Higgs boson discovery

ATLAS search results of Higgs boson decay to 4 leptons

V.Schegelsky,

PNPI-HEPD-Council,Gatchina
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ATLAS NOTE

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Electron identification and a high selection efficiency of the Higgs boson in the ATLAS experiment.

Valery Schegelsky[a], Youri Tikhonov[b], Alexei Kharlamov[b]

[a] *PetersburgNuclearPhysicsInstitute,Gatchina,NRC "Kurchatov Institute",Russia*
[b] *BudkerInstituteofNuclearPhysics,SBRAS,Novosibirsk,Russia*

Abstract

As reported by the ATLAS collaboration,the Higgs boson detection efficiency with ZZ^* final state is rather low if Z^* decays to electrons. The alternative approach is considered with the tight electron identification as a main tool. An essential efficiency increase is demonstrated, and reasons of such increase are discussed.

1 Introduction

In the recent ATLAS publications [1] [2] all properties of newly observed particle - SM Higgs boson - are reported. In our note, only the decays $H \to e^+e^-e^+e^-$ and $H \to \mu^+\mu^-e^+e^-$ are considered.

The Higgs boson decays with rather high probability into two Z-bosons. As the mass of discovered Higgs boson is ~ 125 GeV, one of Z-boson is real (with the mass of 91.19 GeV) and another is a virtual Z^* with smooth slightly rising mass distribution in the region (0-40) GeV.The channels where each Z-boson decays into lepton pair are being considered as a "gold plated" final state. The main background is the direct production of ZZ^* - quark-antiquark annihilation with initial state γ/Z^* radiation - and there is sharp peak at small Z^* mass. The signal can be cleaned up from this background by an appropriate cut in the Z^* mass.

One might expect that the number of signal events for 4e(2μ2e) and 4μ (2e2μ) final states should be approximately the same: the triggers mainly select real Z-bosons and have equally high efficiency to detect leptonic Z-boson decays into 2e and 2μ , as it was observed in the ATLAS study of Z-boson production[3].The reconstruction and selection efficiencies for a SM Higgs boson with the mass of 125 GeV are 39% for the 4μ sub-channel and 19% for the 4e sub-channel[2]. This can be considered as an indication that the efficiency of Z^* identification is very much lower in the $Z^* \to e^+e^-$ case. However it looks strange: Z^* decays to relatively soft electrons and the ATLAS TRT detector provides high electron selection power [4][5].

Table 7: The numbers of expected signal events for the m_H=125 GeV hypothesis and background events together with the numbers of observed events, in a window of ±5 GeV around 125 GeV for 20.7 fb^{-1} at $\sqrt{s}$ = 8 TeV and 4.6 fb^{-1} at $\sqrt{s}$ = 7 TeV as well as for their combination.

	total signal full mass range	signal	$ZZ^{(*)}$	$Z + \text{jets}, t\bar{t}$	S/B	expected	observed
			$\sqrt{s}$ = 8 TeV				
4μ	5.8 ± 0.7	5.3 ± 0.7	2.3 ± 0.1	0.50 ± 0.13	1.9	8.1 ± 0.9	11
$2\mu 2e$	3.0 ± 0.4	2.6 ± 0.4	1.2 ± 0.1	1.01 ± 0.21	1.2	4.8 ± 0.7	4
$2e2\mu$	4.0 ± 0.5	3.4 ± 0.4	1.7 ± 0.1	0.51 ± 0.16	1.5	5.6 ± 0.7	6
$4e$	2.9 ± 0.4	2.3 ± 0.3	1.0 ± 0.1	0.62 ± 0.16	1.4	3.9 ± 0.6	6
total	15.7 ± 2.0	13.7 ± 1.8	6.2 ± 0.4	2.62 ± 0.34	1.6	22.5 ± 2.9	27

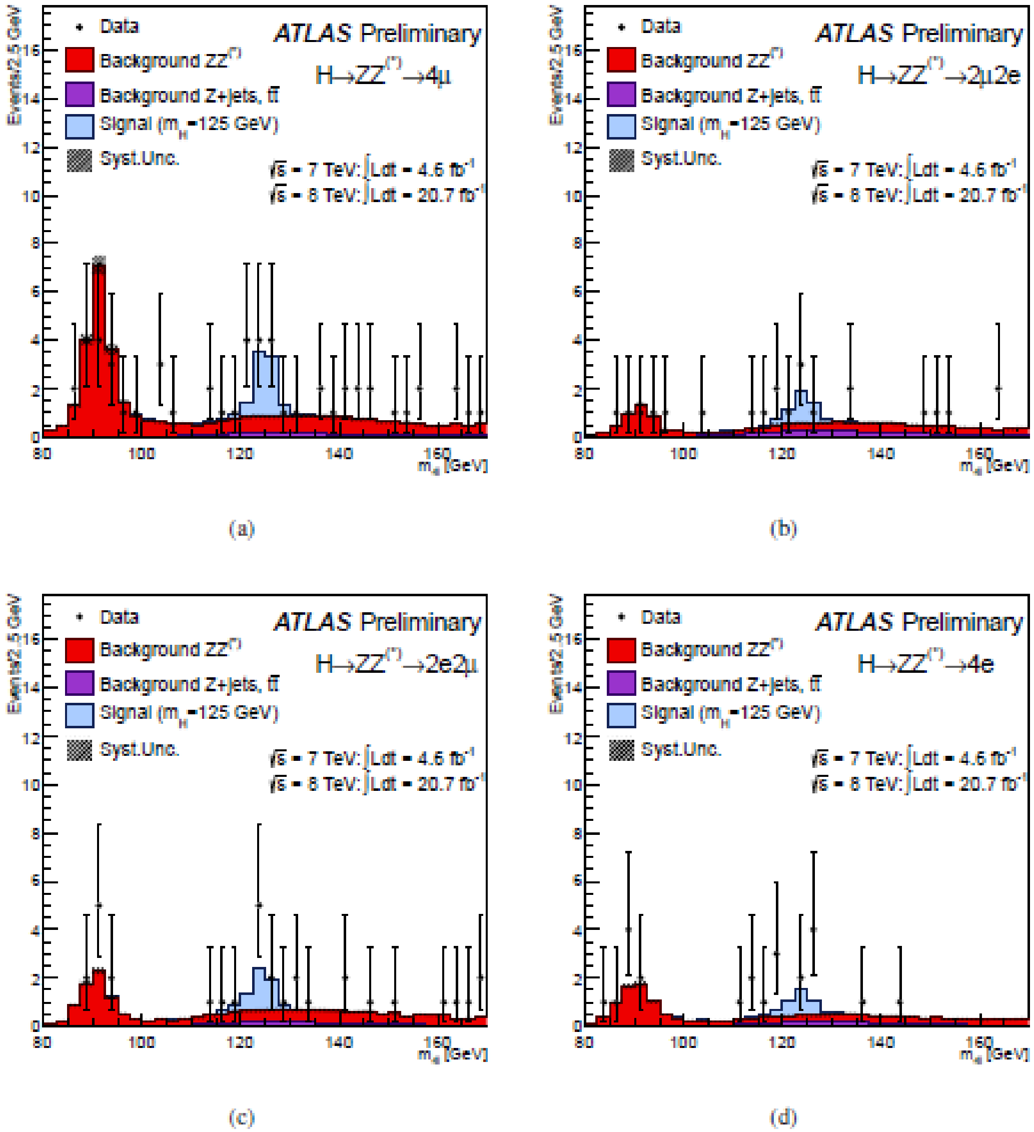


Figure 6: The distributions of the four-lepton invariant mass, $m_{4\ell}$, for the selected candidates for the combined $\sqrt{s} = 8$ TeV and $\sqrt{s} = 7$ TeV data sets for the various sub-channels, (a) 4μ, (b) $2\mu 2e$, (c) $2e2\mu$ and (d) $4e$, compared to the background expectation for the 80 − 170 GeV mass range. The error bars represent 68.3% central confidence intervals. The signal expectation for the $m_H = 125$ GeV hypothesis is also shown.

3 Observations

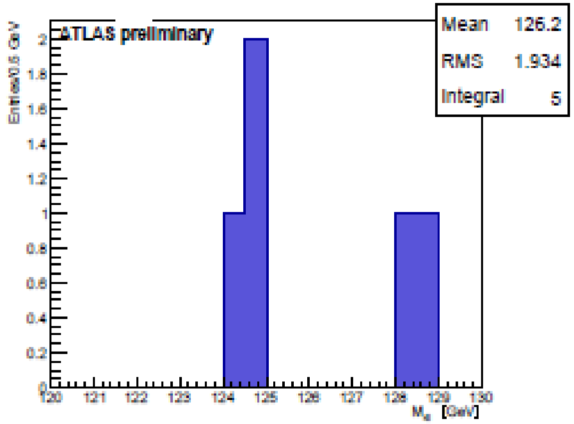
3.1 Basic current approach to event selection

Each electron (muon) must satisfy $E_T > 7$ GeV ($p_T > 6$ GeV). The highest p_T lepton in the quadruplet must satisfy $p_T > 20$ GeV, and the second (third) lepton in p_T order must satisfy $p_T > 15$ GeV ($p_T > 10 GeV$).

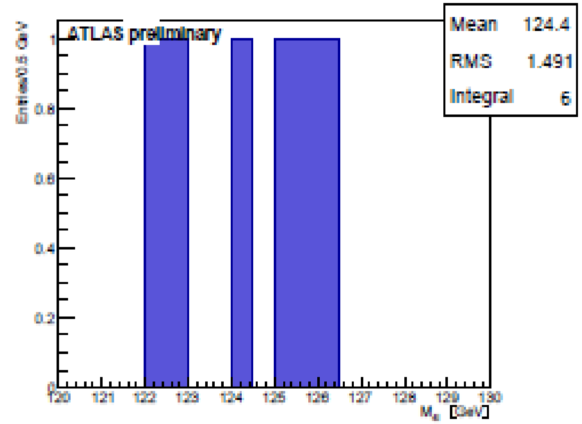
The background contributions are further reduced by applying impact parameter requirements as well as track- and calorimeter-based isolation requirements on the leptons. The normalized track isolation discriminant is defined as the sum of the transverse momenta of tracks, Σp_T, inside a cone of $\Delta R < 0.2$ around the lepton, excluding the lepton track, divided by the lepton E_T. The tracks considered in the sum must come from the primary vertex and be of good quality; i.e. they must have at least four hits in the pixel and silicon strip detectors (silicon hits), and $p_T > 1$ GeV for muon isolation, and at least nine silicon hits, one hit in the innermost pixel layer (the b-layer), and $p_T > 0.4$ GeV for electron isolation. Each lepton is required to have a normalized track isolation smaller than 0.2. The normalized calorimetric isolation for electrons is computed as the sum of the positive energy topological clusters in the electromagnetic and hadronic calorimeter with a reconstructed barycenter falling in a cone of $\Delta R < 0.2$ around the candidate electron cluster, divided by the electron E_T. The cut value is 0.2.In the case of muons, the normalized calorimetric isolation discriminant is defined as the sum of the calorimeter cells, ΣE_T, above $3.4\sigma_{noise}$ inside a cone of $\Delta R < 0.2$ around the muon direction, divided by the muon p_T. Muons are required to have a normalized calorimetric isolation less than 0.2.

Figures 1 show results of the final selection events for $H \to 4e$ and $H \to 2\mu 2e$ decays. The number of events shown corresponds in the four leptons invariant mass window of size ± 5 GeV around M_{4l}=125 GeV and are in good agreement with [2] although our analysis chains is not identical to [2] .

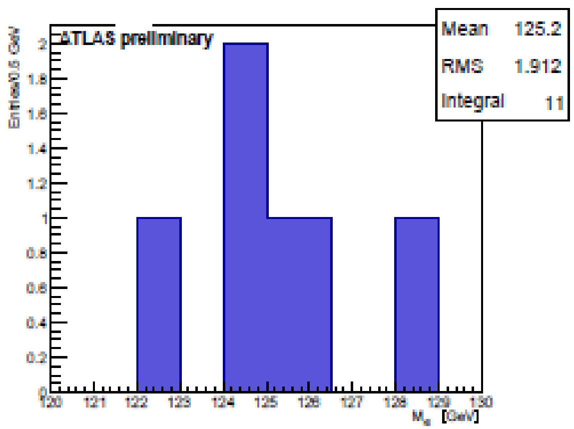
3.2 Electron identification



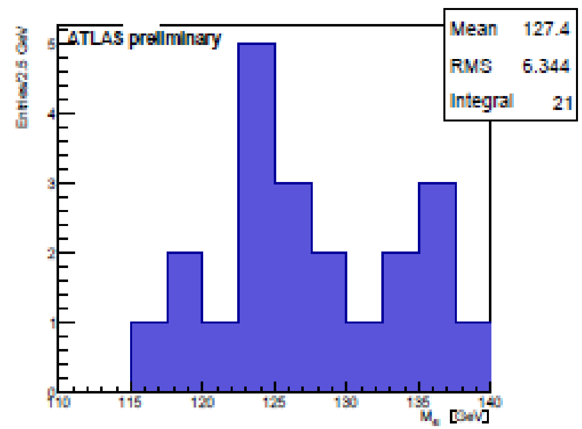
(a)



(b)



(c)



(d)

Figure 1: Four leptons invariant mass (M_{4l}) distributions for $H \to 4e$ and $H \to 2\mu 2e$ decays. The isolations and P_T cuts are applied as in ATLAS publications. Only events with $M_{34} > 10GeV$ are accepted. a)$H \to 4e$ decay. b)$H \to 2\mu 2e$ decay.c)Sum of M_{4l} distributions for both processes.d)Distribution c) with wide M_{4l} window.

3.2 Electron identification as a key element in events selection

Identification of final state particles is the natural first step in the analysis. It is easy to see Z-boson as a resonance peak with the di-electron mass $(85.0 < M_{12} < 95.0)$ GeV. To identify $(Z^*) \rightarrow e^+e^-$ decay one can request the highest possible strong selection, so called tight++, for both electron candidates. We do see a clean signal in four leptons invariant mass distribution (Fig 2(a) and 2(b)). The correlation $(M_{4l} : (M_{34})$ indicates that two selected events are on the high edge of the phase space and one event (easy to exclude) has small Z^* mass. "Too clean signal" may indicate that selection criteria are too strong, so backgrounds are eliminated nearly completely, however some(significant) part of the signal events can also been excluded. It looks that severe kinematical cuts are imposed implicitly. This might be the case indeed, because of the tight++ definition:" Tight++(medium++) is not yet defined below 10 GeV..."(Author: John Alison,Chris Lester).

One has to make identification a bit weaker: only at least one of the electron candidate from $Z^* \rightarrow e^+e^-$ decay has to be selected as tight++. Now a strong signal is seen on top of smooth mass distribution of Z^* decay (Fig 2(c) and 2(d)), as it is expected . Of course, more background appears.

The number of events shown in figures 2(b) and 2(d) are presented in a window of size ± 5 GeV around M_{4l}=125 GeV as in [2]. It looks that our selection efficiency is higher than in [2] by a factor ~ 4. Similar result we get for the $2\mu 2e$ final state (Fig 3(a) and 3(b)). For the $2\mu 2e$ case, it is requested additionally that muon distance to the closest jet $dr = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ should be large than 0.2.

Figure 4 shows the sum of four leptons invariant mass distributions(M_{4l}) for $H \rightarrow 4e$ and $H \rightarrow 2\mu 2e$ decays. There are 35 events in the mass window (120÷130) GeV (fig 4(a))being compared with 12 events found before [1]). One can estimate the number of signal events by a simple fit (fig 4(b). The resonance mass is $M_h = (125.3 \pm .5)$ GeV with the width $\Gamma = (.94 \pm .45)$ GeV. An estimate of the total number of signal events is ~ 17. The similar fit of M_{4l} the distribution in the wide mass window

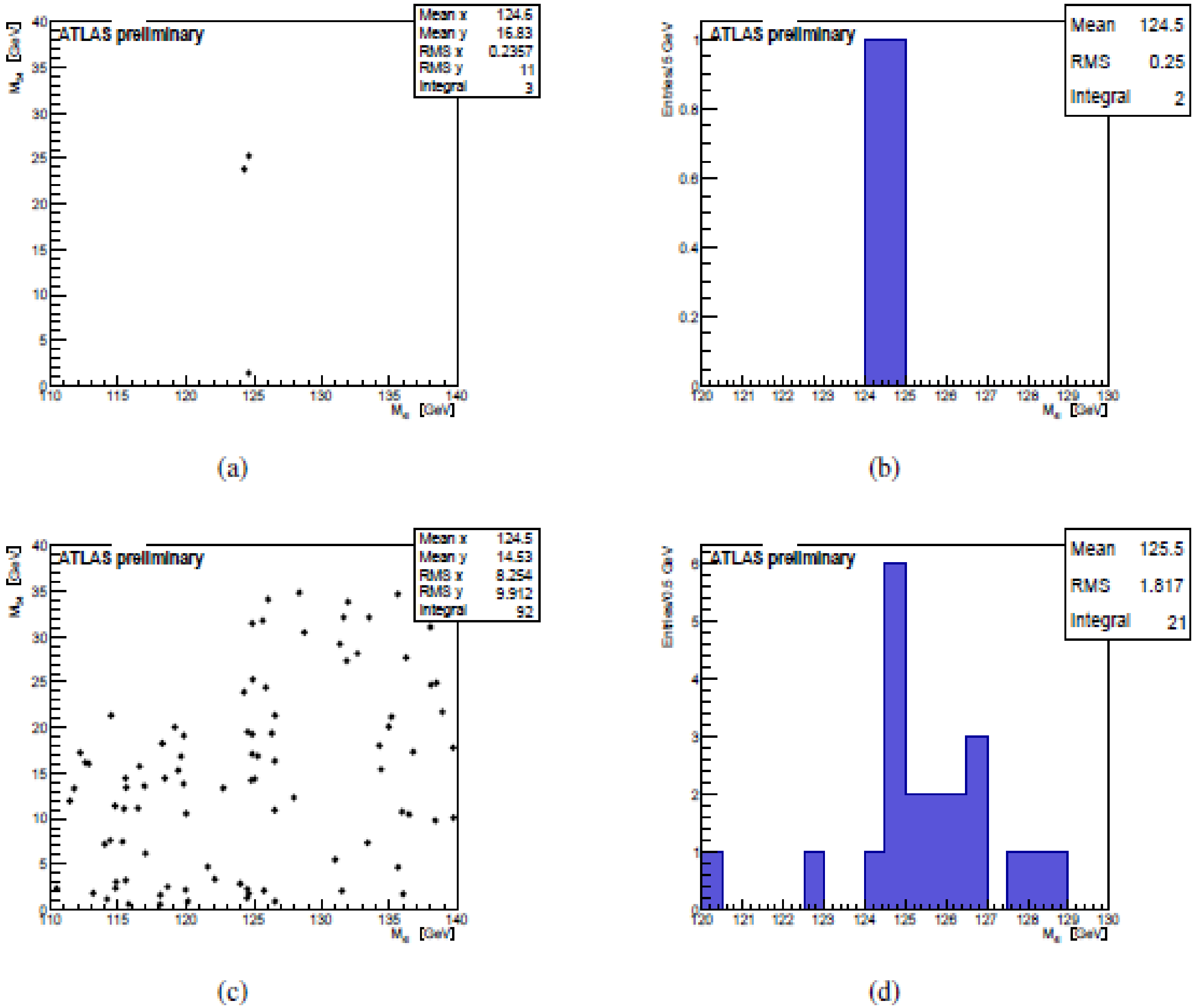


Figure 2: Distributions for $H \rightarrow 4e$ decay. M_{4l} distribution with $M_{34} > 10GeV$. a)M_{34} versus the M_{12} , both electrons from Z^* decay tagged as tight++.b)M_{4l} distribution with both electrons from Z^* decay tagged as tight++. c)M_{34} versus the M_{12} , one or both electrons from Z^* decay tagged as tight++.d) M_{4l} distribution,one or both electrons from Z^* decay tagged as tight++.

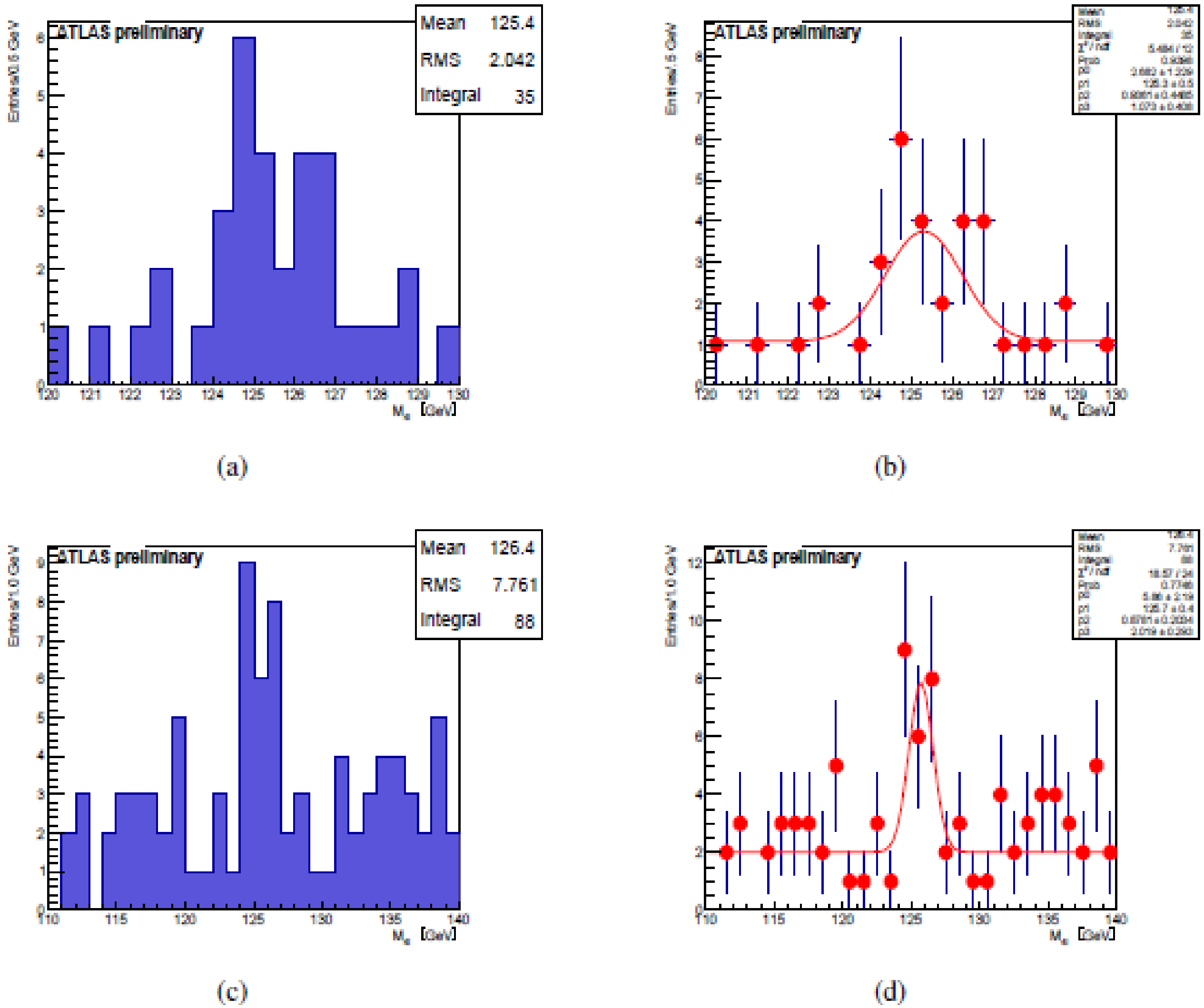


Figure 4: Sum of M_{4l} distributions for $H \to 4e$ and $H \to 2\mu 2e$ decay.One or both electrons from Z^* decay tagged as tight++.Cut $M_{34} > 10GeV$ is applied. a)Mass window (120÷130) GeV. b)Gaussian fit of a). c) The M_{4l} wide window (110÷140) GeV.d)Gaussian fit of c).

4 Conclusions

Tight electron identification instead of isolation and kinematical (P_T) cuts provide clean resonance signal in $e^+e^-e^+e^-$ and $\mu^+\mu^-e^+e^-$ states with the efficiency much higher than in the current ATLAS analysis: in a window of size ± 5 GeV around M_{4l}=125 GeV in publications [1] [2] 12 events were found being compare with 35 events in our analysis. To consider problems in more details let us have a look an individual influence of cuts in the wide M_{4l} window (110÷140) GeV.

Figure 5(a) shows M_{4l} distribution for the process $H \to 4e$ where at least one electron of Z^* decay is of tight++ category ,and it is used as a reference. Figures 5(b) and 5(c) show the results of the application the isolation and transverse momenta P_T cuts. One can see that both cuts strongly suppress (by factor of 5) events with low M_{4l} mass including the region of Higgs boson mass. Simultaneous application of these cuts (fig 5(d)) decrease event detection efficiencies in the M_{4l} window (110÷140) GeV by a factor of 8. The sample of signal events in the region of (120÷130) GeV was suppressed by at least by a factor 4. One can see (compare fig 1(a) and 5(d)) that after hard cuts only one event in the signal window has no tight++ electrons.

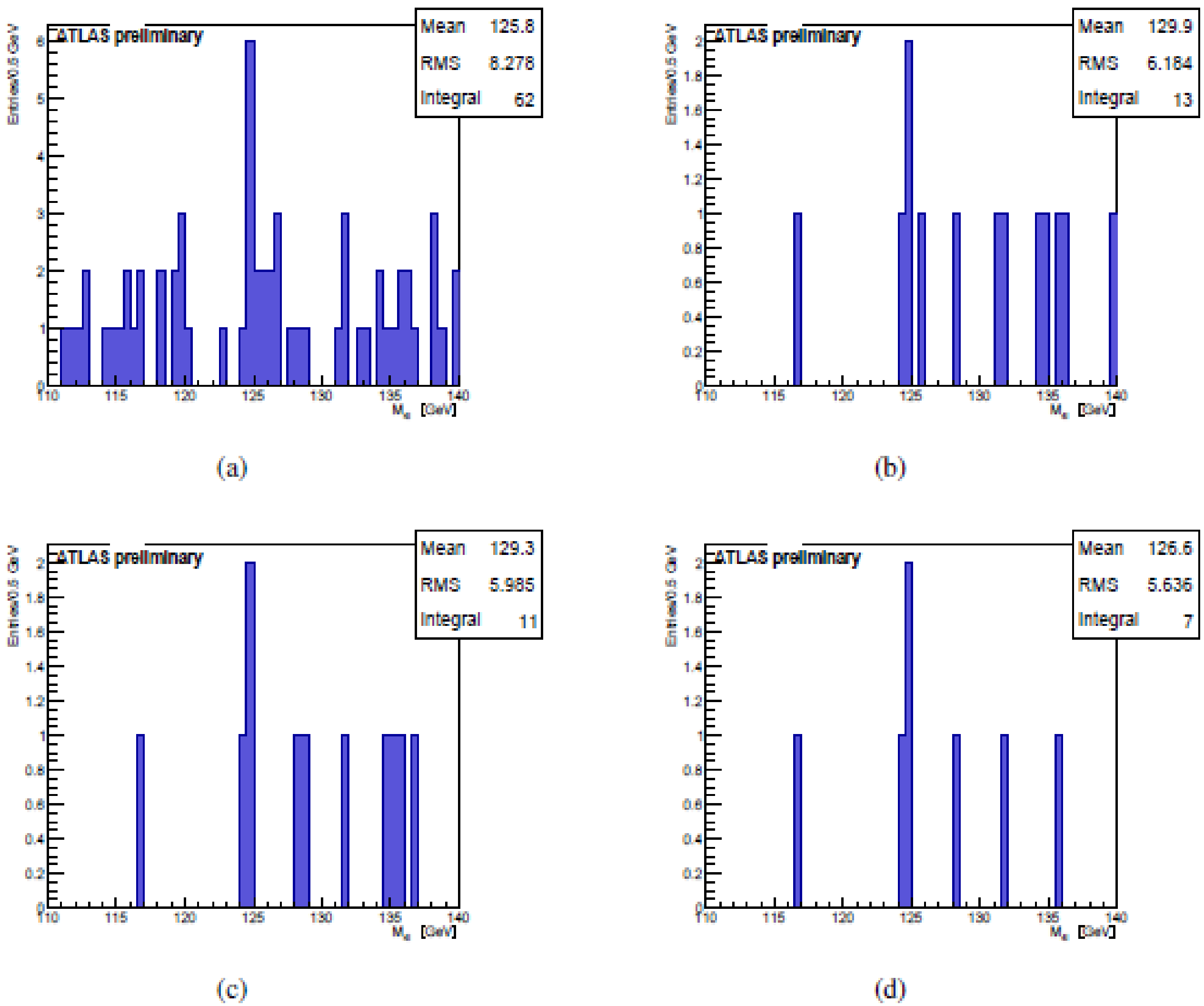
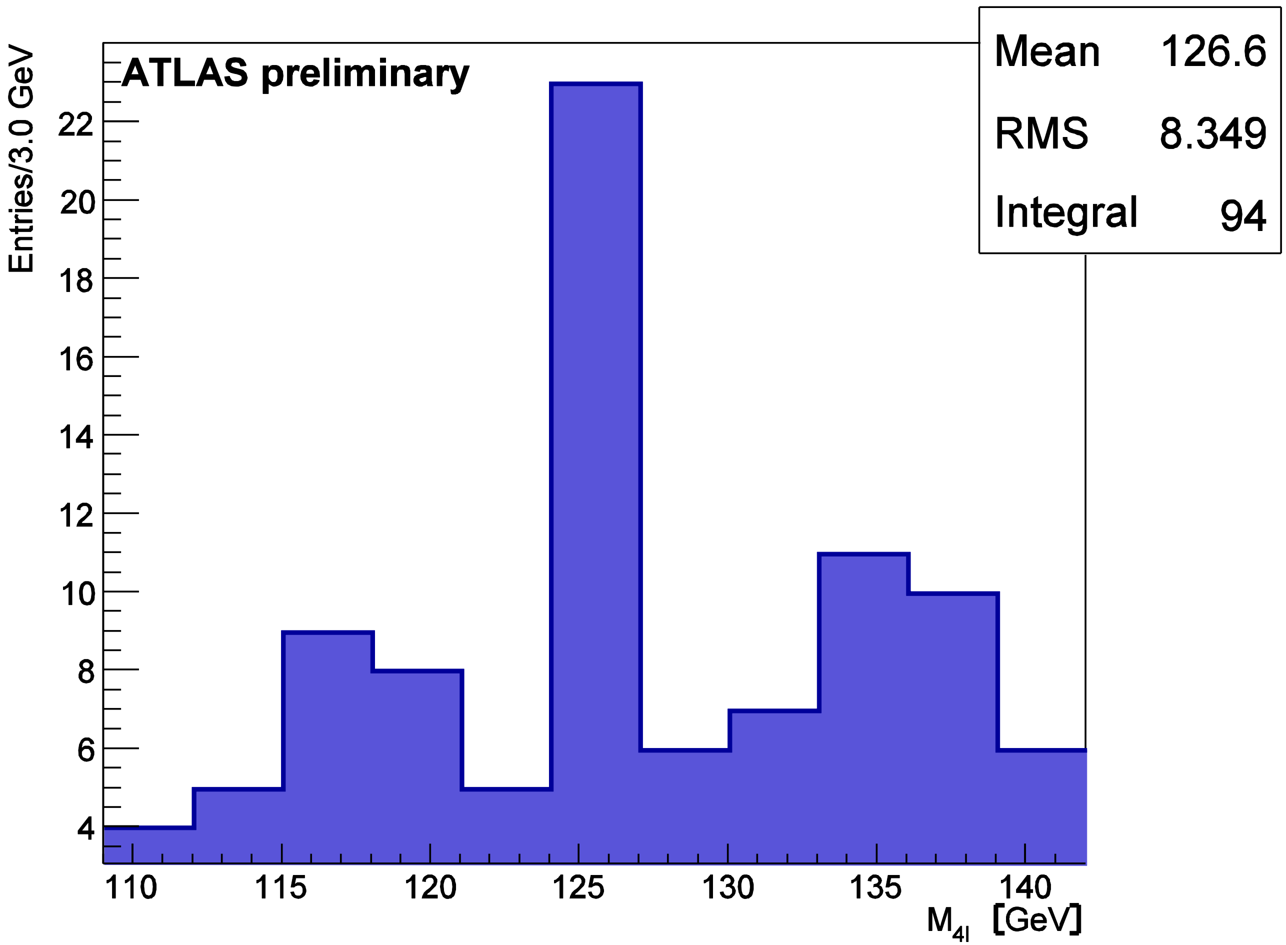


Figure 5: The distribution of invariant mass M_{4l} for $H \rightarrow 4e$ process.One or both electrons from Z^* decay tagged as tight++.Cut $M_{34} > 10GeV$ is applied. Influence of isolations and P_T cuts. a) No cuts. b) Isolations cut. c) Standard ATLAS analyses P_T cuts.d)Standard analyses isolations and P_T cuts.

To conclude,events selection based on electrons identification provide for the first time the clean resonance signal in $e^+e^-e^+e^-$ and $\mu^+\mu^-e^+e^-$ states with statistics high enough to determine the Higgs boson mass with good accuracy $M_h = (125.7 \pm .4)$ GeV. This value is in a good agreement with the one determined from $H \to \gamma\gamma$ decay of the ATLAS experiment [2] and also with the CMS publication [6].



ATLAS preliminary
Mean 126.6
RMS 8.349
Integral 94
Entries/3.0 GeV
22
20
18
16
14
12
10
8
6
4
110
115
120
125
130
135
140
M4l [GeV]