ZHH Analysis

preliminary results on different detector models

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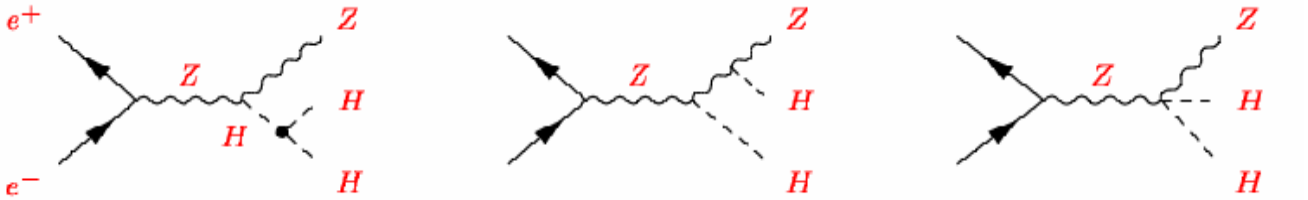
Outline

- Why use ZHH events?
- Description of MC events used
- The ZHH analysis:
  - Calibration of ECal
  - Z and H selection
- Preliminary results

Why ZHH events?

- Study of Higgs self coupling constant



- These events can also be used as benchmark events for several detector/PFlow studies:
  - ECAL & HCAL performances,
  - Jet-finding algorithms,
  - b-tagging,
  - tracker, etc...

see: M.Battaglia et al, "Physics Benchmarks for the ILC Detectors" (2005 ILC Workshop, Stanford, USA)

- At the moment focus on $Z \rightarrow \mu/e$

Detectors description

- LDC00:
  - RPC Hcal
  - TPC has 200 layers
  - ECal is 30+10 layers

- LDC01: smaller radius than LDC00
  - RPC Hcal
  - TPC has 185 layers
  - ECal is 20+10 layers

Signal MC events

- Events generated with Pandora Pythia:
  - M(Higgs) = 120 GeV
  - Electron polarization 80%
  - Positron polarization 0%
  - E_{CM} = 500 GeV

- Detector simulation performed using Mokka v5.5 (Geant4 v8.0, LCPhys physics list)

Events reconstruction

- Marlin 0.9.1
  - Processors used:
    - VTXDigi
    - FTDDigi
    - SimpleCaloDigi
    - TPCDigi
    - LEPTracking
    - Wolf
    - PairSelector
    - SatoruJetFinder
    - MyROOTProcessor & analysis

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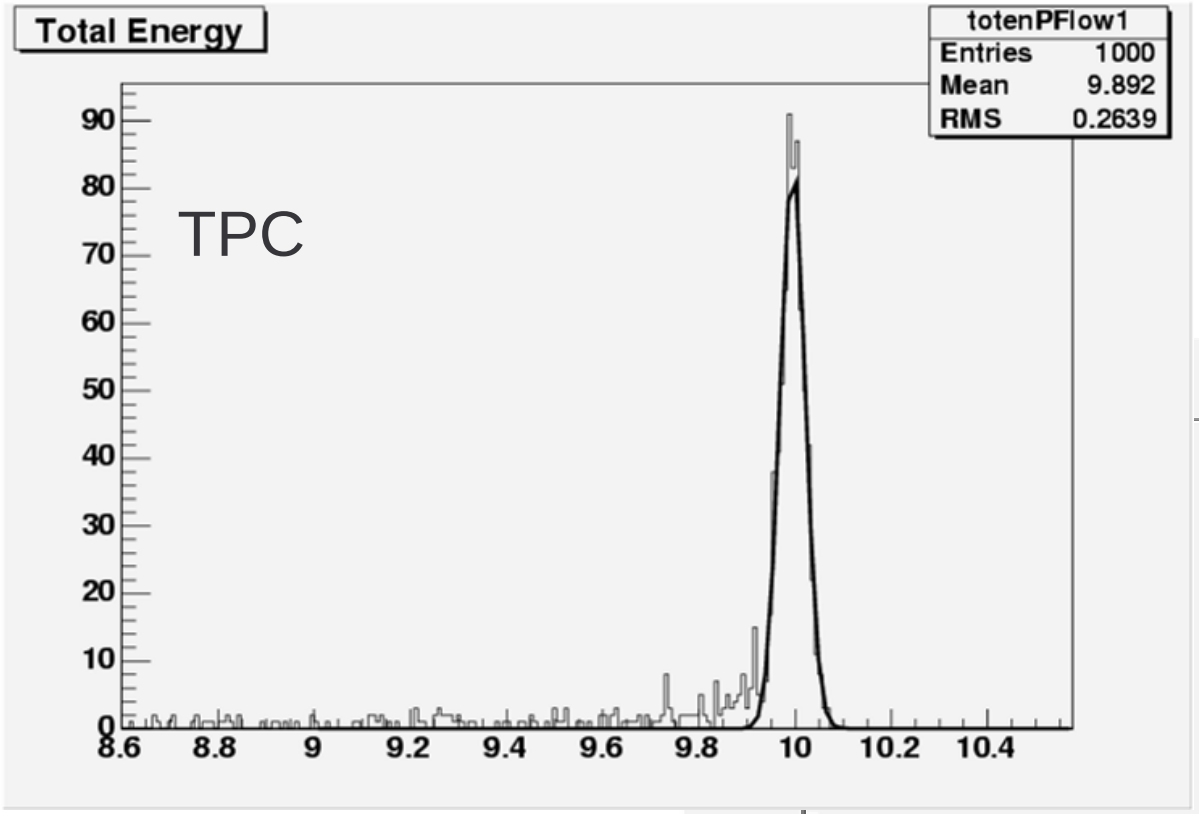
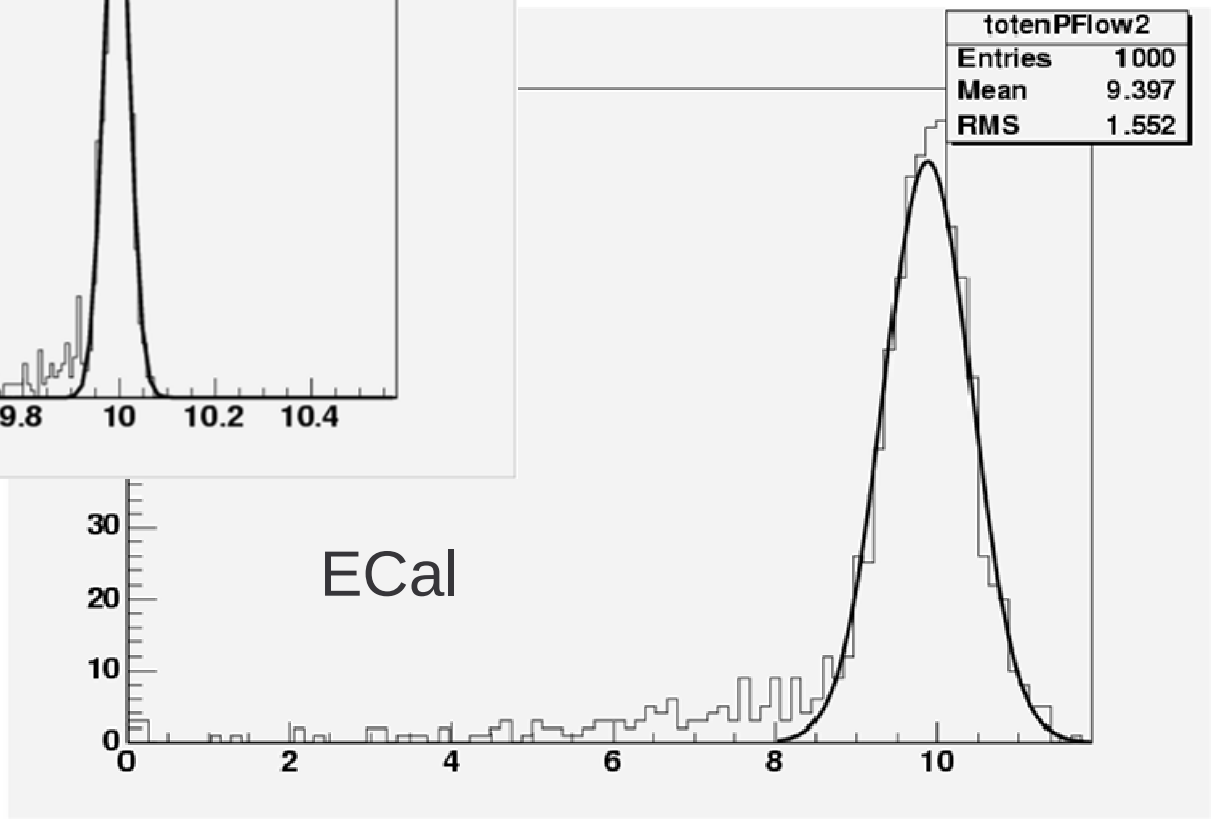
Detectors Calibration

- The LDC0X detectors need to be calibrated:
  - Because of the different geometry
  - Because we used the new version of Mokka and Geant4
- The procedure:
  - At first ECal calibration (2 values, first and second part) using single electron
- Scan in energy to find the $1/\sqrt{E}$ constant

ECal calibration



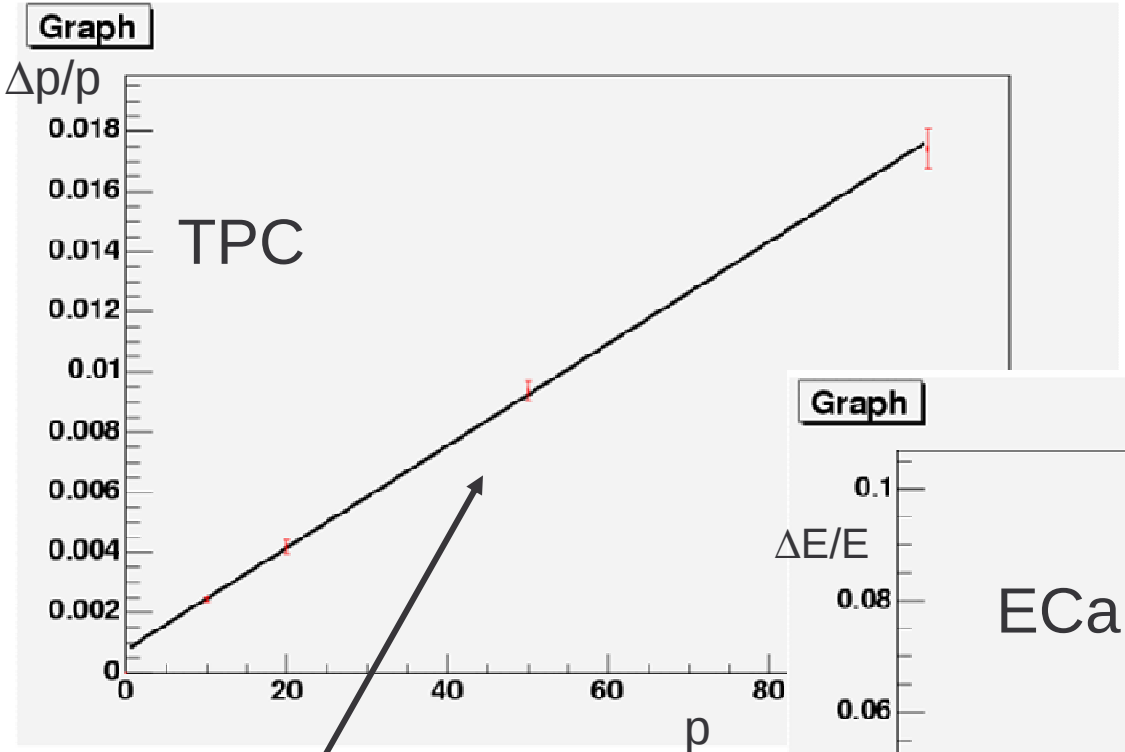
Example: 10 GeV e^-



ECal calibration

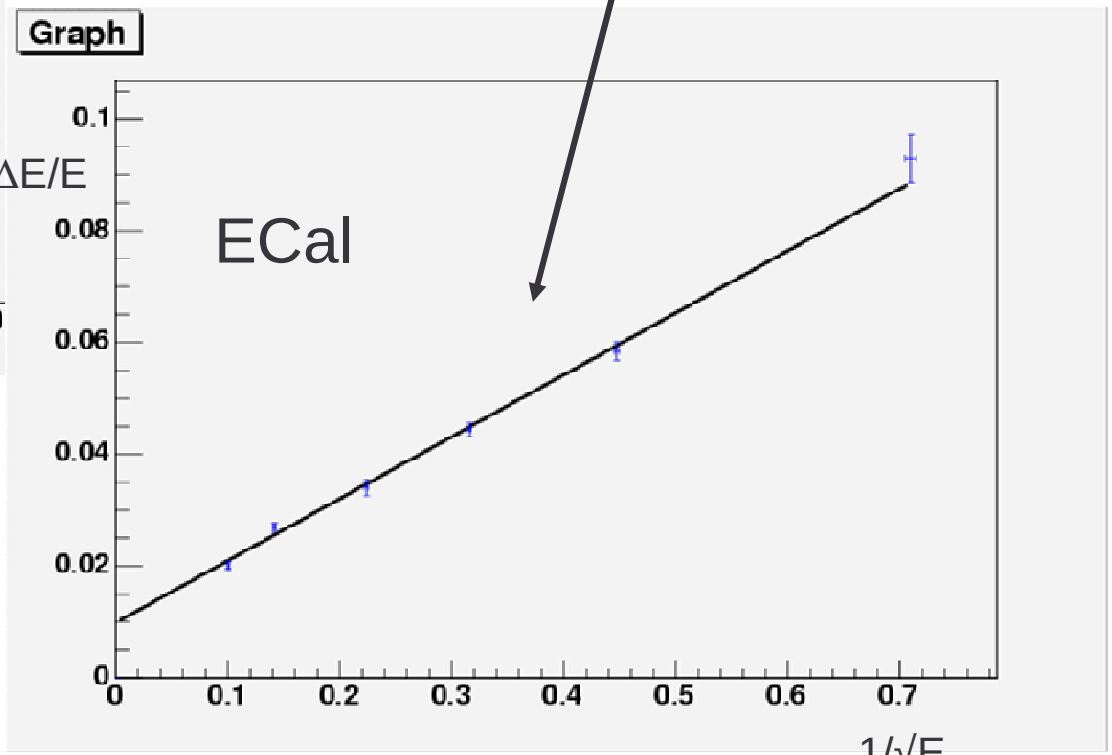
- The calibration values used:
  - For LDC00:
    - CalibrECAL: 27.4 & 74
    - ECALThreshold: 1e-04
    - ECALLayers: 30 40
  - For LDC01:
    - CalibrECAL: 40.4 & 71.5
    - ECALThreshold: 1e-04
    - ECALLayers: 20 30

ECal resolution (LDC00)

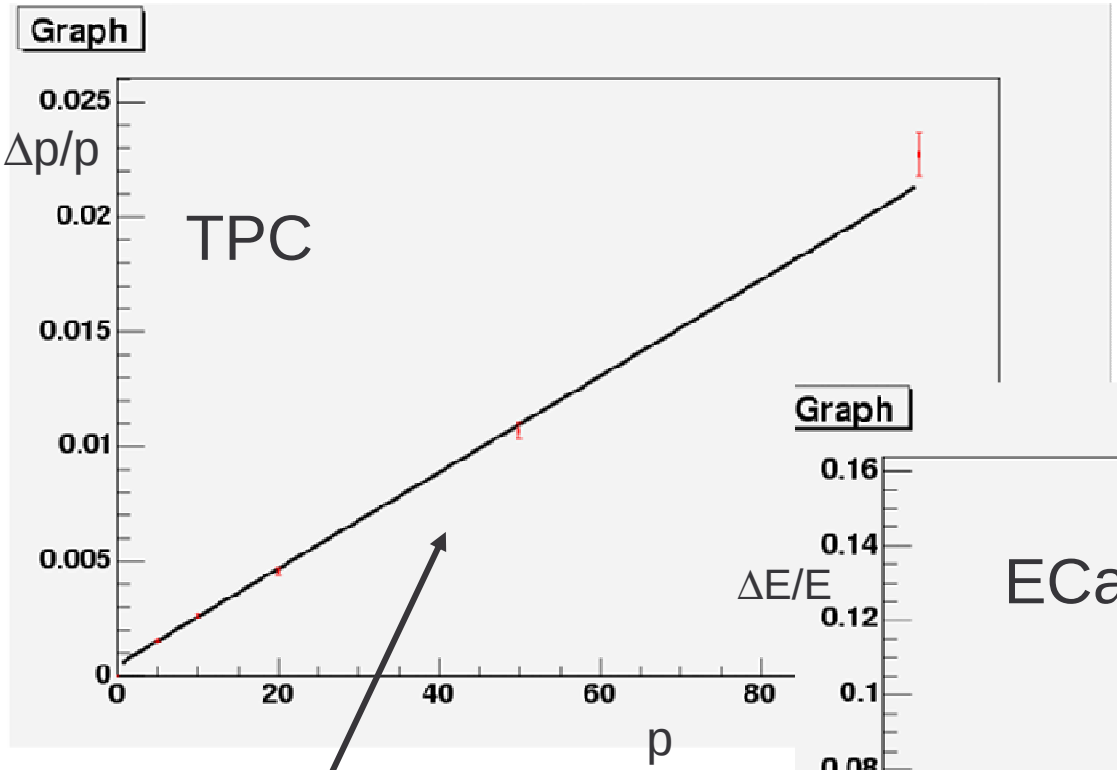


$$\frac{\Delta p}{p} = (0.016\%) * p + 0.1\%$$

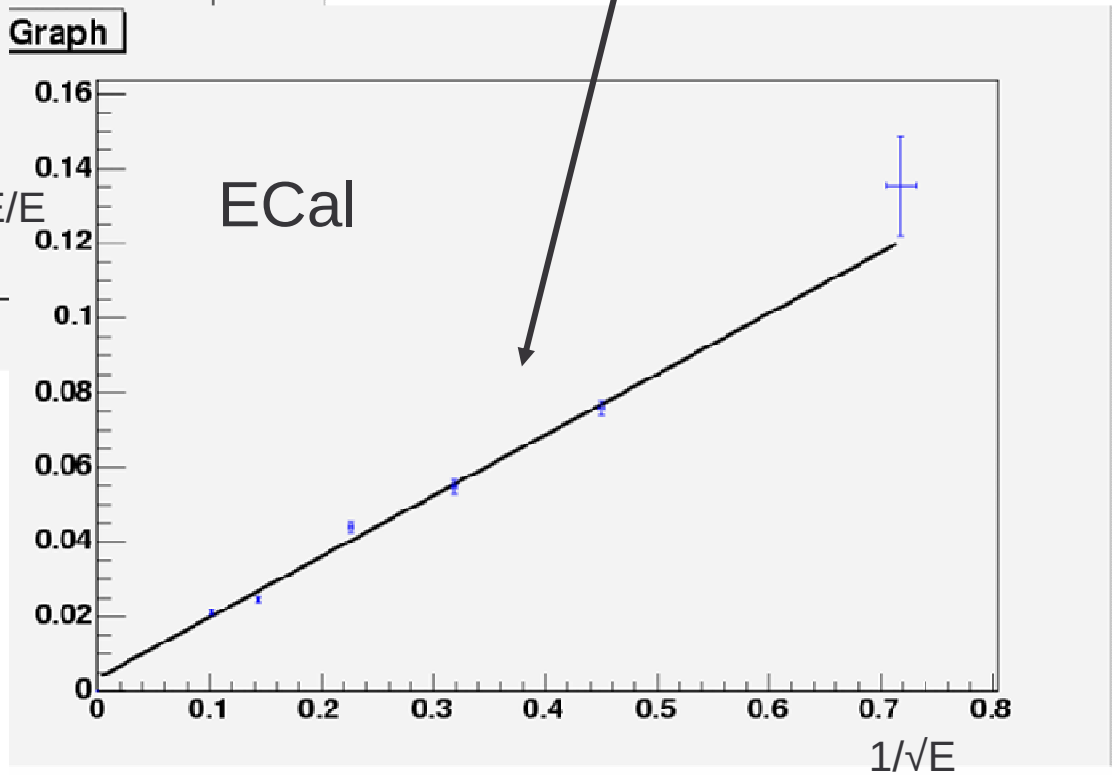
$$\frac{\Delta E}{E} = \frac{11.5\%}{\sqrt{E}} + 0.6\%$$



ECal resolution (LDC01)



$$\frac{\Delta p}{p} = (0.020\%) * p + 0.05\%$$



$$\frac{\Delta E}{E} = \frac{16.3\%}{\sqrt{E}} + 0.3\%$$

Modification in Wolf

- Wolf is the particle flow processor
- New parameter added ElectronThreshold:

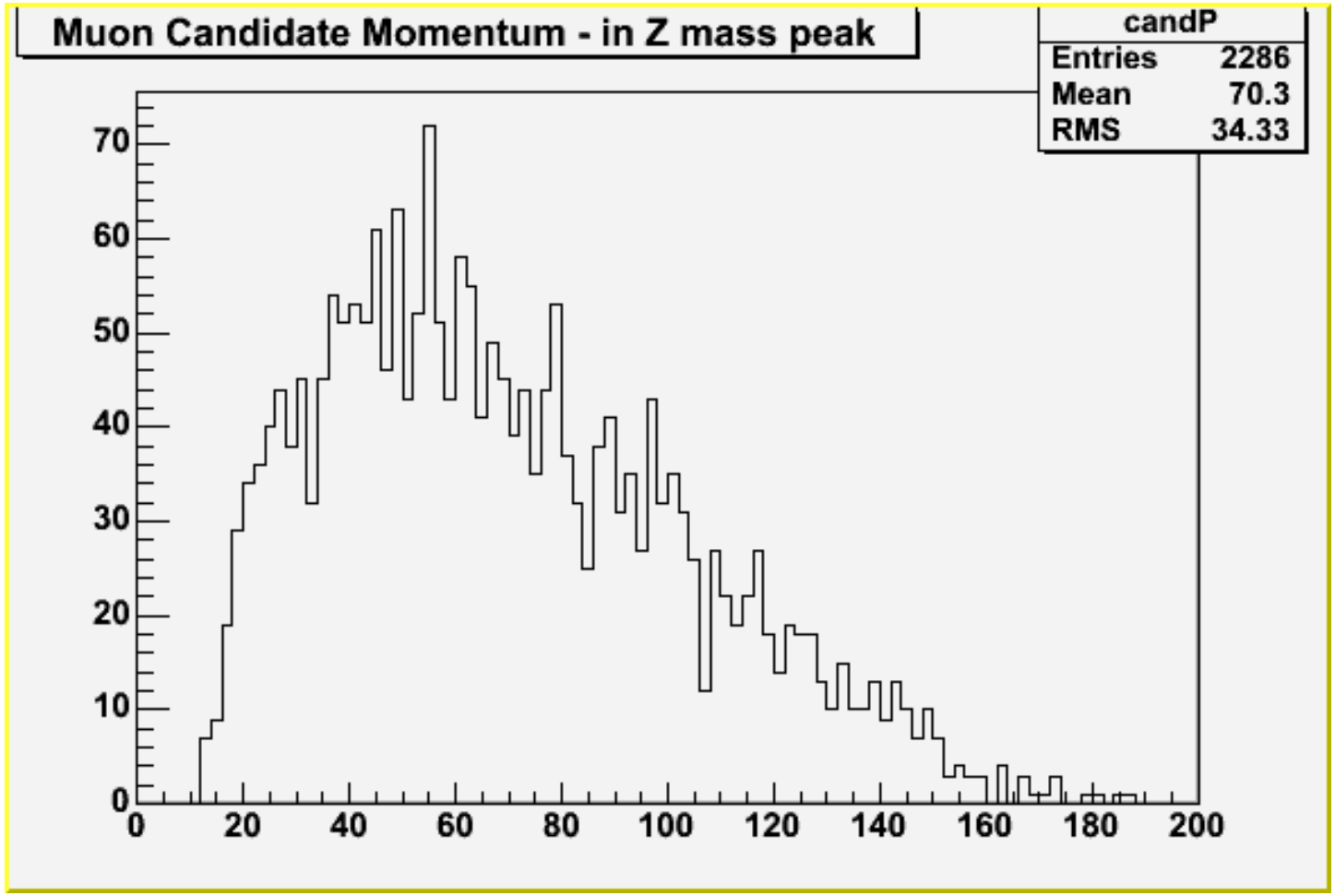
  Value above which the energy resolution for electrons of ECal is better than the TPC.

  If electrons have an energy deposit in the ECal higher than ElectronThreshold, ECal energy is used instead of TPC energy.

ElectronThreshold = 80 GeV for LDC00
ElectronThreshold = 92 GeV for LDC01

Modification in Wolf

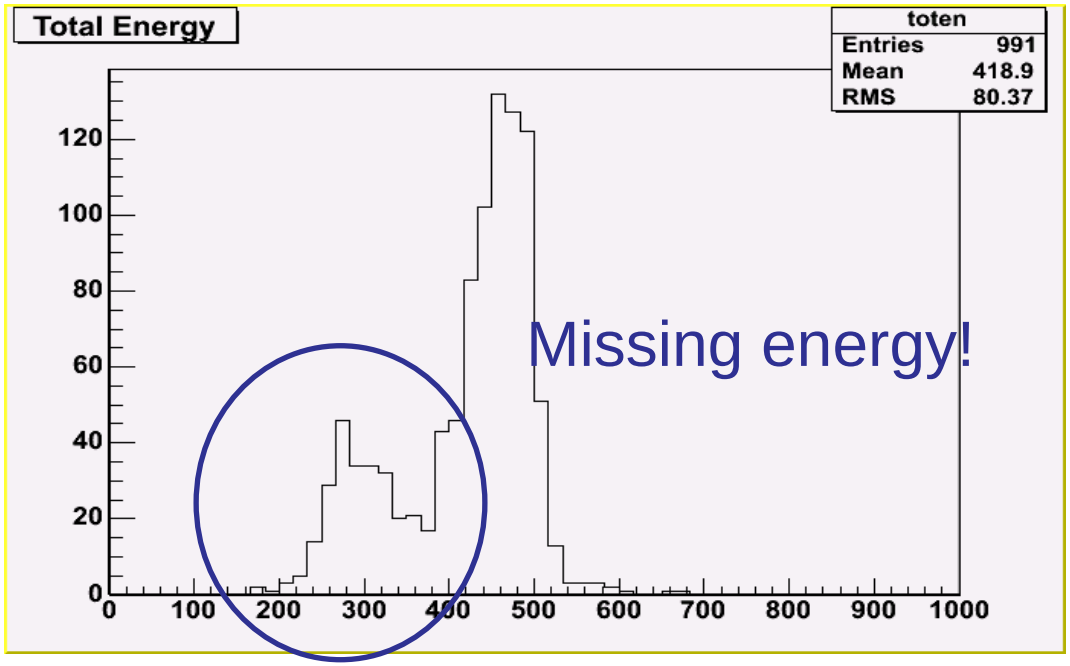
- Muon momentum from Z decay



Event reconstruction

- Marlin 0.9.1
  - Processors used:
    - VTXDigi
    - FTDDigi
    - SimpleCaloDigi
    - TPCDigi
    - LEPTracking
    - Wolf
    - PairSelector
    - SatoruJetFinder
    - MyROOTProcessor & analysis

Problem with LEPTrack



This problem was caused by a failure in LEPTrack Processor: if a track curls in the TPC, it produces too many hits and the algorithm fails to reconstruct any track. Therefore, no momentum is associated to any track in the event. Since muon energy is obtained from its momentum, we have missing energy.

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    - TPCDigi
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The PairSelection processor

- Need to identify μ/e from the Z decay
- At the moment, no sophisticated particle id in Marlin: muon = pion (PId = 2)
- Look at all possible combinations of opposite charge tracks with PId=2 and select the combination which has invariant mass closest to the Z mass
- Put selected ‘muons’ in separate reconstructed particle collection and remove them from track list used in jet-finding

Event reconstruction

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    - TPCDigi
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Satoru input parameters

- Use as input reconstructed particle collection obtained removing the two identified muons/electrons
- Use Durham jet algorithm
- Request exactly 4 jets

Event reconstruction

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    - FTDDigi
    - SimpleCaloDigi
    - TPCDigi
    - LEPTracking
    - Wolf
    - PairSelector
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The ROOTOutput processor

- A preliminary processor creates a ROOT file, it can “save” object of the *ReconstructedParticle* and the *MCParticle* classes.
- Collections obtained from PairSelector, jet finding algorithm (Satoru) and MC truth saved in output ntuple

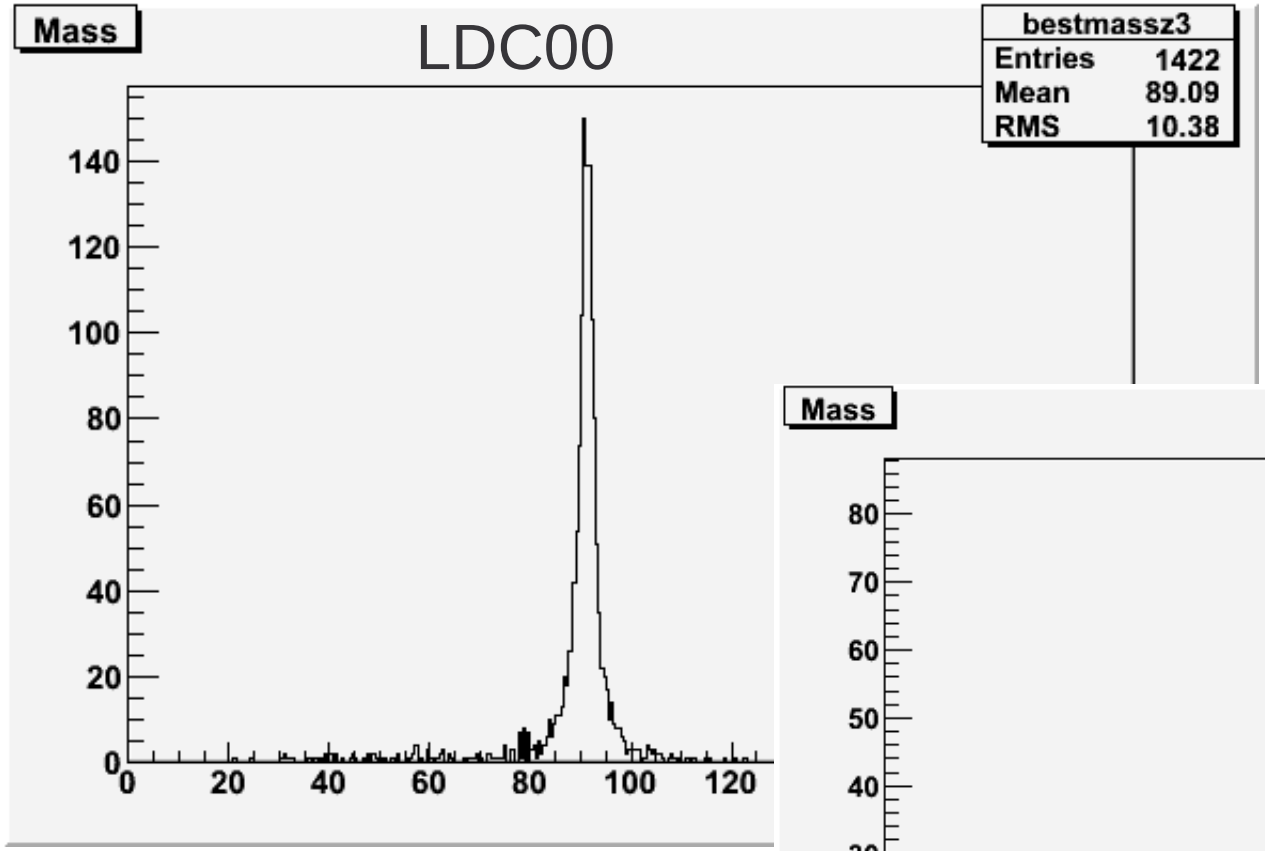
$Z(\rightarrow \mu^+\mu^-)HH$ analysis

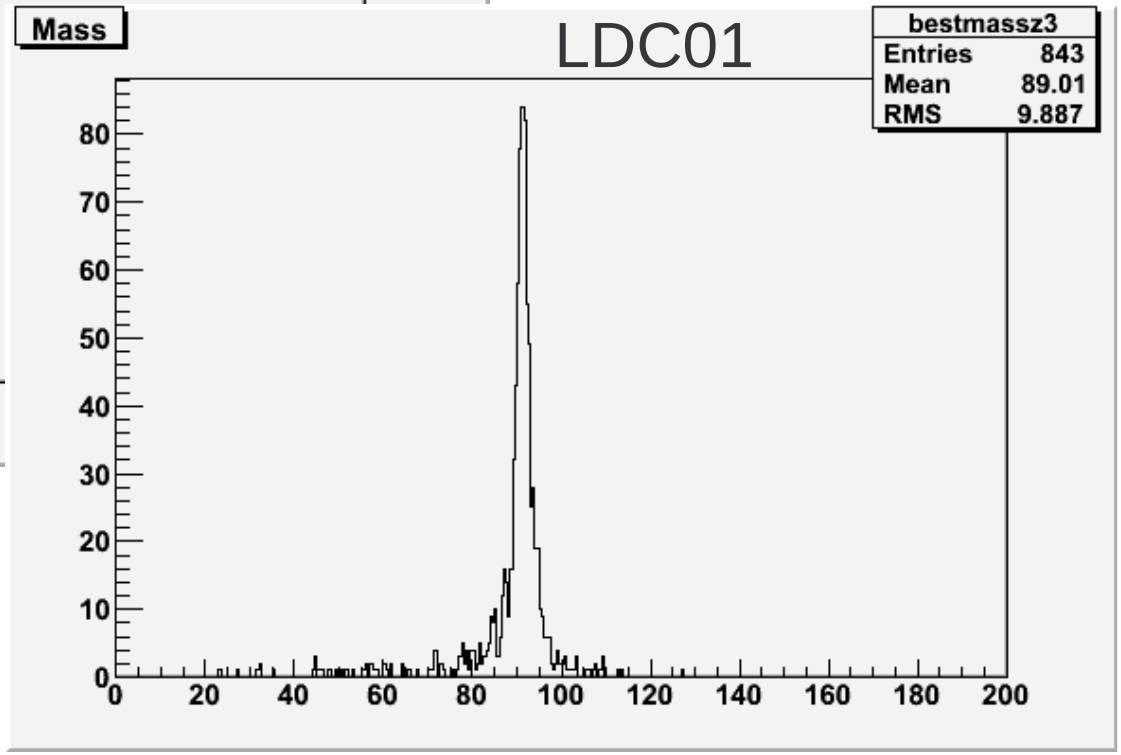
- Higgs selection:
  - 4 jets are combined in all 3 possible ways,
  - the combination that minimizes:

$$D_h^2 = (m_{12} - m_h)^2 + (m_{34} - m_h)^2$$

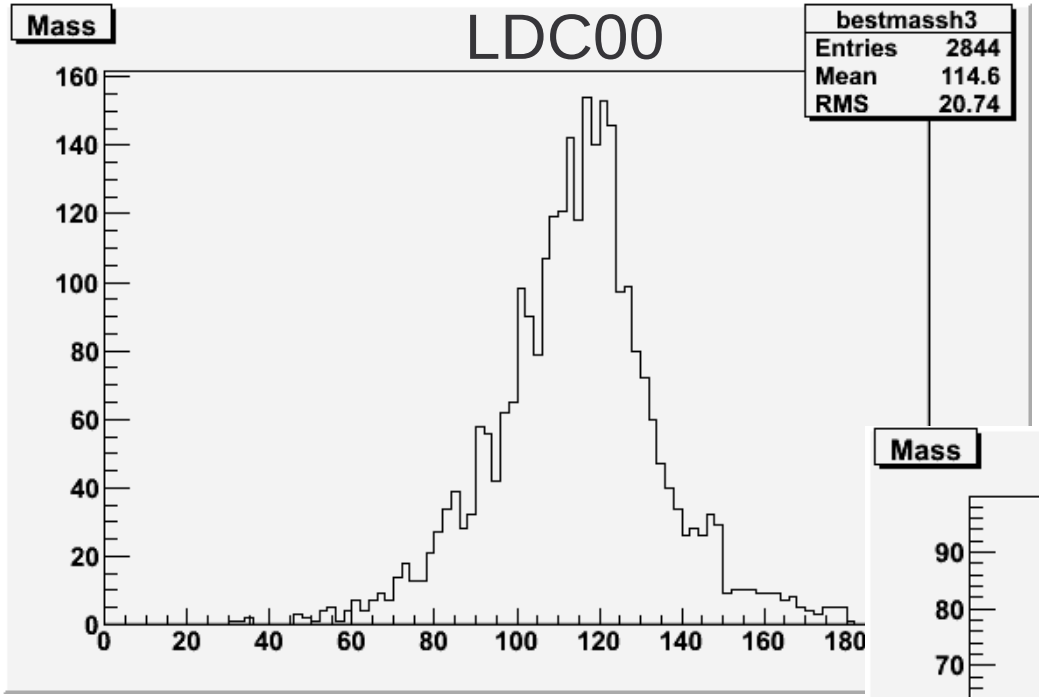
is used to calculate the Higgs mass

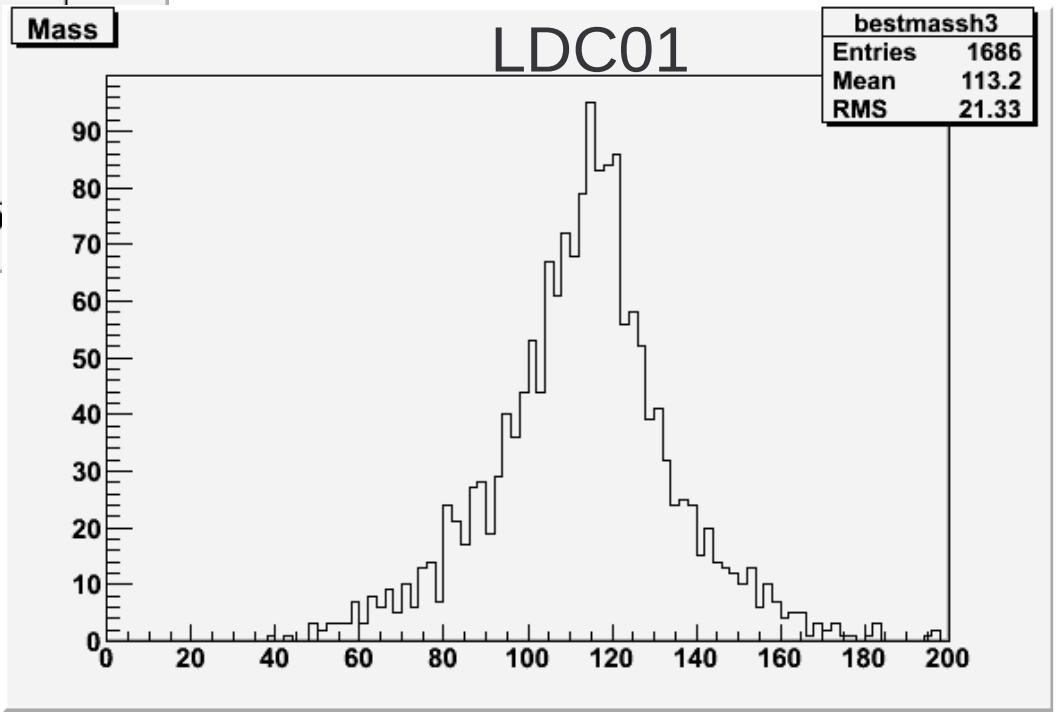
Z ($\rightarrow \mu^+\mu^-$) mass plot





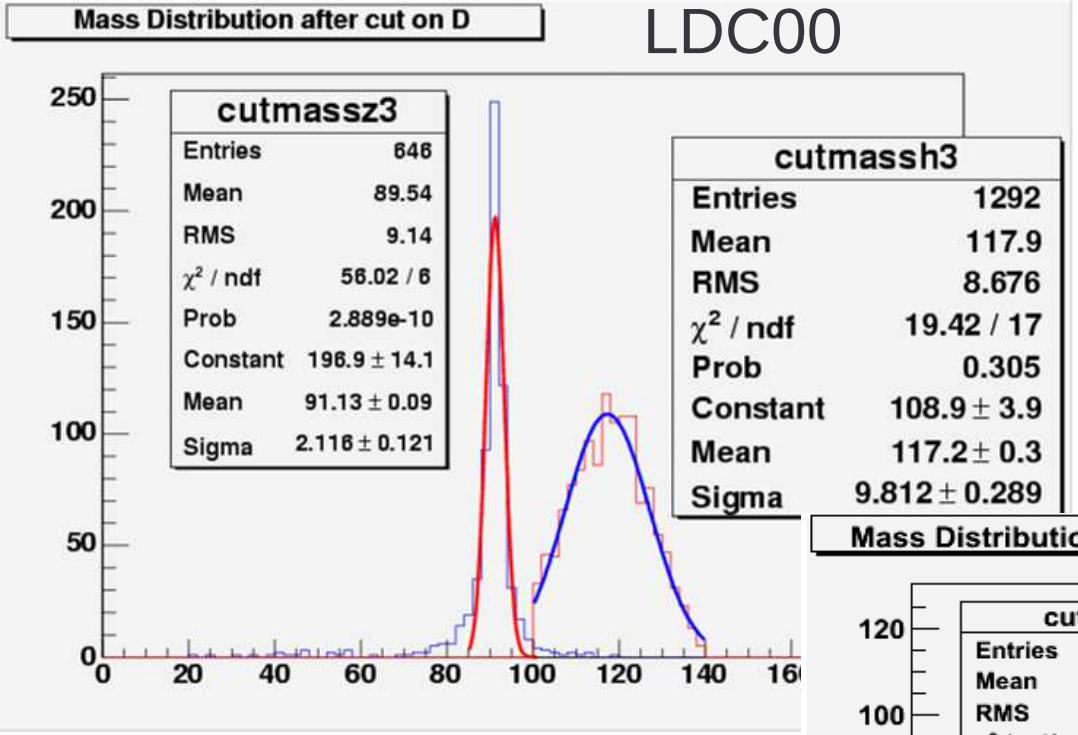
H mass plot


Mass
LDC00
bestmassh3
Entries 2844
Mean 114.6
RMS 20.74
160
140
120
100
80
60
40
20
0
0 20 40 60 80 100 120 140 160 180

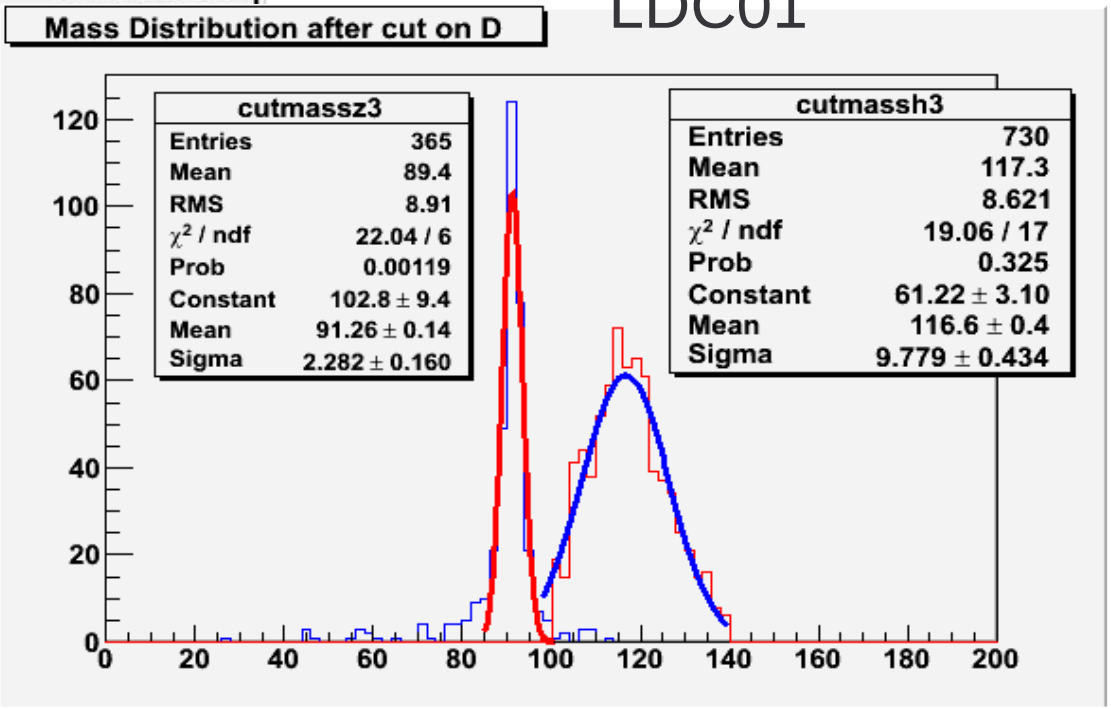

Mass
LDC01
bestmassh3
Entries 1686
Mean 113.2
RMS 21.33
90
80
70
60
50
40
30
20
10
0
0 20 40 60 80 100 120 140 160 180 200

Cut on D^2 (<400)

LDC00



LDC01



Z(→e⁺e⁻)HH analysis

- Higgs selection:
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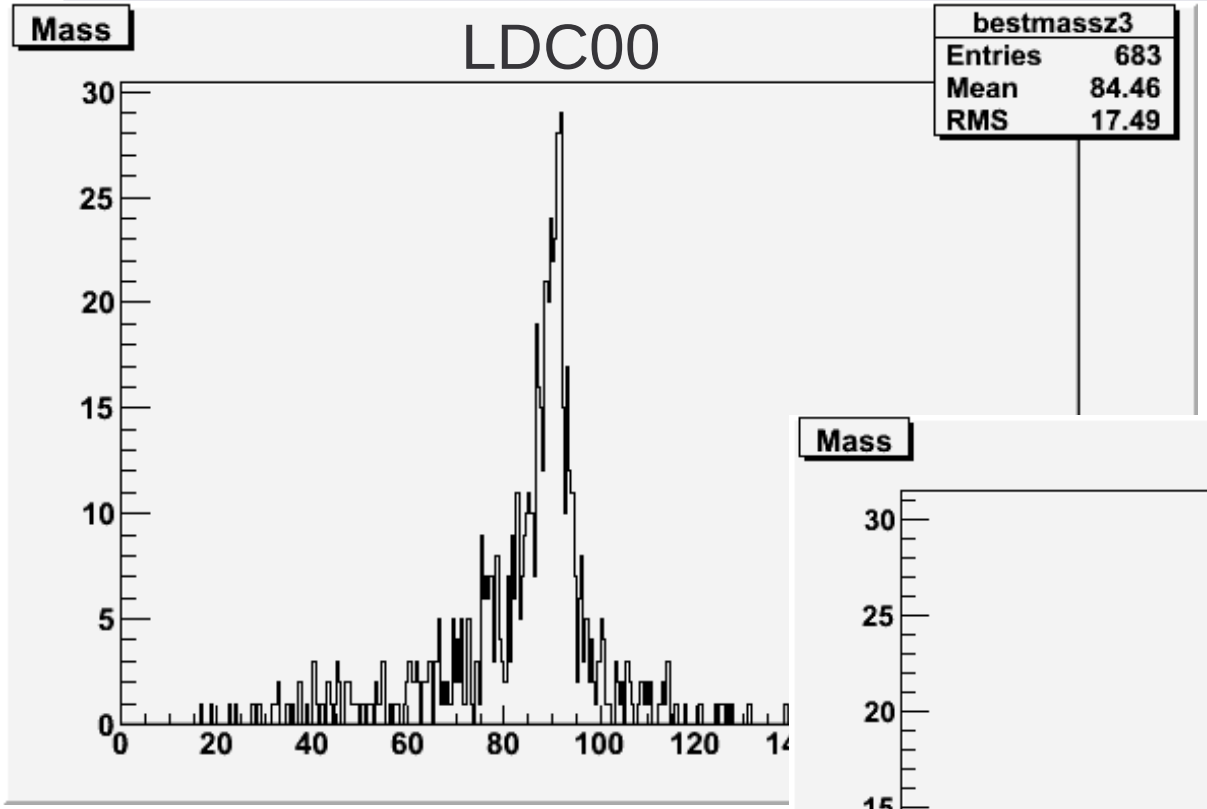
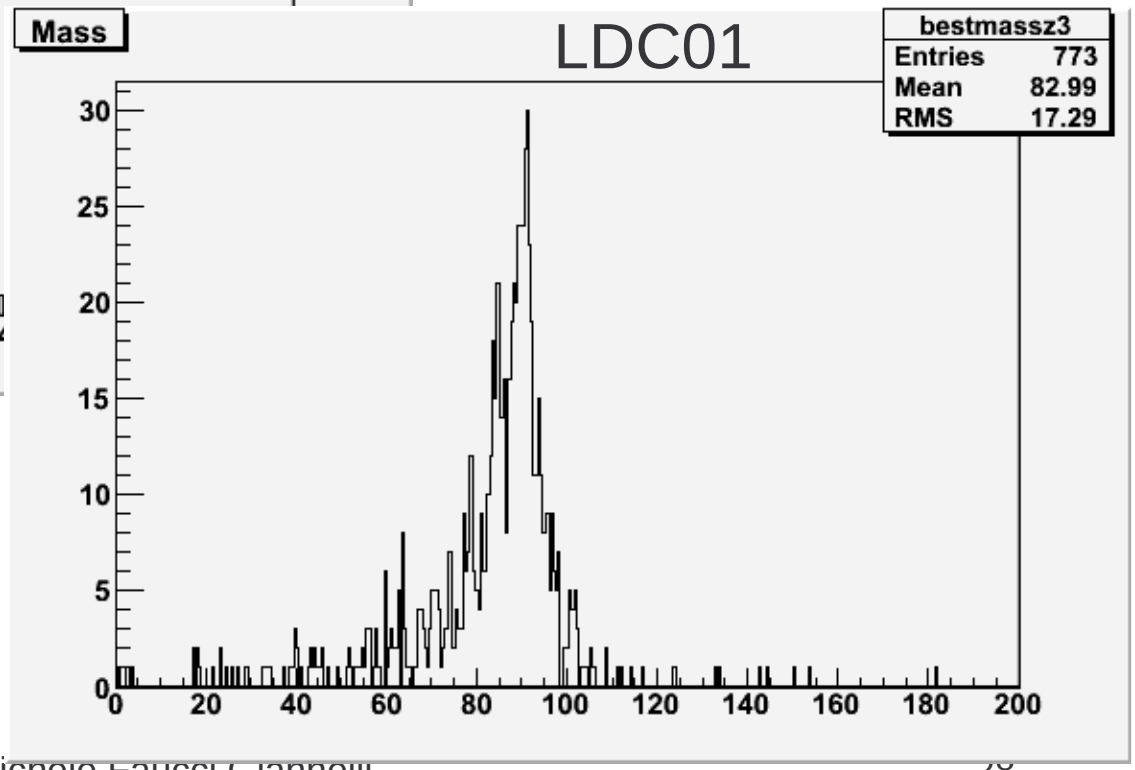
  - the combination that minimizes:

$$D_h^2 = \left(m_{12} - m_1\right)^2 + \left(m_{34} - m_2\right)^2$$

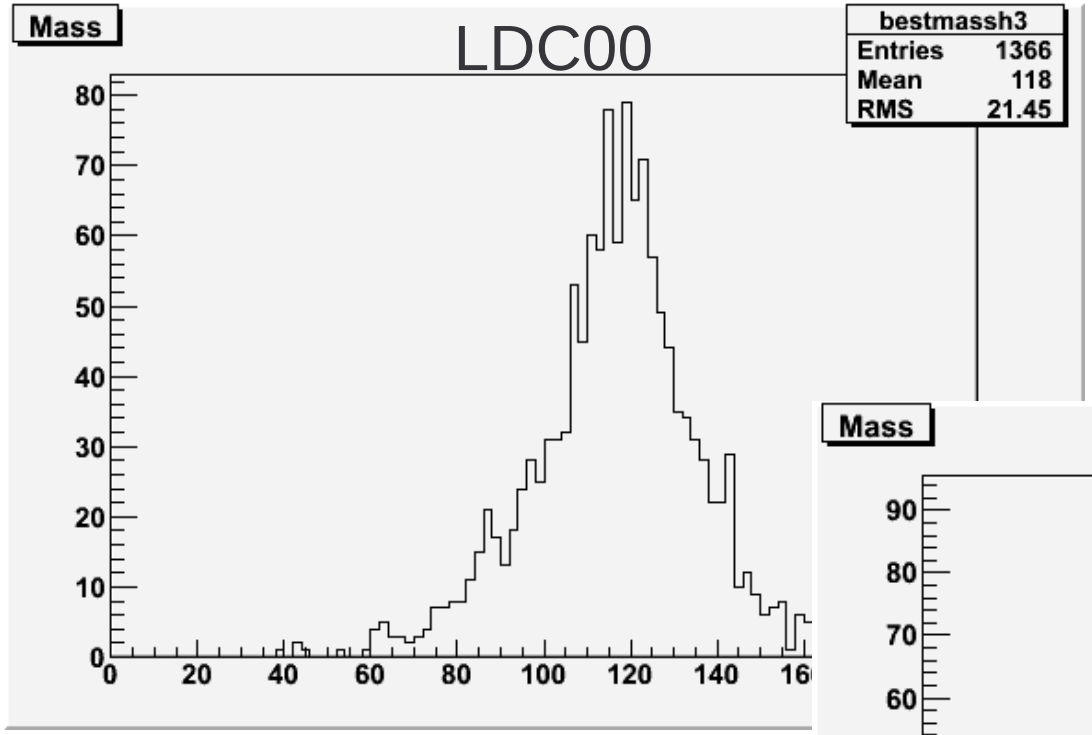
is used to calculate the Higgs mass

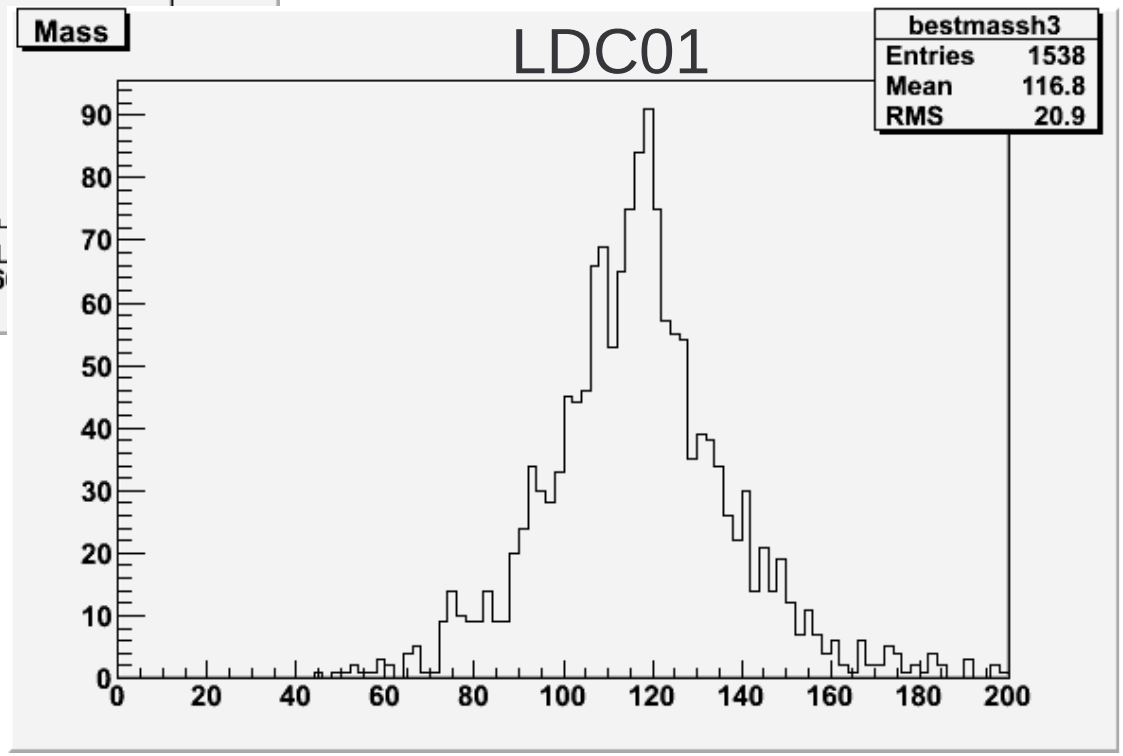
Z mass plot


Mass
LDC00
bestmassz3
Entries 683
Mean 84.46
RMS 17.49
0 5 10 15 20 25 30
0 20 40 60 80 100 120


Mass
LDC01
bestmassz3
Entries 773
Mean 82.99
RMS 17.29
0 5 10 15 20 25 30
0 20 40 60 80 100 120 140 160 180 200

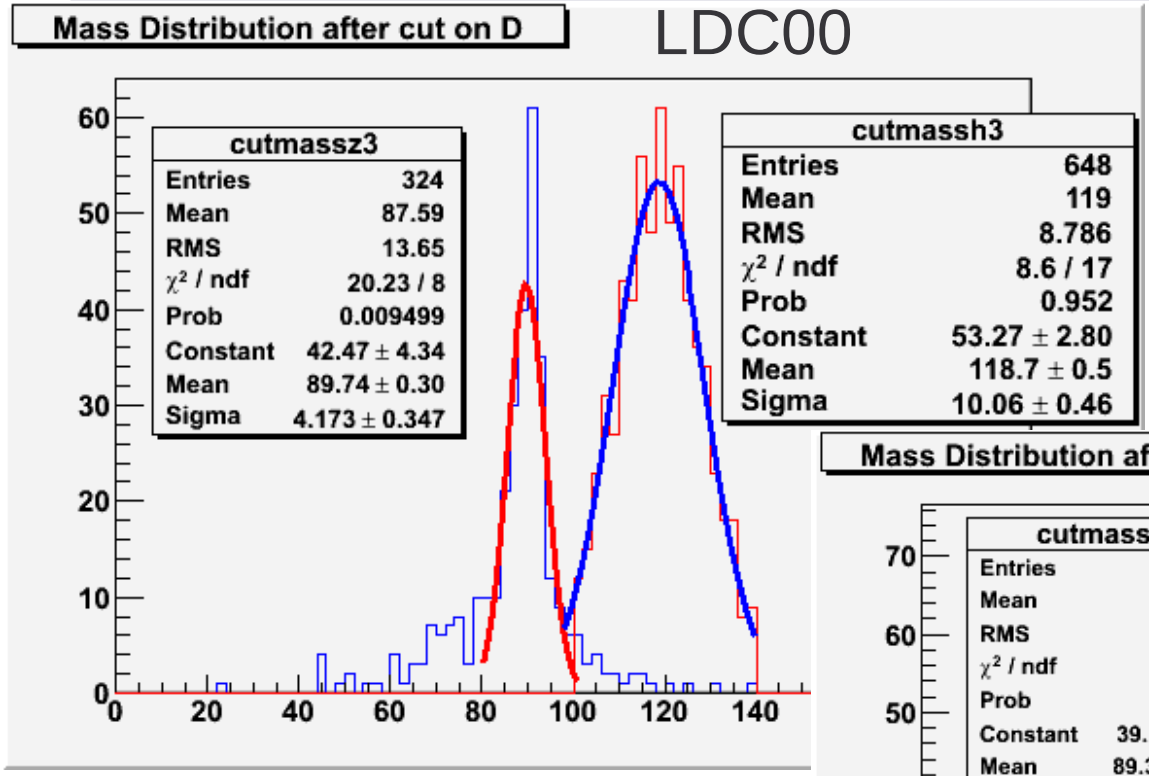
H mass plot


Mass
LDC00
bestmassh3
Entries 1366
Mean 118
RMS 21.45
0 10 20 30 40 50 60 70 80
0 20 40 60 80 100 120 140

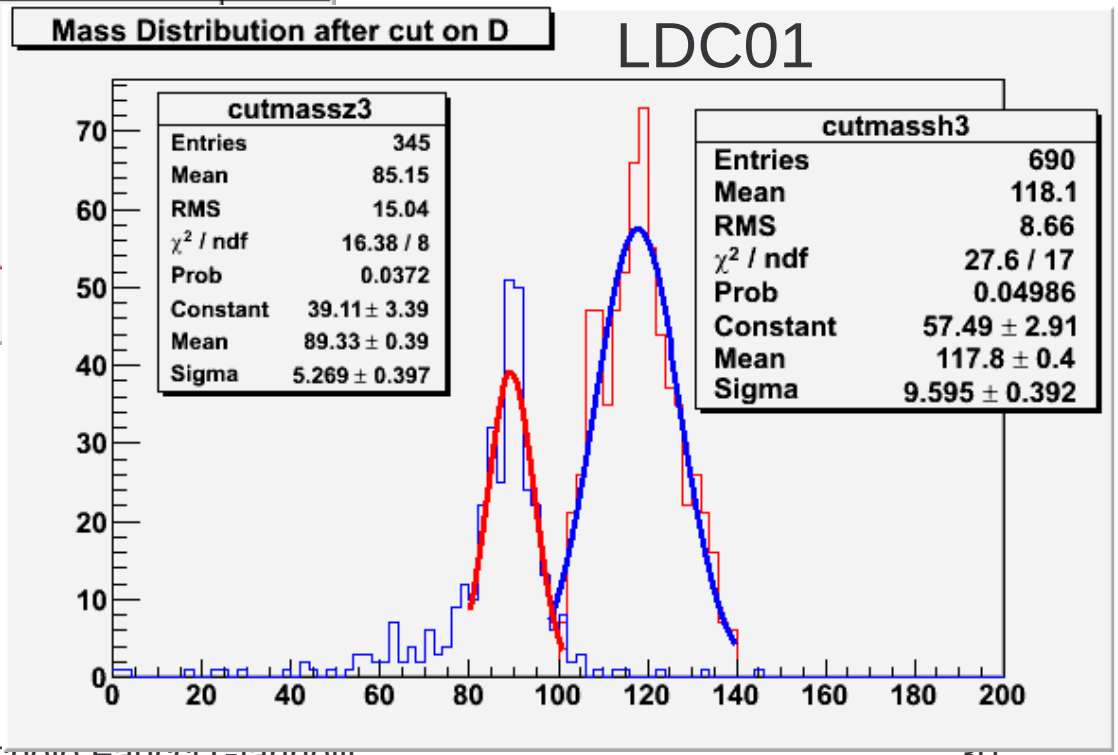

Mass
LDC01
bestmassh3
Entries 1538
Mean 116.8
RMS 20.9
0 10 20 30 40 50 60 70 80 90
0 20 40 60 80 100 120 140 160 180 200

Cut on D^2

LDC00



LDC01



Efficiency

Events	#	ε
Generated	2000	1
After LEPTrack	1422	0.71
After Z selection	1422	0.71
After H selection	1422	0.71

Study on D^2

Sigma of Higgs

D^2	Events	ε'	LDC00	LDC01
No cut	1422	1	-	-
400	646	0.45	9.8±0.3	9.8±0.4
300	538	0.38	8.2±0.2	8.1±0.3
200	426	0.30	8.1±0.4	7.5±0.5
100	242	0.17	5.6±0.3	5.7±0.5

But the cut depends on background… NEXT to DO!!

Summary of differences

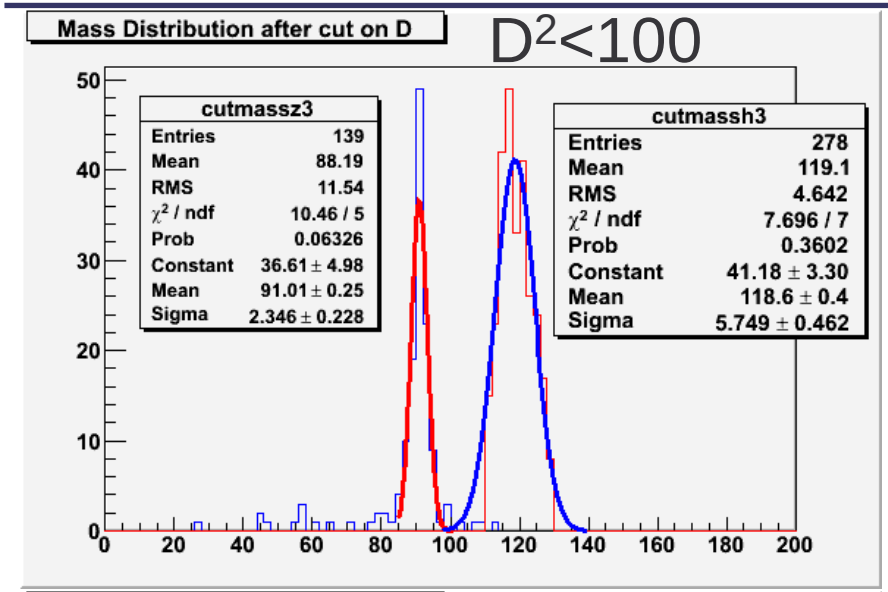
	LDC00	LDC01
Tracker resolution	0.016%*p+0.12%	0.020%*p+0.05%
ECal resolution	$\frac{11.5\%}{\sqrt{E}} + 0.6\%$	$\frac{16.3\%}{\sqrt{E}} + 0.3\%$
$Z \rightarrow \mu$ resolution (σ)	2.12±0.12	2.28±0.16
$Z \rightarrow e$ resolution (σ)	4.2±0.3	5.3±0.4
H res. (D^2 cut =100)	5.6±0.3	5.7±0.5

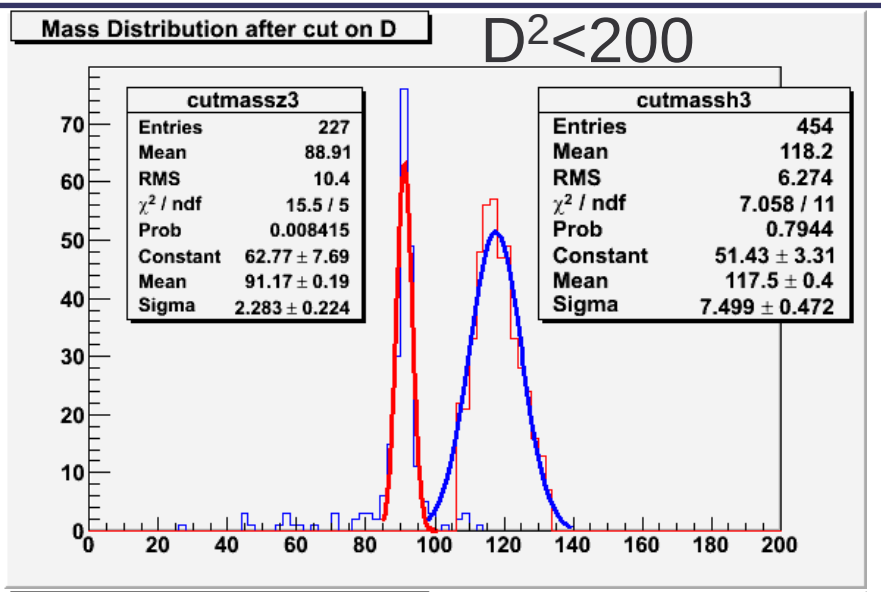
Summary and Outlook

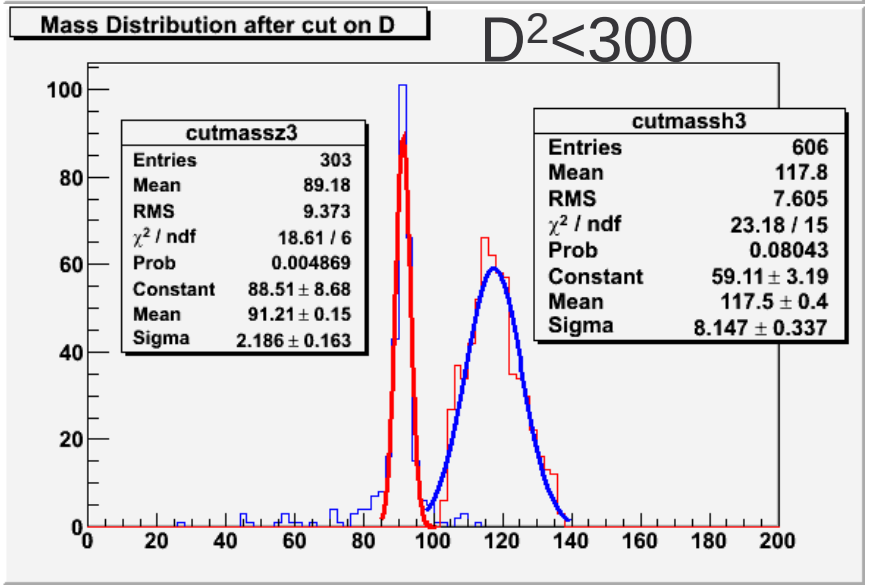
- ZHH channel can be very useful benchmark channel to perform detector studies
  - first look at 2 different models: LDC00/01
- Calibration constants for LDC00/01 have been obtained
- New processor to select μ/e from Z decay
  - available as Marlin processor
- Preliminary results of the analysis (with almost no cuts) are promising
  - Need to look at backgrounds: next in the to-do list
- Still many improvements have to be done
  - e.g.: b tagging

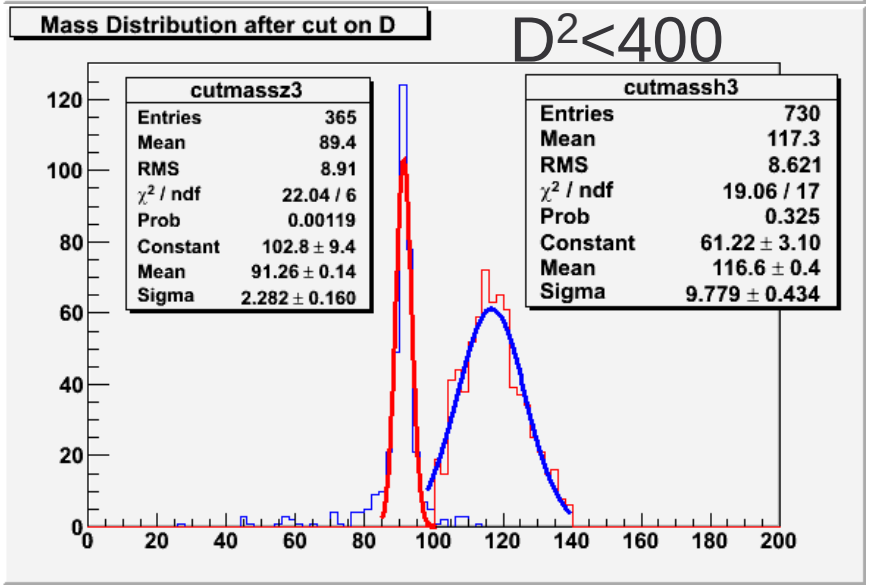
Backup Slides

LDC01, D cut

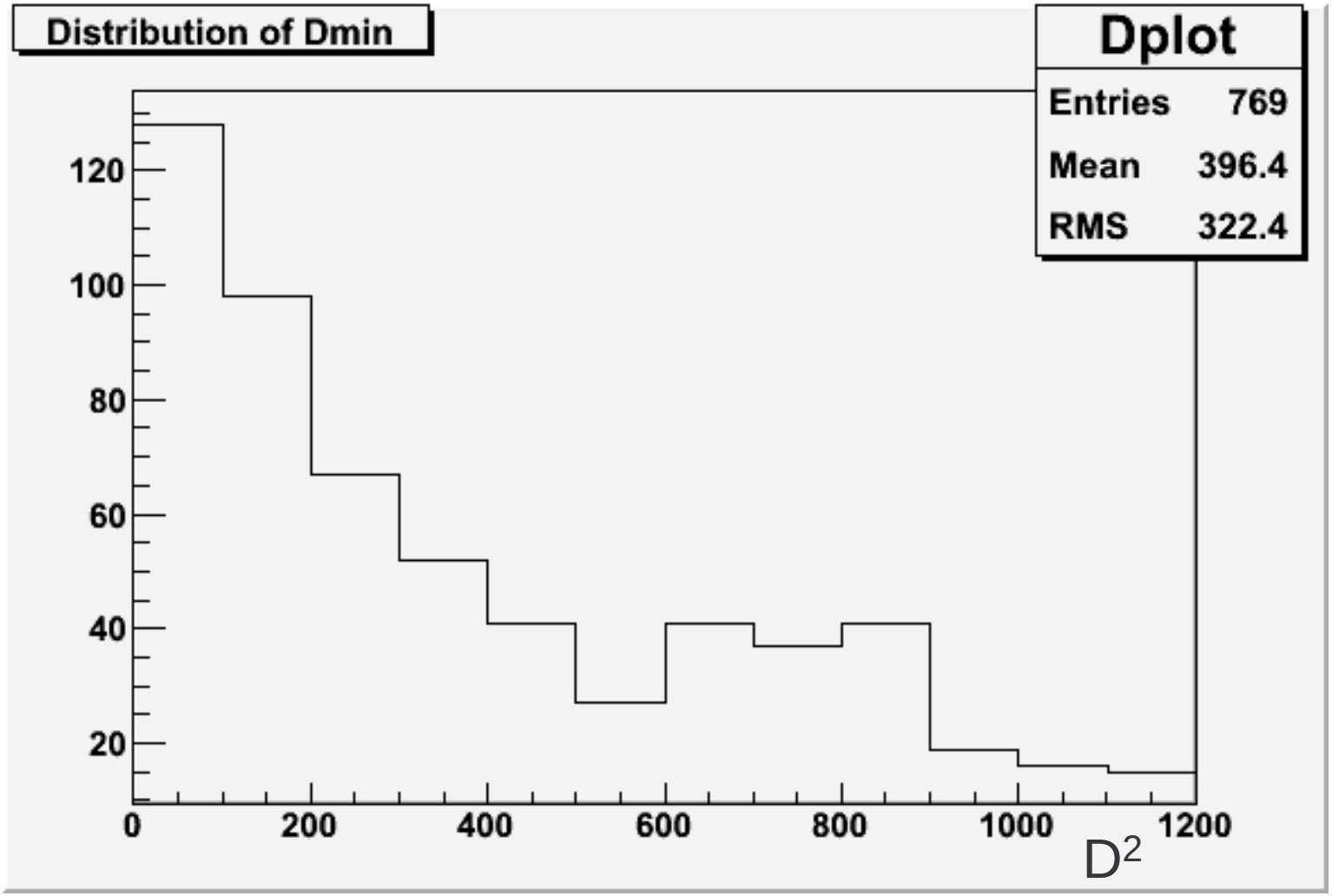

Mass Distribution after cut on D
D²<100
cutmassz3
Entries 139
Mean 88.19
RMS 11.54
χ² / ndf 10.46 / 5
Prob 0.06326
Constant 36.61 ± 4.98
Mean 91.01 ± 0.25
Sigma 2.346 ± 0.228
cutmassh3
Entries 278
Mean 119.1
RMS 4.642
χ² / ndf 7.696 / 7
Prob 0.3602
Constant 41.18 ± 3.30
Mean 118.6 ± 0.4
Sigma 5.749 ± 0.462


Mass Distribution after cut on D
D²<200
cutmassz3
Entries 227
Mean 88.91
RMS 10.4
χ² / ndf 15.5 / 5
Prob 0.008415
Constant 62.77 ± 7.69
Mean 91.17 ± 0.19
Sigma 2.283 ± 0.224
cutmassh3
Entries 454
Mean 118.2
RMS 6.274
χ² / ndf 7.058 / 11
Prob 0.7944
Constant 51.43 ± 3.31
Mean 117.5 ± 0.4
Sigma 7.499 ± 0.472


Mass Distribution after cut on D
D²<300
cutmassz3
Entries 303
Mean 89.18
RMS 9.373
χ² / ndf 18.61 / 6
Prob 0.004869
Constant 88.51 ± 8.68
Mean 91.21 ± 0.15
Sigma 2.186 ± 0.163
cutmassh3
Entries 606
Mean 117.8
RMS 7.605
χ² / ndf 23.18 / 15
Prob 0.08043
Constant 59.11 ± 3.19
Mean 117.5 ± 0.4
Sigma 8.147 ± 0.337

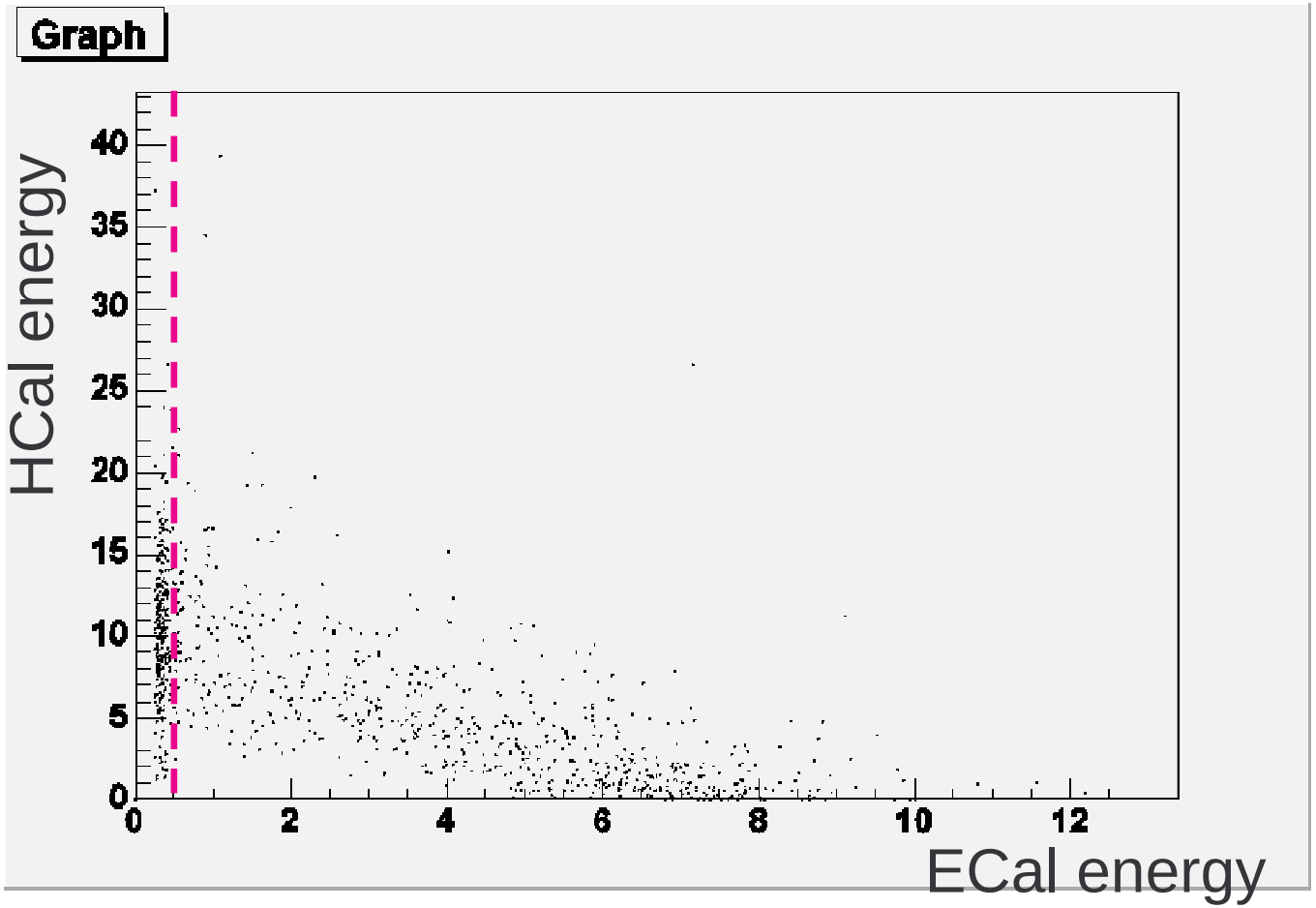

Mass Distribution after cut on D
D²<400
cutmassz3
Entries 365
Mean 89.4
RMS 8.91
χ² / ndf 22.04 / 6
Prob 0.00119
Constant 102.8 ± 9.4
Mean 91.26 ± 0.14
Sigma 2.282 ± 0.160
cutmassh3
Entries 730
Mean 117.3
RMS 8.621
χ² / ndf 19.06 / 17
Prob 0.325
Constant 61.22 ± 3.10
Mean 116.6 ± 0.4
Sigma 9.779 ± 0.434

D plot


Distribution of Dmin
Dplot
Entries 769
Mean 396.4
RMS 322.4
120
100
80
60
40
20
0
200
400
600
800
1000
1200
D2

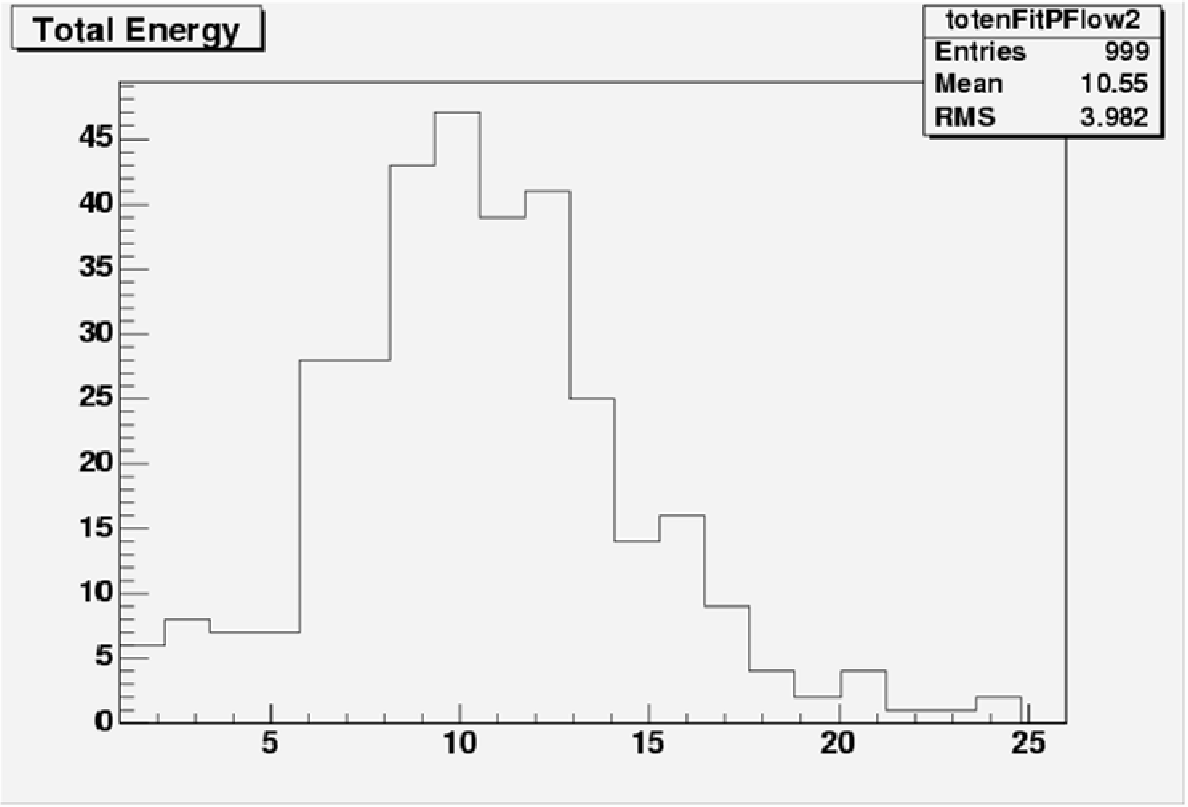
HCal calibration

- Use pions that had interacted in the HCal:



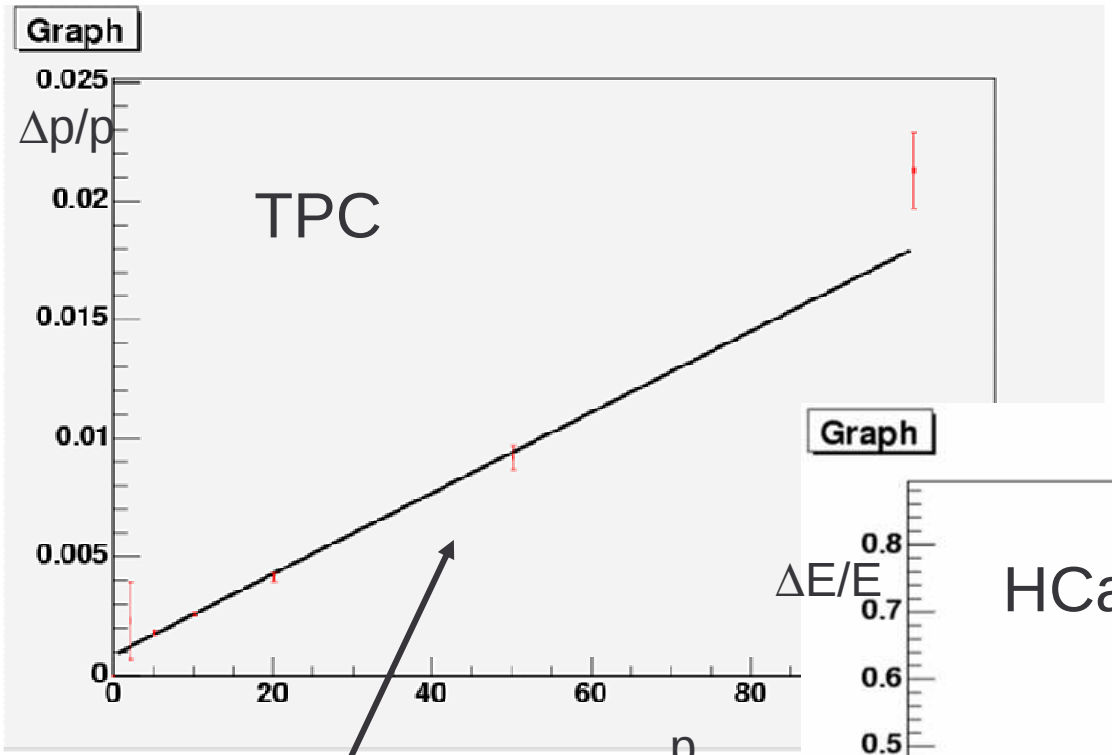
HCal calibration

Example: 10 GeV π^-



- The value for the threshold is 1e-07,
- The calibration value is 40000.

HCal resolution (LDC01)



$$\frac{\Delta p}{p} = (0.020\%) * p + 0.05\%$$

$$\frac{\Delta E}{E} = \frac{42\%}{\sqrt{E}} + 18\%$$