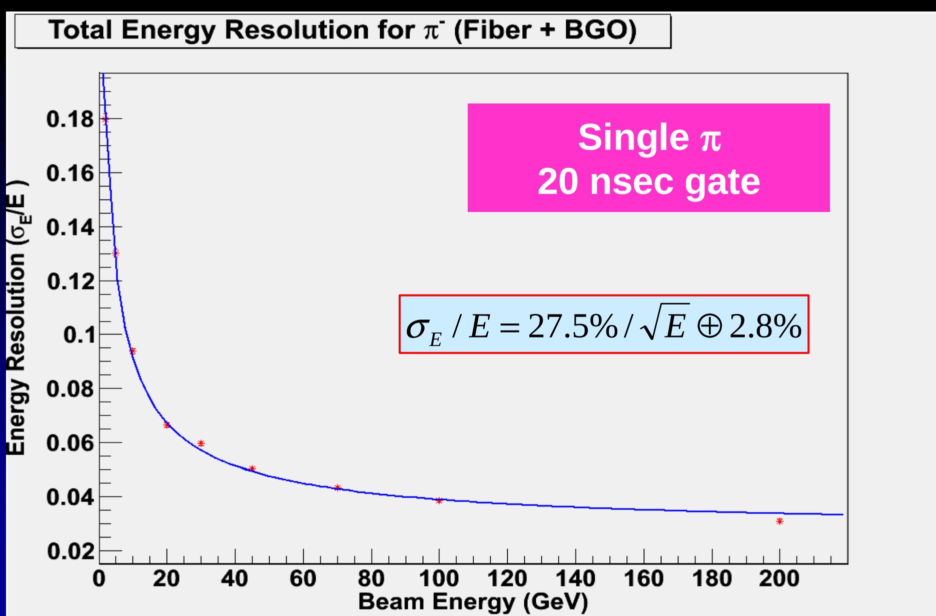
ILCRoot simulation

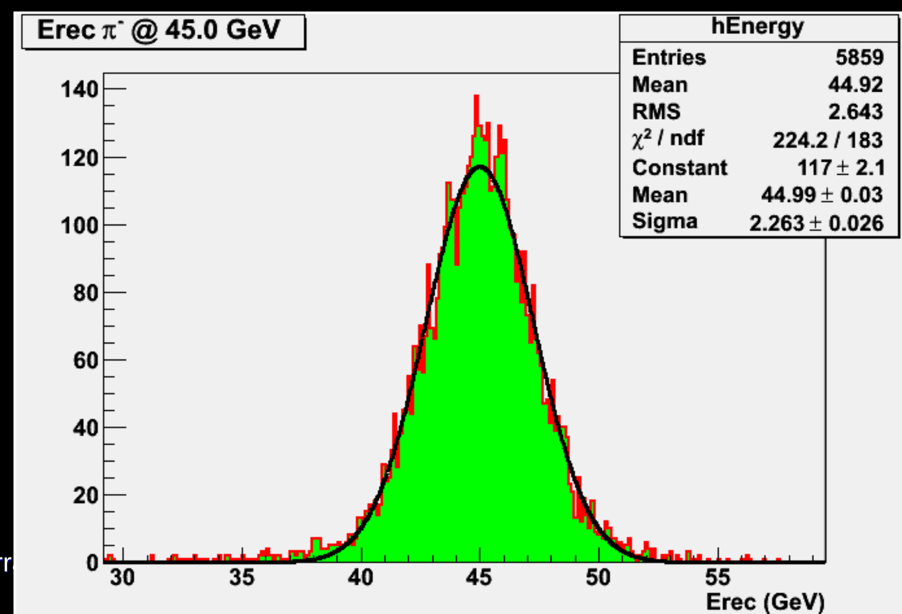
V. Di Benedetto

Performance (μCollider vs CLIC)



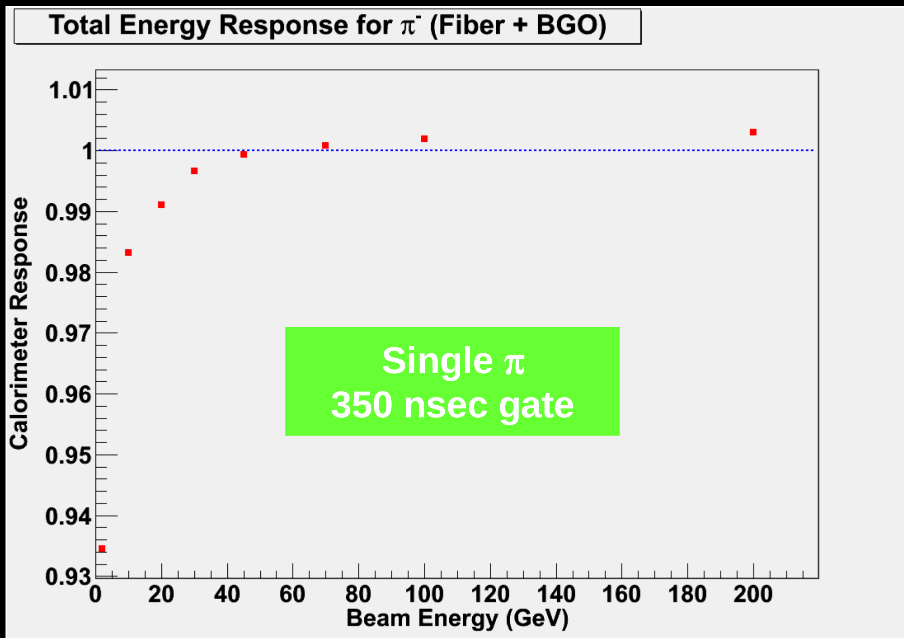


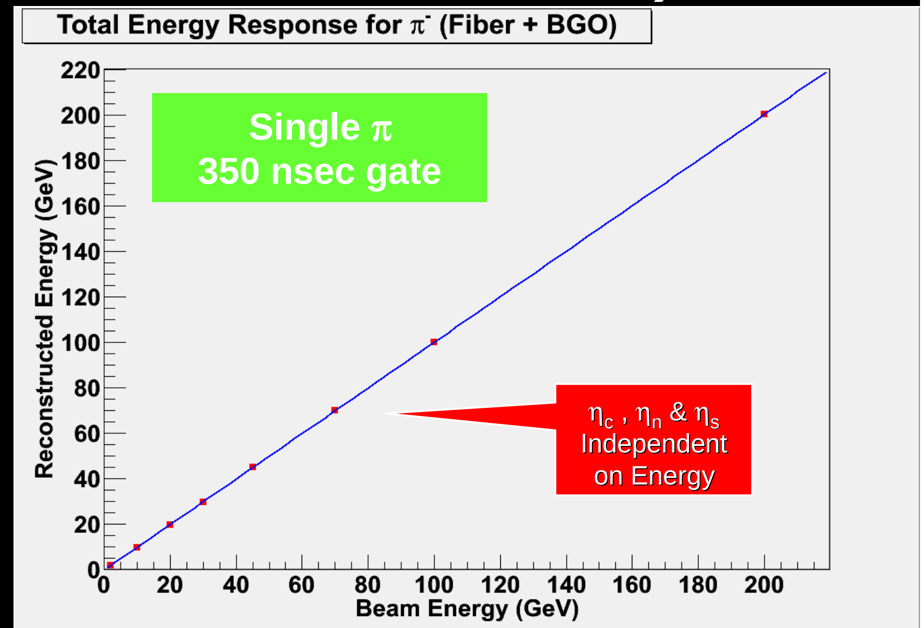


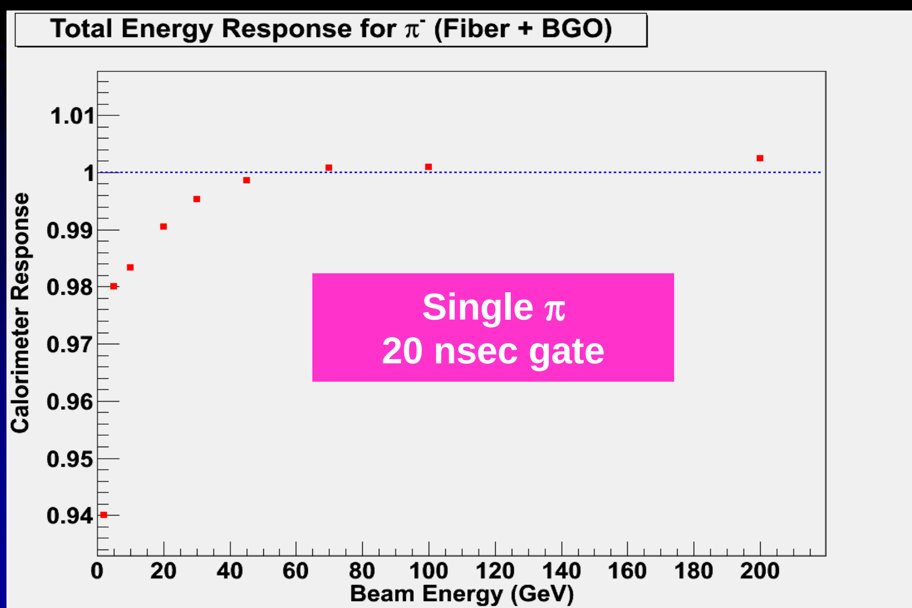


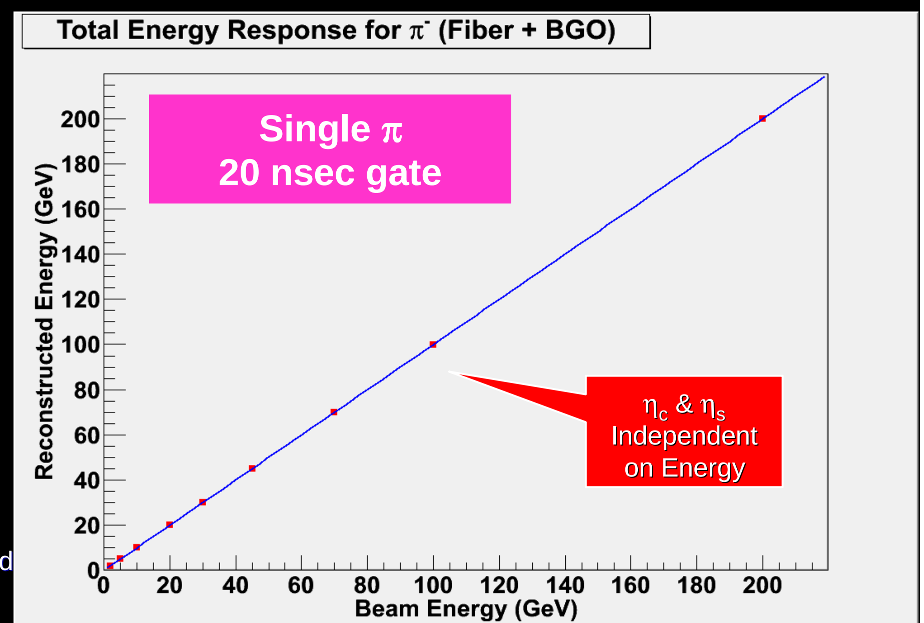
V. Di Benedetto

Performance (μCollider vs CLIC)

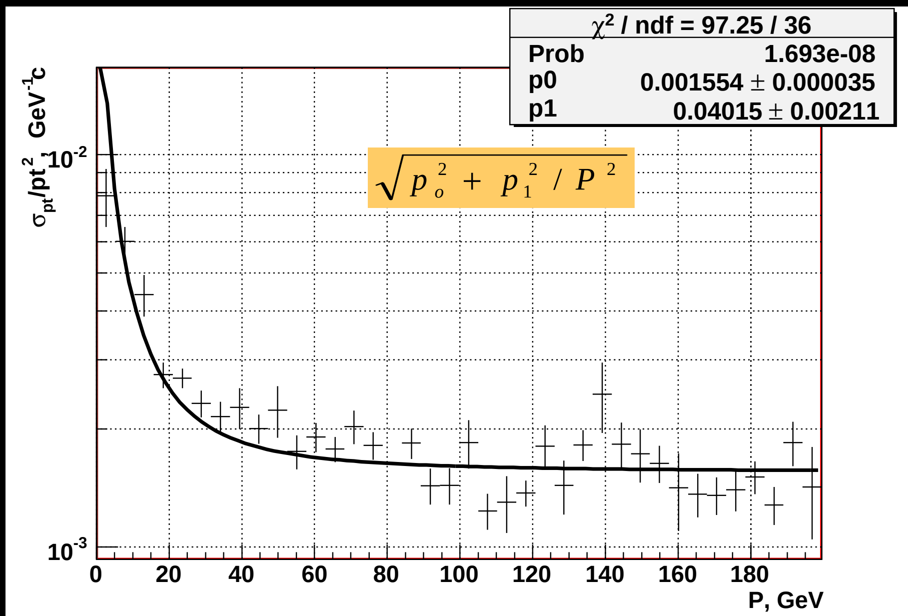








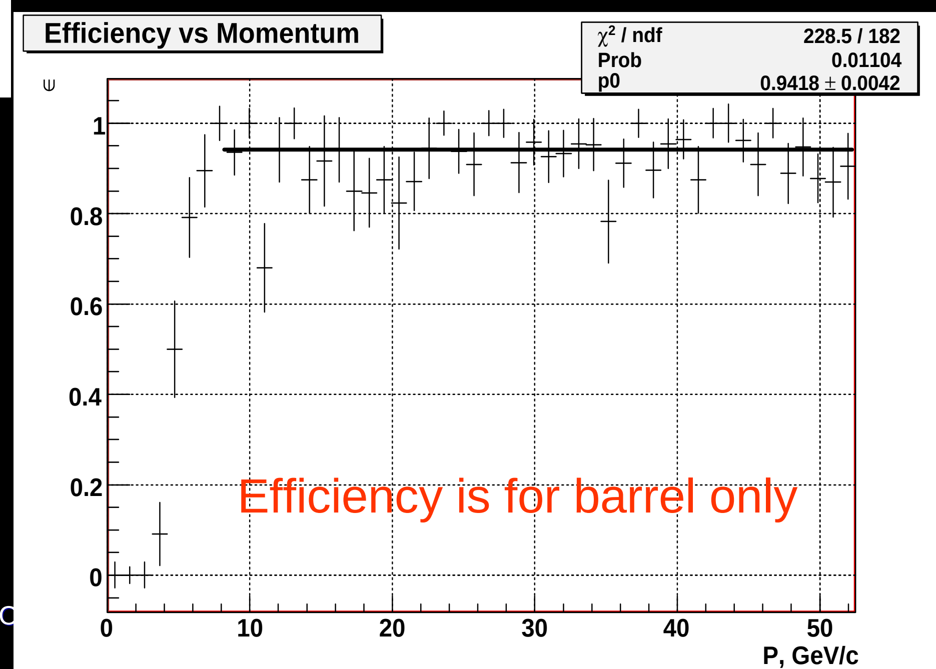
Muon Spectrometer Performance



ILCRoot simulation

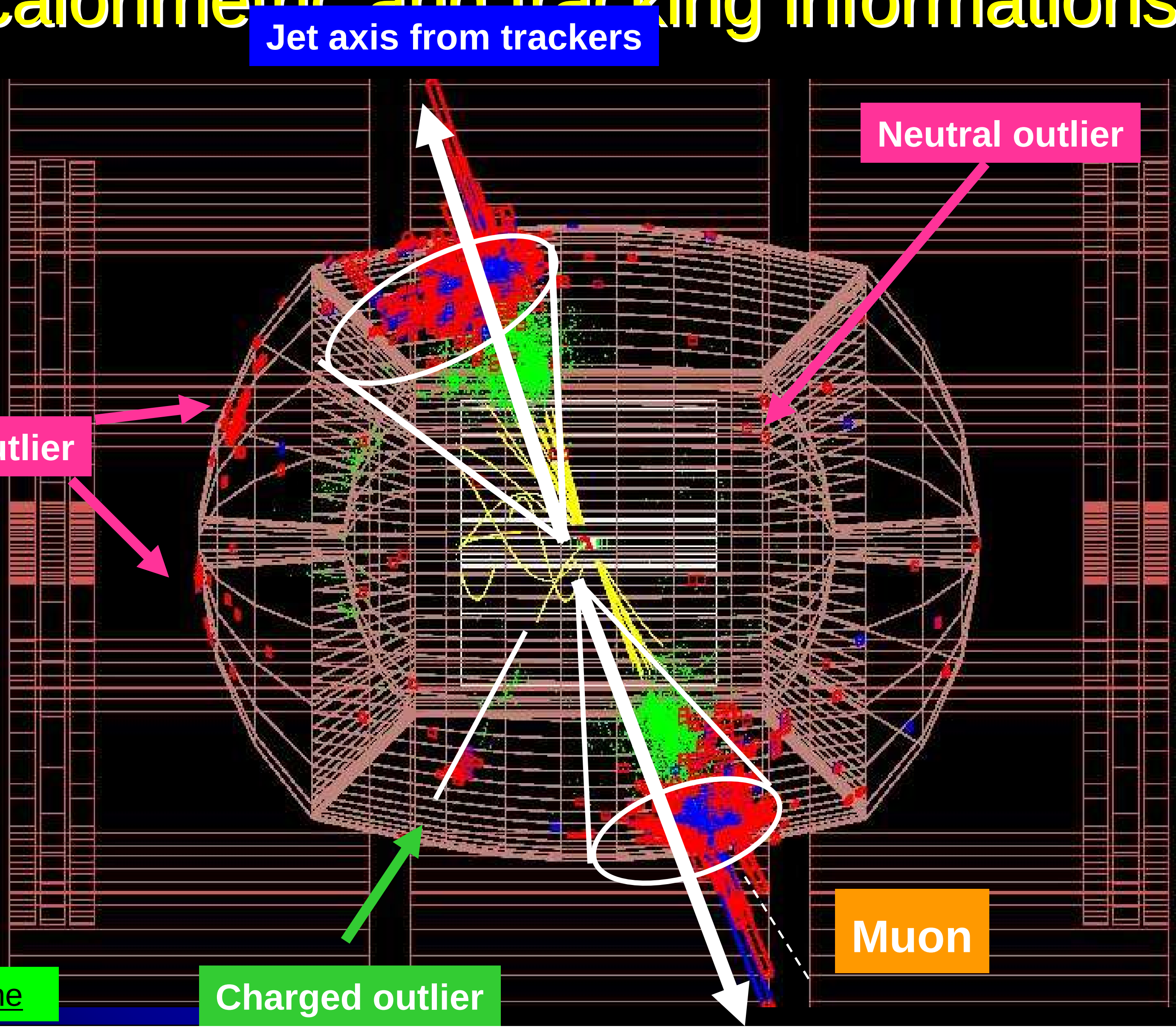
$$\sigma(P_t^{-1}) = 0.04 / P \oplus 1.5 \times 10^{-3} GeV^{-1} c$$

vs 10% for a range based detector



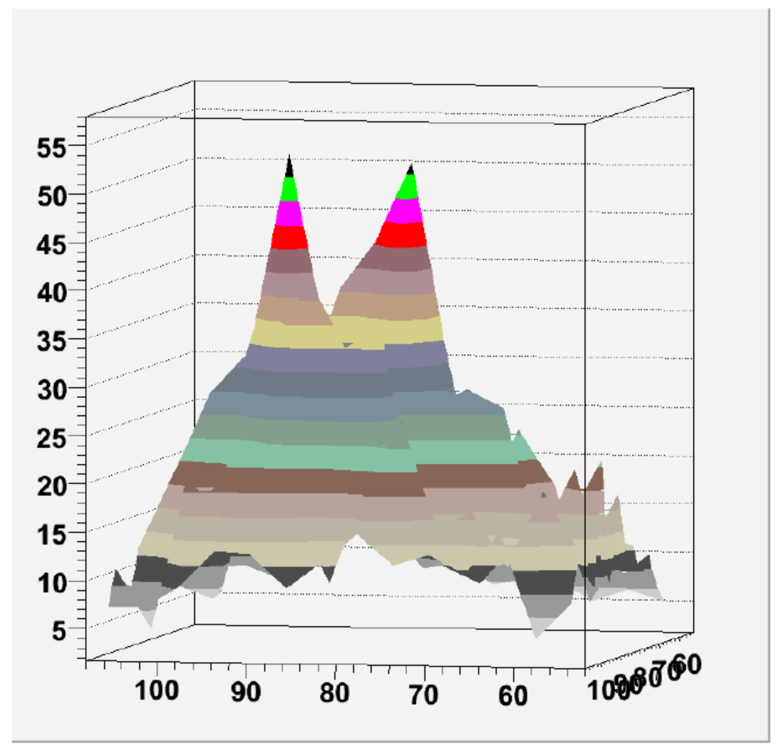
W/Z separation

Jet Reconstruction Strategy: combine calorimetric and tracking informations



A. Mazzacane

W/Z Mass Separation at 500 GeV with Triple Readout

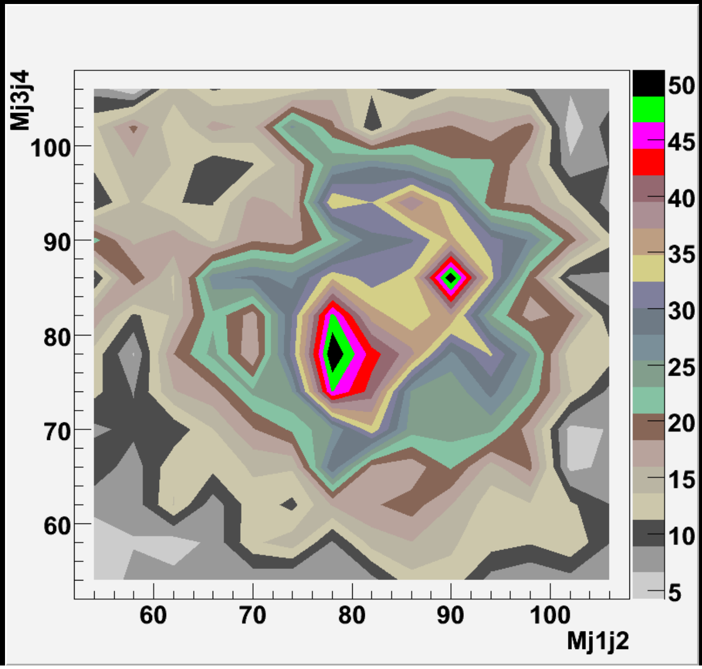


All combination plotted

(3 entries/event)

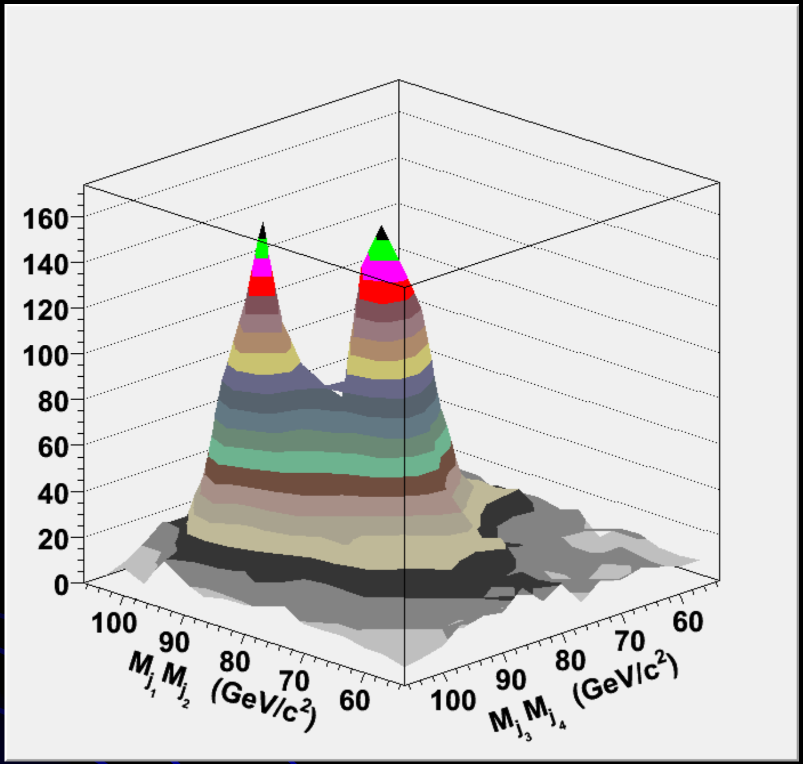
$$e^+e^- \rightarrow W^+W^-\nu\overline{\nu}, Z^oZ^o\nu\overline{\nu}$$

- No fully combined information with tracking yet
- No ECAL
- 4-jets finding efficiency: 95%



A. Mazzacane

W/Z Mass Separation at 3 TeV with Dual Readout

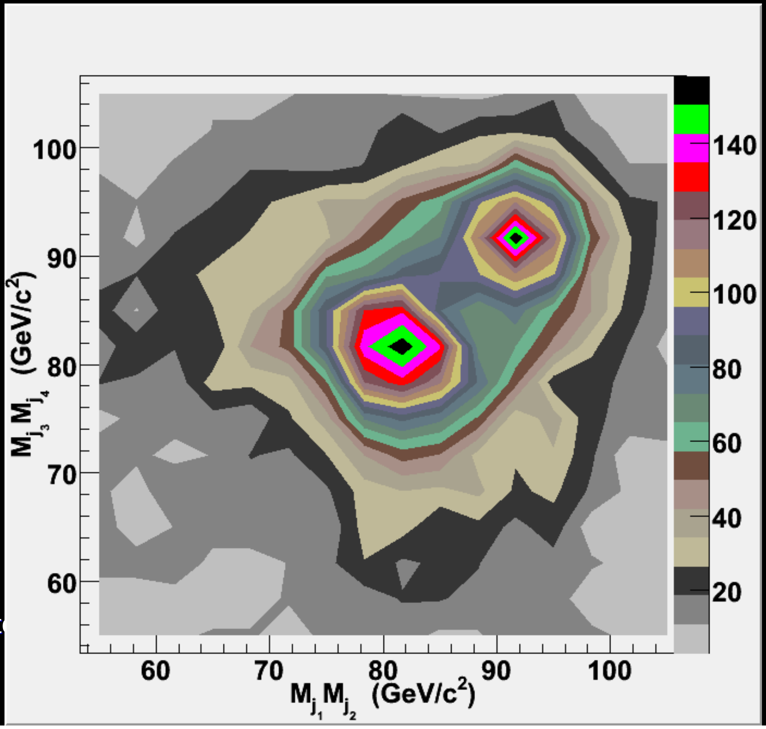


$$e^+e^- \rightarrow W^+W^-\nu\bar{\nu}, Z^oZ^o\nu\bar{\nu}$$

- No fully combined information with tracking yet
- ECAL included

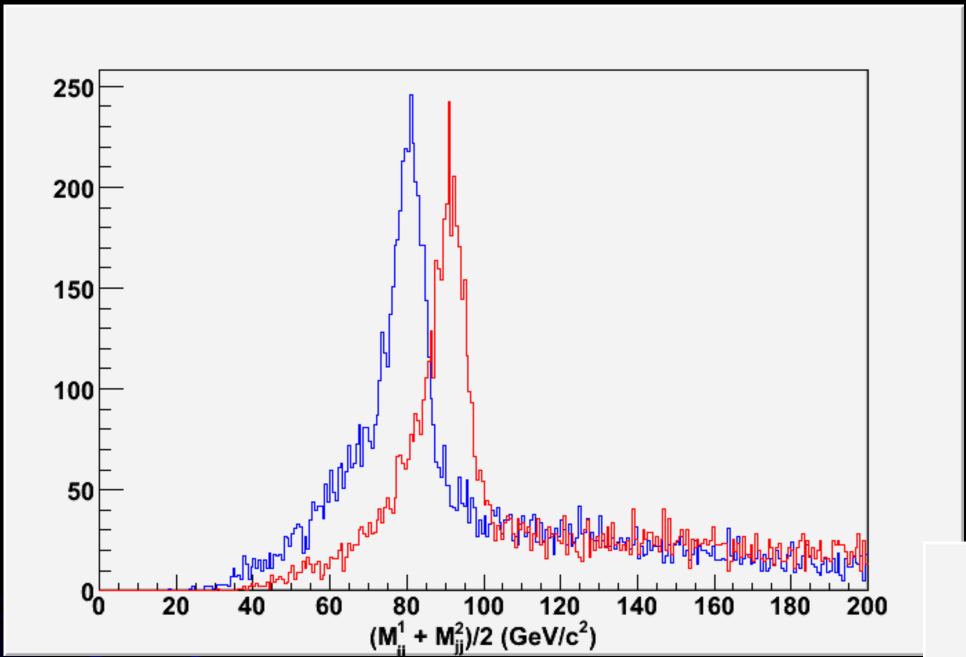
All combination plotted

(3 entries/event)



A. Mazzacane

W/Z Mass Separation at 3 TeV with Dual Readout

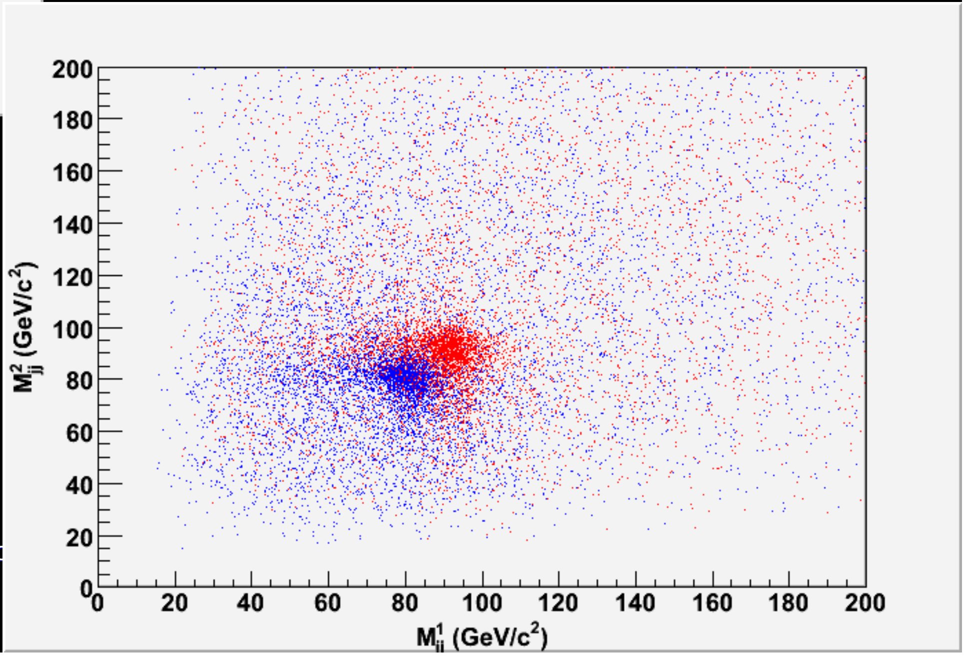


$$e^+e^- \rightarrow W^+W^-\nu\bar{\nu}, Z^oZ^o\nu\bar{\nu}$$

- No fully combined information with tracking yet
- ECAL included

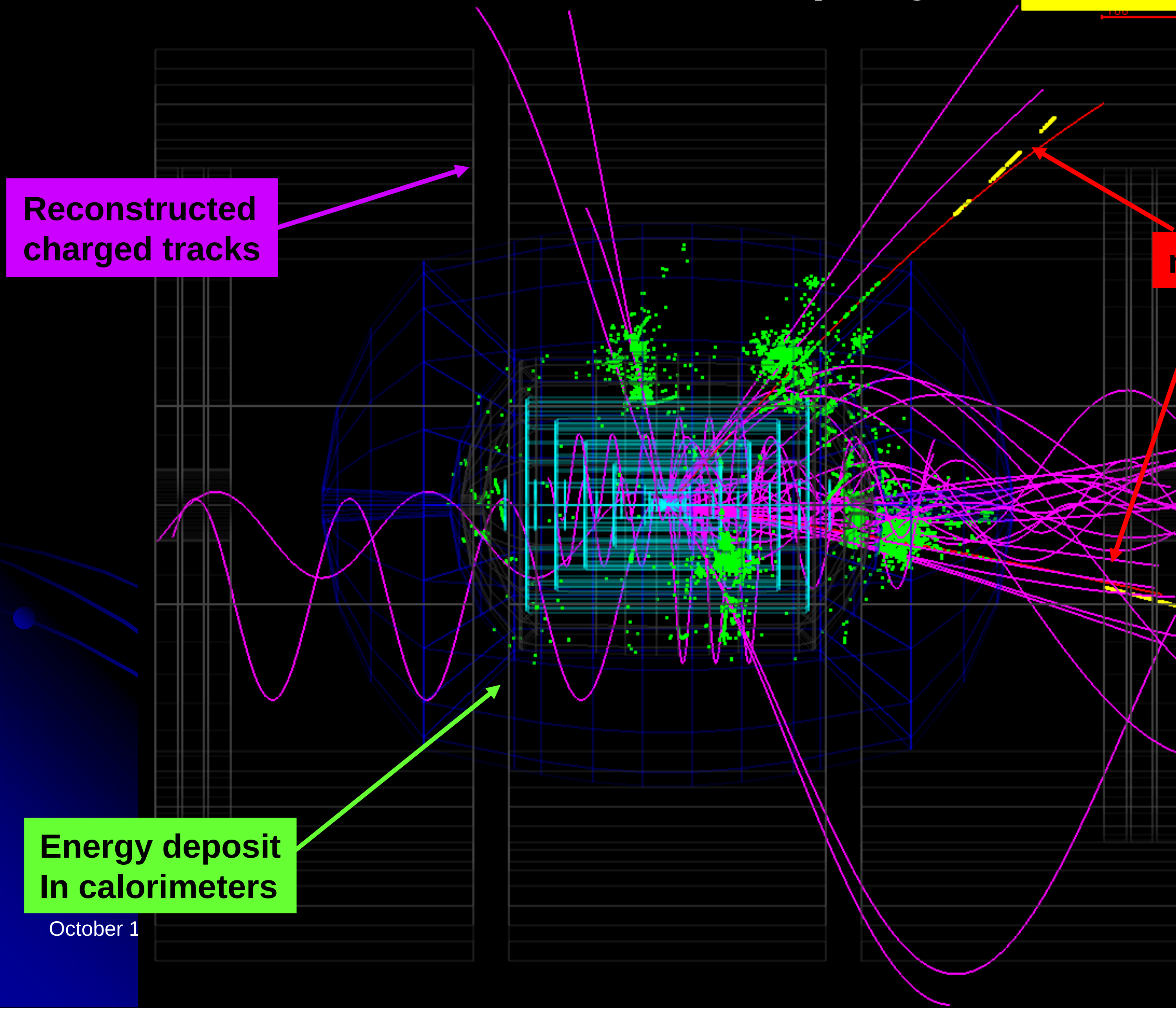
All combination plotted

(3 entries/event)



Event Display

$$e^+e^- \to W^+W^-\nu\bar{\nu}, Z^oZ^o\nu\bar{\nu}$$
$$E_{CM} = 3\,TeV$$



$e^+e^- \rightarrow \chi_1^+\chi_1^- \rightarrow \chi_1^o\chi_1^o\ W^+W^-$ $\sqrt{s}$=500 GeV

$e^+e^- \rightarrow \chi_2^o\chi_2^o \rightarrow \chi_1^o\chi_1^o\ Z^oZ^o$

Event reconstruction :

List charged traks from trackers

List of HCAL towers and ECAL cells with E >10 MeV

after calorimeters calibration

Jet pairing :

min $|m_{ij} - m_{kl}|$

To further reduce background:

$|m_{ij} - m_{kl}| < 5$ GeV/c^2

WW/ZZ selection :

Fit on dijet-mass invariant distribution

Event selection :

Events forced into 4jets (Durham)

$E_{jet} \geq$ 5 GeV

$|\cos\theta_{jet}| <$ 0.99

$N_{total\ lcharged\ tracks\ \ in\ jet} \geq$ 2

$N_{total\ charged\ tracks} \geq$ 20

$Y_{cut} > 0.001$

100 GeV < E_{vis} < 250 GeV

$|\cos\theta_{miss\ P}| <$ 0.8

$M_{miss} >$ 220 GeV/c^2

No lepton with $E_{lepton} >$ 25 GeV

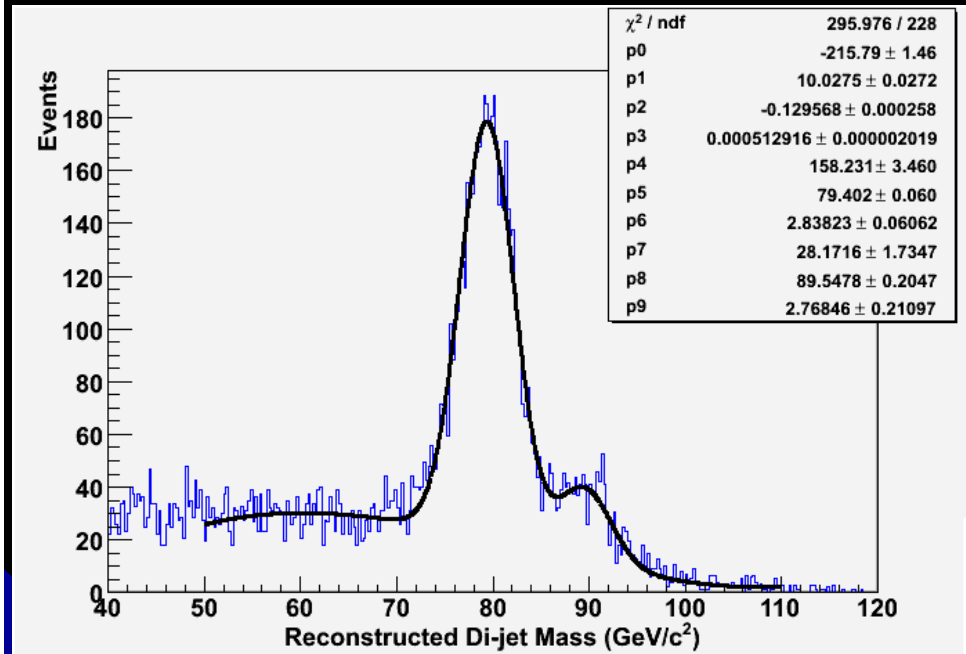
$\varepsilon_{chargino}$ = 30.3%

$\varepsilon_{neutralino}$ = 28.6%

A. Mazzacane

$e^+e^- \to \chi_1^+\chi_1^- \to \chi_1^o\chi_1^o\, W^+W^-$ $\sqrt{s}$=500 GeV

$e^+e^- \to \chi_2^o\chi_2^o \to \chi_1^o\chi_1^o\, Z^oZ^o$

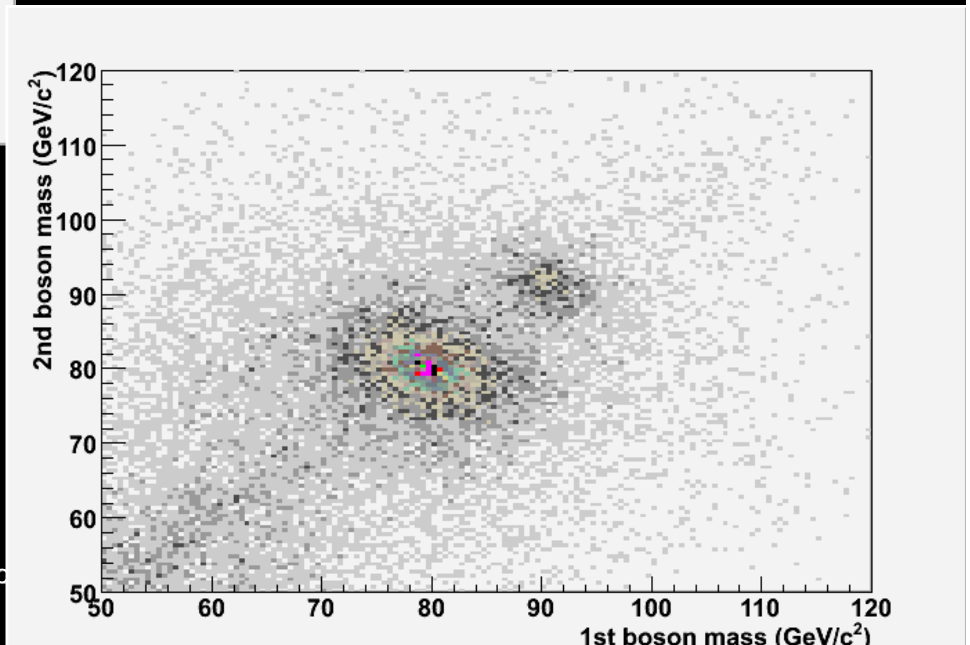


Fitted distribution (double gaussian plus 3rd order polynomial)

M_W = 79.40 ± 0.06 GeV/c^2
σ_W = 2.84 ± 0.06 GeV/c^2

M_Z = 89.55 ± 0.20 GeV/c^2
σ_Z = 2.77 ± 0.21 GeV/c^2

Reconstructed masses after selection cuts and jet pairing



Conclusions

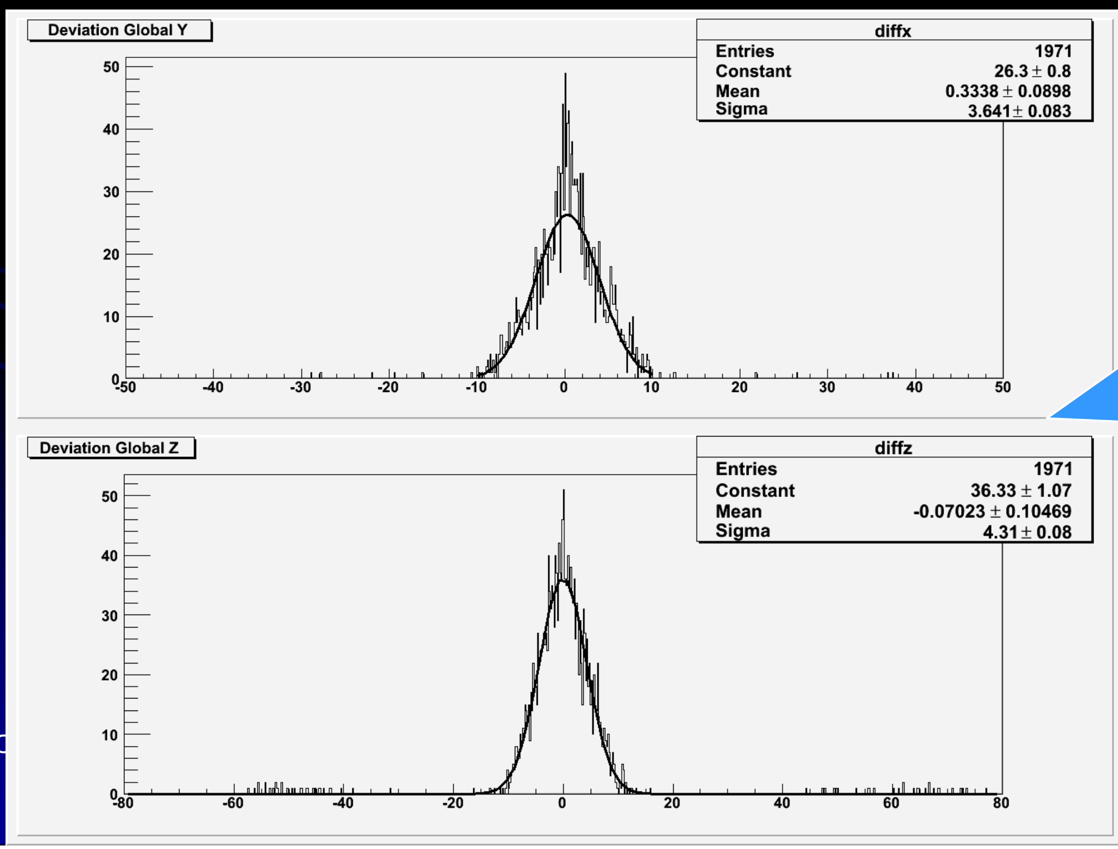
- An alternative detector layout is presented by the 4th Concept Collaboration for Physics at Multi TeV Lepton Collider
  - Si pixel detector + Forward Tracker replace Drift Chamber
  - Time gate of Dual Readout calorimeter reduced to 20ns
- Eventual collaboration with SiLC will strengthen the project
- Simulation machinery (ILCroot) already in place
- It has run flawlessly along the benchmark process for LOI at ILC (200-1000 CPU on Fermi-GRID almost no-stop since August 2008)
- Overall detector performance is excellent
- Physics studies at Multi TeV E_{CM} are in progress: must include bckgnd
- W and Z separation is preserved at 3 TeV with short DR time gate

Backup slides

D. Barbareschi
M. Rucco

VXD Single Cluster Residual (single track)

- FNAL/SLAC layout more than adequate for current requirements at ILC
- Main Issue is choice of technology
- Mostly driven by Montecarlo studies on beam background



Includes:

1. Diffusion in Si
2. Cross talk
3. Gaussian noise
4. Electronic thresholds
5. Clusterization

ILCRoot simulation

The Virtual Montecarlo Concept

- Virtual MC provides a virtual interface to Monte Carlo
- It allows to run the same user application with all supported Monte Carlo programs
- The concrete Monte Carlo (Geant3, Geant4, Fluka) is selected and loaded at run time
  - Compare Montecarlo performance and possible flows
  - Choose the optimal Montecarlo for the study

Perfect Tool for Designing/Optimizing new Detectors

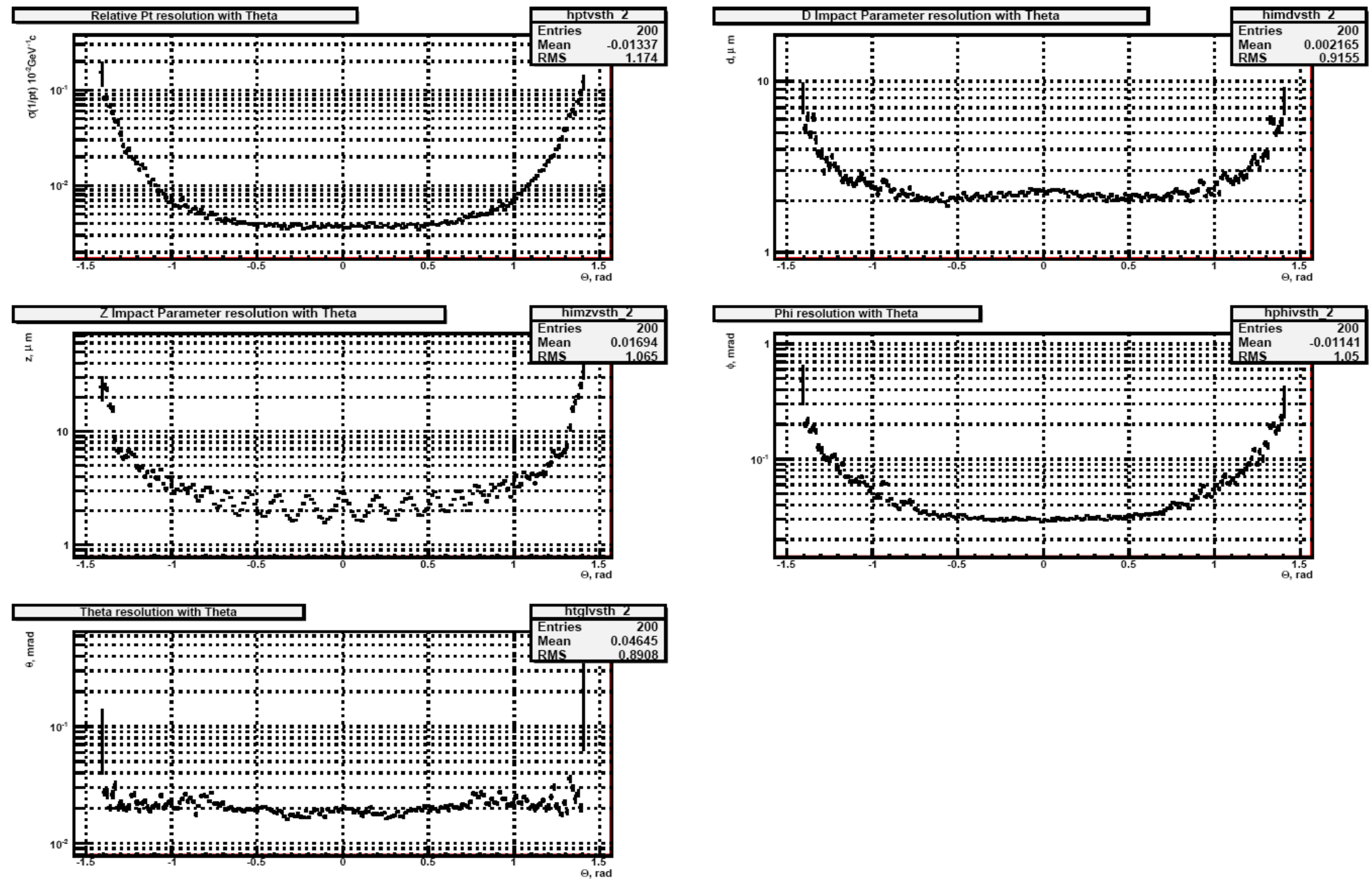
4th Concept Software Strategy: ILCroot

- 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
- TGenerator for events generation
- Virtual Geometry Modeler (VGM) for geometry
- Based on Virtual Montecarlo
- Could it ever evolve into a general purpose entity for the HEP community (as ROOT)?
- Growing number of experiments have adopted it: Alice, Opera, CMB, (Meg), Panda, 4th Concept
- Six MDC have proven robustness, reliability and portability

Do not Reinvent the wheel

Concentrate on Detector studies and Physics

VXD + SiPT + FTD

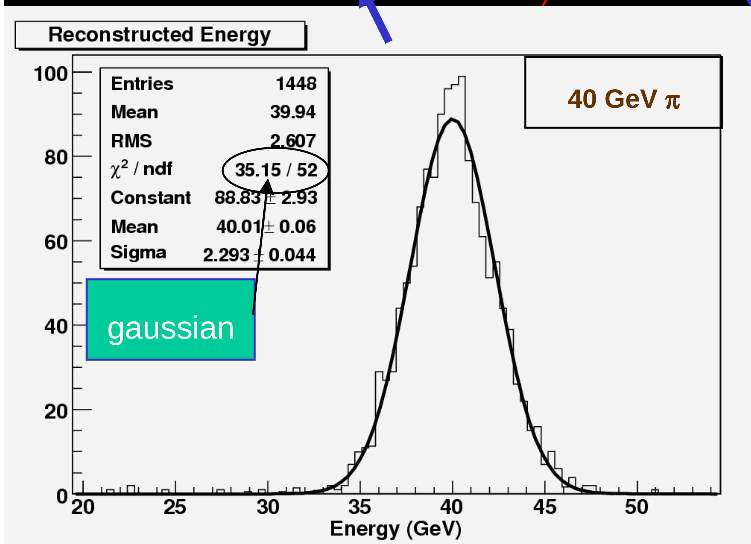


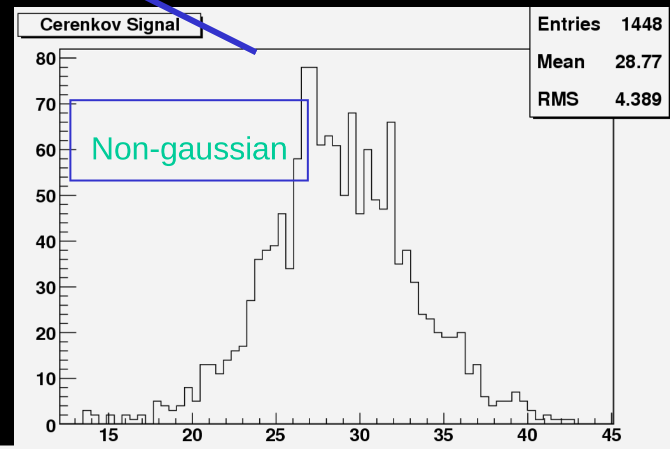
Relative Pt resolution with Theta
hptvsth_2
Entries 200
Mean -0.01337
RMS 1.174
σ(1/pt) 10⁻²GeV⁻¹c
Θ, rad
D Impact Parameter resolution with Theta
himdvsth_2
Entries 200
Mean 0.002165
RMS 0.9155
d, μ m
Θ, rad
Z Impact Parameter resolution with Theta
himzvsth_2
Entries 200
Mean 0.01694
RMS 1.065
z, μ m
Θ, rad
Phi resolution with Theta
hphivsth_2
Entries 200
Mean -0.01141
RMS 1.05
ϕ, mrad
Θ, rad
Theta resolution with Theta
htglvsth_2
Entries 200
Mean 0.04645
RMS 0.8908
θ, mrad
Θ, rad

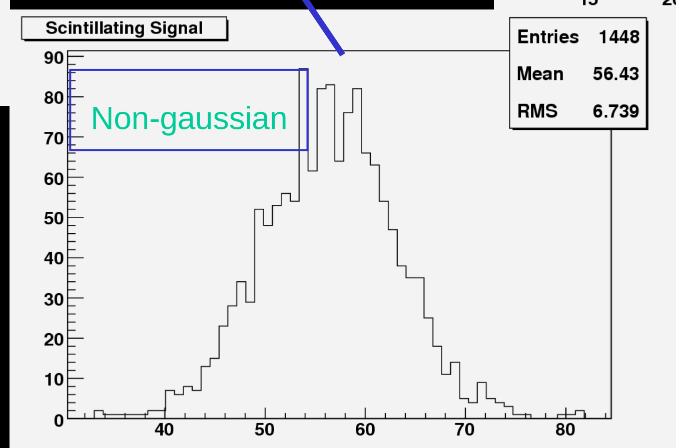
Dual Readout Calorimetry

Total calorimeter energy: use two measured signals and two, energy-independent, calibration constants

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







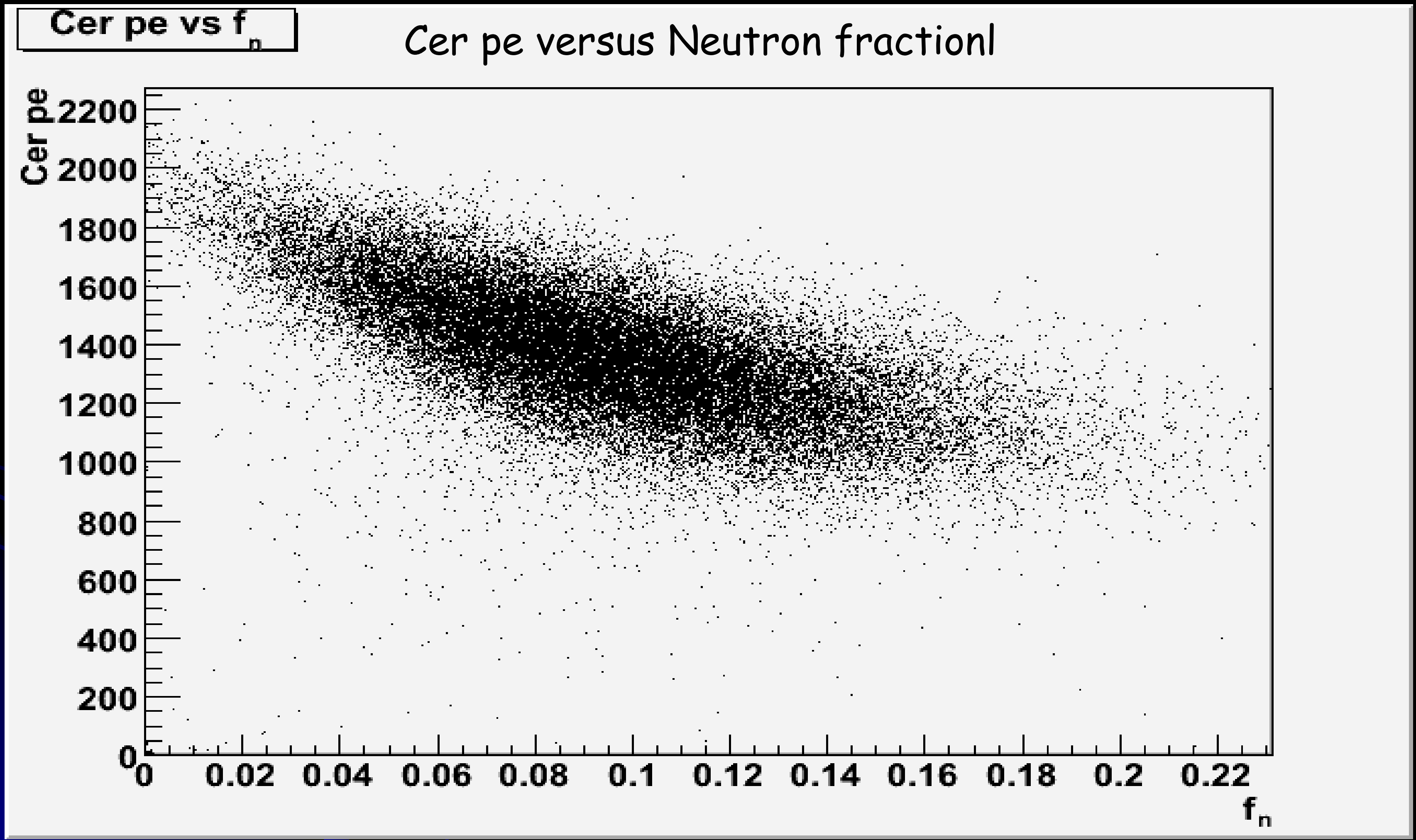
$$\eta_c = \left(\frac{e}{h}\right)_C \quad \eta_S = \left(\frac{e}{h}\right)_S$$

From calibration

@ 1 Energy only

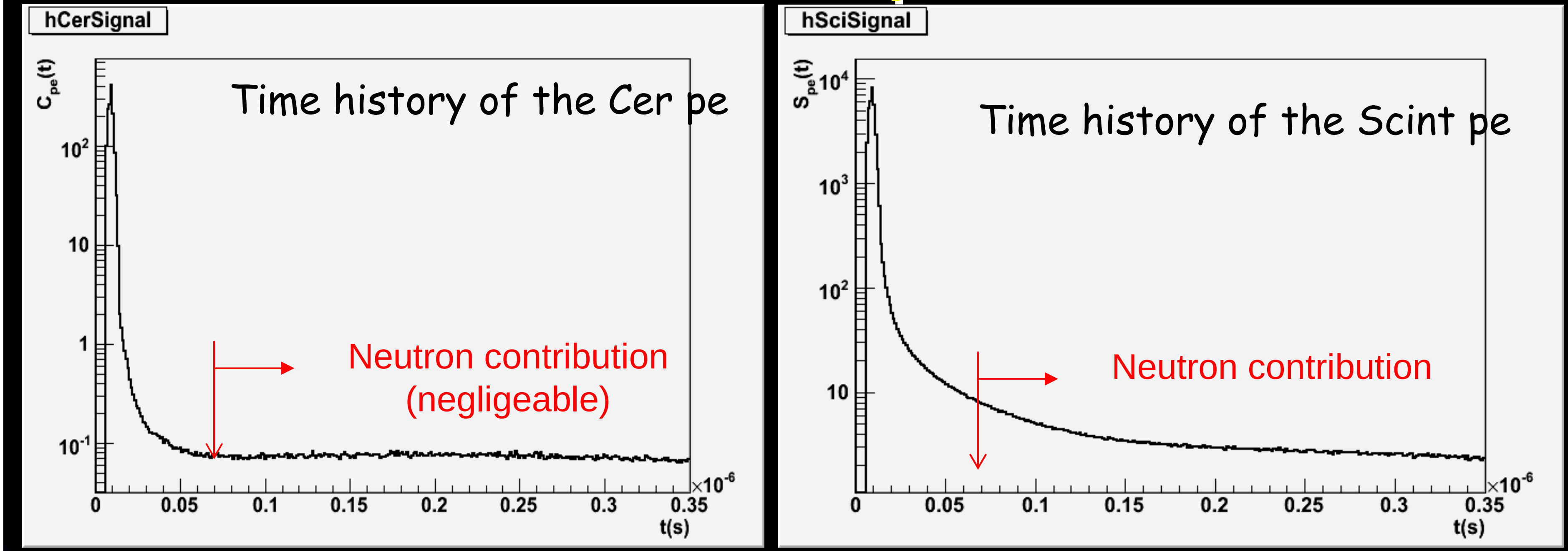
Improving the Energy Resolution: The Effect of Neutrons

45 GeV π⁻



ILCRoot simulation

From Dual to Triple Readout



45 GeV π⁻

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

Triple readout aka Dual Readout with time history readout

ILCRoot simulation

Compensation with ECAL and HCAL

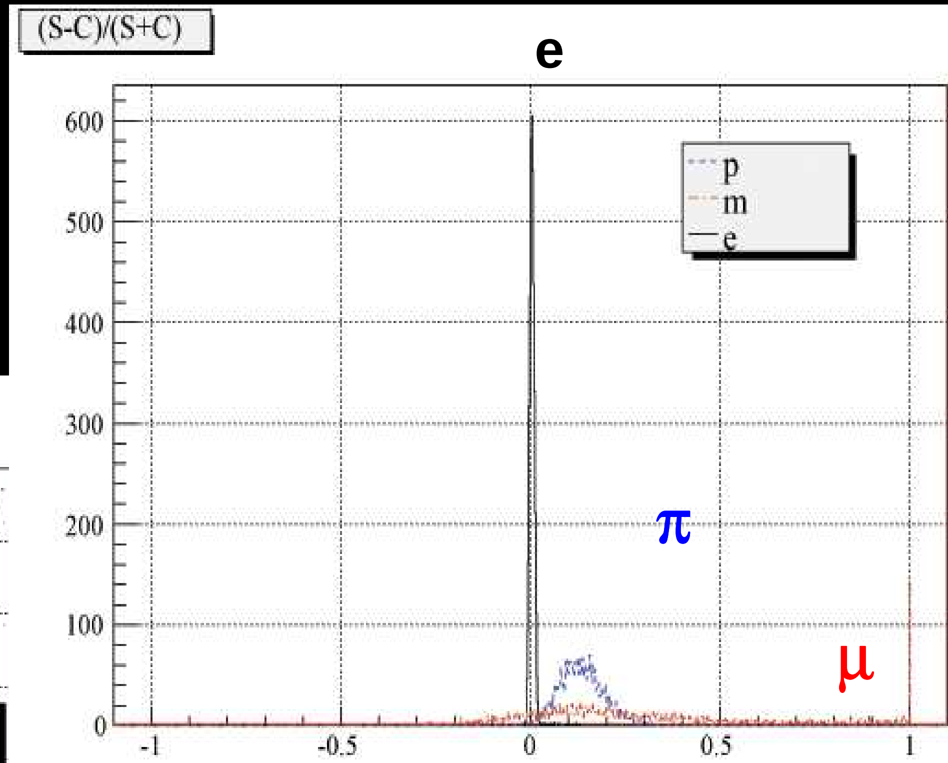
- Get E_{Scint} and E_{Cer} from ECAL (disregard neutrons as $Z_{BGO} >> 1$)
- Get E_{Scint}, E_{Cer} and E_{neutr} from HCAL
- Then:

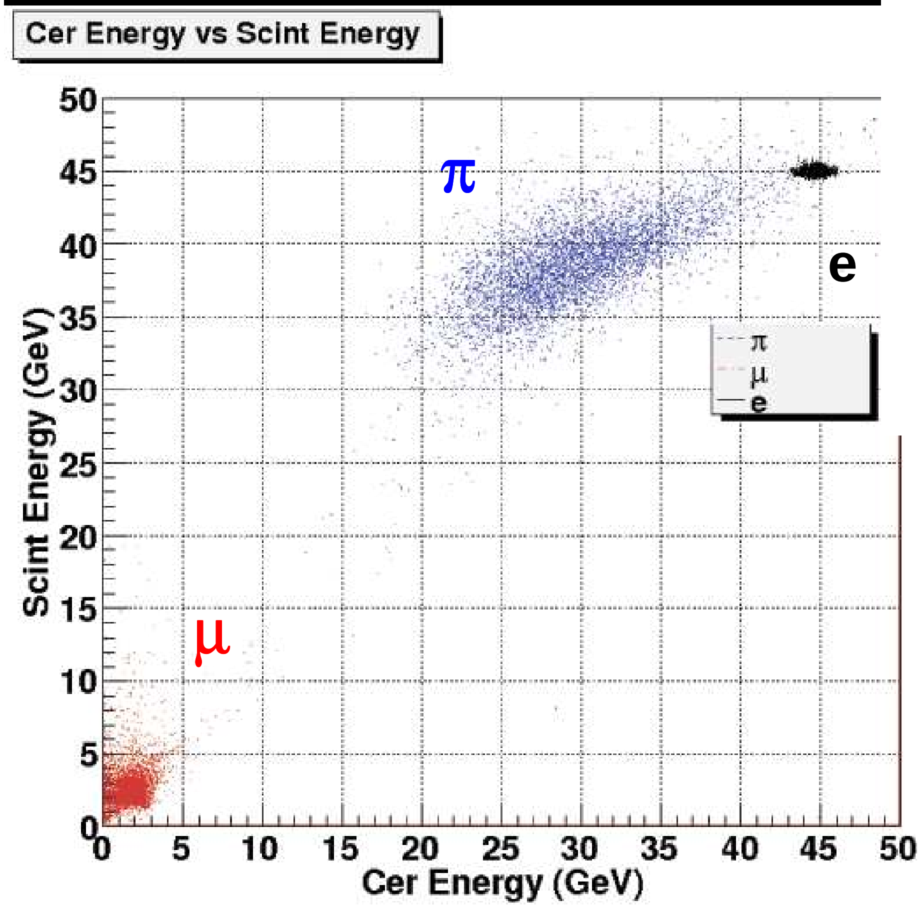
$$E_{Total} = \frac{\eta_S \cdot (E_{Scint}^{ECAL} + E_{Scint}^{HCAL}) \cdot (\eta_C - 1) - \eta_C \cdot (E_{Cer}^{ECAL} + E_{Cer}^{HCAL}) \cdot (\eta_S - 1)}{\eta_C - \eta_S} + \eta_n \cdot E_{neutrons}^{HCAL}$$

- Estimate η_C, η_S and η_{neu} from a 45 GeV run (π^- and e^-) by minimizing the spread of E_{tot}

Particle Identification with Triple Readout

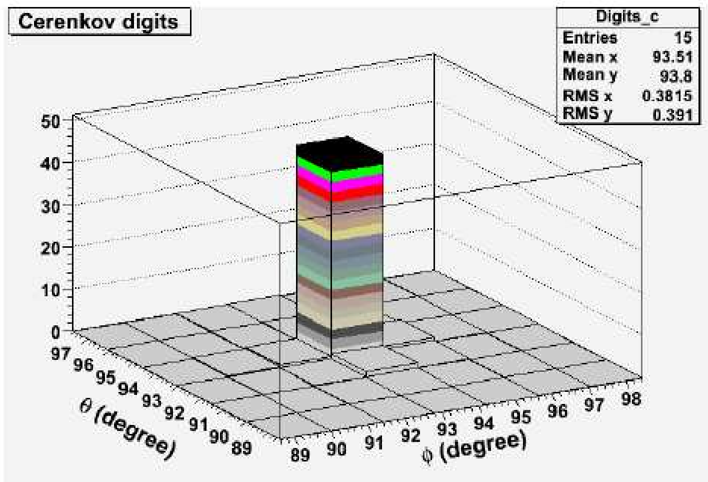
45 GeV particles



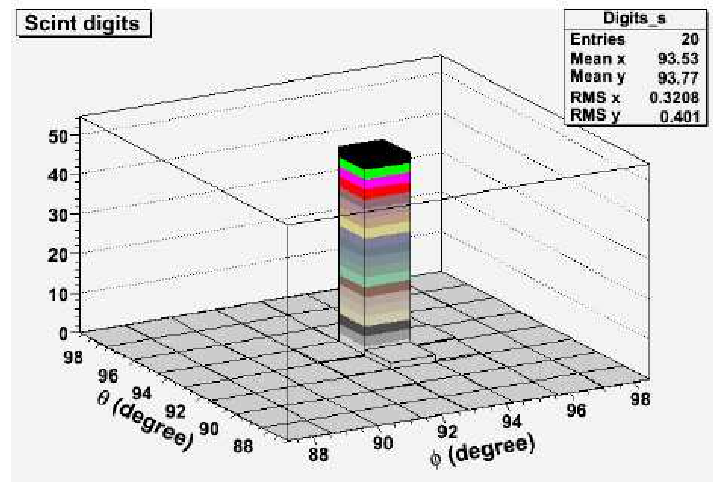


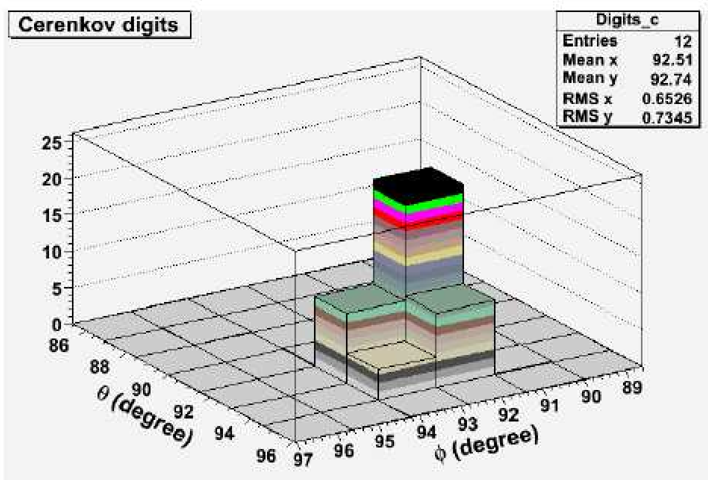
ILCRoot simulation

Calorimeter Response for 45 GeV e^-

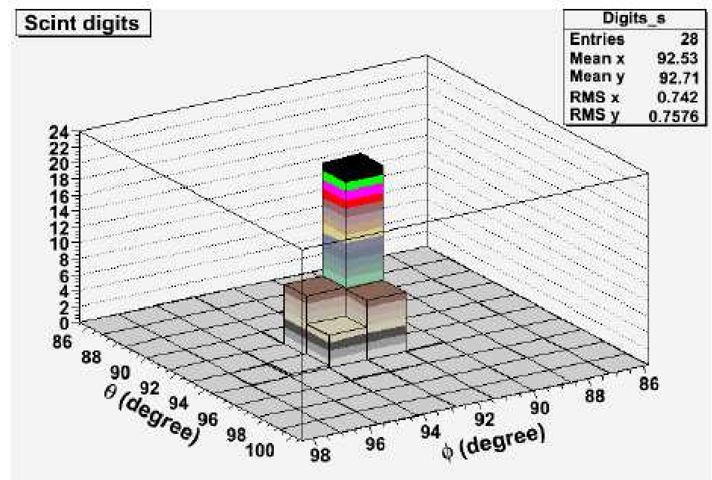


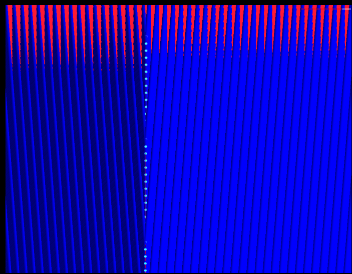
core





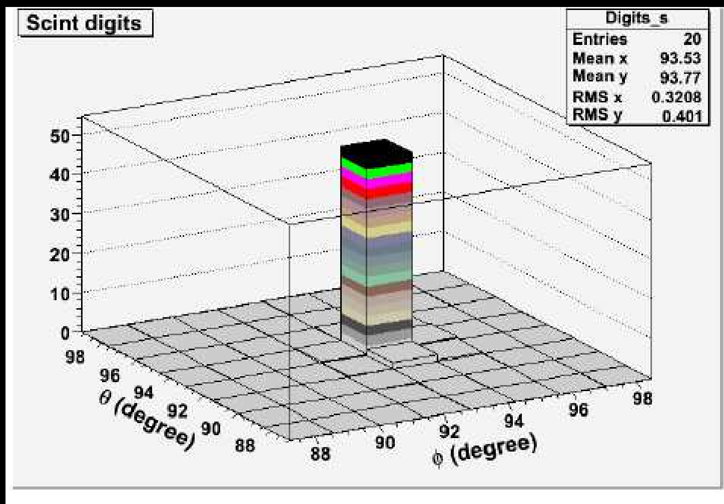
boundary

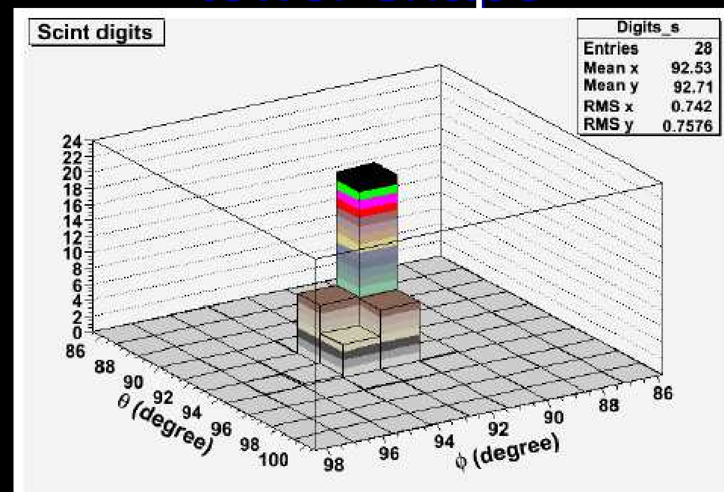


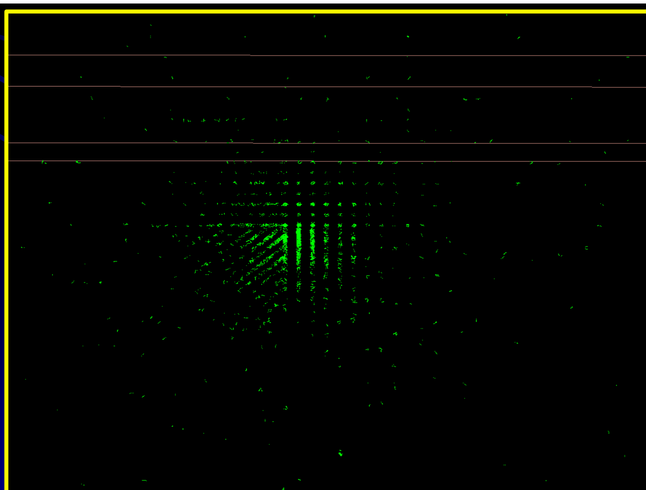


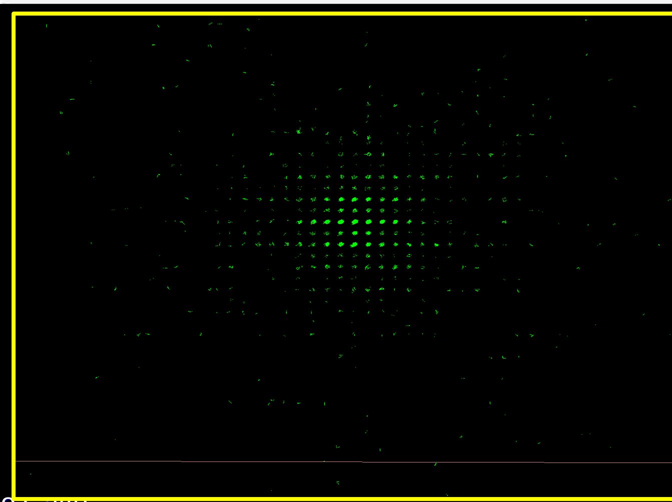
HCAL Optimization

Main Source of Constant Term: tower shape





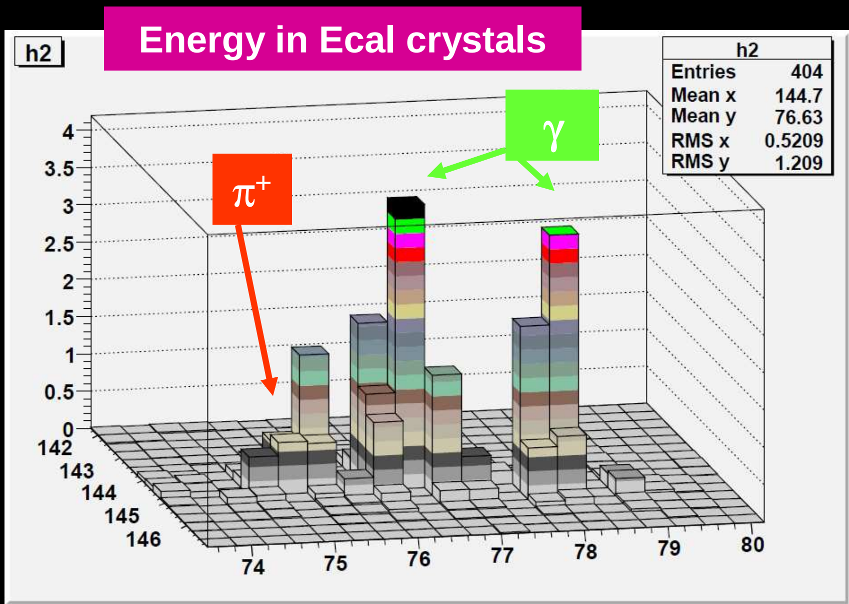


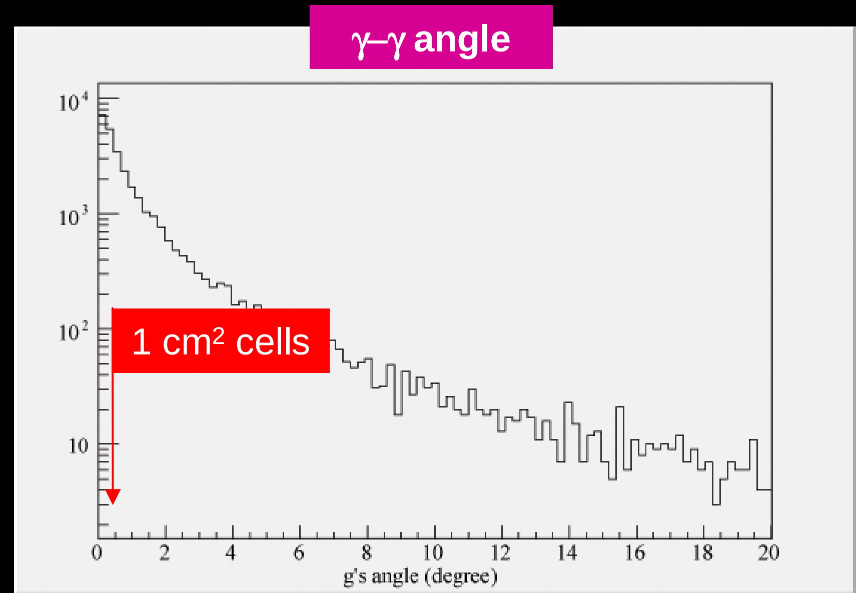


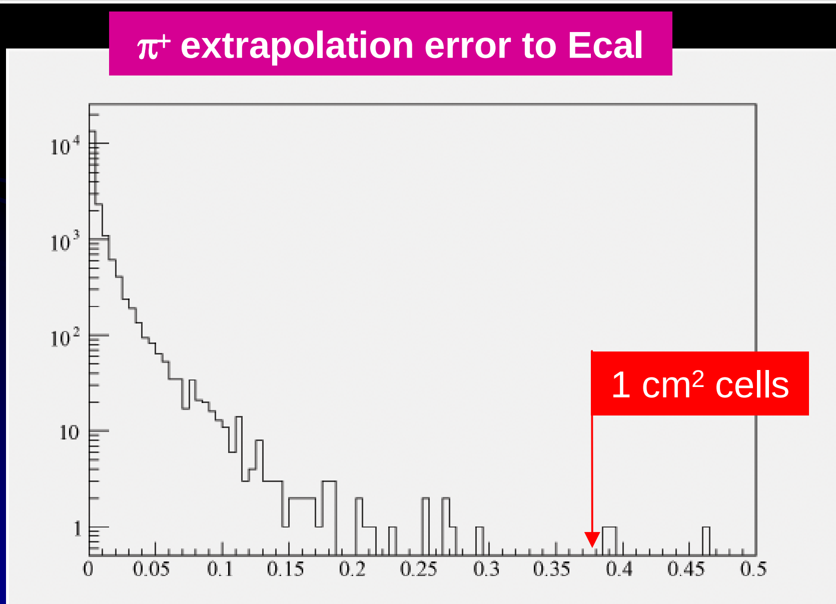
boundary | Top view of the shower of a 45 GeV e^- | **core**

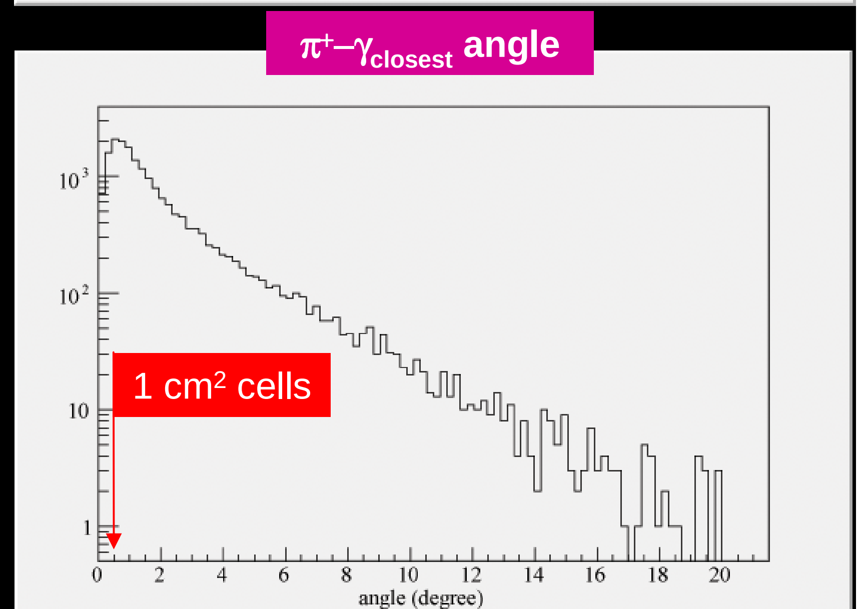
ττ, τ–>ρν @ 500 GeV

ECAL Optimization





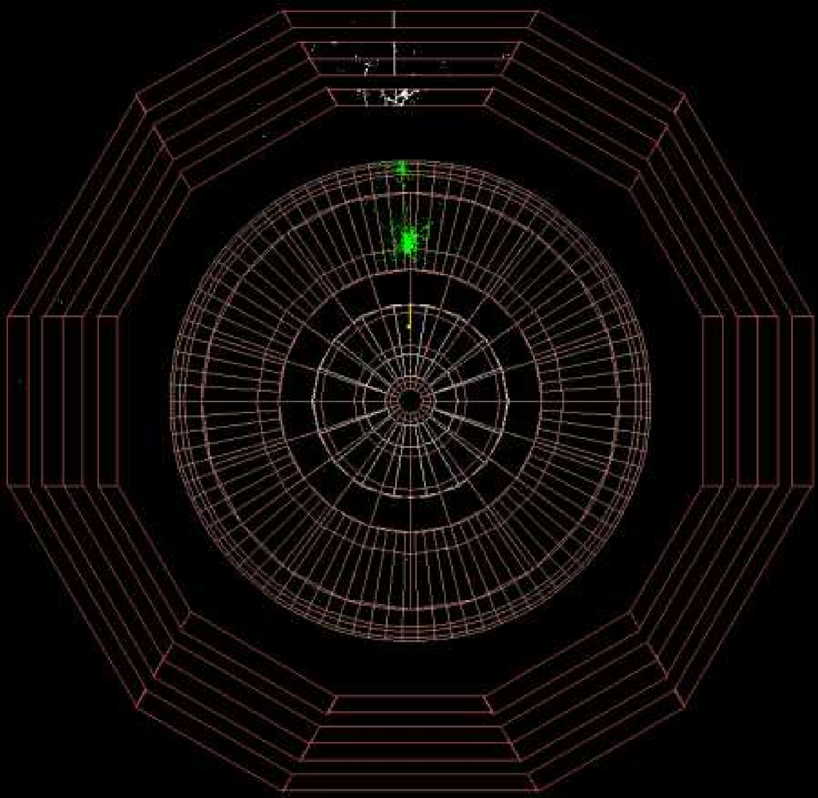


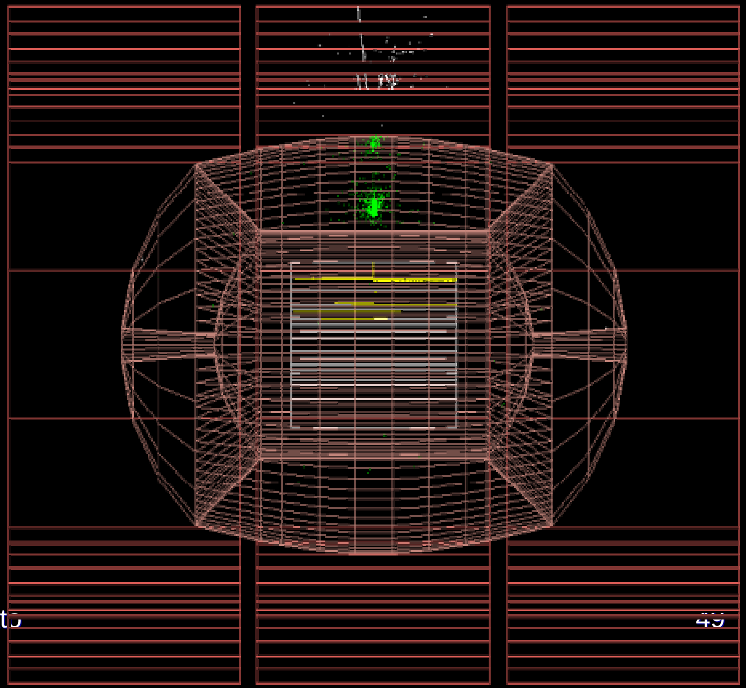


Clear indication that 1 cm² cells is overkilling

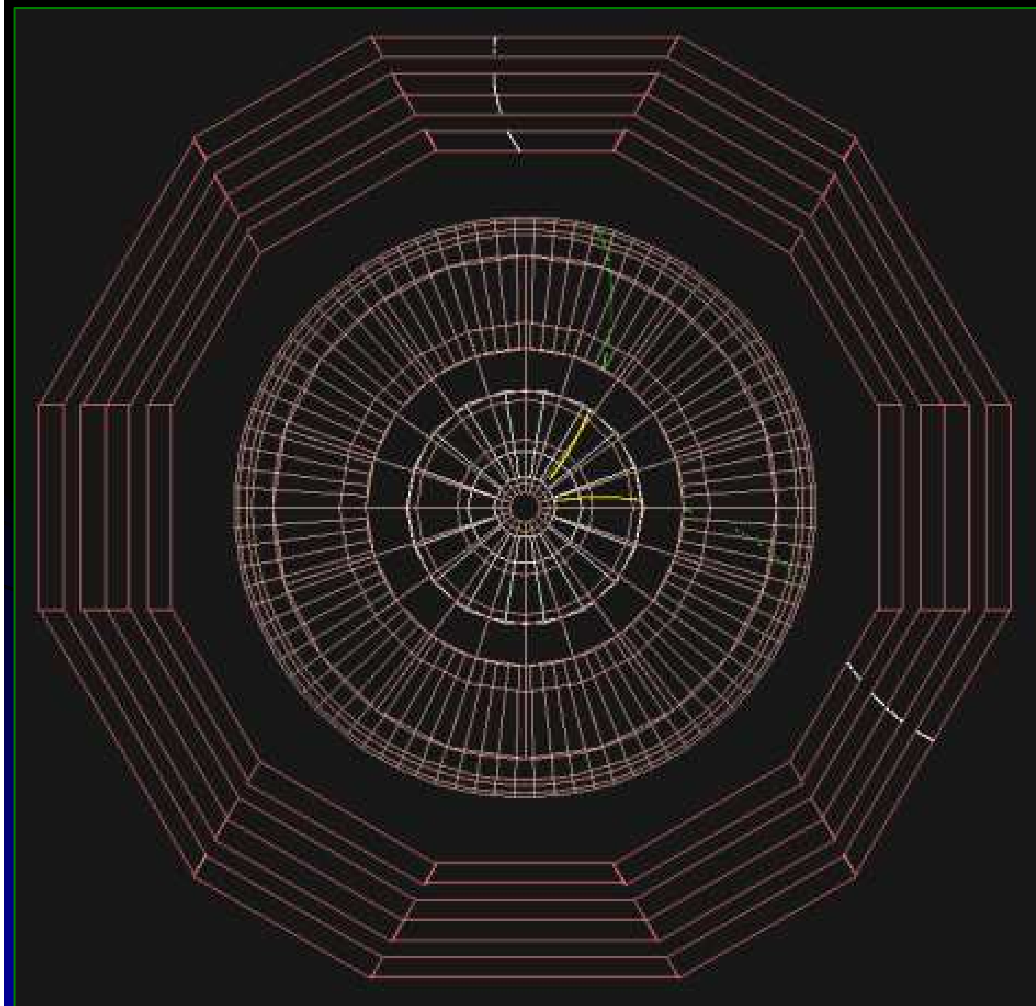
80 GeV jet with escaping particles

ILCRoot simulation





$\mu^+ \mu^-$ at 3.5 GeV/c



ILCRoot simulation