Full Simulation Physics Studies

C.Carloganu, P.Gay, Ph.Gris – LPC Clermont-Ferrand

- Introduction
- First steps in full simulation
- Background filtering
- Conclusions

Introduction: physics studies

- Beyond their fundamental interest, physics studies are means/guides to
  - evaluate the detector performance
  - optimize the design of the detector (-> impact on cost)

- Lots of possible benchmarks (see M.Battaglia et al – LCWS05 Proceedings) – three classes:
  - Higgs mechanism and strong electroweak breaking
  - Supersymmetry
  - EW precision measurements and indirect sensitivity to New Physics

Physics benchmarks

Physics Benchmarks - Detector Performance Matrix

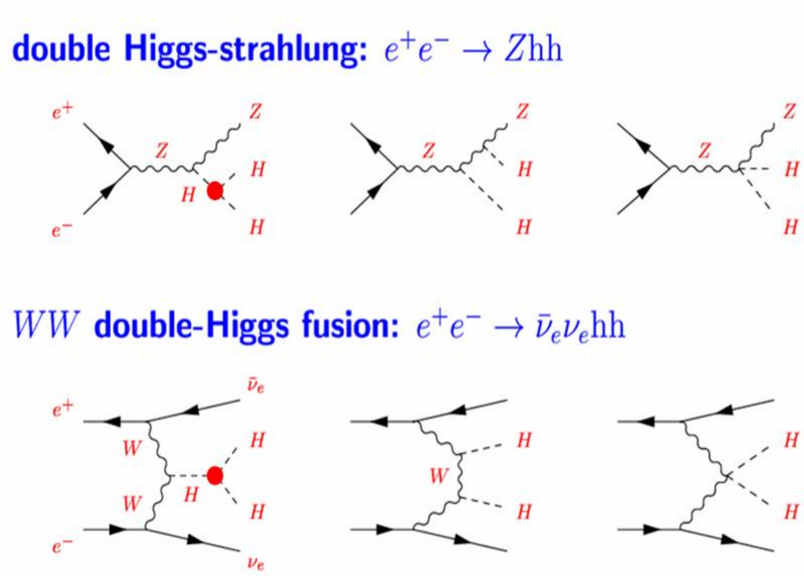
Process	Vertex	Tracking		Calorimetry		Fwd		Very Fwd	Integration					Pol.
	σ_{IP}	$\delta p/p^2$	ϵ	δE	$\delta\theta,\ \delta\phi$	Trk	Cal	θ^e_{min}	δE_{jet}	M_{jj}	ℓ-Id	V^0-Id	$Q_{jet/vtx}$	
$ee \to Zh \to \ell\ell X$		x									x			
$ee \to Zh \to jjbb$	x	x	x			x				x	x			
$ee \to Zh,h \to bb/cc/\tau\tau$	x		x							x	x			
$ee \to Zh,h \to WW$	x		x		x				x	x	x			
$ee \to Zh,\ h \to \mu\mu$	x	x									x			
$ee \to Zh,\ h \to \gamma\gamma$				x	x		x							
$ee \to Zh,h \to invisible$			x			x	x							
$ee \to \nu\nu h$	x	x	x	x			x			x	x			
$ee \to tth$	x	x	x	x	x		x	x	x		x			
$ee \to Zhh,\ \nu\nu hh$	x	x	x	x	x	x	x		x	x	x	x	x	x
$ee \to WW$										x			x	
$ee \to \nu\nu WW/ZZ$						x	x		x	x	x			
$ee \to \tilde{e}_R\tilde{e}_R$ (Point 1)		x						x			x			x
$ee \to \tilde{\tau}_1\tilde{\tau}_1$	x	x						x						
$ee \to \tilde{t}_1\tilde{t}_1$	x	x							x	x		x		
$ee \to \tilde{\tau}_1\tilde{\tau}_1$ (Point 3)	x	x			x	x	x	x	x					
$ee \to \tilde{\chi}^0_2\tilde{\chi}^0_3$ (Point 5)									x	x				
$ee \to HA \to bbbb$	x	x								x	x			
$ee \to \tilde{\tau}_1\tilde{\tau}_1$			x											
$\chi^0_1 \to \gamma + \not{E}$					x									
$\tilde{\chi}^{\pm}_1 \to \tilde{\chi}^0_1 + \pi^{\pm}_{soft}$			x					x						
$ee \to tt \to 6\ jets$	x		x						x	x	x			
$ee \to ff\ [e,\mu,\tau;b,c]$	x		x				x		x		x		x	x
$ee \to \gamma G$ (ADD)				x	x			x						x
$ee \to KK \to f\bar{f}$		x									x			
$ee \to ee_{fwd}$						x	x	x						
$ee \to Z\gamma$		x		x	x	x	x							

ECFA Workshop nov 2005

Benchmarking the ILC Detectors
M. Battaglia

Higgs trilinear coupling

- Important measurement: direct access to the Higgs mechanism
- Measurement « ILC exclusive only » (impossible at the LHC)
- But: a difficult job:
  - precision requested: 10 to 20%
  - few events:



Light Higgs (110 – 120 GeV) $\mathcal{L}$=500 fb^{-1}
hhZ @ 500 GeV N_{exp} ~ 100 evts
$\nu\nu$hh @ 800 GeV N_{exp} ~100 evts
backg: tth, ttZ, ZZZ/hZ, eeZZ, $\nu\nu$ZZ

  - high sensitivity to pFlow
  - multijet environment
  - dijet reconstruction

pFlow @ 500 and 800 GeV! different from pFlow @ 91 GeV

→ resolution improvement ↔ data taking reduction (↘ cost)

Measurement already performed in fast simulation
$\Delta\lambda/\lambda$~14% @800 GeV, 2 ab^{-1}

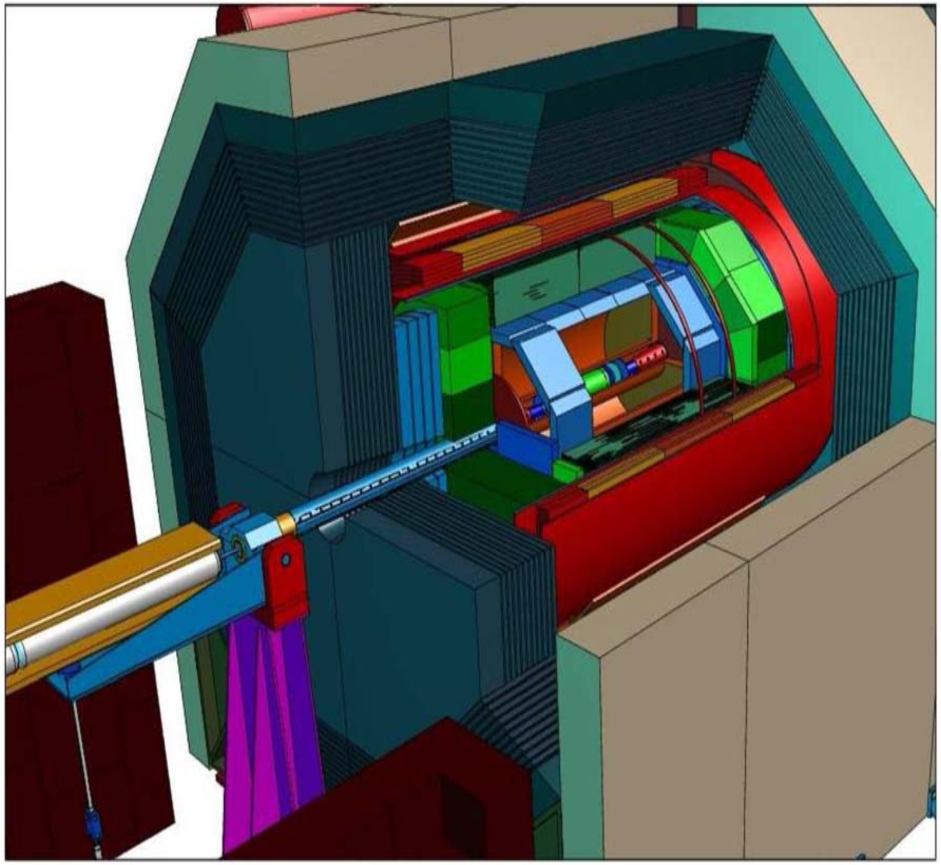
First steps in full simulation/reconstruction…

- Is it possible to perform the hhZ/ννhh analyses in full simulation?
  - Tools available?
  - Reconstruction performance (electron, muon, jets, pFlow, …) ?
  - Missing pieces?
  - Detector optimisation ?

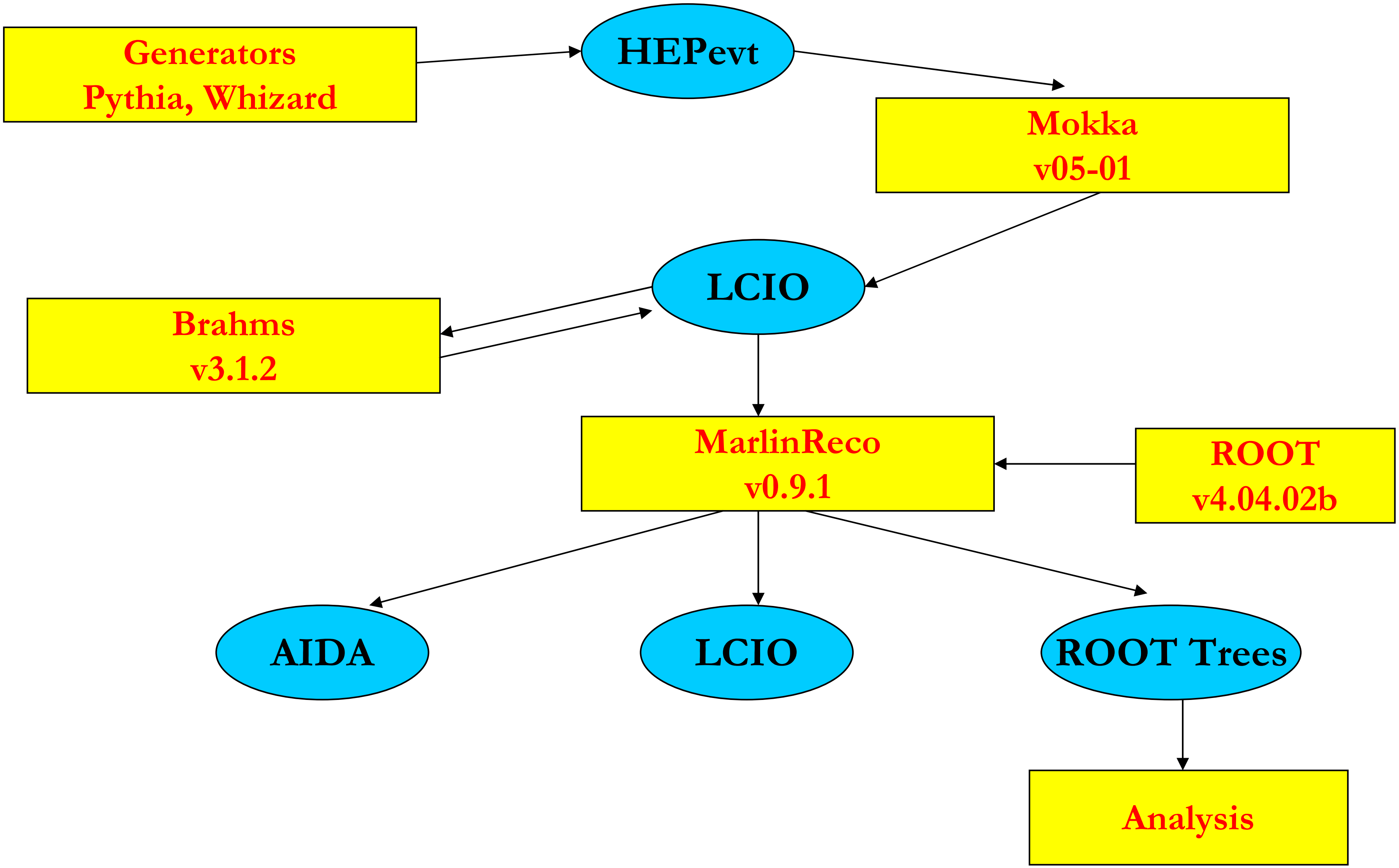
- LDC concept under consideration

Geometry - LDC

- 3 LDC geometries considered:
  - D09: by default in the Mokka version used. Nearly identical to the TDR TESLA
  - LDC00: same as D09 with improvements (FCAL+TPC).
  - LDC00Sc: same as LDC00 but with a hadronic calorimeter scintillator-based.

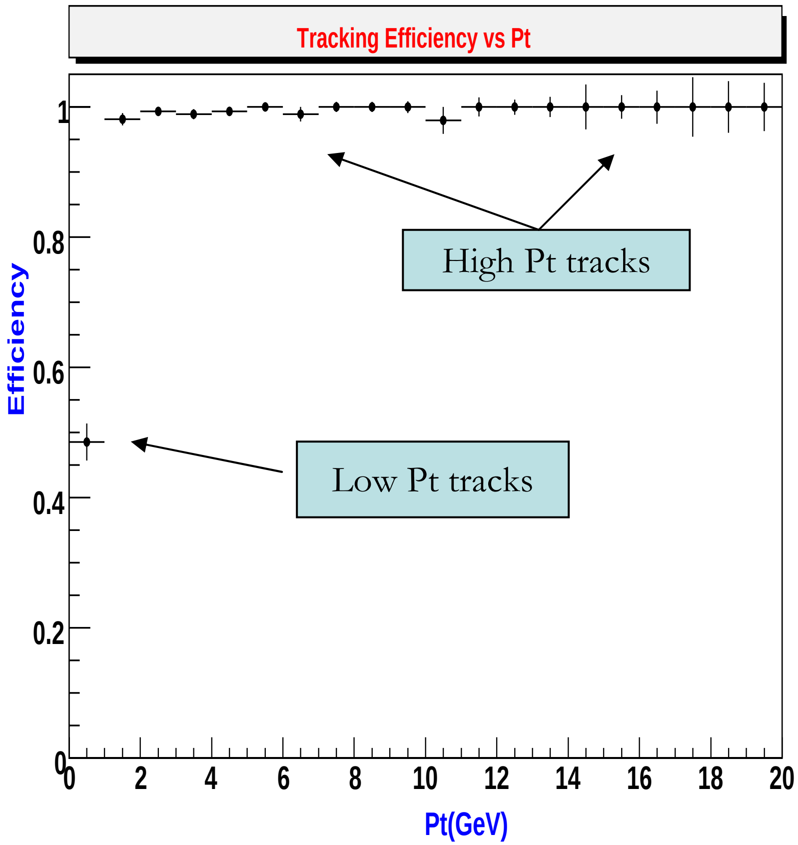


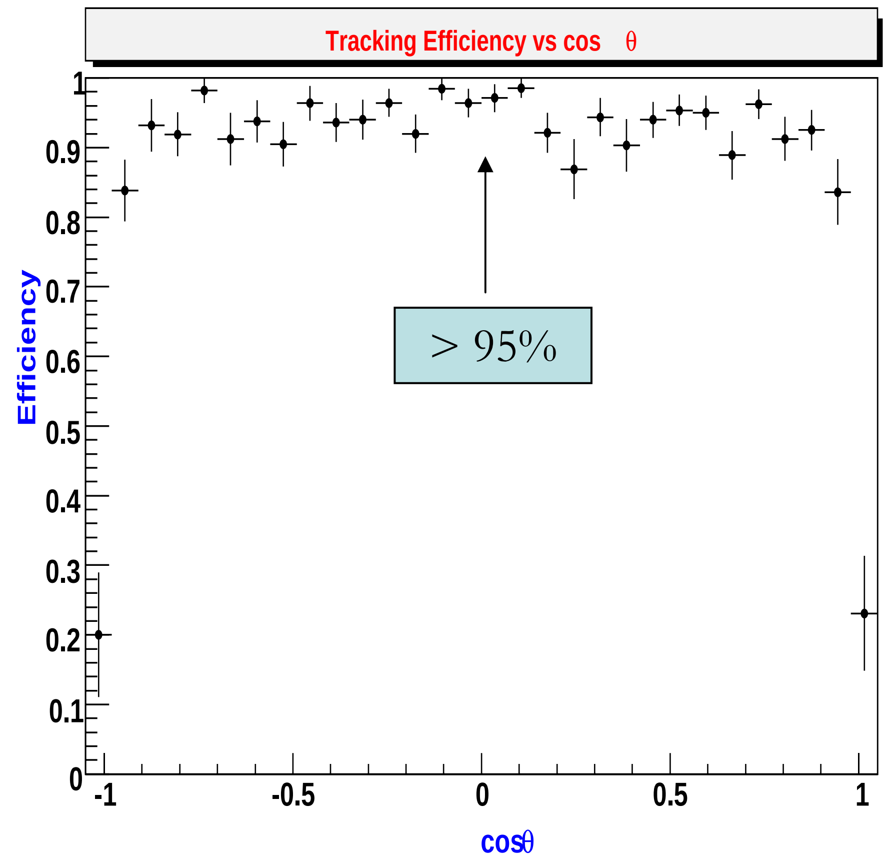
Road to analysis



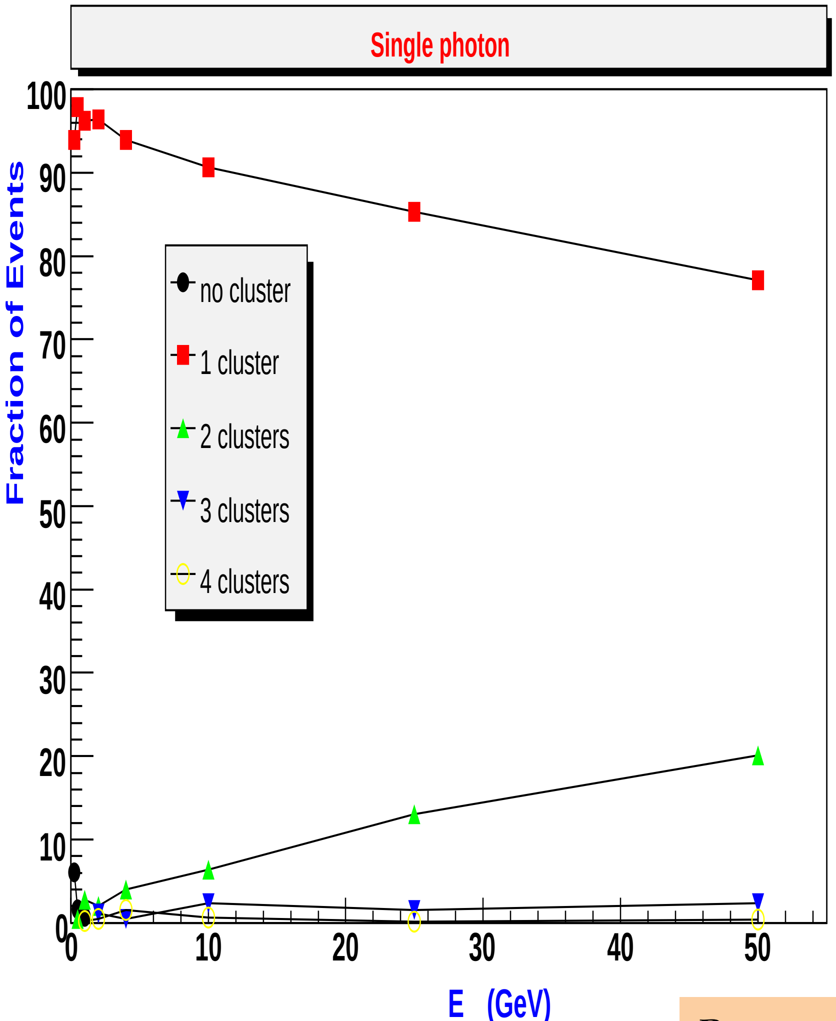
Tracking performance

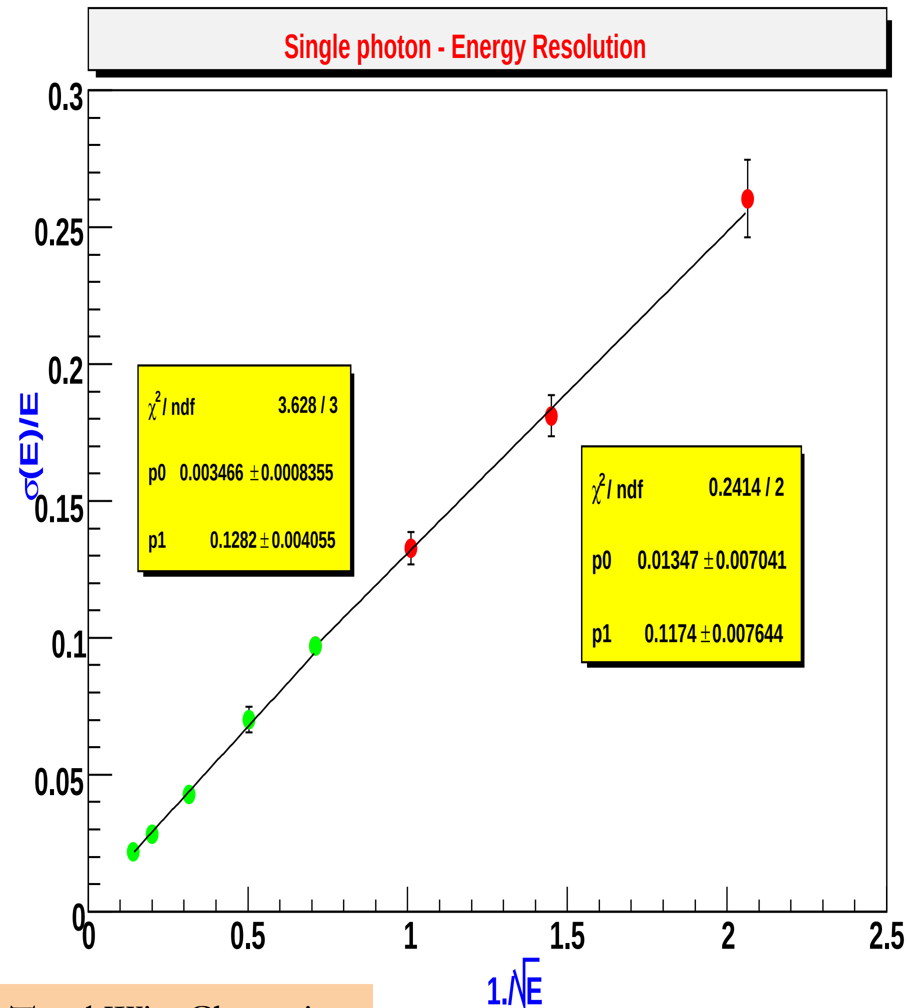
- Tracking efficiency (single e+μ + π) – spectrum from ννhh evts @ 800 GeV - LEPTracking processor





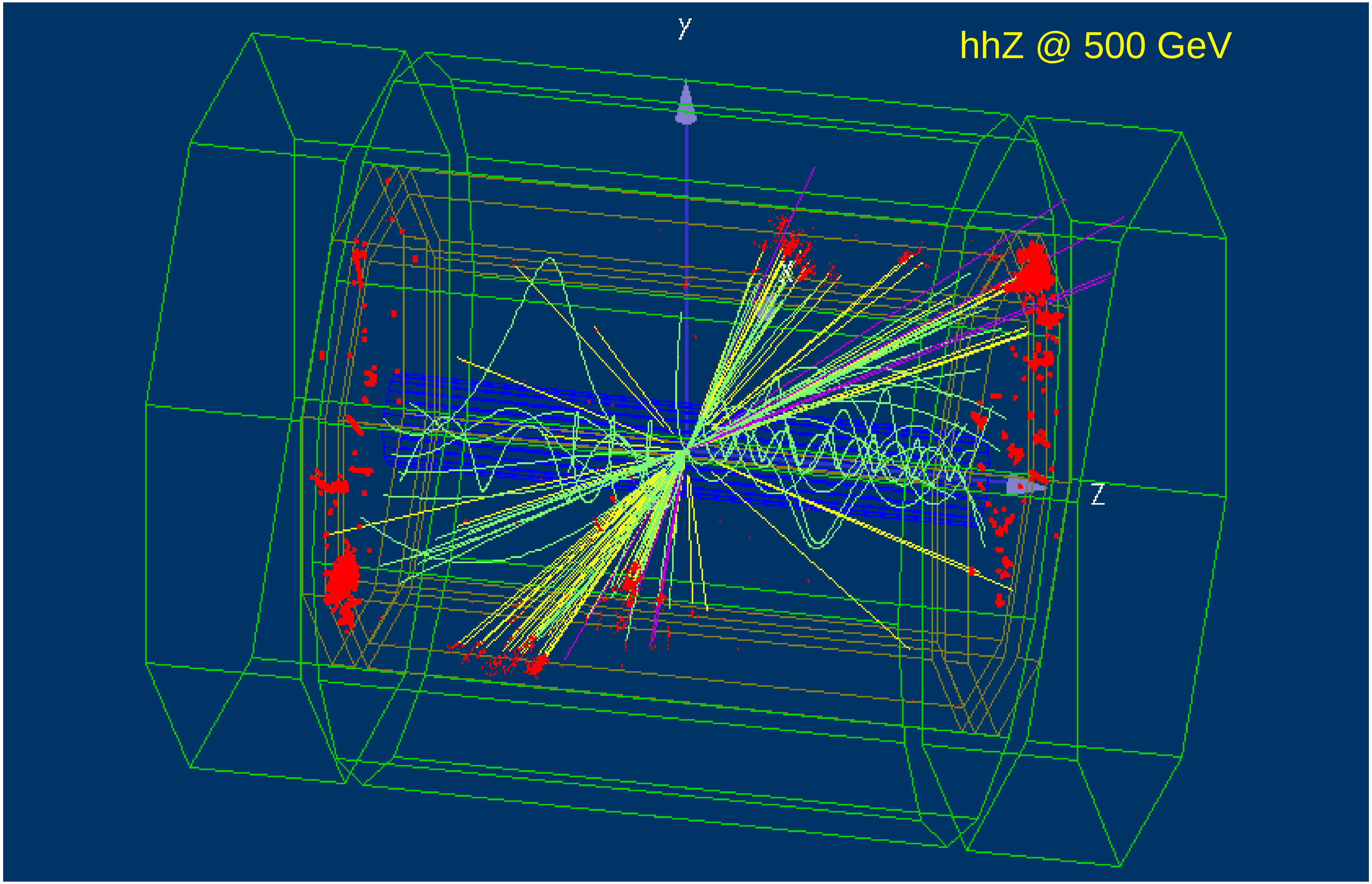
Single photon reconstruction





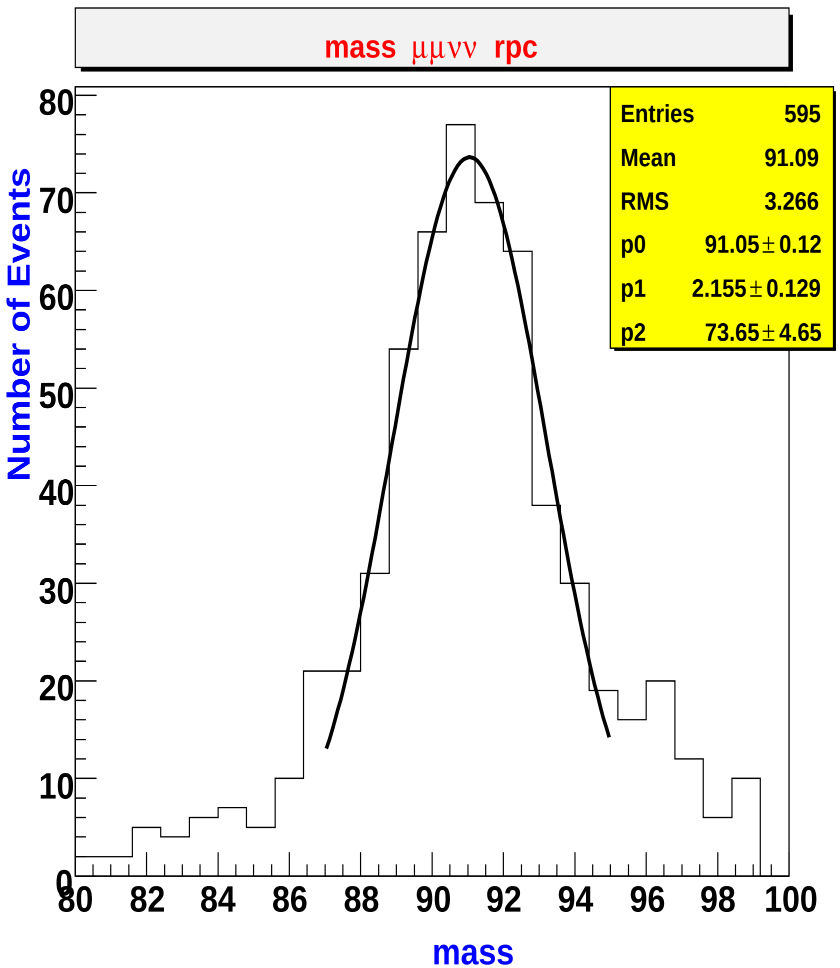
Processor: TrackWiseClustering

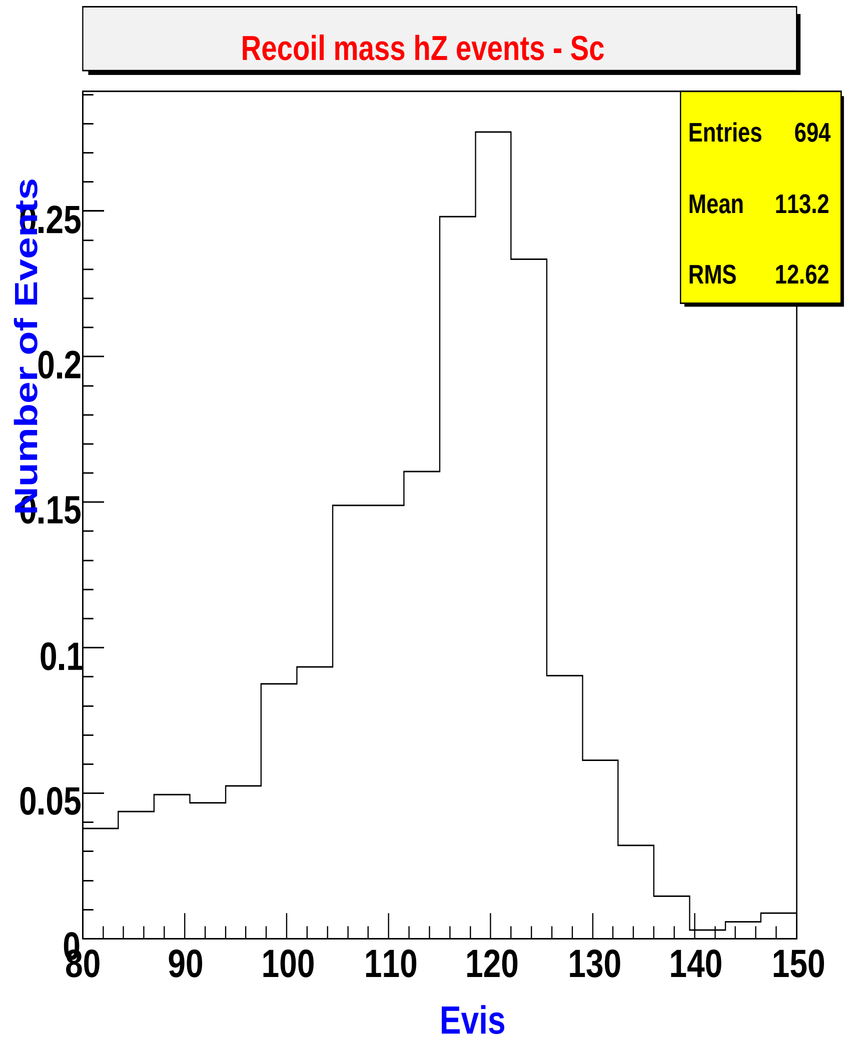
Event Display - CED



@ 500 GeV - LDC

ZZ Z->νν Z->μμ





@ 800 GeV - LDC

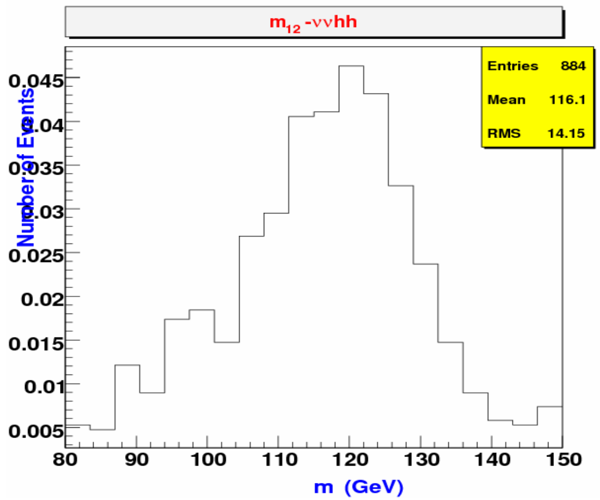
$$e^+e^- \rightarrow \bar{\nu}_e \nu_e hh$$

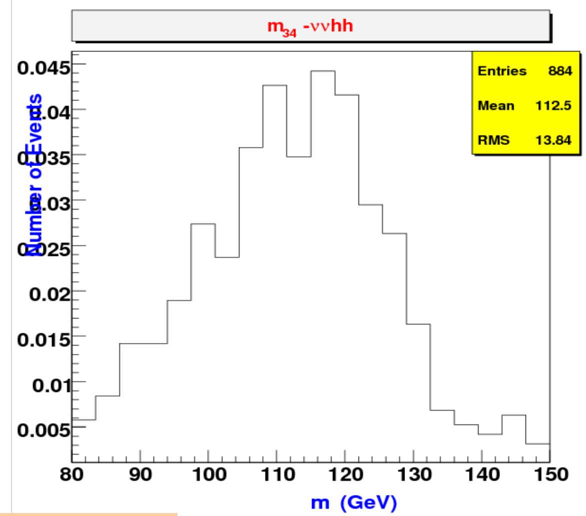
Beamstrahlung

No constraints

No selection cuts

4 jets (SatoruJetFinder)

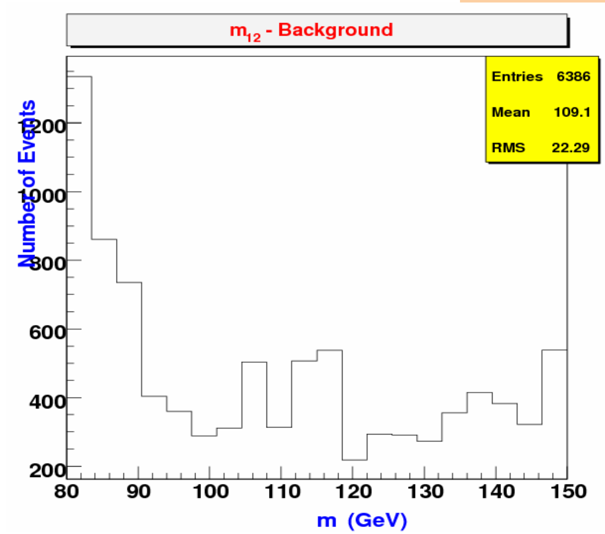


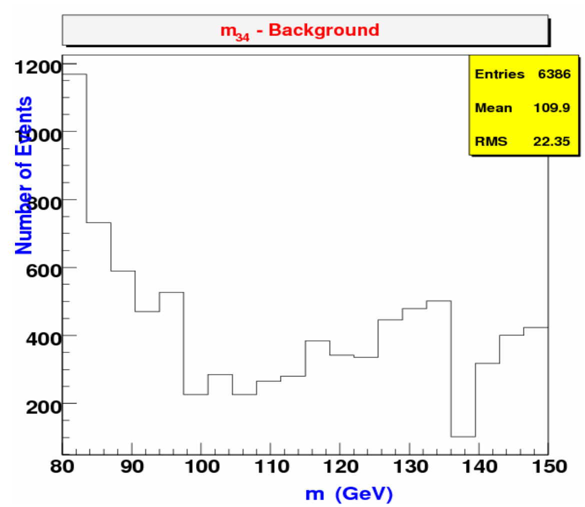


Dijet masses

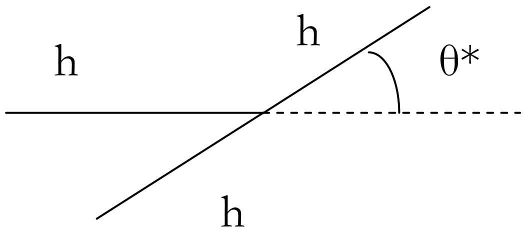
Background "full simulation"
~0.3 fb-1 simulated

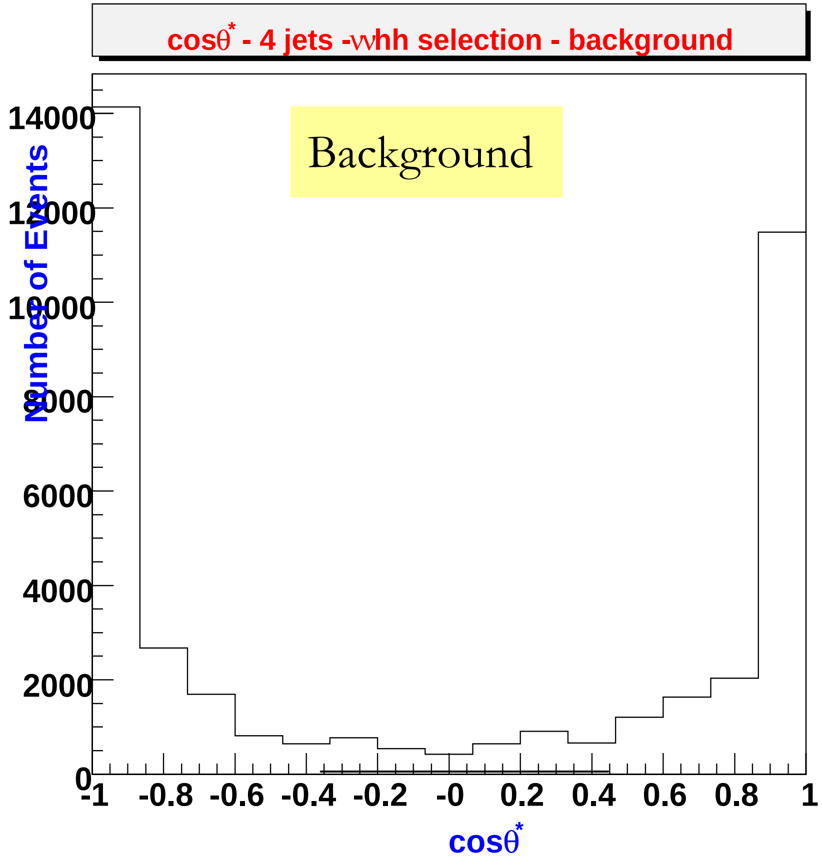
tth	1k
ttZ	1k
tt	1k
hZ	1k
eeZZ	1k
WW	1k
WWZ	1k

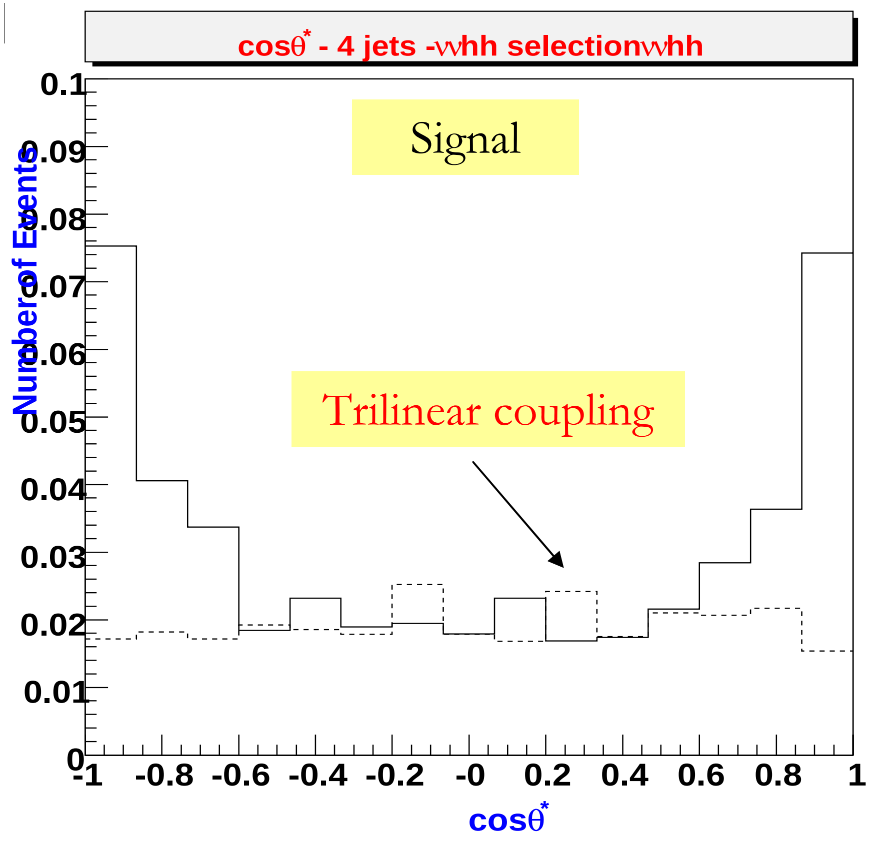




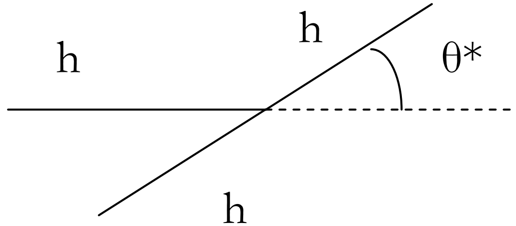
ννhh @800 GeV - LDC

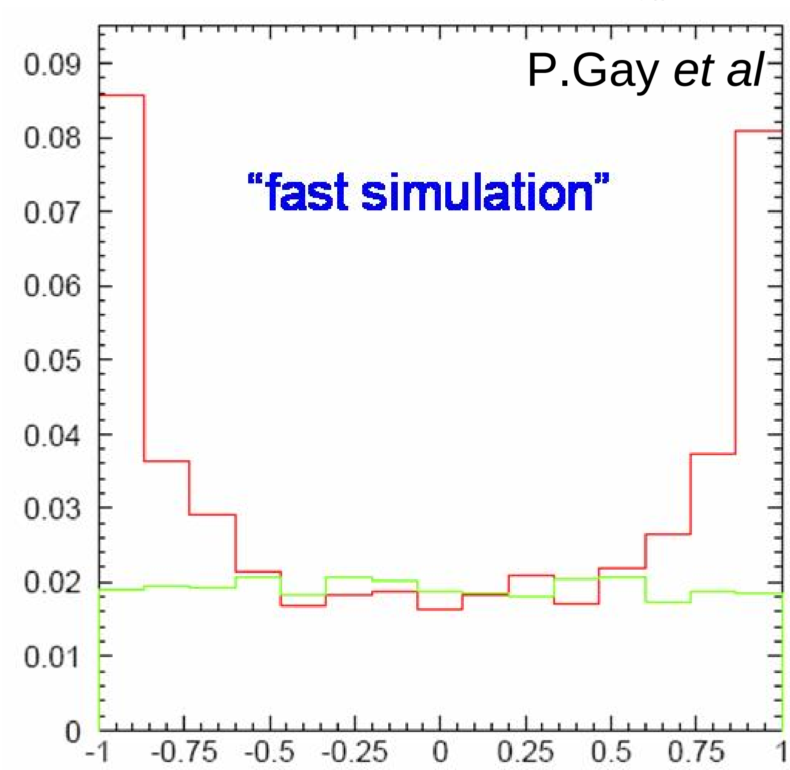


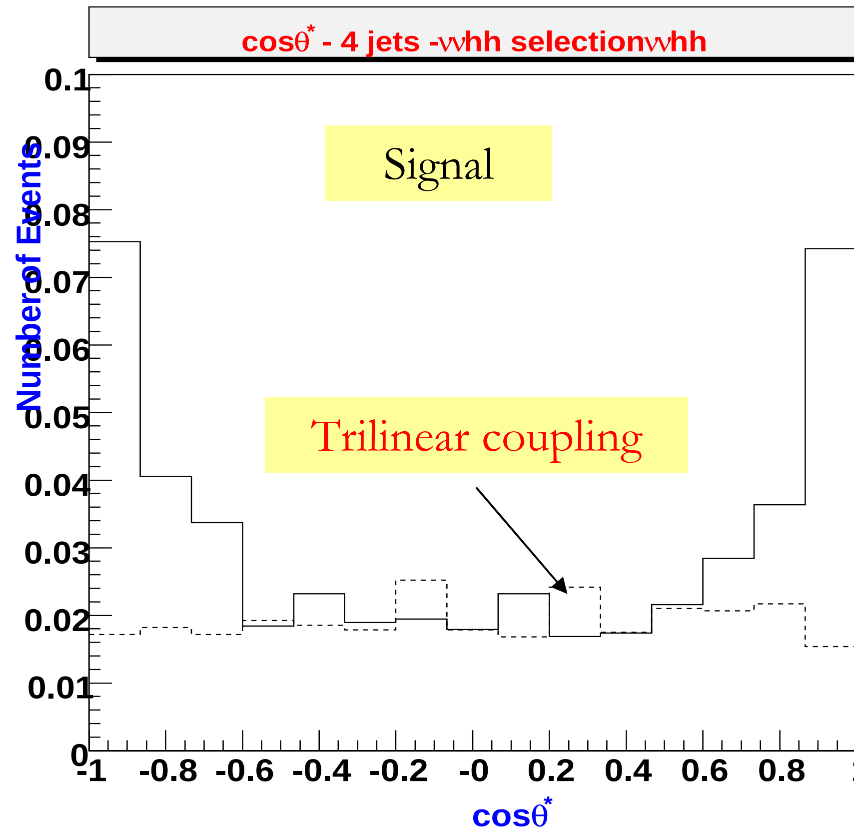




ννhh @800 GeV – Comparaison with fast sim







Good agreement between fast and full simulations

Few comments on the use of the software

☺

- Framework to perform full simulation studies in place
- Easy to install and use
- LCIO based
- Flexible choice of processors (xml file)/ interface of fortran program possible
- packages available:

  digitization, clustering, part of tracking, track/cluster matching, jet clustering, shape variables
- Some processors have

  MC truth ⇔ reconstruction relation

  ➔ « fast sim like » information

☹

- Missing implementations:
  - Tracking (low Pt)
  - Object identification (photon,electron, muon, tau…)
  - Flavour tagging (b and c)
- Most of these implementations already exist and may just need to be interfaced in Marlin
- Geometry file (gear.xml): matching with Mokka not so obvious.

Improvements expected with new software version

Few comments…

Evaluation of the detector performance through the hhZ/$\nu\nu$hh analyses request the use of discriminant variables that were pointed out by the fast simulation (jet masses, $\cos\theta^*$, flavour tagging). These variables can not be constructed/used now in full simulation because of missing implementations.

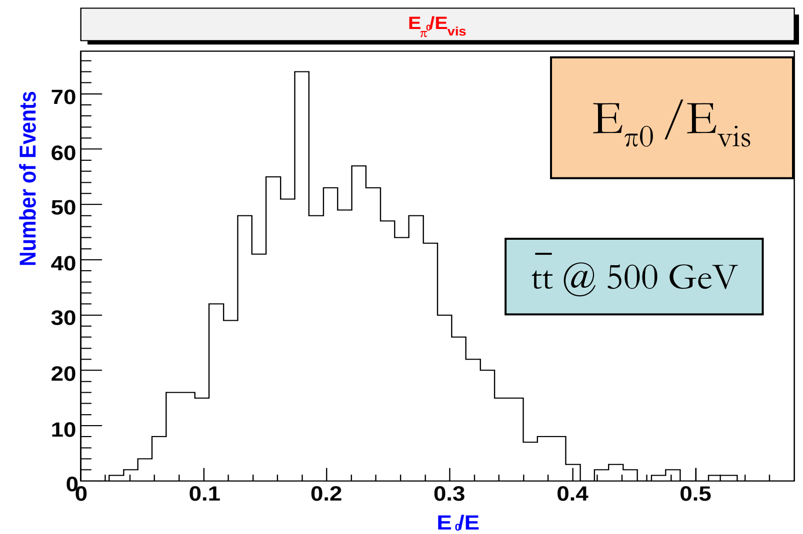
To improve the reconstruction performance, the behaviour of « basic » particles ($\gamma,\pi^{\pm},K^{\pm},K^0$,p,n…) needs to be understood:

- clustering
- tracking
- track/match
- calibration

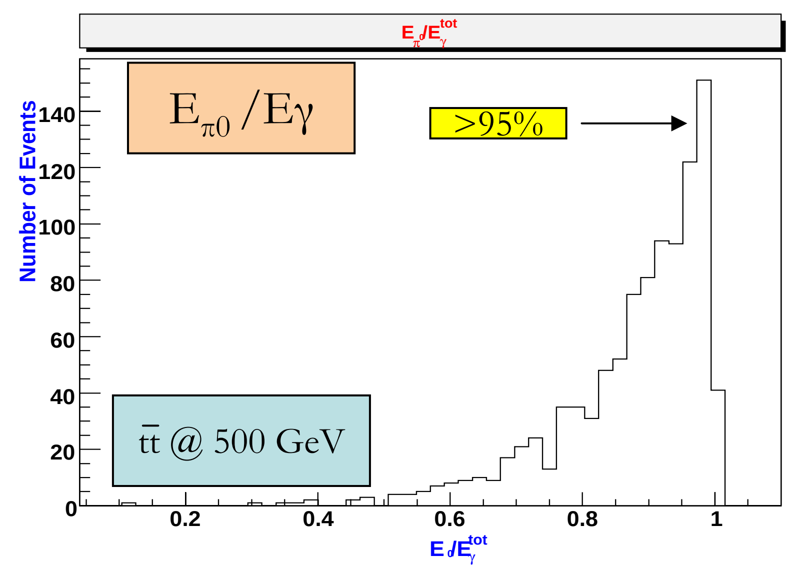
We started having a look on π^0 .

π^0 reconstruction

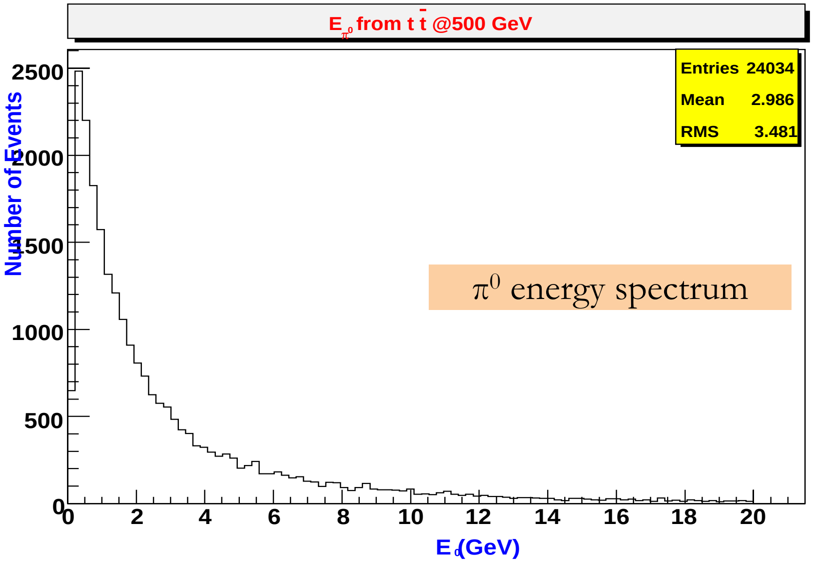
- π^0 represent an important part of the particle content
  - around 20% of the visible energy in tt (@500 GeV) or ννhh (@800 GeV)

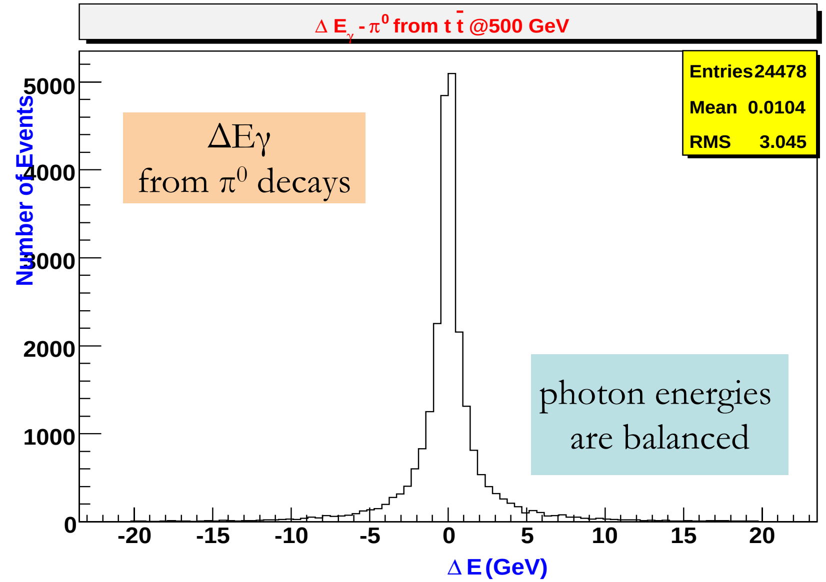


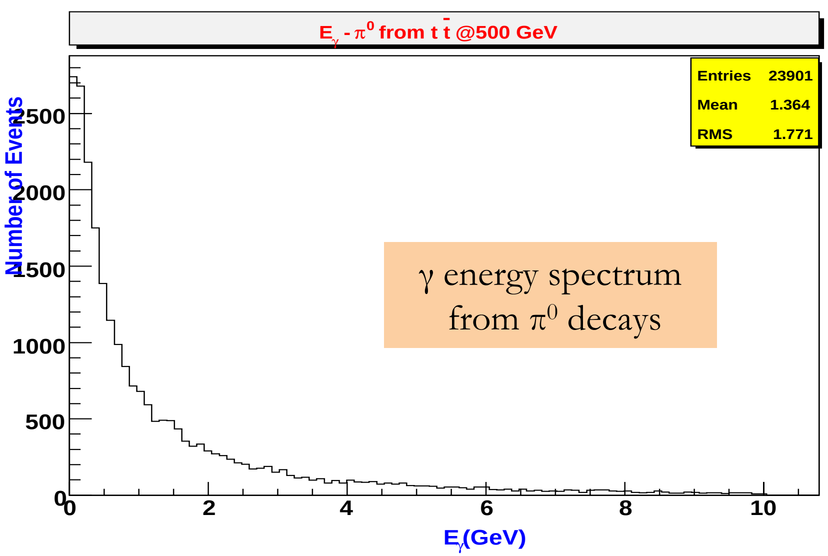
  - most of the photon in an event come from π^0 decays



π^0 – $t\bar{t}$ events @500 GeV







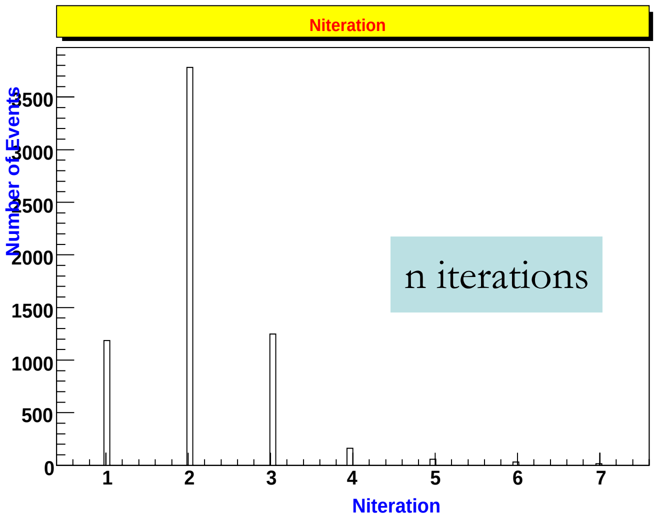
	tt @500 GeV	ννhh @800 GeV
$E\pi^0$ <2GeV	50.7%	54.7%
Eγ < 1 GeV	56%	59.4%
Eγ <2 GeV	73.4%	76.1%

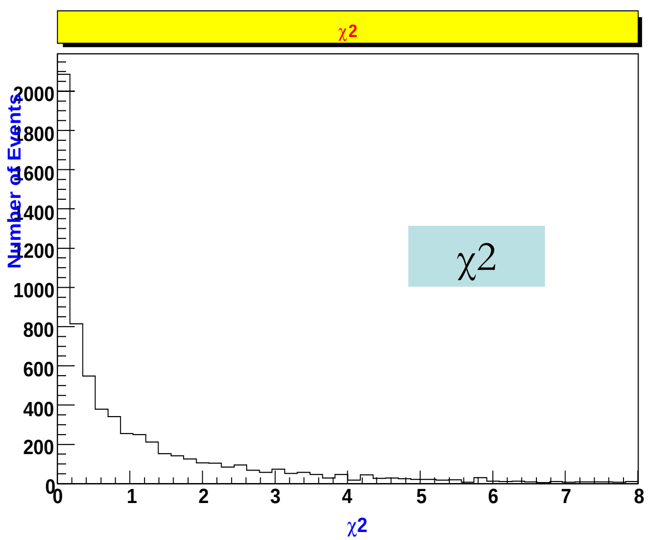
photons are soft

π^0 reconstruction

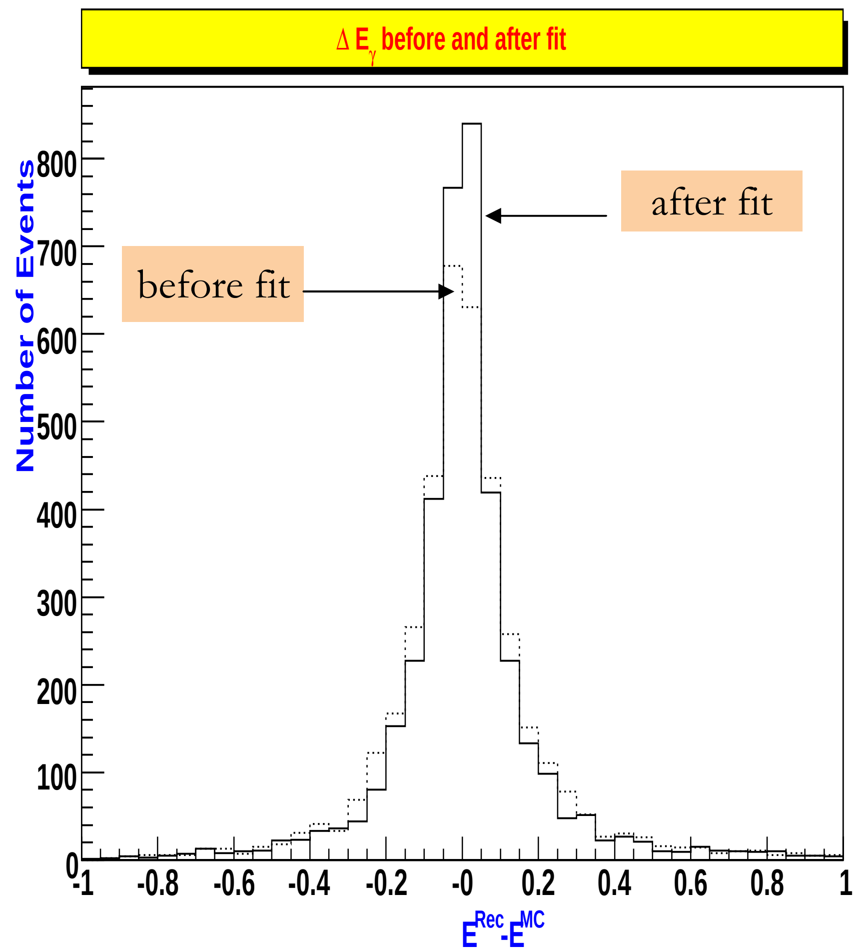
- Photons from π^0 decays have been extracted from $t\bar{t}$ events (Pythia – 500 GeV) and $\nu\nu hh$ events (Whizard – 800 GeV) -> HEPEvt format
- A processing of these events was performed through the full reconstruction chain (Mokka + Marlin)
- Events were selected requesting:
  - two (and only two) reconstructed clusters (processor: trackwiseclustering)
  - no reconstructed tracks (processor: trackcheater)
- A constrained fit was applied on the cluster pair:
  - constraint: m(clus1, clus2)= $m_{\pi 0}$
  - min least square fit
  - variances:
    - Energy: 11.3%/√E or 12.8%/√E depending on the energy value (see slide 9)
    - angles: $\sigma_\theta=\sigma_\Phi$ =0.002 rad
- This fitting procedure was implemented in Marlin as a processor.

π^0 reconstruction – fit results (I)



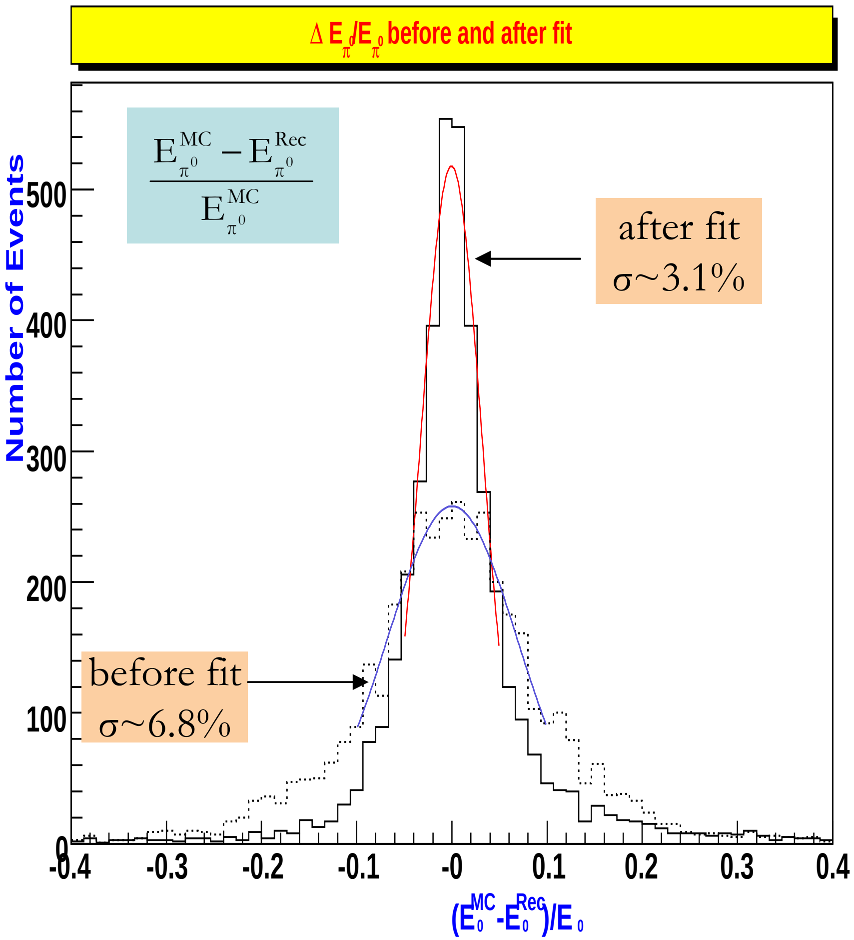


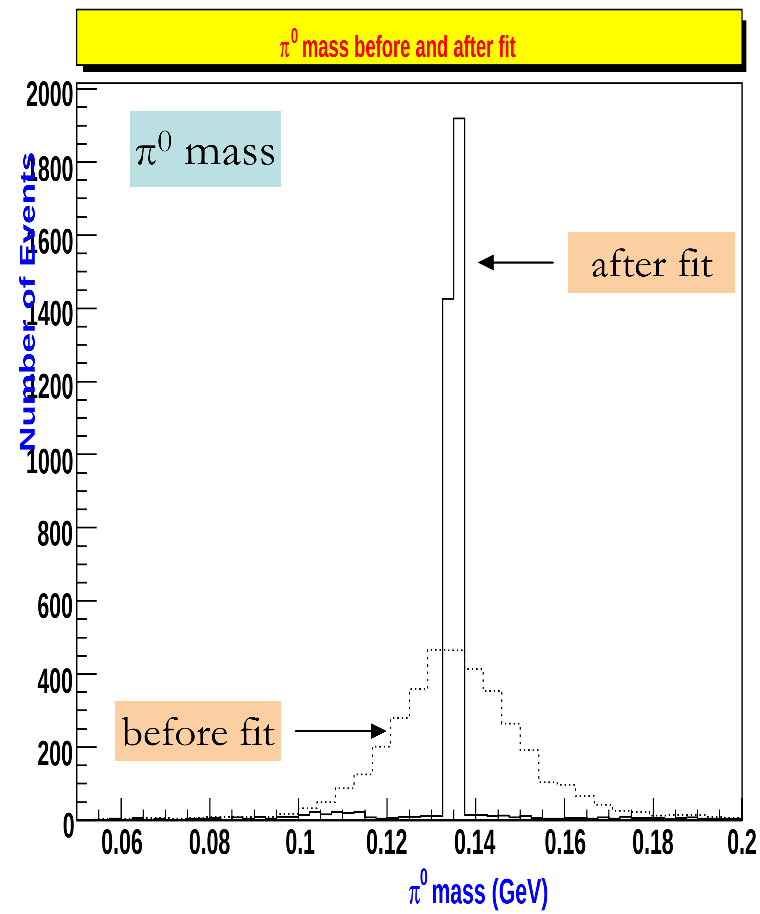
$E_\gamma^{rec} - E\gamma^{MC}$



νhh @ 800 GeV

π^0 reconstruction – fit results (II)

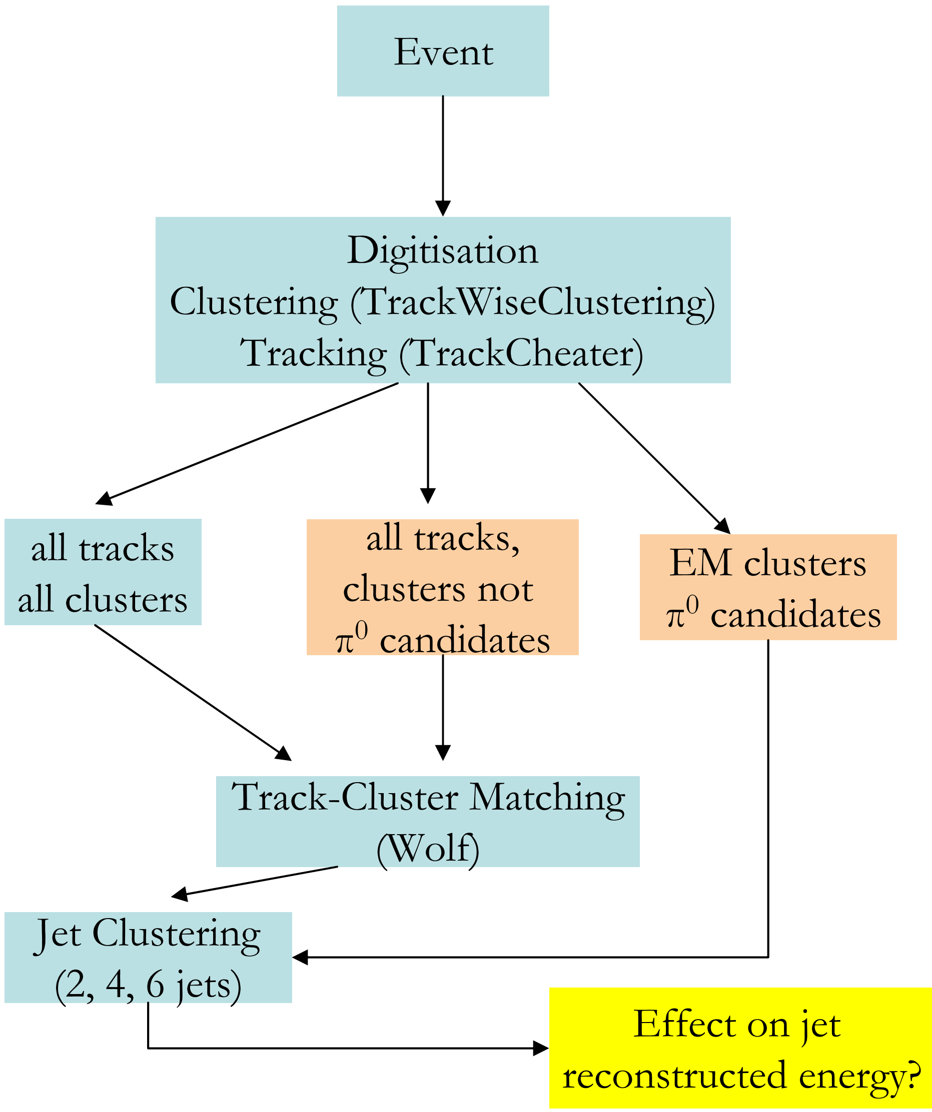




vvhh @ 800 GeV

π^0 reconstruction – next step

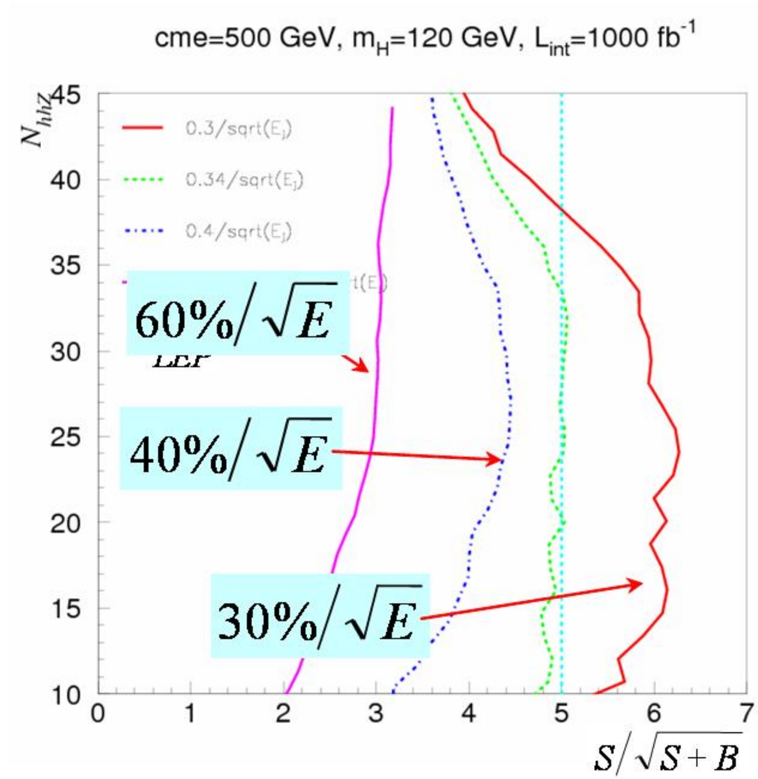
- Apply the fitting procedure on physics events and evaluate impacts on
  - jet energies
  - invariant masses: hh, …
- Scenario: two streams: a « standard » one (all tracks, all clusters) and a filtered one:
  - EM clusters are extracted
  - Cluster pairs inside a window mass around the π^0 are selected and fitted.
  - Only the best χ^2 are kept
  - Clusters not selected by this procedure are then used for the track match
  - Clusters selected are replaced by their fitted values.
- Main difficulty: EM cluster selection (photon id+detector calibration)



The final goal

At the end, with all pieces in hand, the wish is to draw the « pFlow curves » (energy resolutions) for hhZ/ννhh with the full simulation for various detector geometries so as to compare performance/cost.
These curves must be obtained in a reasonable timescale.

Fast simulation hhZ @ 500 GeV



P.G – ECFA Workshop nov2005

Background filtering

do everything with full simulation?

Signal as hhZ, $\nu\nu$hh is not a problem

Background processes present huge cross sections

➡ Produce them one time, and again for any change of the detector geometry! Do/redo it for at different centre of mass energies

- **Enormous CPU and storage resources are mandatory**

tt @800GeV represents 10^6 events for 2 ab^{-1}

a very minimal 'MC' statistics would be $5X10^6$ for only one center of mass energy

Remove a part of the background with loose cuts at the generator level introduces many biases (backg. tails modeling, geometry effect, acceptance, etc.)

➔ confidence on the result could be largely depreciated

Background filtering

Alternatives

Filtering based on simplified tracking (e.g. trackcheater)

a) **Run detector simulation with MOKKA w/ tracking only (VDET, TPC, …)**
   - ➔**LCIO output + rnd numbers status file**

b) **Selection of the event on criteria elaborated with tracking only (trackcheater is enough and quick)**
   - ➔**Rejected or accepted**

c) **If accepted, rnd numbers status file read, and continue the full simulation including the calorimeters**

- Need to define discriminate variables based on tracking only
- Check that the filtering rejection is good enough and time consumption is acceptable

Background filtering

Filtering based on Educated Fast Simulation

not a simple smearing of the particles with thresholds

a) **Inputs information will come from full detector simulation and reconstruction algorithms derived from it**

   ➔parameterization mapping

b) **Tune Educated Fast Simulation on signal until it reproduces the full simulation for complex objects (jets, dijets, b/c jets)**

Observables should be defined

c) **When the agreement is obtained**

   Run the whole background trough the Educated Fast Simulation

Parameterization mapping

For each set of geometry +reconstruction algorithms, elaborate a set of parametrisation which reflects performance

From simple to complex "objects"

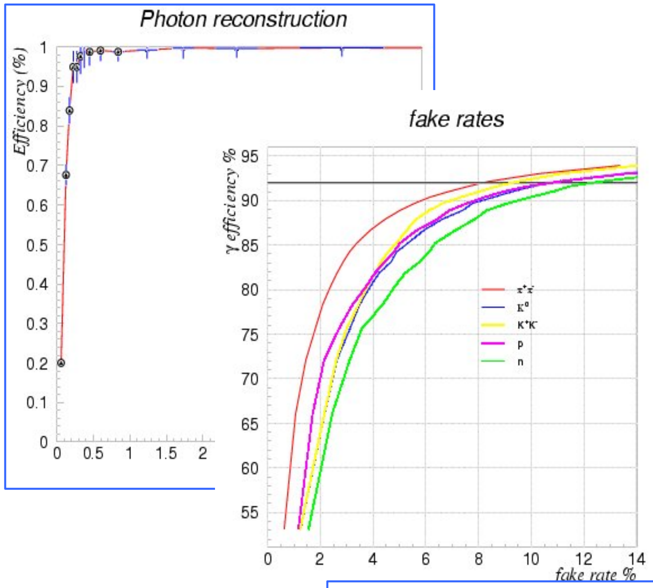
Isolated particles : efficiencies, resolutions, Identification, satellites, …according energy, direction

Couples of particles : (e.g. π/γ h/γ□...) efficiencies, resolutions, fake rates, according to their energy, directions, separation between them

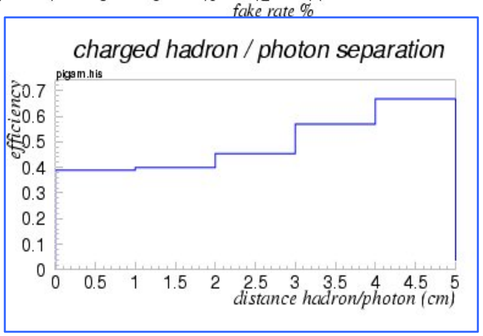
Followed by jets

Similar things for flavor tag

To reflect the benchmark processes the spectrum of particles may be extract from generated events & work face to the real situation we have to deal with



With full simulation of detector and reconstruction of WW @ 800 GeV



Conclusions

- hhZ/ννhh are excellent benchmarks, beyond the physics interest, to
  - evaluate detector performance: pFlow @ 500 and 800 GeV
  - optimize the detector, compare geometries -> cost

- The framework to perform full simulation physics studies:
  - easy to use, flexible
  - preliminary results were produced
  - missing implementations (tracking, object ID, flavour tagging)

- Work to improve the event reconstruction:
  - π^0 studies: impact on hhZ/ννhh discriminant observables.
  - Algorithms implementation (photon ID: EMILE, clustering, …): no new developments: these algorithms already exist and « just » need to be integrated in Marlin -> example: event display CALIMERO

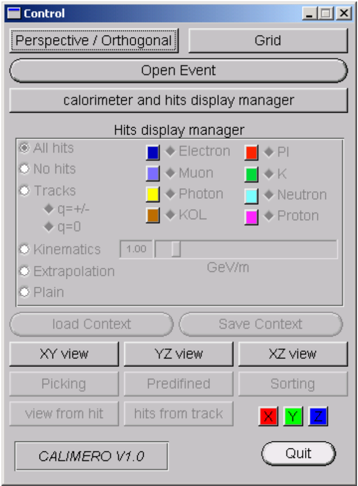
CALorimeter IMagE for RecO

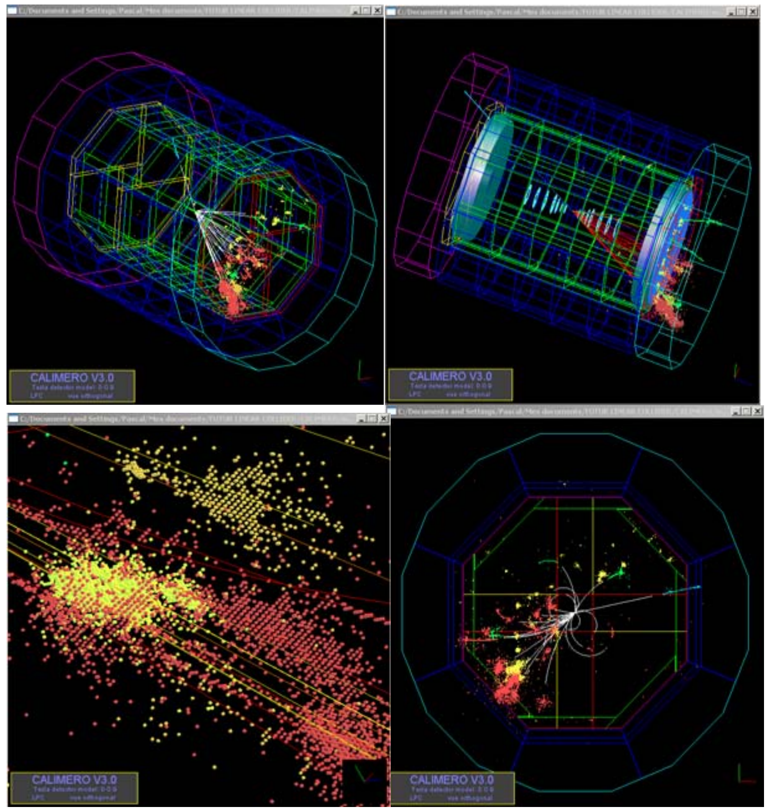
➤provide a tool for event analysis and guideline for reconstruction

➤**many functionalities** not only pretty displays

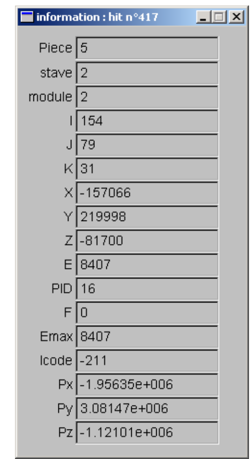
❖Graphics are handled with OpenGL & GLUT, creation of graphics interface with Fast Light Tool Kit (FLTK), MySQL database, C++

Control & management

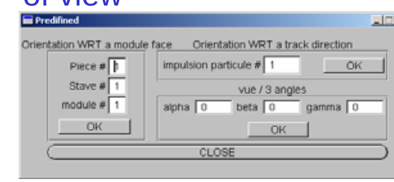




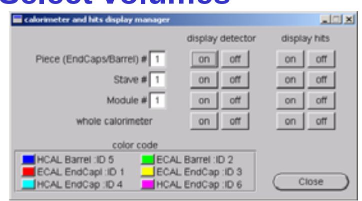
Picking



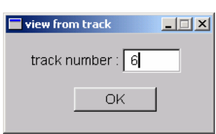
User defined points of view



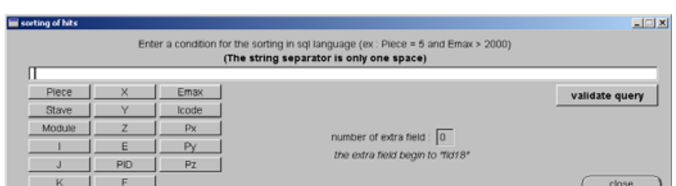
Select volumes

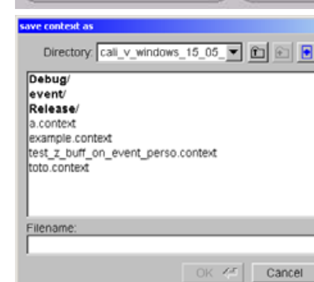


Select a given track



selection condition in SQL language





Save/Load Context