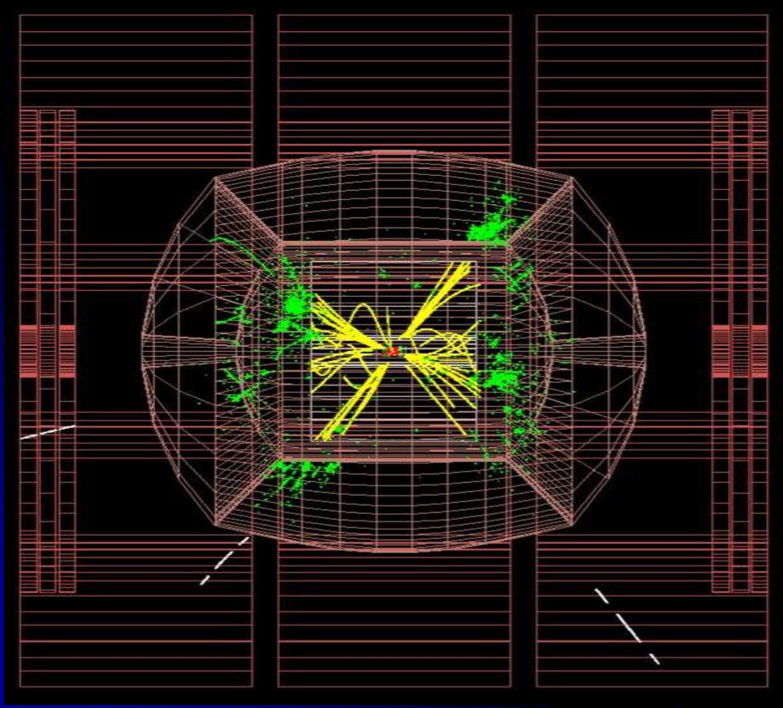
Status of the Physics Analyses of the 4th Concept



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

Post-Tsukuba Software Activities

- SUSY analysis (previously missing)
- Remake of two recoil mass analyses
- Further comparison between DREAM data and ILCroot algorithms

See also the following talk:

V. Di Benedetto on Friday
J. Hauptman tomorrow
A. Mazzacane on Friday

Status of ILCroot

- New central tracker for higher energies studies (temporary module while waiting for Paris VI new proposal)
- New reallignement with latest Aliroot version (v4.17 release)
- **Main differences vs 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**

Physics Studies for LoI

- Detector simulation frozen in July 2008 (except Ecal). Simu & Reco started August 2008 (expect some discrepancy with LOI)
- 4th Concept used SiD sample for SUSY and recoil mass studies and ILD sample for the rest
- Not only ILCroot: MarlinKinFit & Rave
- 99% computing resources are from Fermilab
- 1% computing resources are from INFN
- ILCroot is freely available at Fermilab

http://ilc.fnal.gov/detector/rd/physics/technical/resources/ilcroot.shtml

Processes for LOI

Process	e^- polar.	e^+ polar.	Ecal	Beam bkgnd	MC
$Z^oH^o \rightarrow \mu^+ \mu^- X$	80%	30%	yes	yes	Fluka
$Z^oH^o \rightarrow e^+ e^- X$	80%	30%	yes	yes	Fluka
$Z^oH \rightarrow$ 4 jets	100%	100%	no	no	Fluka
$Z^oH^o \rightarrow \nu\underline{\nu} X$	100%	100%	no	no	Fluka
$e^+e^- \rightarrow t\,\underline{t}$	100%	100%	no	yes	Fluka
$e^+e^- \rightarrow \chi_1^+\chi_1^- \rightarrow \chi_1^o\chi_1^o W^+W^-$ $e^+e^- \rightarrow \chi_2^o\chi_2^o \rightarrow \chi_1^o\chi_1^o Z^oZ^o$	80%	30%	yes	yes	Fluka
$e^+e^- \rightarrow \tau^+\tau^-$	100%	100%	yes	yes	Fluka

Worst case polarization scenario considered in some cases: largest WW background

$e^+e^- \to Z^oH^o \to \mu^+ \mu^- X \; \sqrt{s}=250$ GeV
$e^+e^- \to Z^oH^o \to e^+ e^- X \; \sqrt{s}=250$ GeV

- Repeat the recoil analysis with Z -> μ+μ−, e+e−, including the corrected ISR spectrum
- M_μ = 0 also corrected (inducing wrong muon bremsstrahlung)
- 80/30 polarization of background by re-waiting method
- The analysis methods are the same as described in the LoI, and we solve the problem for three cases (μ+μ−, e+e− with tracking only, and e+e− with tracking and calorimetry)

G. Tassielli, G. Terracciano, M. Peccarisi

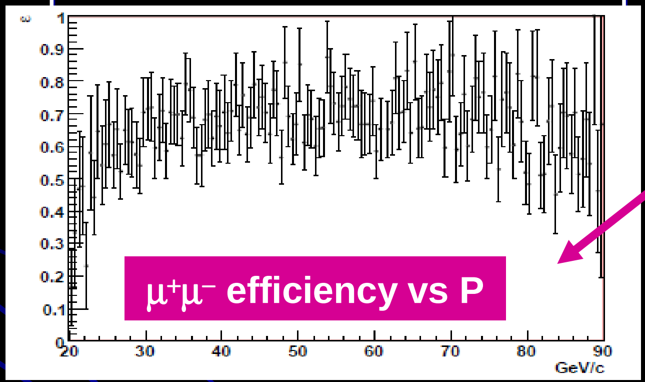
$e^+e^- \to Z^oH^o \to \mu^+ \mu^- X$ $\sqrt{s}$=250 GeV

Analysis strategy

1. Initial cuts to reduce background

    1. $|cos\theta_\mu| < 0.98$
    2. $P_t(\mu^\pm) > 9$ GeV
    3. $72 < M(\mu^+\mu^-) < 110$ GeV
    4. $102 < M_{recoil}(\mu^+\mu^-) < 168$ GeV
    5. At least 4 charged tracks for the

2. Require two tracks in the Muon Spectrometer

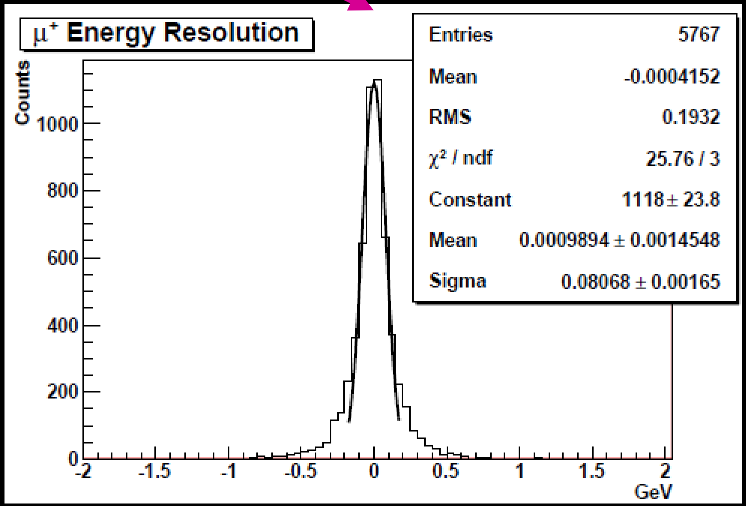


3. Final cuts for S/N enjhancement

    1. largest $P_\mu > 20$ GeV
    2. At least 5 charged tracks successfully reconstructed (including the muons)
    3. Distance of closest approach to the origin for the candidate muon tracks < 6 mm

	Final state
signal	$e^+e^- \to Z^0H^0 \to \mu^+\mu^- + X$
bkgnd	$e^+e^- \to \mu^+\mu^-$
	$e^+e^- \to \mu^+\mu^-\mu^+\mu^-$
	$e^+e^- \to \mu^+\mu^-\tau^+\tau^-$
	$e^+e^- \to \mu^+\mu^-e^+e^-$
	$e^+e^- \to \mu^+\mu^-\nu\overline{\nu}$
	$e^+e^- \to \mu^+\mu^-u\overline{u}$
	$e^+e^- \to \mu^+\mu^-d\overline{d}$
	$e^+e^- \to \mu^+\mu^-s\overline{s}$
	$e^+e^- \to \mu^+\mu^-c\overline{c}$
	$e^+e^- \to \mu^+\mu^-b\overline{b}$

$\varepsilon_{\mu\mu}$ = 80.5%
Purity= 99.9%



G. Tassielli, G. Terracciano, M. Peccarisi

$e^+e^- \rightarrow Z^oH^o \rightarrow \mu^+ \mu^- X$ $\sqrt{s}$=250 GeV

Old

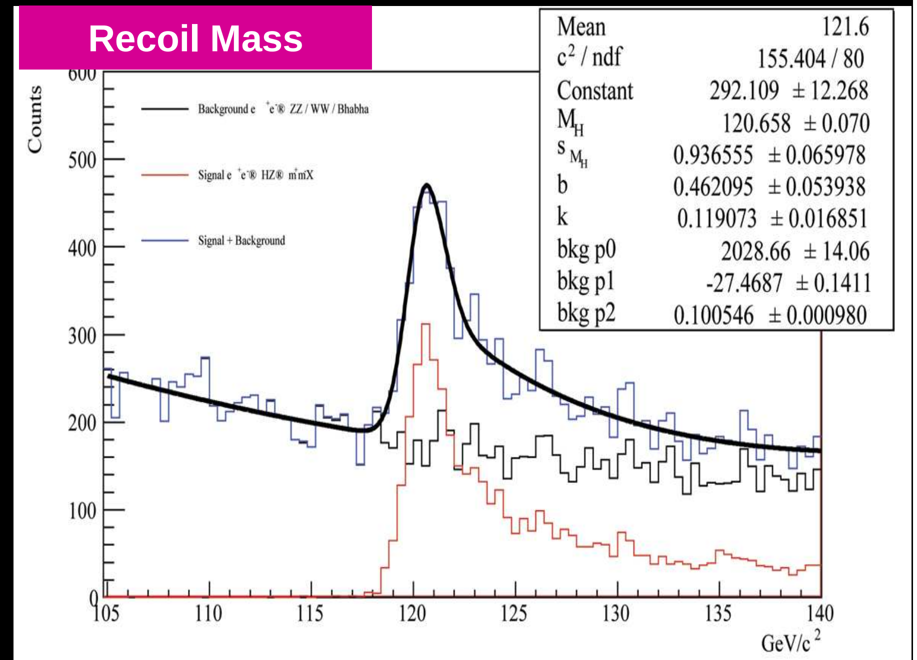
Results

$$\Delta M^{stat}_{Higgs} = 936\ MeV/c^2 \quad \Delta M^{syst}_{Higgs} = 660\ MeV/c^2$$

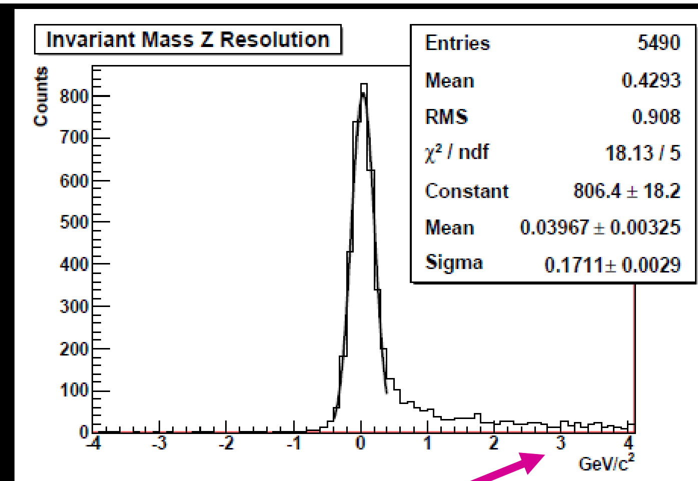
$$\Delta M^{stat}_{Z^o} = 171\ MeV/c^2 \quad \Delta M^{syst}_{Z^o} = 40\ MeV/c^2$$

$$\sigma_{e^+e^- \rightarrow Z^oH^o} = 13.62 \pm 0.77\ fb$$

$$\varepsilon_{reconstruction} = 64.1\%$$



Results affected by M_μ=0 (and consequent μ brehemstralung)



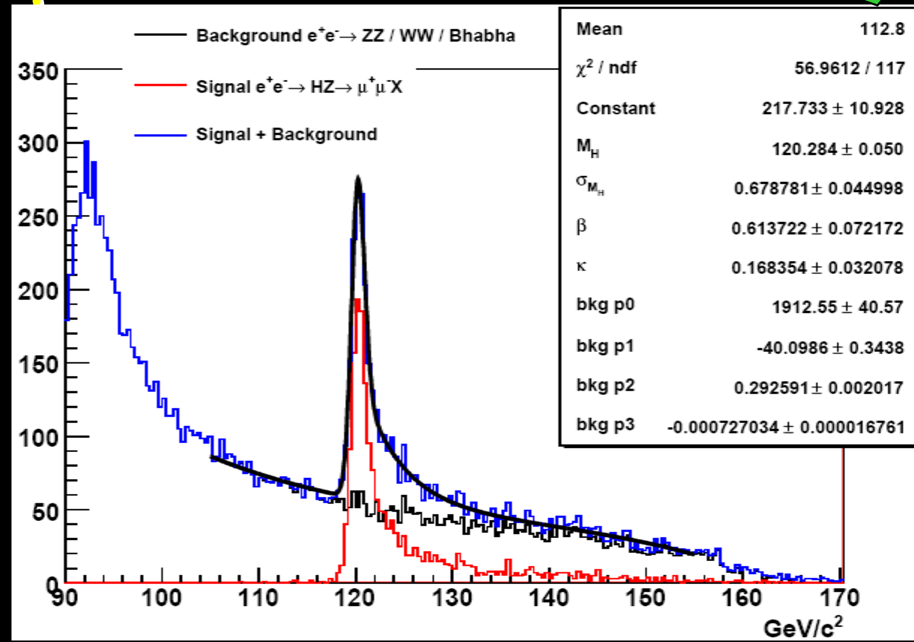
tails from erroneous μ bremsstrahlung

G. Tassielli, G. Terracciano, M. Peccarisi

$e^+e^- \to Z^oH^o \to \mu^+\mu^- X$ $\sqrt{s}$=250 GeV

New

Recoil Mass



Results

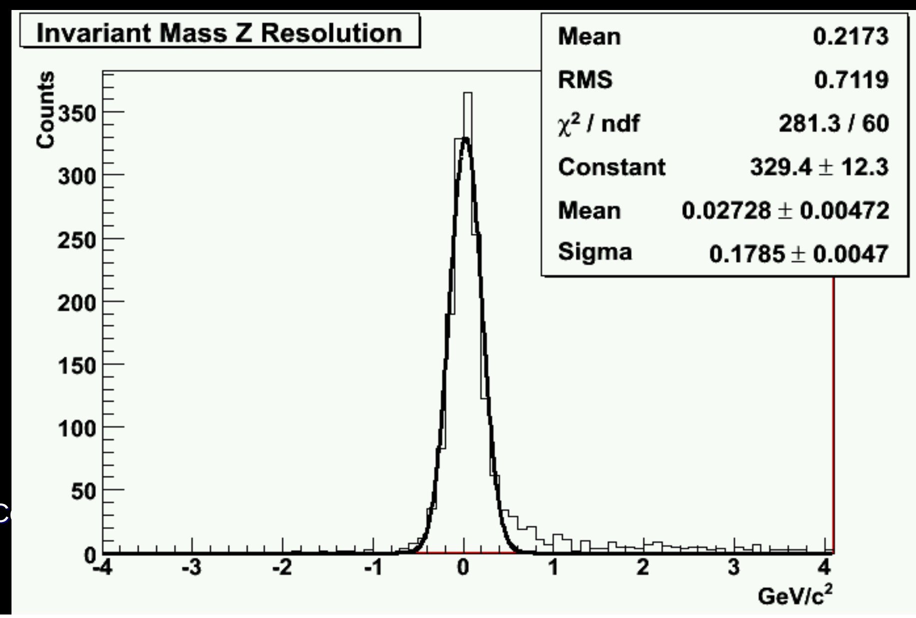
$$\Delta M^{stat}_{Higgs} = 679\ MeV/c^2 \qquad \Delta M^{syst}_{Higgs} = 280\ MeV/c^2$$

$$\Delta M^{stat}_{Z^o} = 179\ MeV/c^2 \qquad \Delta M^{syst}_{Z^o} = 27\ MeV/c^2$$

$$\sigma_{e^+e^- \to Z^oH^o} = 8.95 \pm 0.91\ fb$$

$$\varepsilon_{reconstruction} = 71.8\%$$

Z^o Mass Resolution



G. Tassielli, G. Terracciano, M. Peccarisi

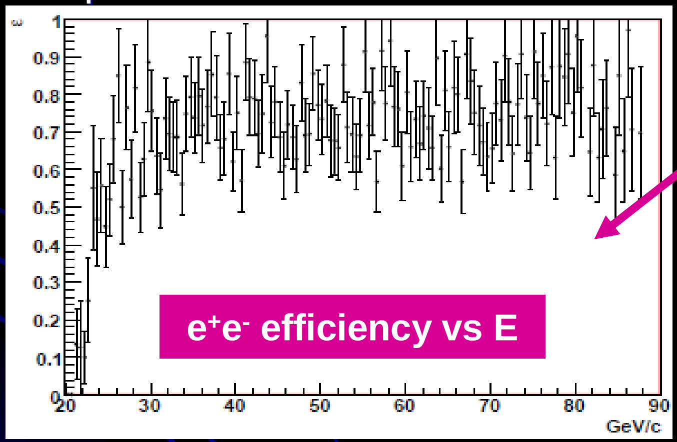
$e^+e^- \to Z^oH^o \to e^+ e^- X$ $\sqrt{s}$=250 GeV

Analysis strategy

1. Initial cuts to reduce background

    1. $|cos\theta_e| < 0.95$
    2. $P_t(e^{\pm}) > 9$ GeV
    3. $72 < M(e^+e^-) < 110$ GeV/c²
    4. $102 < M_{recoil}(e^+e^-) < 168$ GeV/c²
    5. At least 4 charged tracks for the $e^+e^- \to e^+e^-$ montecarlo sample
    6. At least 6 charged tracks for the $e^+e^- \to e^+e^-\mu^+\mu^-$ montecarlo sample

2. Require two electrons in the ECAL/DCH



ε_{ee} = 93.4%
Purity= 98.2%

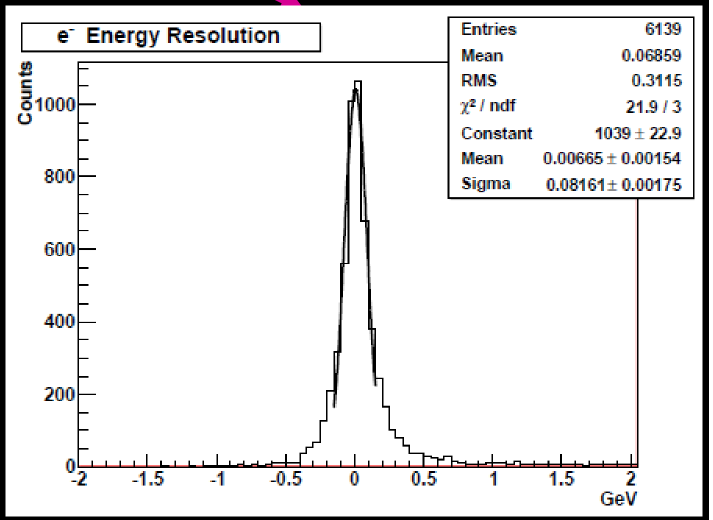
3. Final cuts for S/N enjhancement

    1. largest $P_e > 20$ GeV
    2. At least 5 charged tracks successfully reconstructed
    3. Distance of closest approach to the origin for the candidate electron tracks < 6 mm

signal

bkgnd

Final state
$e^+e^- \to Z^0H^0 \to e^+e^- + X$
$e^+e^- \to e^+e^-$
$e^+e^- \to e^+e^-e^+e^-$
$e^+e^- \to e^+e^-\tau^+\tau^-$
$e^+e^- \to e^+e^-\mu^+\mu^-$
$e^+e^- \to e^+e^-\nu\bar{\nu}$
$e^+e^- \to e^+e^-u\bar{u}$
$e^+e^- \to e^+e^-d\bar{d}$
$e^+e^- \to e^+e^-s\bar{s}$
$e^+e^- \to e^+e^-c\bar{c}$
$e^+e^- \to e^+e^-b\bar{b}$



G. Tassielli, G. Terracciano, M. Peccarisi

$e^+e^- \to Z^oH^o \to e^+ e^- X$ $\sqrt{s}$=250 GeV

Old

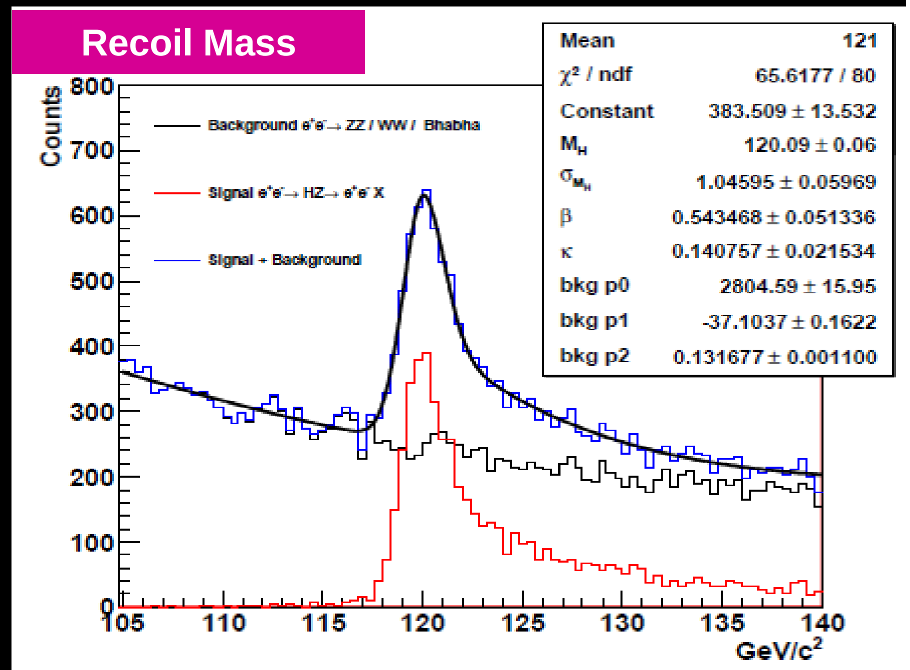
Results

$$\Delta M^{stat}_{Higgs} = 1050\ MeV/c^2 \quad \Delta M^{syst}_{Higgs} = 90\ MeV/c^2$$

$$\Delta M^{stat}_{Z^o} \approx 400 MeV/c^2 \quad \Delta M^{syst}_{Z^o} = 20\ MeV/c^2$$

$$\sigma_{e^+e^- \to Z^oH^o} = 15.08 \pm 0.76\ fb$$

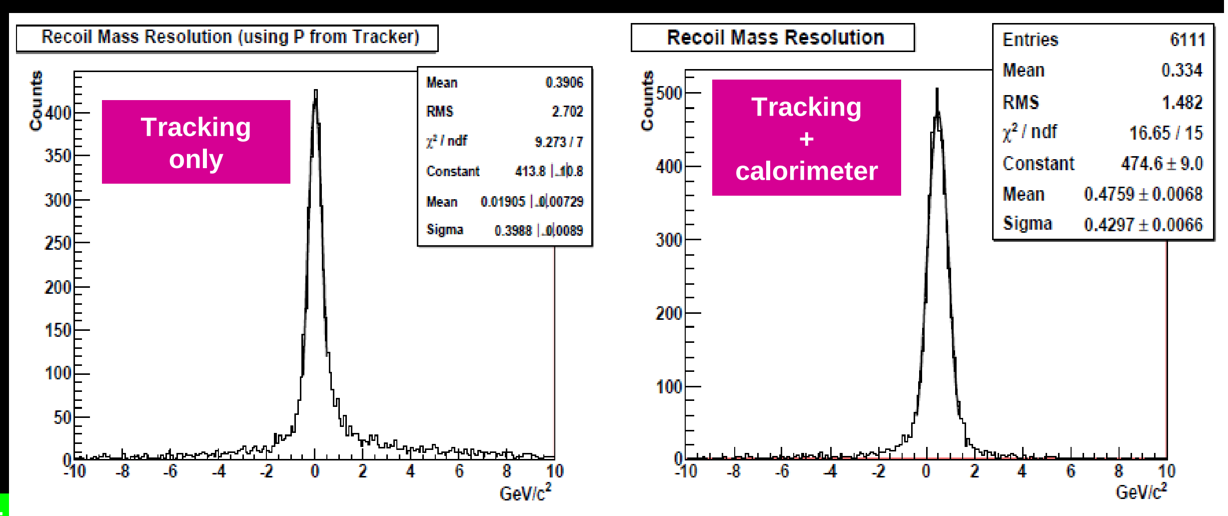
$$\varepsilon_{reconstruction} = 68.3\%$$



Two different analyses using:

1) Only the tracking system
2) Tracking systems + Calorimeter

Need a better integration of the informations from the two systems

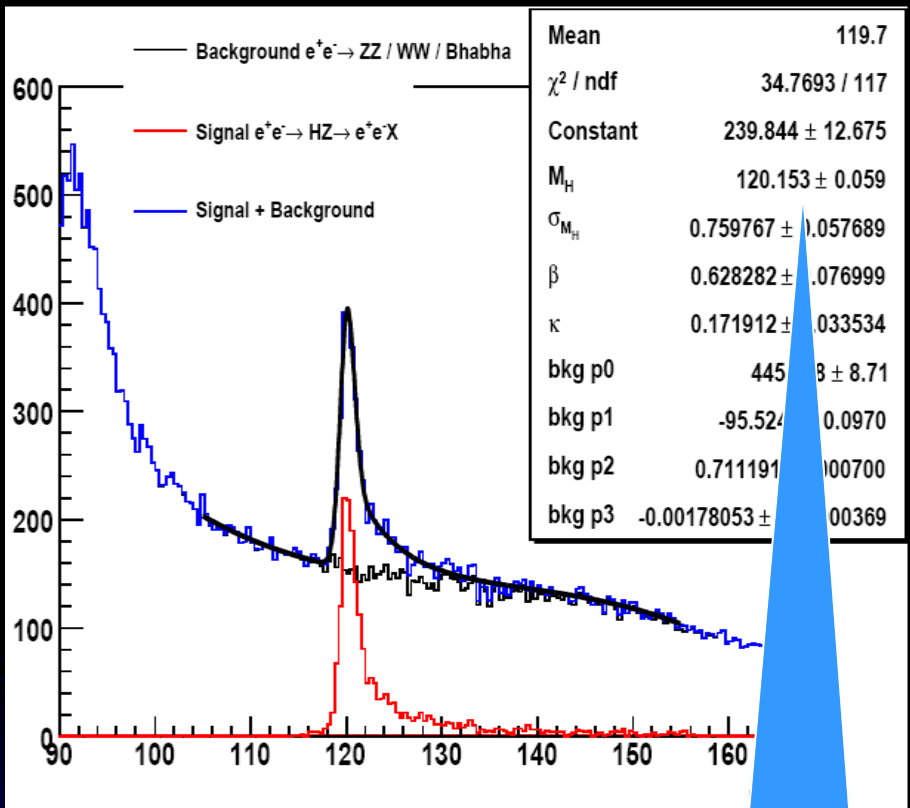


September 30th, 2009

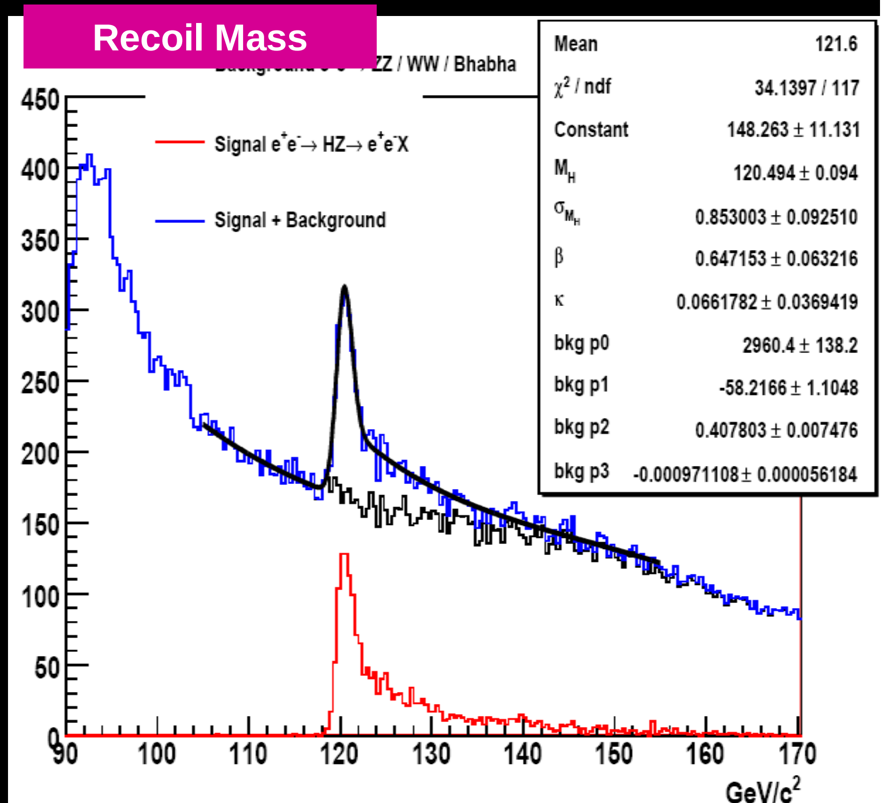
G. Tassielli, G. Terracciano, M. Peccarisi

$e^+e^- \rightarrow Z^oH^o \rightarrow e^+ e^- X$ $\sqrt{s}$=250 GeV

New



Tracking + calorimeter



Tracking only

Systematic error better than the muon channel

G. Tassielli, G. Terracciano

Summary of Recoil Mass Studies

Event sample	expected cross section	meas'd cross section	uncertainty on cross section	selection efficiency	Figure number	fitted Higgs mass (GeV/c^2)
$Z^0 \rightarrow \mu^+\mu^-$	11.664 fb	8.952 fb	$\pm$ 0.907 fb	71.8%	Fig. 8	120.28 ± 0.68
$Z^0 \rightarrow e^+e^-$ tracking only	12.532 fb	13.472 fb	$\pm$ 1.748 fb	67.2%	Fig. 9	120.49 ± 0.85
$Z^0 \rightarrow e^+e^-$ tracking + calorimeter	12.532 fb	10.884 fb	$\pm$ 1.594 fb	70.9%	Fig. 10	120.15 ± 0.76

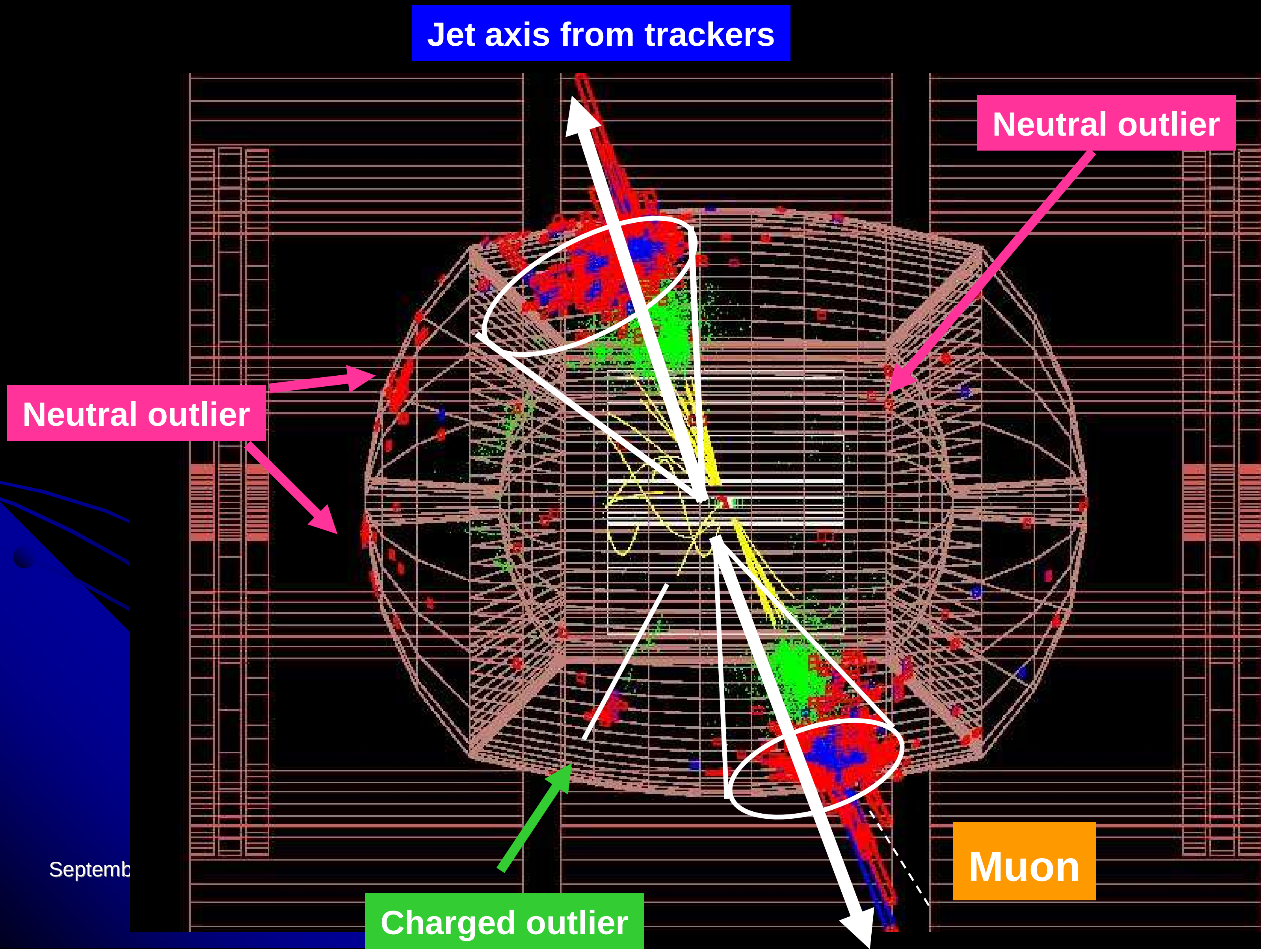
Jet reconstrucion: combine calorimetric and tracking informations

(work in progress)

A. Mazzacane

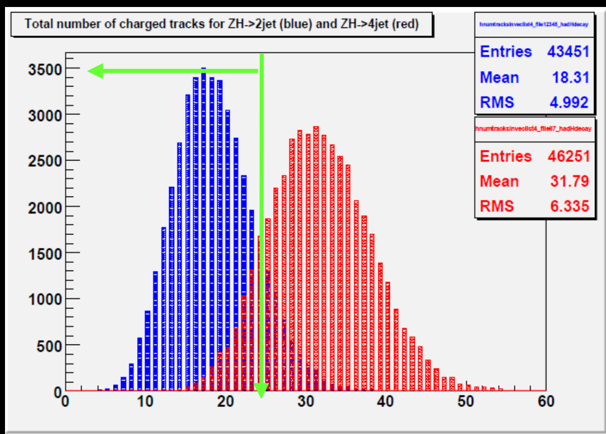
A. Mazzacane

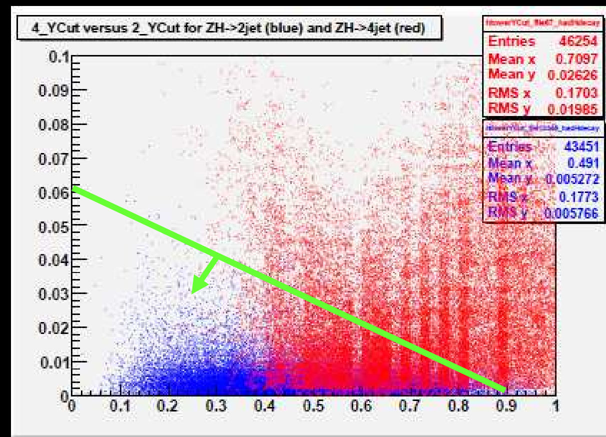
Jet Reconstruction Strategy



$e^+e^- \to Z^oH^o \to \nu\underline{\nu}\ X\ \sqrt{s}=250$ GeV

1. Disentangle 2-jets from multi-jets events





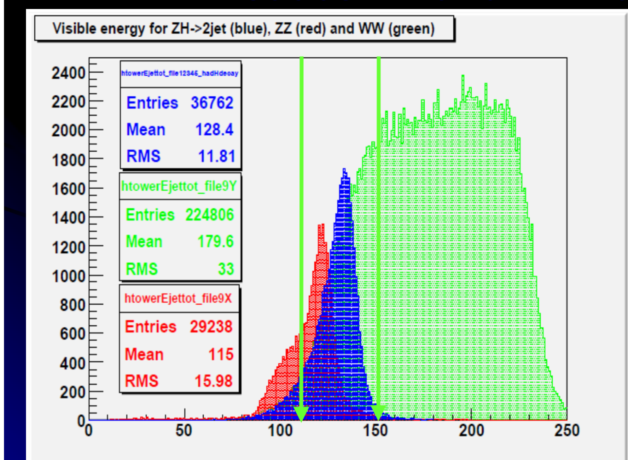
signal

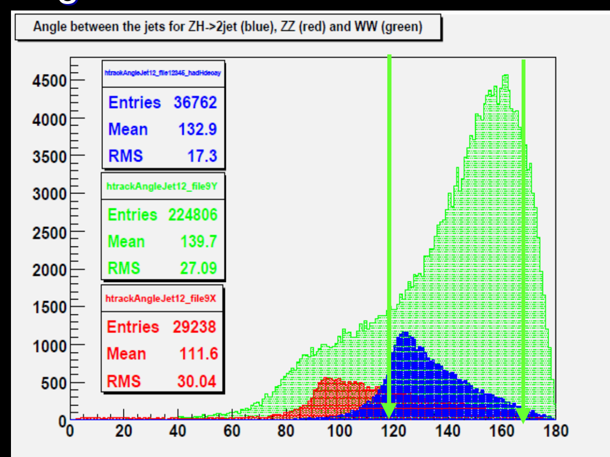
4 jets bkgnd

2 jets bkgnd

Final State
$e^+e^- \to H°Z°$; $H \to qq$, $Z \to \nu\nu$
$e^+e^- \to H°Z°$; $H \to qq$, $Z \to qq$
$e^+e^- \to W^+W^- \to qq\ l\nu$
$e^+e^- \to Z°Z° \to qq\ l\ l$

2. Reduce ZZ and WW background



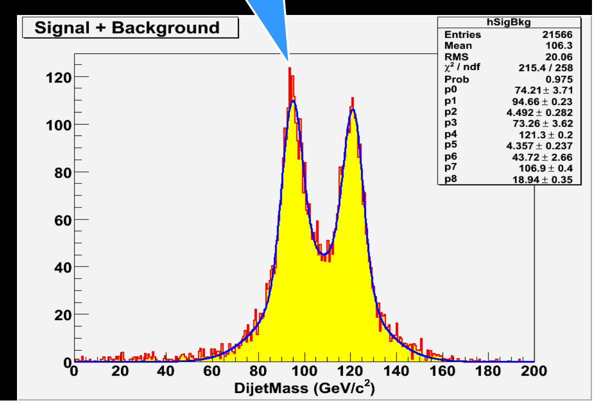


$e^+e^- \to H°Z° \to qq\ \nu\nu$

+

$e^+e^- \to Z°Z° \to qq\ \nu\nu$

Already studied



3. Reject prompt muons (via the Muon Spectrometer) from leptonic WW decay

A. Mazzacane

$e^+e^- \to Z^oH^o \to \nu\bar{\nu}\ X \ \sqrt{s}=250\ GeV$

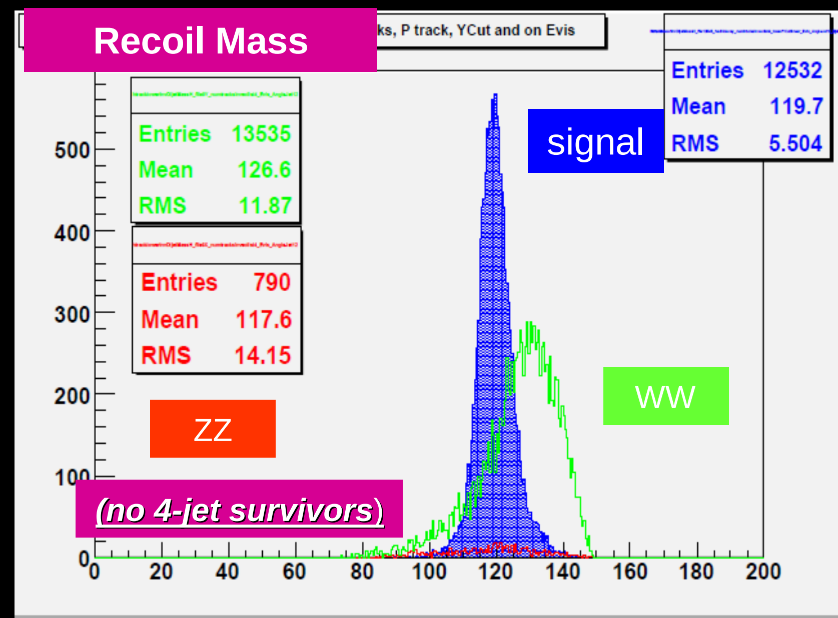
Results

$$M_{Higgs} = 119.60 \pm 0.07\ GeV/c^2$$

$$\sigma_{Higgs} = 3.83 \pm 0.07\ GeV/c^2$$

$$\sigma\ (e^+e^- \to Z^oH^o; Z \to \nu\bar{\nu}; H \to q\bar{q}) = 155.3 \pm 2.2\ fb$$

$$\varepsilon_{reconstrution} = 28.8\%$$



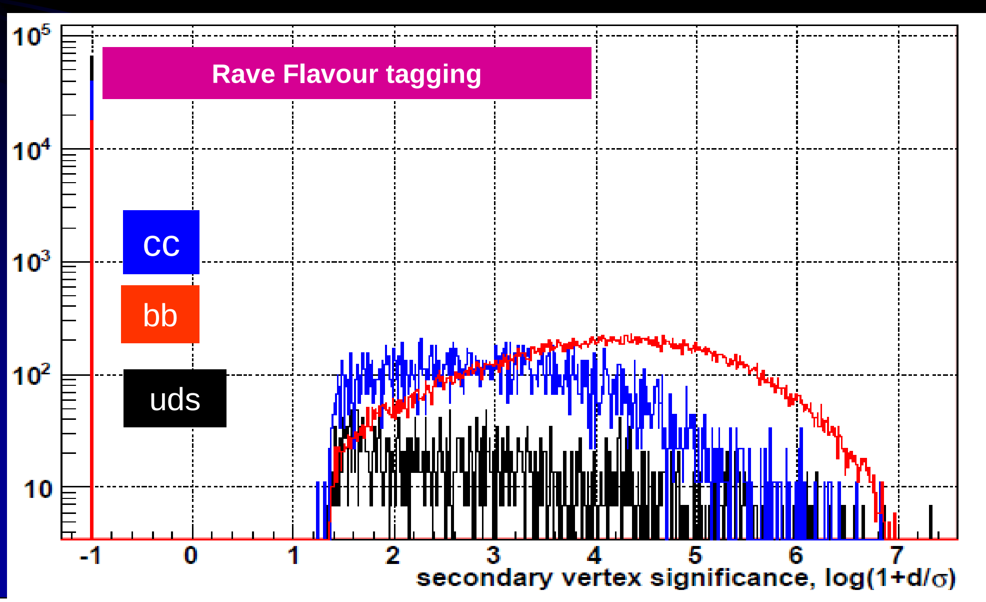
Next step is to consider

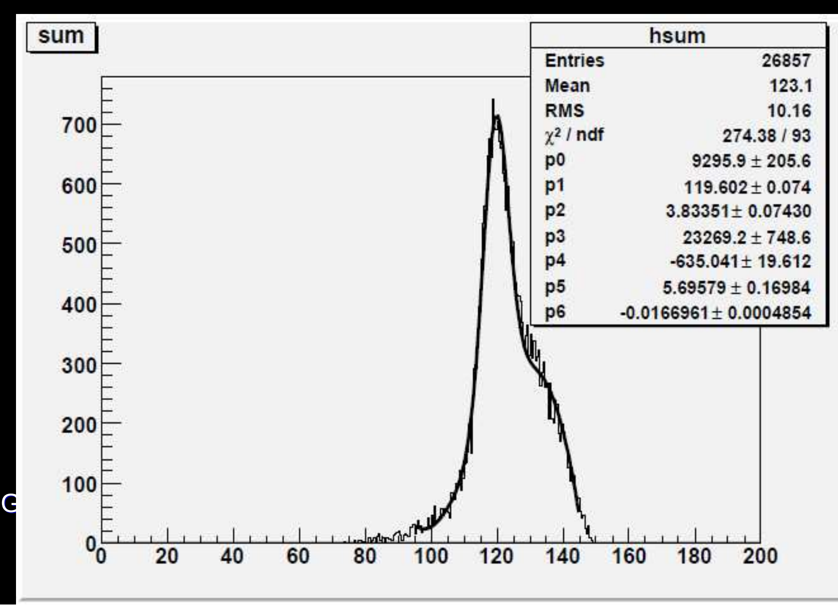
$e^+e^- \to Z^oZ^o \to qq\ \nu\nu$

and

$e^+e^- \to Z^oZ^o \to qq\ qq$

$e^+e^- \to W^+W^- \to qq\ qq$



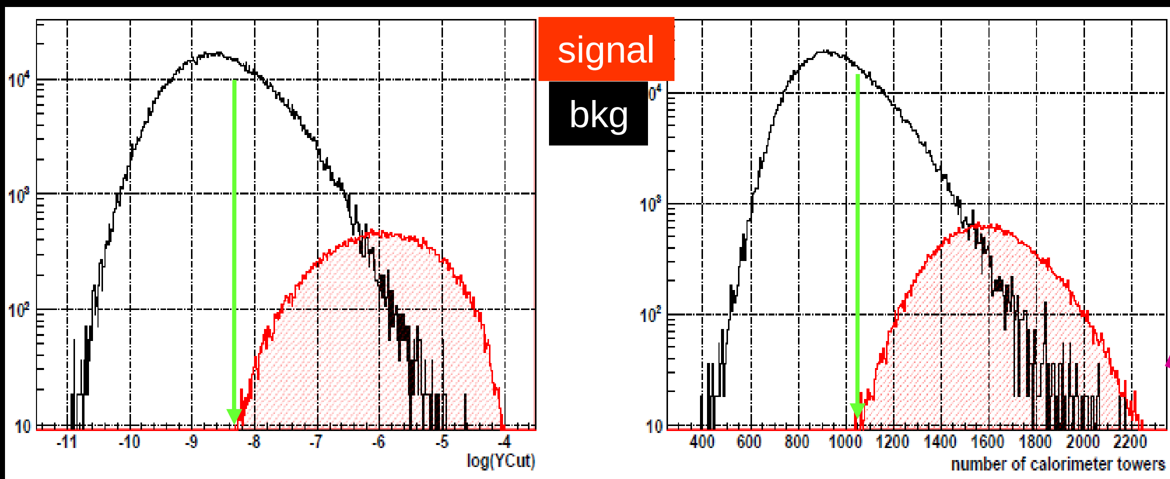


$e^+e^- \to t\bar{t} \to W^+bW^-\bar{b} \to qqbqq\bar{b}$ $\sqrt{s}$=500 GeV

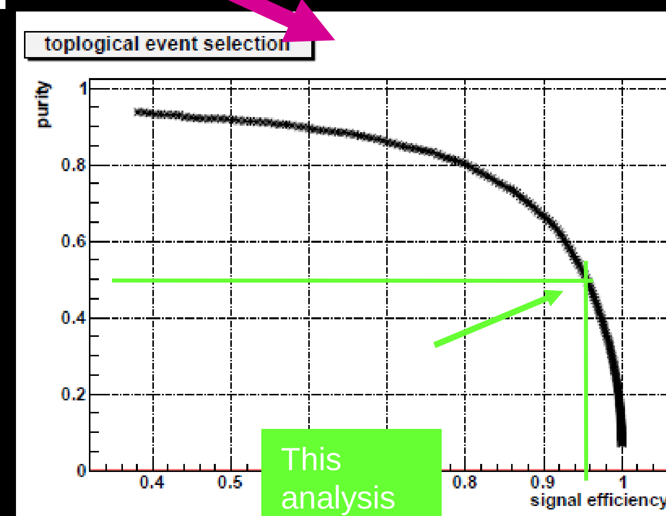
Final State

- signal → $e^+e^- \to t\bar{t} \to qqb\ qq\bar{b}$
- 4 jets bkgnd → $e^+e^- \to W^+W^- \to qq\ qq$

1. Disentangle 6-jets from 2 and 4-jets events



2. Choose best jet-jet combination with a χ^2 based on M_{jj} close to M_W
3. 7-C Kinematic fit (MarlinKinFit)
   - $\sum \vec{P}_i = 0$
   - $\sum E_i = 500$ GeV
   - $M_{W1} = M_{W2} = 80.4$ GeV/c^2
   - $M_t - M_{\bar{t}} = 0$
4. Final cut: χ^2/ndf<45/7



F. Ignatov

$e^+e^- \rightarrow t\bar{t} \rightarrow W^+bW^-\bar{b} \rightarrow q\bar{q}bq\bar{q}\bar{b}$ $\sqrt{s}$=500 GeV

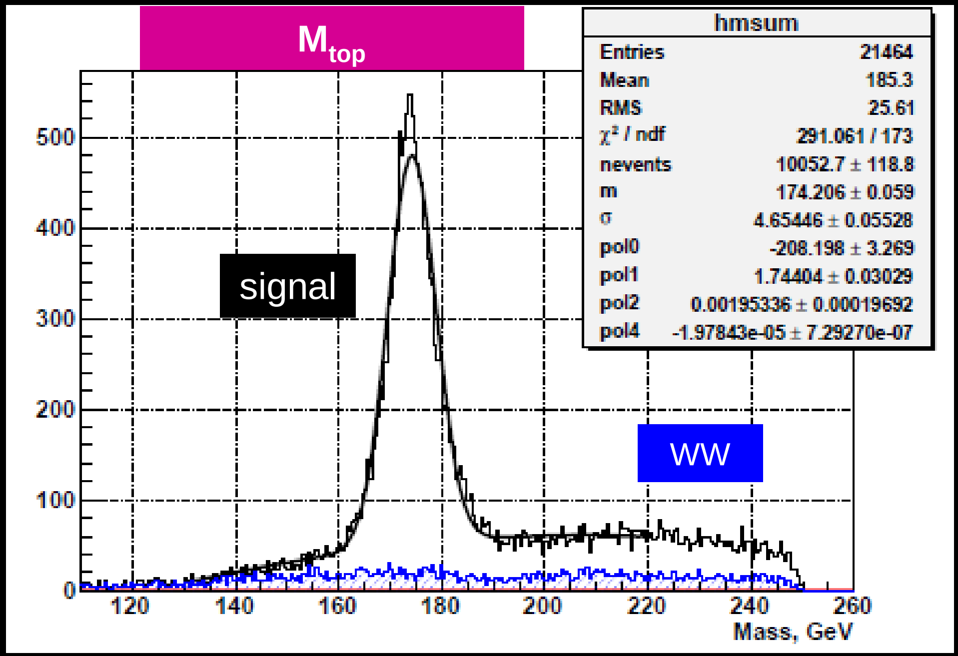
Results

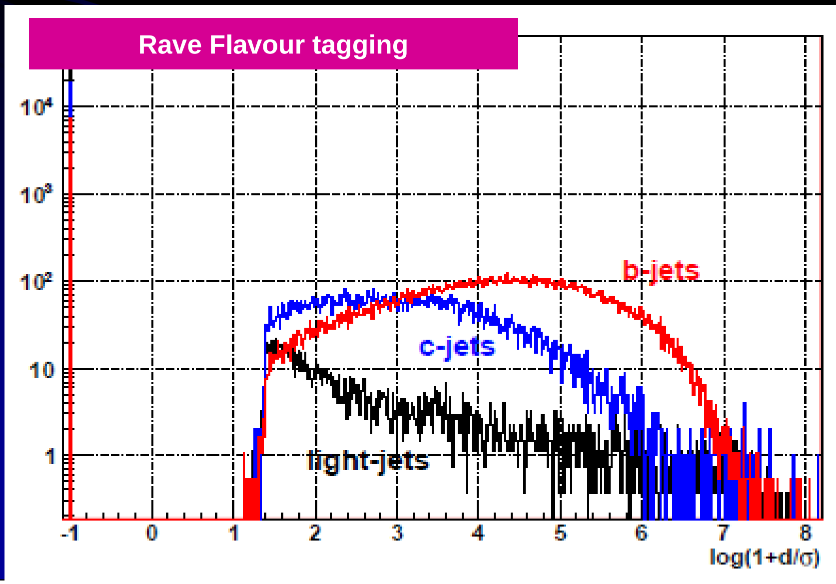
$$M_{top} = 174.21 \pm 0.06\ GeV/c^2$$

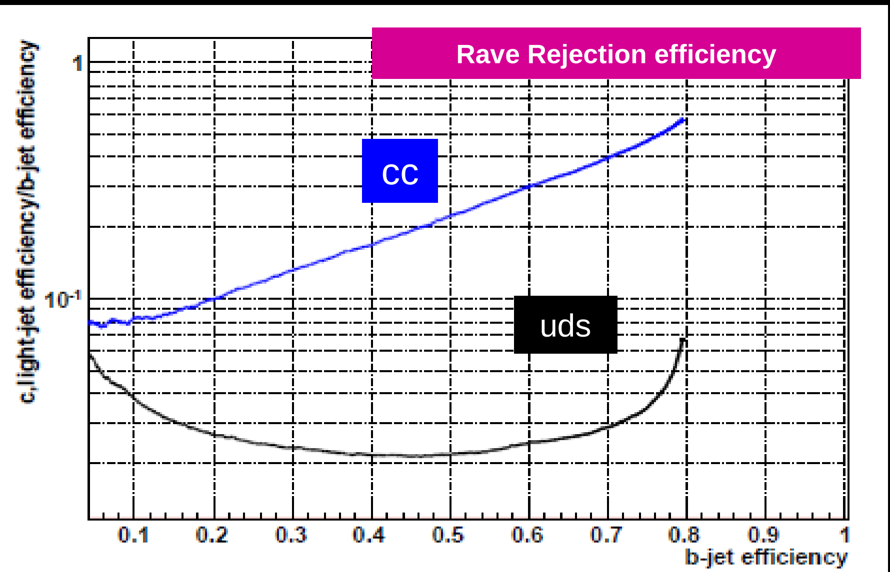
$$\sigma_{top} = 4.65 \pm 0.06\ GeV/c^2$$

$$\varepsilon_{reconstruction} = 16\%$$

Next step is to complete
the flavour tagging analysis







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

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

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:

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

WW/ZZ selection :

Fit on dijet-mass invariant distribution

Event selection :

- Events forced into 4jets (Durham)
- $E_{jet} \geq 5$ GeV
- $|\cos\theta_{jet}| < 0.99$
- $N_{total\ lcharged\ tracks\ in\ jet} \geq 2$
- $N_{total\ charged\ tracks} \geq 20$
- $Y_{cut} > 0.001$
- $100\ \mathrm{GeV} < E_{vis} < 250\ \mathrm{GeV}$
- $|\cos\theta_{miss\ P}| < 0.8$
- $M_{miss} > 220\ \mathrm{GeV}/c^2$
- No lepton with $E_{lepton} > 25$ GeV

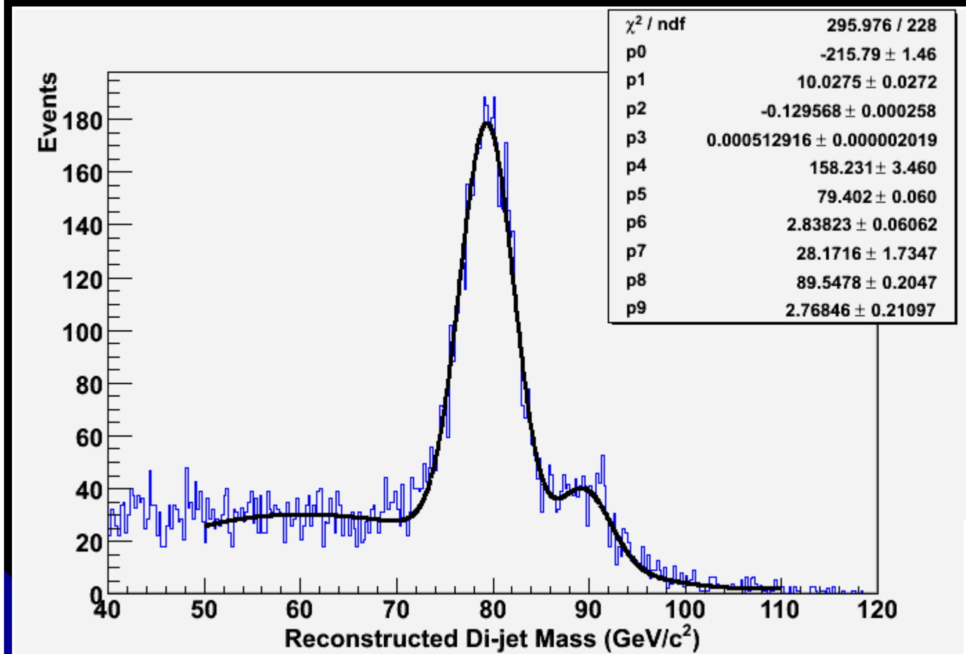
$\varepsilon_{chargino} = 30.3\%$

$\varepsilon_{neutralino} = 28.6\%$

A. Mazzacane

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

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

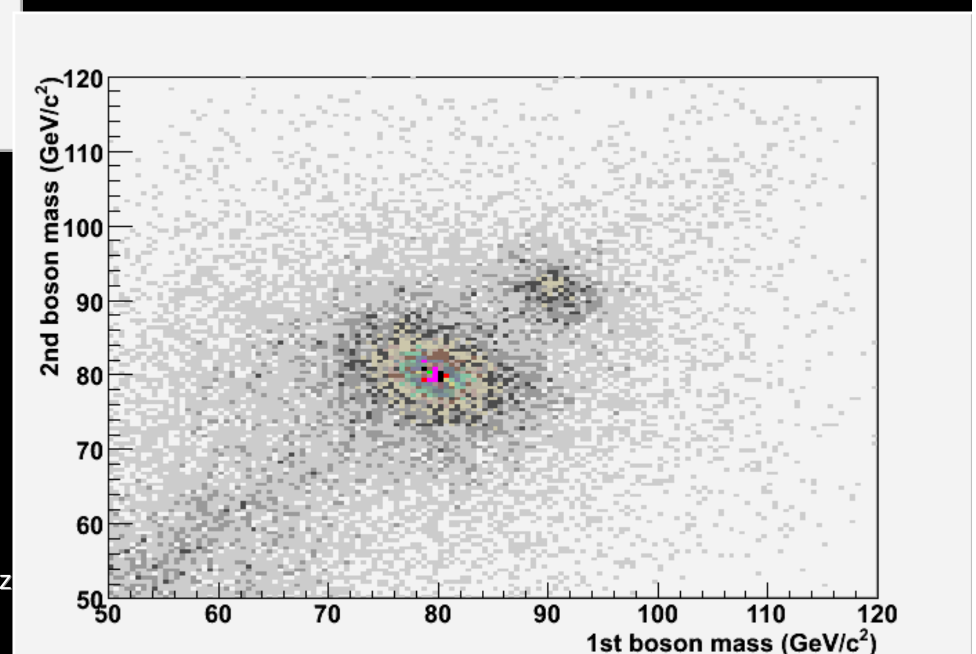


Fitted distribution (double gaussian plus 3rd order polynomial)

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



$e^+e^- \to \tau^+\tau^-$; $\tau \to \rho\nu$ $\sqrt{s}$=500 GeV

signal → $e^+e^- \to \tau^+\tau^-, \quad \tau \to \rho\nu$

bkgnd { $\gamma\gamma \to \tau\tau$; $W^+W^- \to l l \nu\nu$

Final state
$e^+e^- \to \tau^+\tau^-, \quad \tau \to \rho\nu$
$\gamma\gamma \to \tau\tau$
$W^+W^- \to l l \nu\nu$

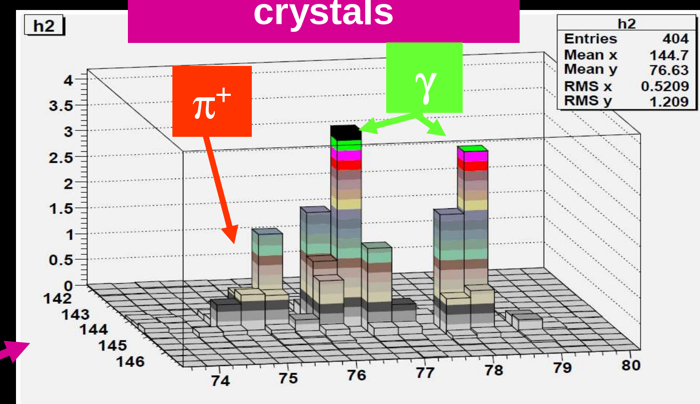
Analysis strategy

1. $\tau^+\tau^-$ selection
   - N_{tracks}<6
   - Two narrow jets (calo only)
   - E_{calo} > 45 GeV (suppress $\gamma\gamma \to \tau\tau$)
   - Angle between two jets > 175°
   - Bhabha rejection (θ > 15°)

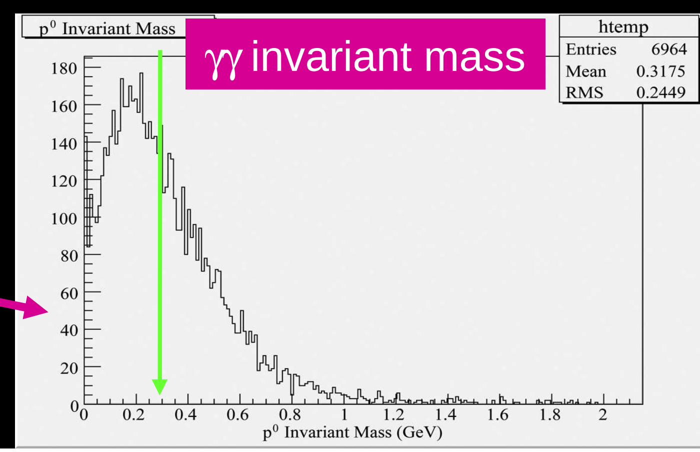
2. Hadronic τ decay selection
   1. Muon veto (use Muon Spectrometer)
   2. Electron veto (combined DCH, ECAL and HCAL)

3. $\tau^+ \to \rho\nu$ selection
   1. $\pi\,\gamma\,\gamma$ unfolding
   2. Cut $M_{\gamma\gamma}$ close to nominal M_{π°

Energy in Ecal crystals



$\gamma\gamma$ invariant mass

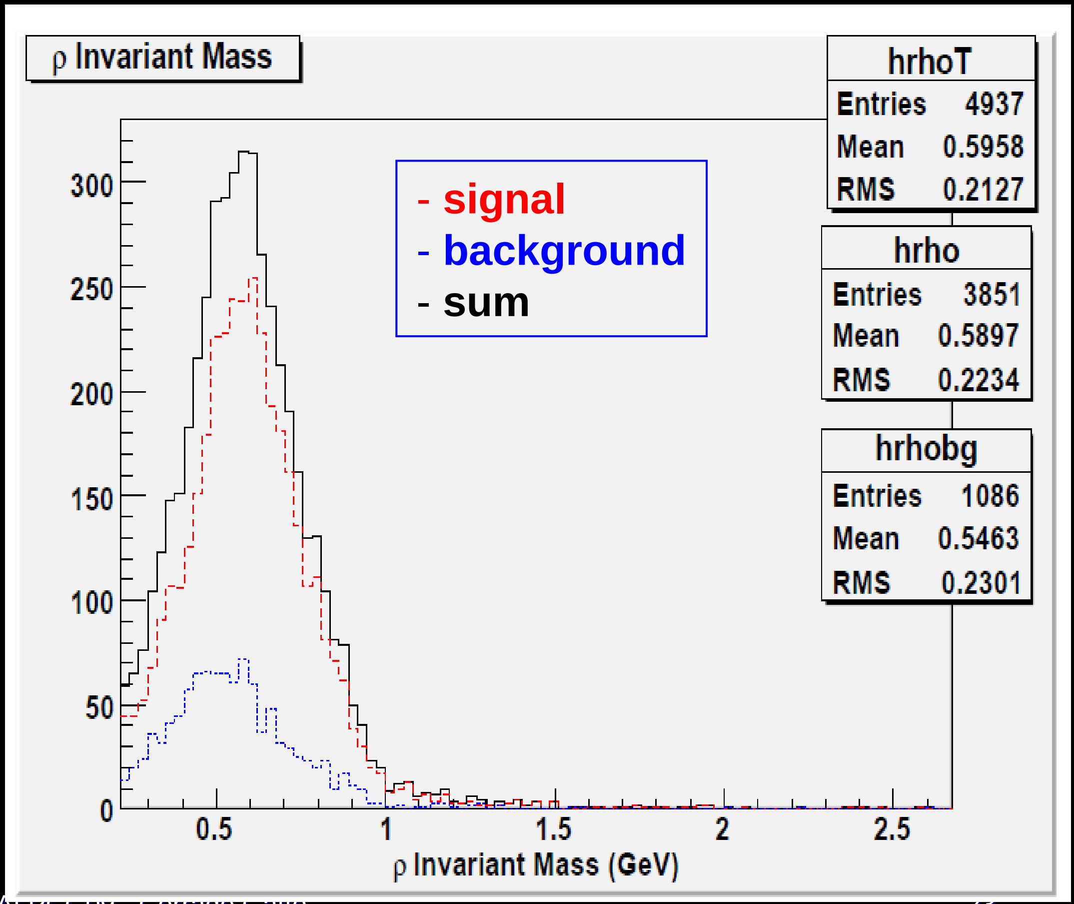


V. Di Benedetto

$e^+e^- \to \tau^+\tau^-$; $\tau \to \rho\nu$ $\sqrt{s}$=500 GeV

Results

Only ρ mass at present
Analysis is still in progress



V. Di Benedetto

$e^+e^- \to Z^oH^o$; and $Z^o \to c\underline{c}$ $H^o \to b\underline{b}$ $\sqrt{s}=250$ GeV

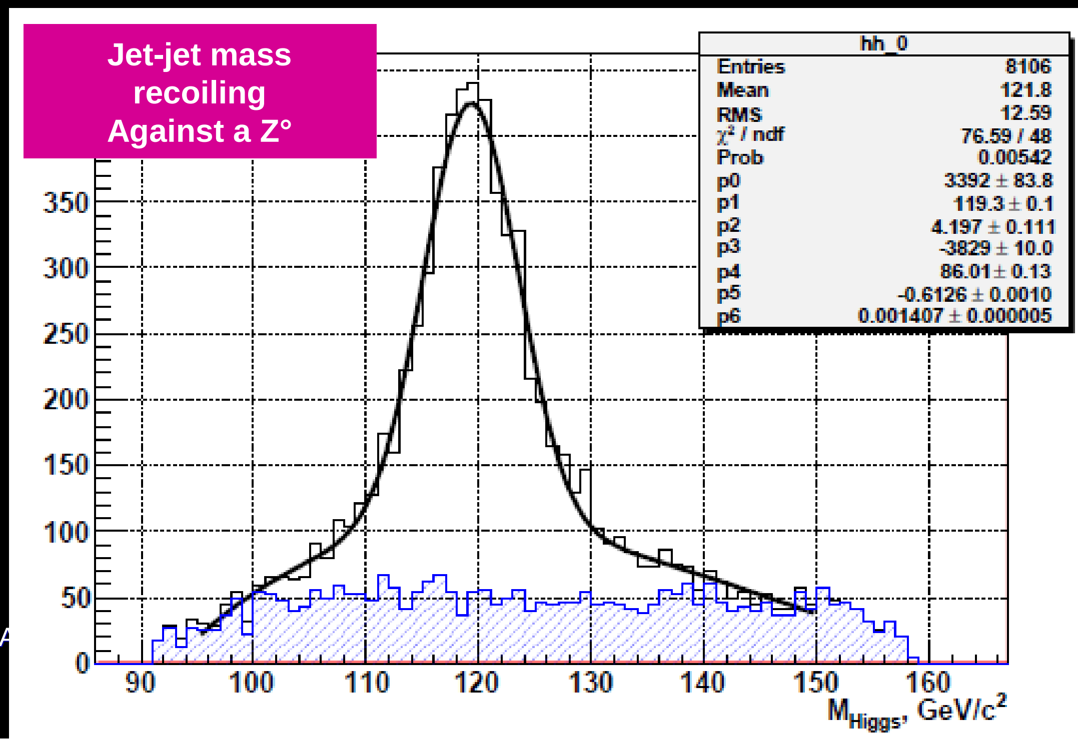
Analysis strategy

1. Select Event with 4 jets (use jet finder with recursive y_{cut})
2. E_{calo} + E_{muon} cut to reduce background (events with neutrino or ISR)
3. 5-C kinematic fit to all possible jet-jet combinations

$$1.\ \sum \vec{P}_i = 0$$
$$2.\ \sum E_i = 250\ \mathrm{GeV}$$
$$3.\ M_Z = 91\ \mathrm{GeV}/c^2$$

4. Pick combination with highest probability
5. Final cut: χ^2/ndf<16/5

Signal only
No Background



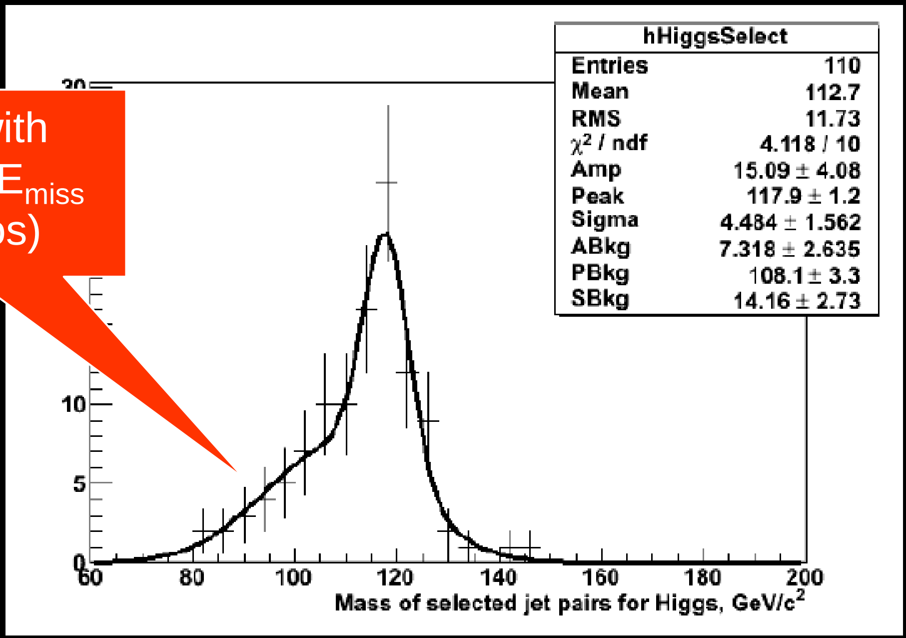
$e^+e^- \rightarrow Z^oH^o$; $Z^o \rightarrow u\bar{u}$ $H^o \rightarrow c\bar{c}$ $\sqrt{s}$=250 GeV

Signal only
No Background

Analysis strategy

1. Select Event with 4 jets (use jet finder with recursive y_{cut})
2. Select M_{j1j3} and M_{j2j4}
3. Requires 1 combination within 10 GeV from nominal Z° mass
4. Plot the other combination

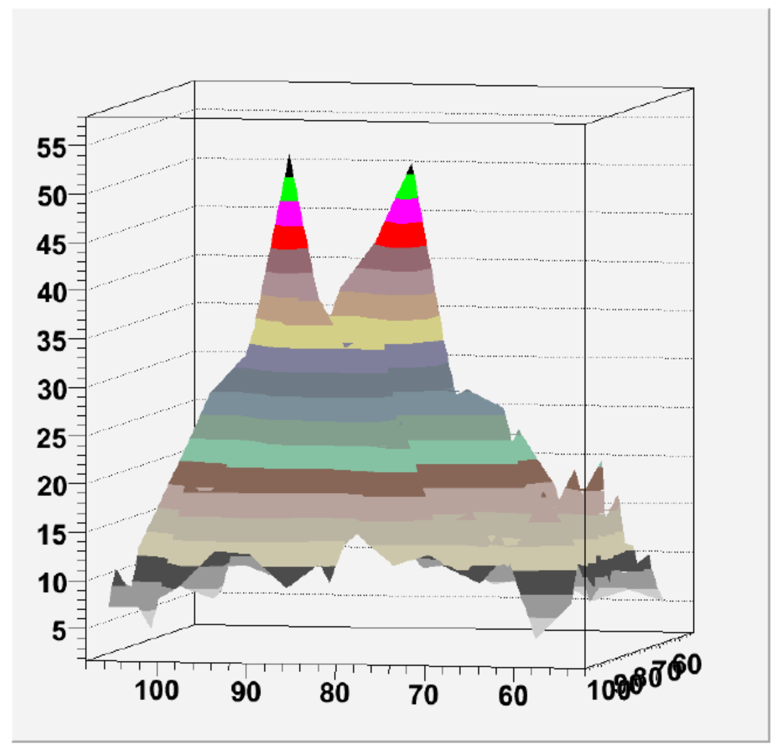
Events with significant E_{miss} (neutrinos)



Analysis is still in progress

Y. C. Chen

W/Z Mass Separation at 500 GeV



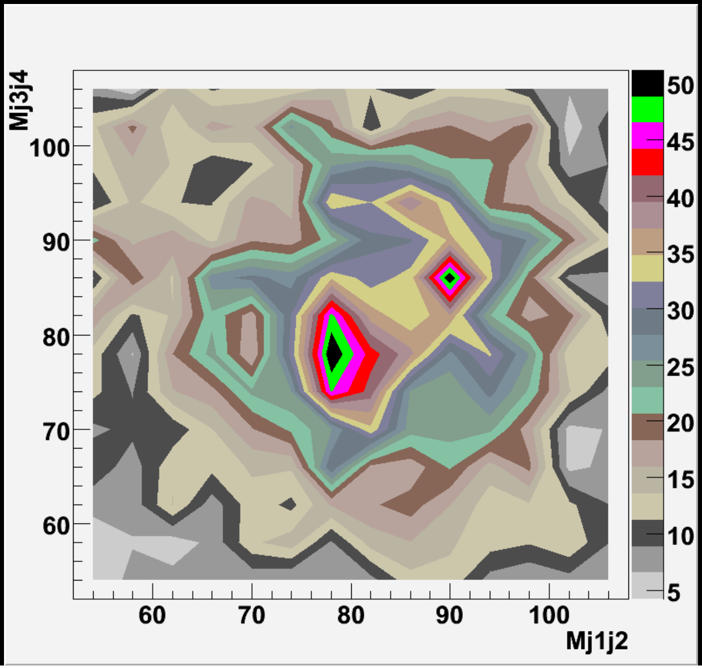
$$e^+e^- \rightarrow W^+W^-\nu\bar{\nu}, Z^oZ^o\nu\bar{\nu}$$

- KEK event sample
- Simple Durham jet-finder a la L3 (recursive y_{cut}) used for this analysis
- No combined information with tracking yet (3 entries/evt)
- No ECAL
- 4-jets finding efficiency: 95%

All combination plotted

(6 entries/event)

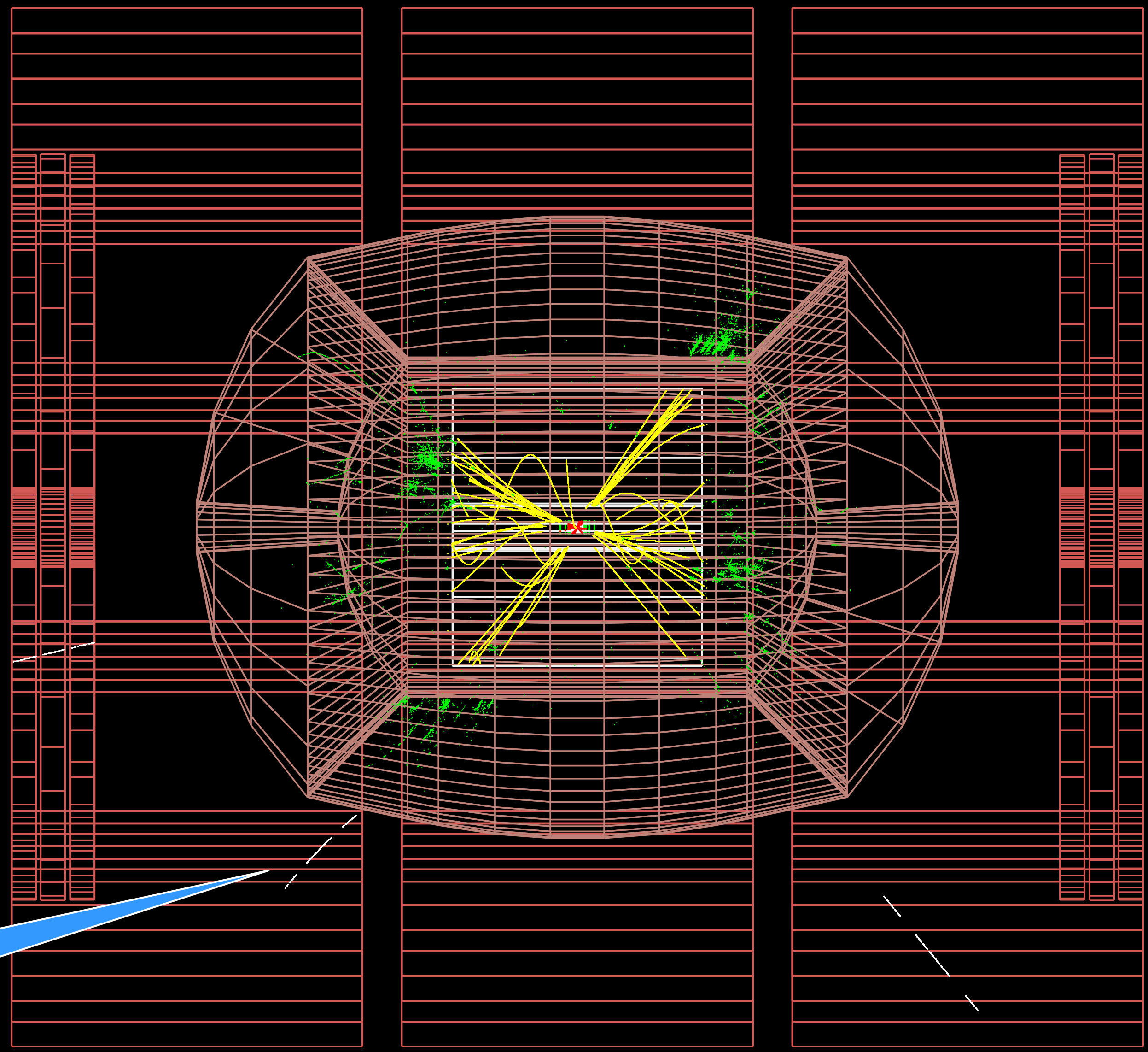
Choose best pair combination



A. Mazzacane

Event Display in ILCroot

$e^+e^- \to H^oH^oZ^o$
$\to$ 4 jets 2 muons
ECM = 500 GeV



Low pt secondary muon

Conclusions

- Several Physics studies have been performed by the 4th Concept
- Overall performance of 4th Concept detector is excellent
- Software framework (ILCroot) has run flawlessly along the benchmark process (200-1000 CPU on Fermi-GRID almost no-stop since August 2008)
- Update version of ILCroot will be released soon
- Plans are to complete the current studies into a publishable form and then move the simulation activities to support generic detector R&D and physics studies at energies higher than ILC

Backup slides

Outline

- The simulations in the *4th Concept*
  - ILCroot
  - Detector simulations
- Performance & Optimization
- Physics benchmarks for the LoI
- Future prospects

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

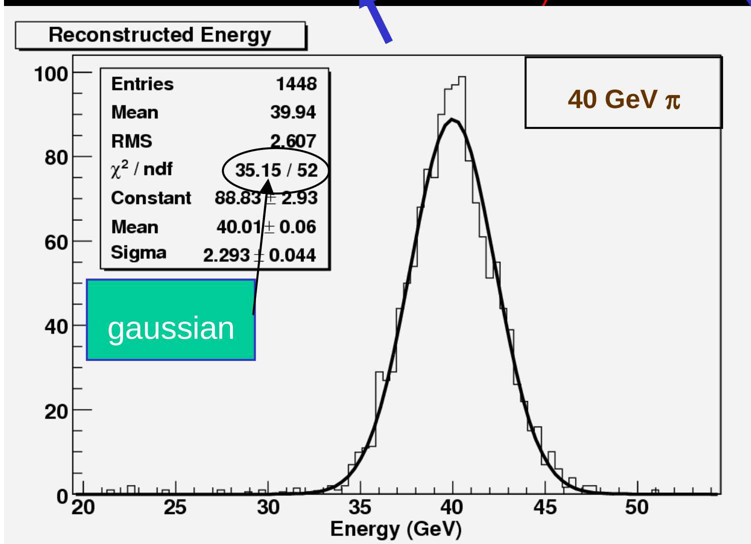
Do not Reinvent the wheel

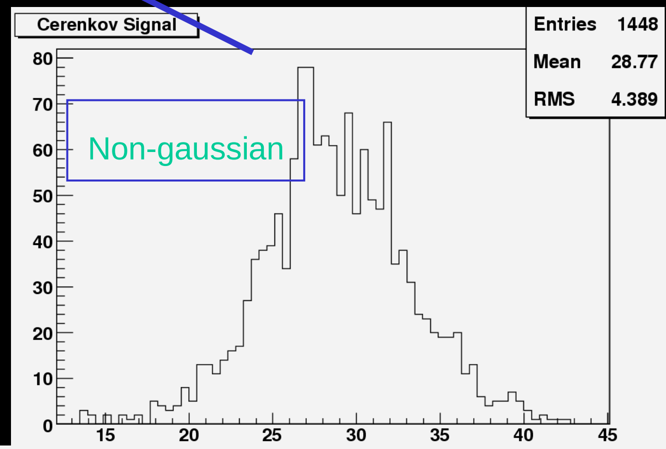
Concentrate on Detector studies and Physics

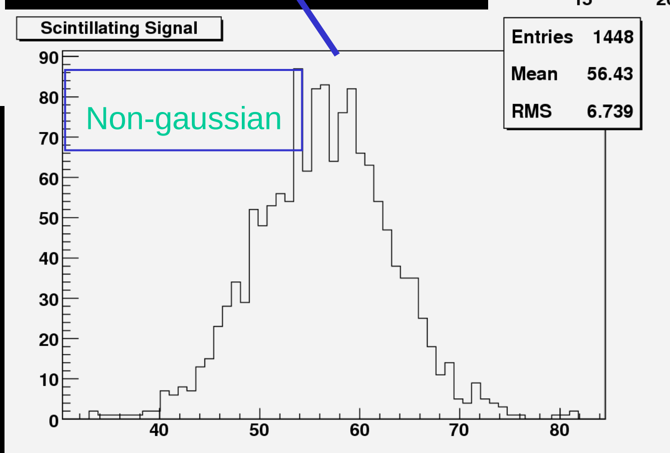
Dual Readout Calorimetry

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

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





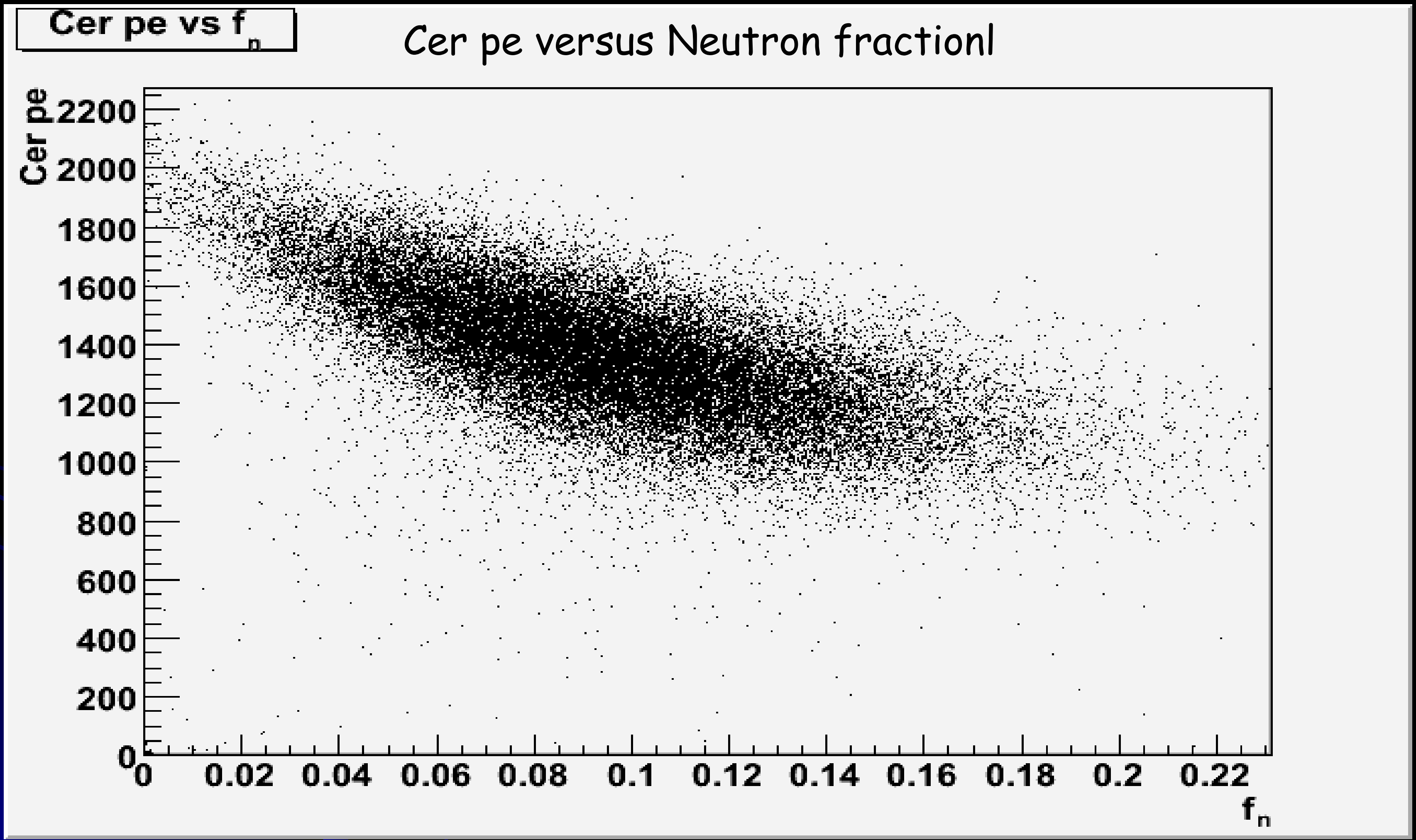


$$\eta_c = \left(\frac{e}{h}\right)_C \qquad \eta_S = \left(\frac{e}{h}\right)_S$$

From calibration @ 1 Energy only

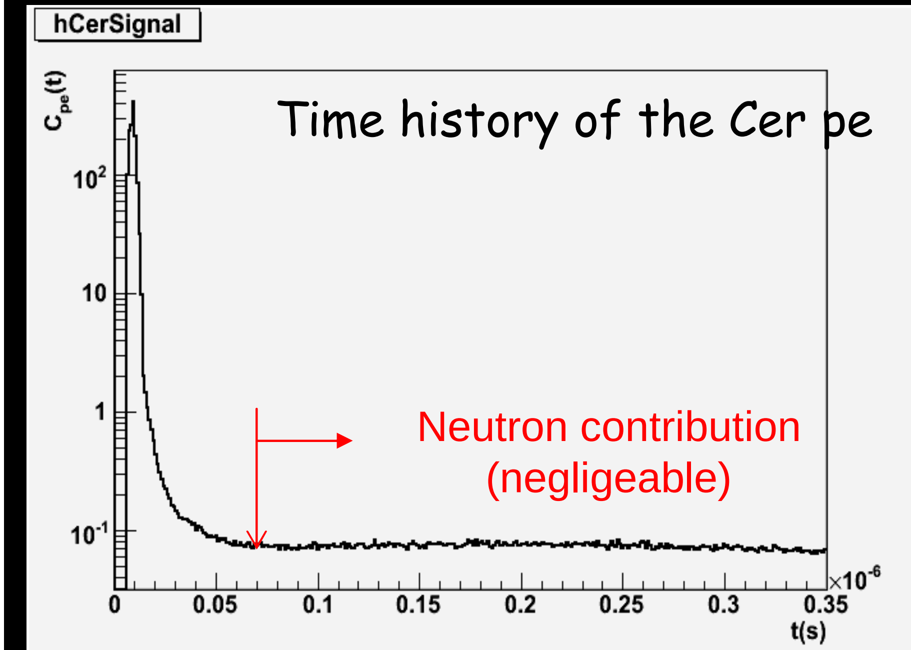
Improving the Energy Resolution: The Effect of Neutrons

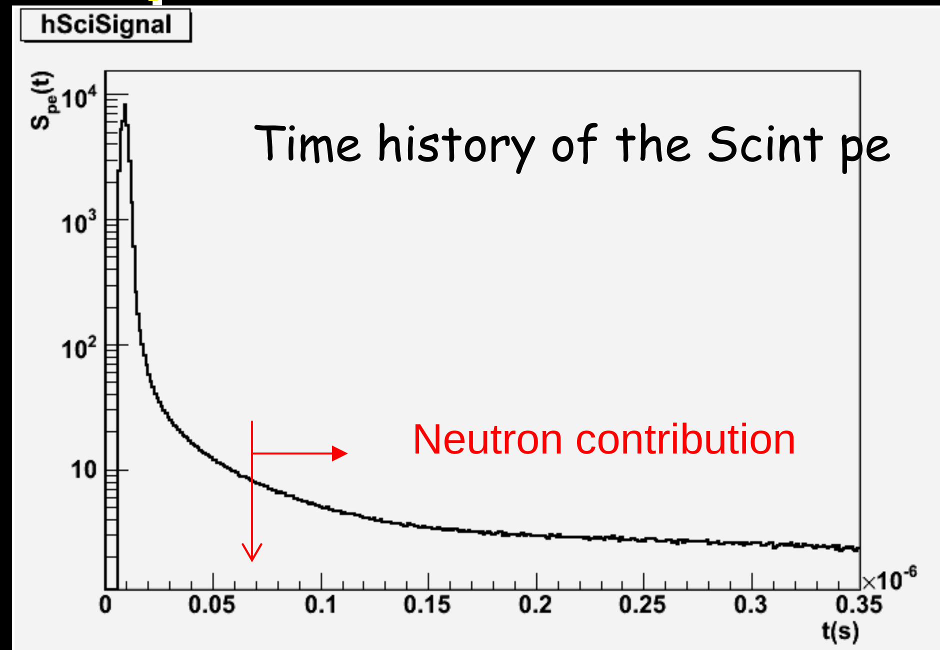
45 GeV π^-



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

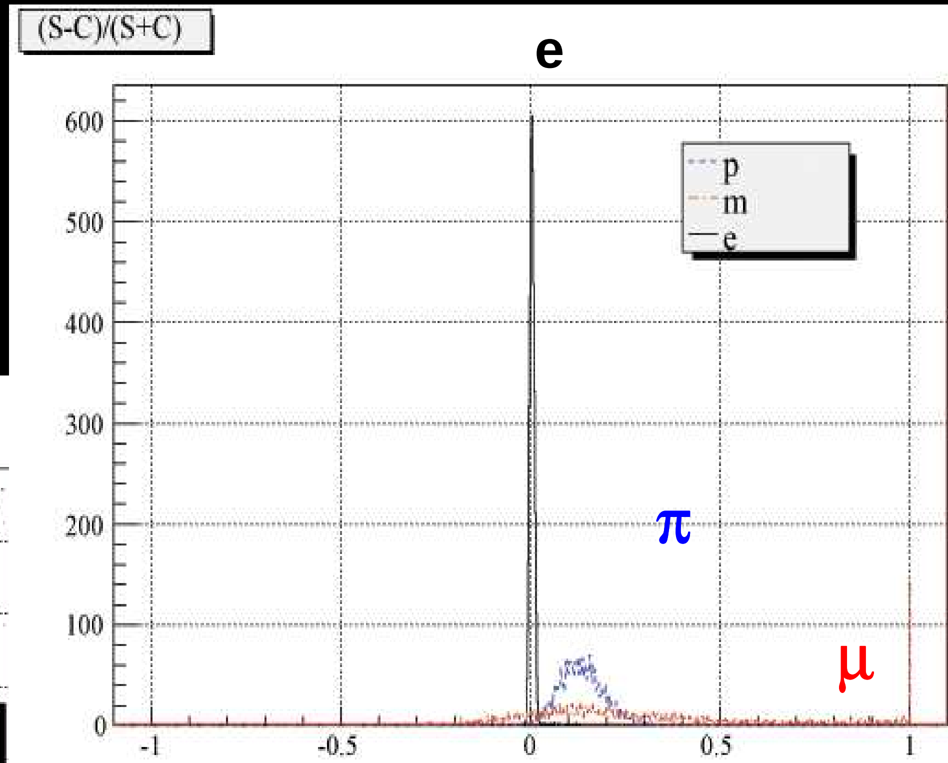
- Get E_{Scint} and E_{Cer} from ECAL (disregard neutrons as $Z_{BGO} >> 1$)
- Get E_{Scint}, E_{Cer} and E_{neutr} from HCAL
- Then:

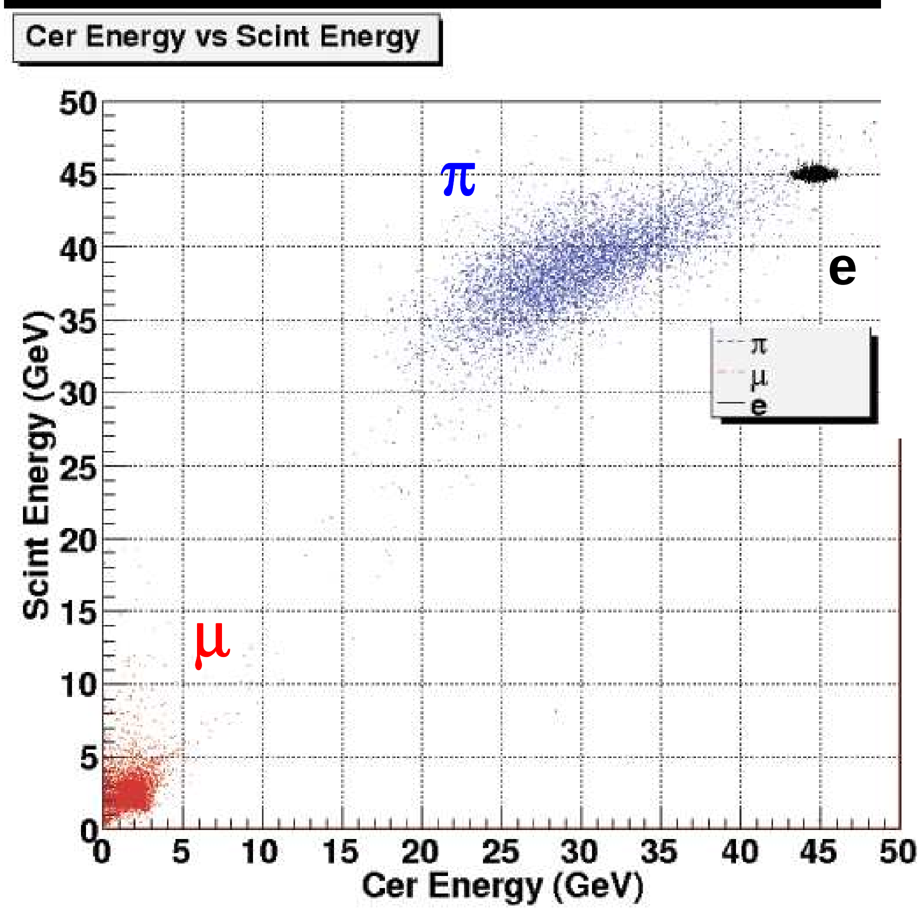
$$E_{Total} = \frac{\eta_S \cdot (E_{Scint}^{ECAL} + E_{Scint}^{HCAL}) \cdot (\eta_C - 1) - \eta_C \cdot (E_{Cer}^{ECAL} + E_{Cer}^{HCAL}) \cdot (\eta_S - 1)}{\eta_C - \eta_S} + \eta_n \cdot E_{neutrons}^{HCAL}$$

- 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

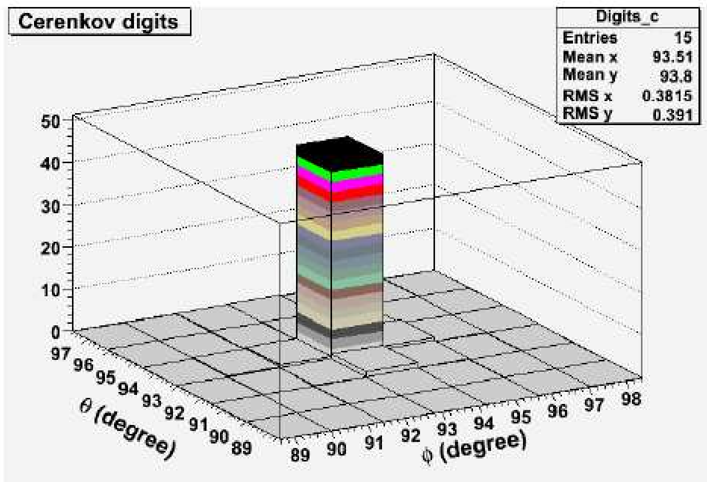
45 GeV particles

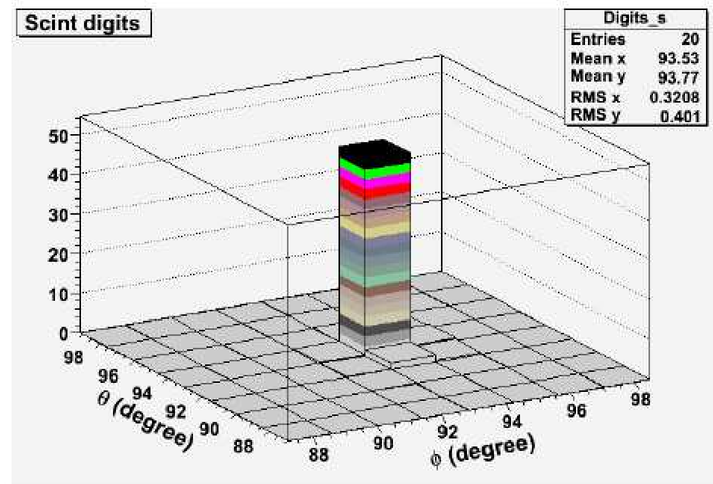




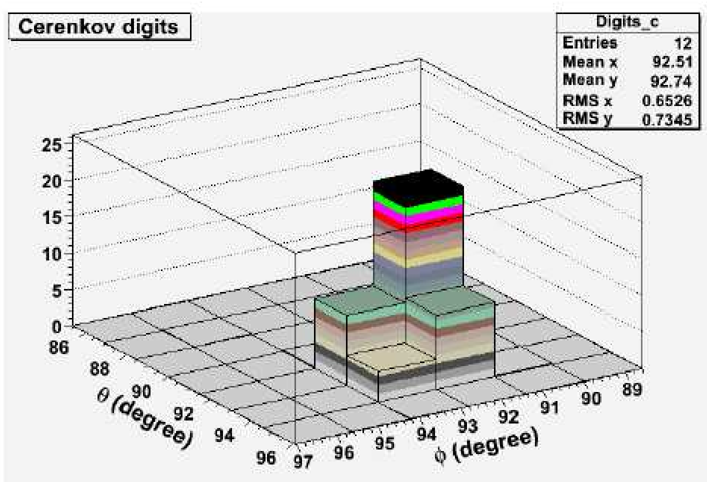
ILCRoot simulation

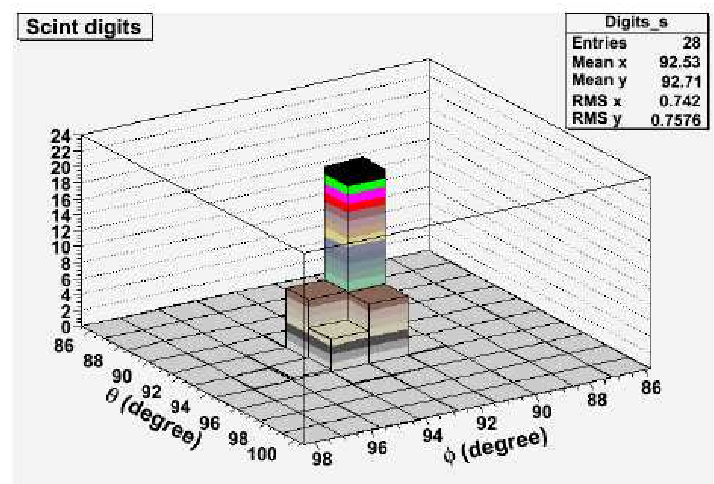
Calorimeter Response for 45 GeV e^-





core

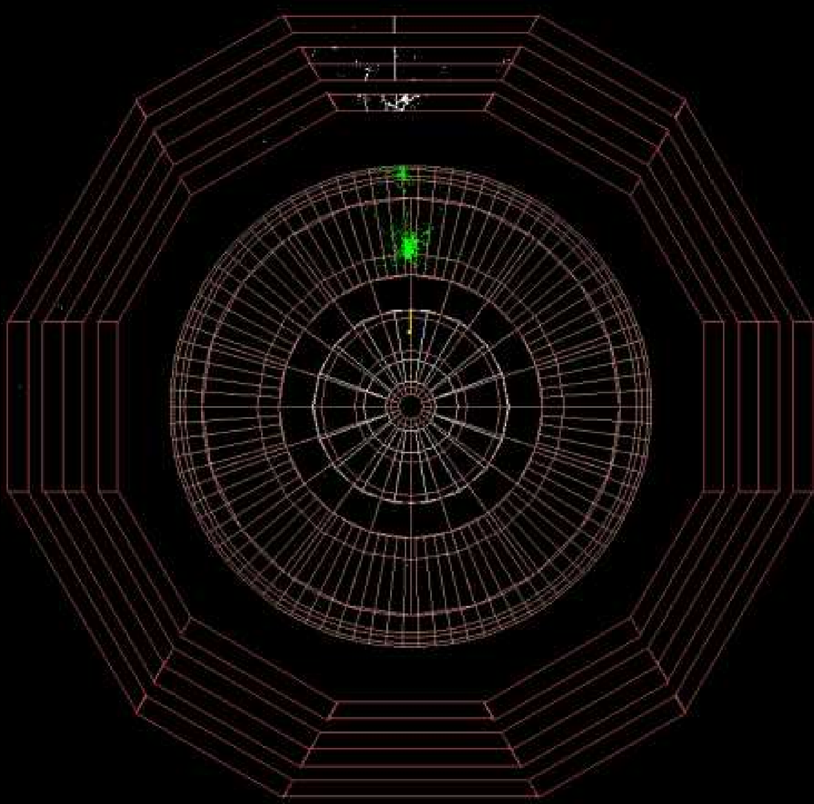


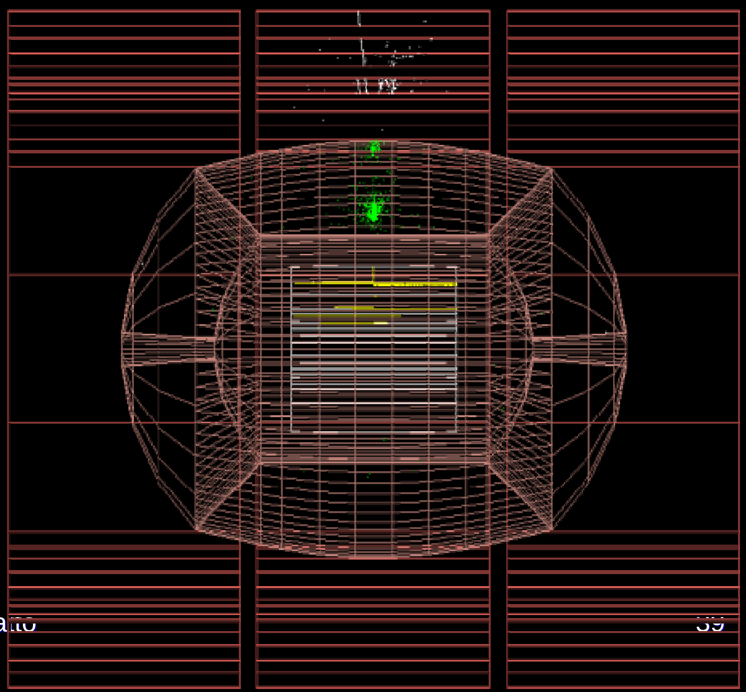


boundary

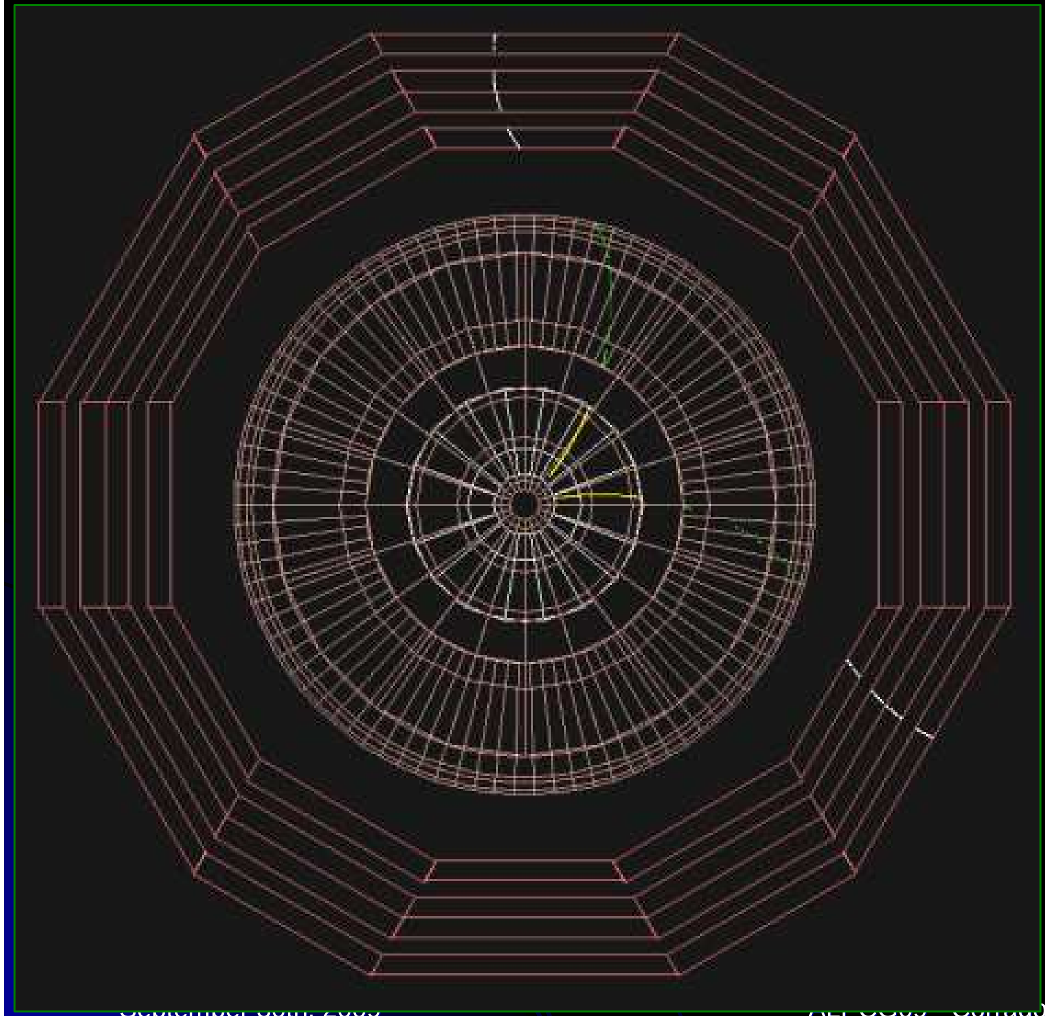
80 GeV jet with escaping particles

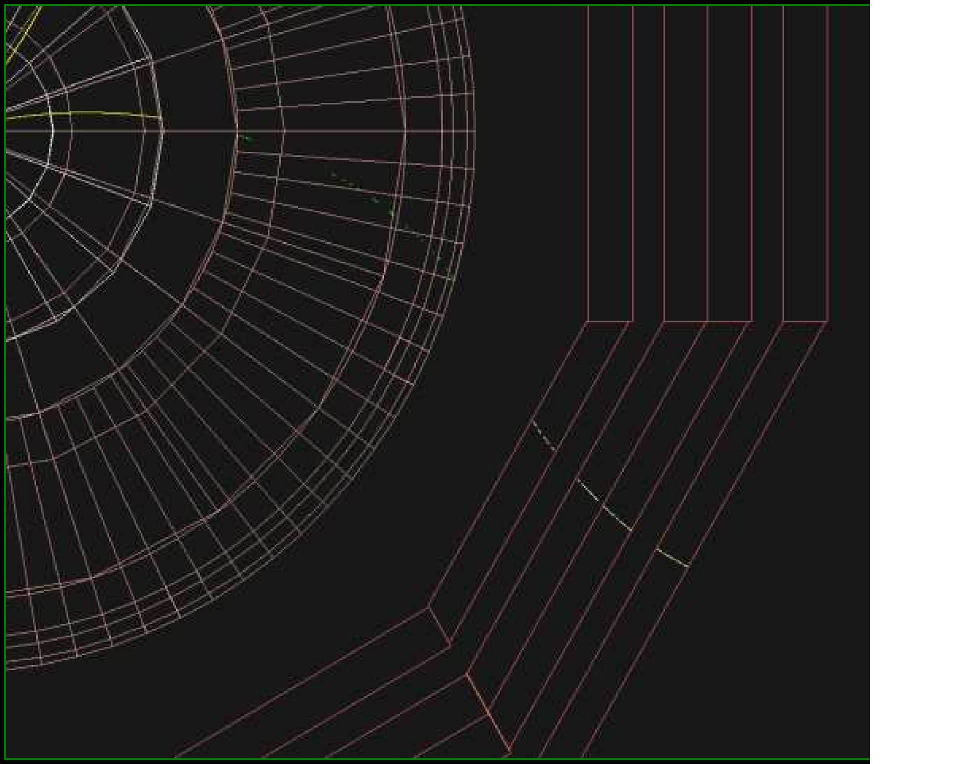
ILCRoot simulation





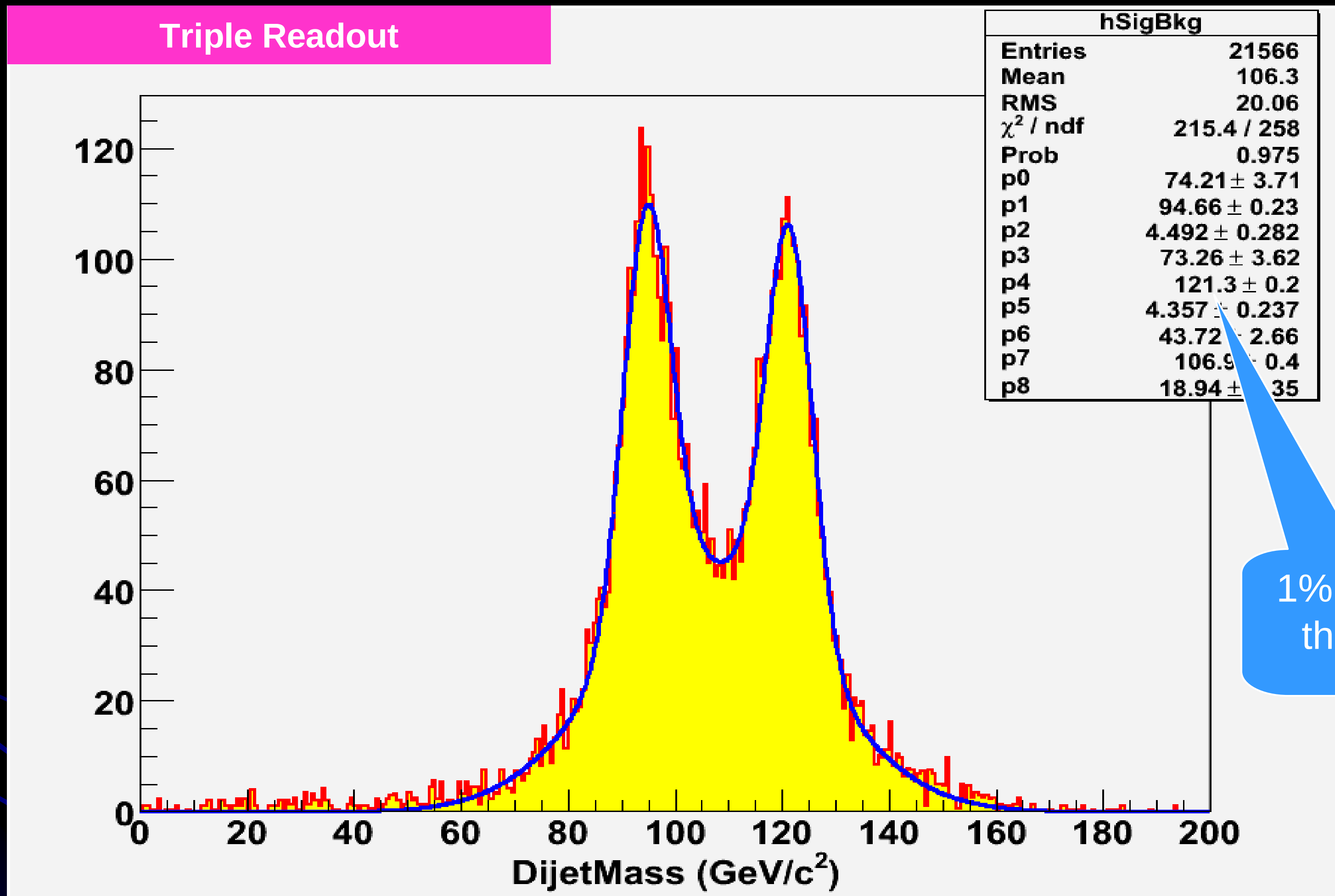
μ^+ μ^- at 3.5 GeV/c





ILCRoot simulation

$e^+e^- \rightarrow Z^0H^0 \rightarrow \nu\bar{\nu}\, c\bar{c}$ + ZZ Background



1% Error on the mass

- Signal + ZZ background
- Requires 2 jets from jet-finder
- Evis > 130 GeV
- **No flavor tagging**
- Fit with three gaussians
- Selection Efficiency = 80.2%