Search for RpV SUSY in the tri-electron channel (λ_{121} coupling)

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Y. Arnoud, A-M. Magnan, G. Sajot

LPSC Grenoble

abstract

A search has been performed for the tri-electron signature from the R-parity Conserved (RpC) production of Supersymmetric particles followed by a R-parity Violating (RpV) decay through a λ_{121} coupling . The analysis uses data collected with the DØ detector at Fermilab $p\bar{p}$ collider at a center of mass of 1.96 TeV during the period september 2002-mid june 2003 and corresponding to 117.5 ± 12.0 pb^{-1}. Events triggered by a single-EM or a di-EM trigger were selected. 3 events were found for 3.0 ± 1.5 events expected from the Standard Model and from the instrumental background. 1 event is found for 1.2 ± 0.8 expected if one requires that the invariant mass of the 2 leading electron is below 70 Gev. Preliminary study of the region which can be excluded in the mSUGRA parameter space is presented.

1 Introduction

The multi-electron topology is expected in the RpV SUSY processes via the λ_{121} Yukawa coupling. In this analysis it is assumed that the production is Rp conserved (production of a pair of SUSY particles), that the decay goes via RpC or RpV and that the LSP is the $\tilde{\chi}_1^0$. The pair produced SUSY particles cascade decay almost 100 % of the time to a pair of $\tilde{\chi}_1^0$ which then decay through RpV. Figure 1 illustrates the four decay channels of the $m_{\tilde{\chi}_1^0}$ into the four equally probable channels : e$^-$ e$^+$ $\bar{\nu_\mu}$, e$^+$ e$^-$ ν_μ, $\bar{\nu_e}\mu^- e^+$, $\nu_e \mu^+ e^-$.

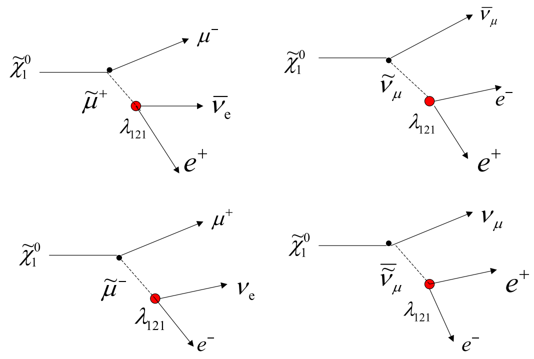

Figure 1: Diagrams of $\tilde{\chi}_1^0$ RpV decay to three leptons (λ_{121} coupling).

At least 4 charged leptons should be present in the final state. The present analysis is relative to final state with electrons only. As some electrons can escape detection, the analysis is focussed on tri-electron search. Channels with at least one μ will be considered in a future analysis.

Despite the fact that RpV decays result in MET owing to neutrinos in the final state, it is not used as discriminator in the present analysis. To reduce the background the selection is based on the presence of 3 electrons matched with a track in the event.

Signal events have been produced with SUSYGEN generator [1] which uses SUSPECT [2] for RGE evolution. Events have been generated for several mSugra points to obtain cross sections, acceptances and event selection efficiencies. Events have been generated with the lepton violating coupling $\lambda_{121} = 0.01$ (present experimental upper limit is 0.05 [3]).The value of the coupling influences only the lifetime of the $\tilde{\chi}_1^0$. With chosen value for λ_{121}, the $\tilde{\chi}_1^0$ decays within few mm.

Some physical properties of the signal are illustrated by figure 2 (p$_T$ of the first three leading reconstructed electrons) and figure 3 (invariant mass of the two leading electrons and missing transverse energy). Those electrons should satisfy the EM-ID criteria explained in section 3.More details on $\tilde{\chi}_1^0$ and $\tilde{\chi}_1^+$ masses and cross sections will be given in section 5.

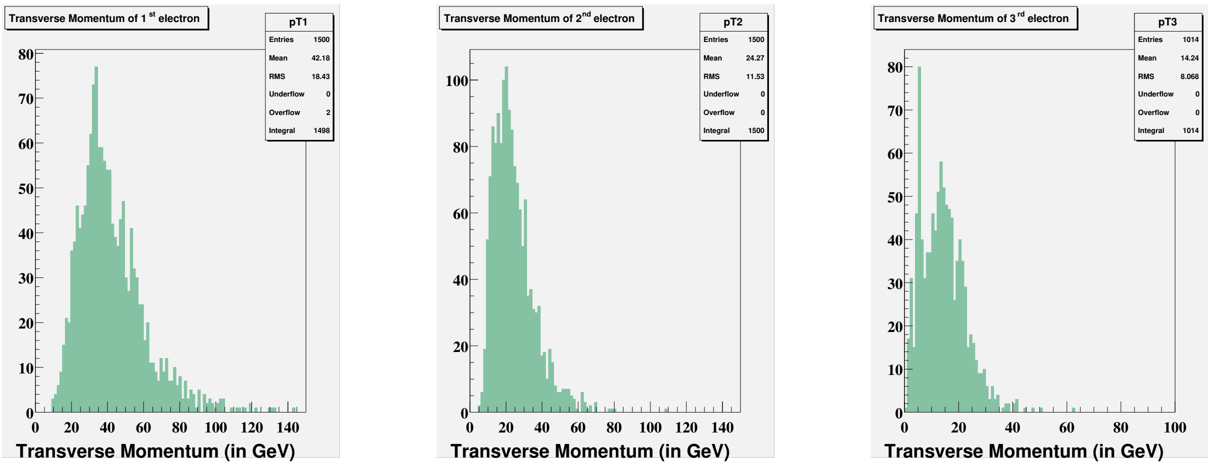

Figure 2: PRELIMINARY : P_T distributions of the leading, next to leading, next-next to leading electron. SUSYGEN full simulation : $m_0 = 750$ GeV, $m_{1/2} = 150$ GeV $\tan\beta = 5$ and $\mu < 0$.

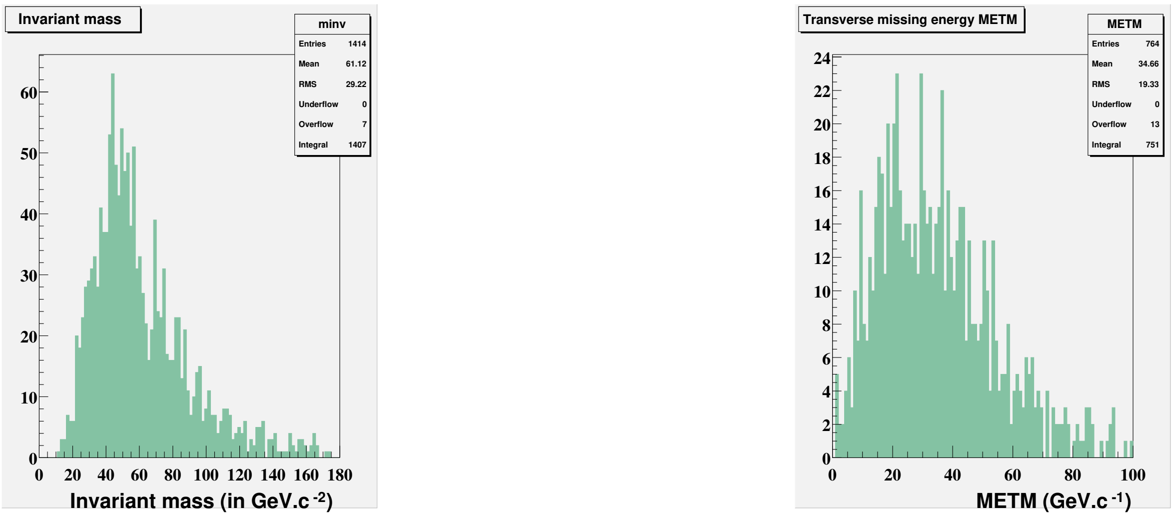

Figure 3: PRELIMINARY : Invariant mass distributions of the two leading electrons (left) and missing E_T distibution (right). SUSYGEN full simulation : $m_0 = 750$ GeV, $m_{1/2} = 150$ GeV $\tan\beta = 5$ and $\mu < 0$.

2 Data Sample

The data set used for this study is the NP 2 EM skimming sample (p13.05.00 and p13.06.01) corresponding to the data taking period extending from september 2002 to june 15th 2003 [4]. Events are selected if they contain at least two electron candidates ($|ID|$=10,11) with $p_T > 7$ GeV. Events are further considered if they satisfy an OR of single-EM and di-EM triggers : EM_MX_SH_TR, EM_MX_SH, EM_MX, EM_MX_EMFR8, EM_MX_F0, EM_HI_SH_TR, EM_HI_SH, EM_HI, EM_HI_EMFR8, EM_HI_F0, 2EM_2MD7.

The analysis presented in this note is done on unpacked ThumbNails [5]. Data have been corrected for the share energy problem in the calorimeter [6].

3 Offline Objects Selection Criteria

The EM-candidates, jets, MET are selected and corrected according to the certified criteria of the EM ID (ver. 4.0) [7], Jet/MET (ver. 3.1) [8], JES (ver. 4.2) [9] groups.

3.1 EM-candidate

The EM-candidate should satisfy the following criteria:

- ID = 10 (no associated track) OR |ID| = 11 (associated track). Association is looked for in a $\Delta\eta \times \Delta Phi$ window= 0.05×0.05 for tracks with P> 1.5 GeV.
- EM Fraction > 0.9, where EM Fraction is the energy fraction of the EM-candidate in the electromagnetic calorimeter with respect to the total EM-candidate energy.
- iso = $\frac{E_{\rm tot}(\mathcal{R}<0.4)-E_{\rm EM}(\mathcal{R}<0.2)}{E_{\rm EM}(\mathcal{R}<0.2)} < 0.15$, where iso is the isolation of the EM-candidate, $E_{\rm EM}(\mathcal{R} < 0.2)$ is the electromagnetic energy within a cone of radius $\mathcal{R} = \sqrt{\Delta\eta^2 + \Delta\varphi^2} = 0.2$ centered around the EM-candidate, $E_{\rm tot}(\mathcal{R} < 0.4)$ is the total energy contained within a concentric cone of radius $\mathcal{R} = 0.4$;
- HMx8 < 20, where HMx8 is a is 8-dimensional matrix χ^2 based on the comparison of the energy deposited in the EM calorimeter with the corresponding distributions obtained from Monte Carlo. The first four observables are the fraction of shower energy in the first, second, third and fourth electromagnetic layers. Two measurements of the cluster size in the third floor are used:
  - S_1 – size of the cluster along r-axis for the EC or $z-$position for the CC;
  - S_2 – size of the cluster in $r \times \Phi$ (r being the radial distance of the cluster to the z axis of D0 and Φ the azimuthal angle of the cluster).

  The last two parameters are the logarithm of the total shower energy and the position of the event vertex along the beam.

A some level of the analysis EM-candidate will be required to be matched with a track. Tracks are matched to EM calorimeter clusters based on a $\chi 2$, which is calculated from delta_phi, delta_z (CC), delta_r (EC) and E/p (taking into account the resolutions for each track type).

3.2 Correction to the EM candidates

In this analysis to account for the noise not described in MC, the EM energies have been smeared by a gaussian of $\sigma = 0.05 \times E$ [7] [12].

Furthermore, the EM ID correction factors [7] for higher efficiencies in MC than in data for :

- offline EMID reconstruction (CC $= 0.88 \pm 0.03$ and EC $= 0.95 \pm 0.06$);
- track match (CC $= 0.93 \pm 0.04$ and EC $= 0.78 \pm 0.07$);

have been applied to the MC events (SM and SUSY processes).

Those numbers have been obtained with p13 MC version. It has been discovered recently that in this MC the polarity of the magnetic field was not correctly treated in TMB produced with p13 and it affects the track matching efficiency.

As all the Monte-Carlo results presented in this analysis (SM and SUSY) have been analyzed with the "correct" B field, we need to use a track match factor taking into account the "correct" track matching (called $EffData/EffMC_{correctB}$ in the following). One can write it as :

$$EffData/EffMC_{correctB} = \\ (EffData/EffMC_{wrongB}) \times (EffMC_{wrongB}/EffMC_{correctB})$$

$EffData/EffMC_{wrongB}$ is the certification track match factor quoted above and $EffMC_{wrongB}/EffMC_{correctB}$ has been obtained using Z MC events according to the following procedure. The same Z MC input events have been processed with the "wrong" (i.e. default rcp in all rcp files of the mag_field_config package) and "correct" field polarity (i.e. setting string MCType="SPTP" in all rcp files of the mag_field_config package and rerunning D0ChunkAnalyze). Results are shown Table 1 for CC and EC :

	CC	EC
$EffMC_{wrongB}/EffMC_{correctB}$	.911	.877

Table 1: PRELIMINARY: Ratio of the track matching efficiencies in the "wrong Bfield" and in the "correct Bfield" case.

So in this analysis, the matching track factors used are:

- CC : $0.93 \times 0.911 = 0.85$
- EC : $0.78 \times 0.877 = 0.68$

3.3 Jets

The Run II cone (of radius $\mathcal{R} = \sqrt{\Delta\eta^2 + \Delta\varphi^2} = 0.5$) algorithm has been used, with

- $0.05 <$ EM Fraction < 0.95, where EM Fraction is the energy fraction of the jet in the electromagnetic calorimeter with respect to the total jet energy;
- CHF < 0.4, where CHF is the energy fraction of the jet in the coarse hadronic calorimeter with respect to the total jet energy;
- HotF < 10, where HotF is the ratio highest and next-highest cell ET of the jet;
- n90 > 1, where n90 is the number of cells with 90% of the jet energy;
- f90 $< 0.8 - 0.5 *$ CHF or CHF < 0.1 where $f90 = n90/nitm$, CHF=coarse hadronic fraction and $nitm$ is the total number of towers in a jet;
- $E_T > 10$ GeV.

3.4 MET

The missing transverse energy is computed according to the following procedure applied on the MET$_X$ and MET$_Y$ components ("subtracted" means it contributes negatively to the MET components and "added" if it contributes positively):

- all the positive energy of the EM+FH calorimeter cells (ilayer < 15) are "subtracted';
- the coarse hadronic fraction of all the jets is "subtracted" ;
- for the jets which are the electron candidates (dist < 0.7) the corrected p$_{T_X}$ and p$_{T_Y}$ of the electron candidate is "subtracted" from MET$_X$ and MET$_Y$ and the p$_{T_X}$ and p$_{T_Y}$ of the corresponding jets are "added" ;
- the components p$_{T_X}$ and p$_{T_Y}$ of the tight muons in the event are "subtracted" ;
- the energy scale correction (subsection 3.3) is applied to certified jets which are not electron candidate and "subtracted".

To be coherent with the 5% energy smearing of the electron-candidate (subsection 3.2), the energies of the EM cells have been smeared with a gaussian of 5% width.

4 Trigger efficiency

As events triggered by a single-EM trigger or by a di-EM trigger have been analyzed (section 2), both trigger efficiencies have been studied and parametrized in order to be applied on MC events (SM and signal). The statistical error on the efficiency has been computed with the EFFIC program [10].

4.1 Single-EM trigger efficiency

The trigger efficiency versus P_T for single electron has been determined using the NP 1mutrk samples p13.05.00 and p13.06.00 (1 medium muon candidate $P_T > 6$ GeV, associated to a track) [4]. Events have been analyzed if they contain one matched EM candidate $P_T > 15$ GeV. The trigger efficiency is measured as the fraction of the events which have also fired a single-EM trigger. Figure 4 shows the resulting efficiency as a function of the P_T of the EM candidate.

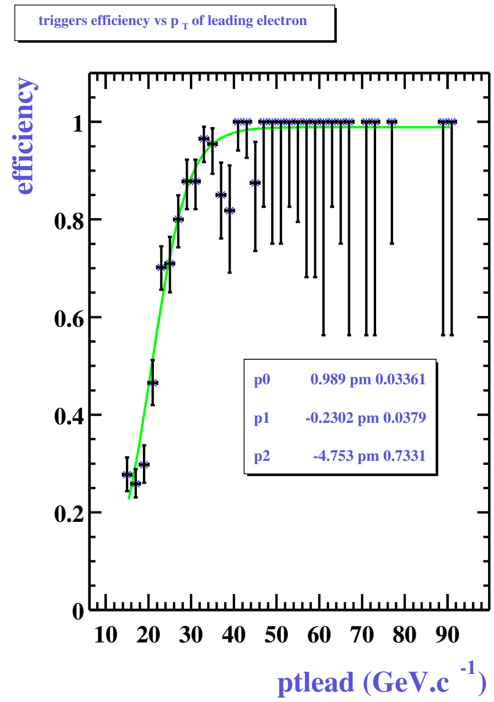

Figure 4: PRELIMINARY: Single-EM trigger efficiency as a function of the p_T of the matched electron candidate.

The measured efficiency was fitted as

$$\epsilon(p_T^{EM-candidate}) = \frac{a}{1 + e^{(b \cdot E_T^{EM-candidate} - c)}}$$

The resulting fit parameters are reported in Table 2.

a	b	c
0.989 ± 0.034	-0.230 ± 0.038	-4.753 ± 0.733

Table 2: PRELIMINARY: Result of the 3-parameter fit applied to the measured turn-on curve for the single-EM triggers.

The overall effective trigger efficiency for EM particles with p_T larger than 50 GeV/c is:

$$\varepsilon_{\text{trig}} = 0.99 \pm 0.05 \tag{1}$$

4.2 Di-EM trigger efficiency

The di-EM trigger efficiency has been studied as a function of the p_T of the leading electron candidate ($p_T > 15$ GeV). The input data sample is the p13.05.00 NP 2em skimmed sample (2 EM objects ID = 10 OR |ID| = 11 $p_T > 7$ GeV) [4]. The trigger efficiency :

- is studied on events with at least 2 EM candidates ($p_{T1} > 15$ and $p_{T2} > 10$) with at least one of them matched with a track;
- is defined as the ratio of the number of events triggered by any muon trigger and 2EM_2MD7 over the number of events triggered by any muon trigger.

Figure 5 shows the resulting efficiency versus the p_T of the leading. Within the limited statistics, no clear p_T dependance is observed and the efficiency is estimated to be 0.6 ± 0.1.

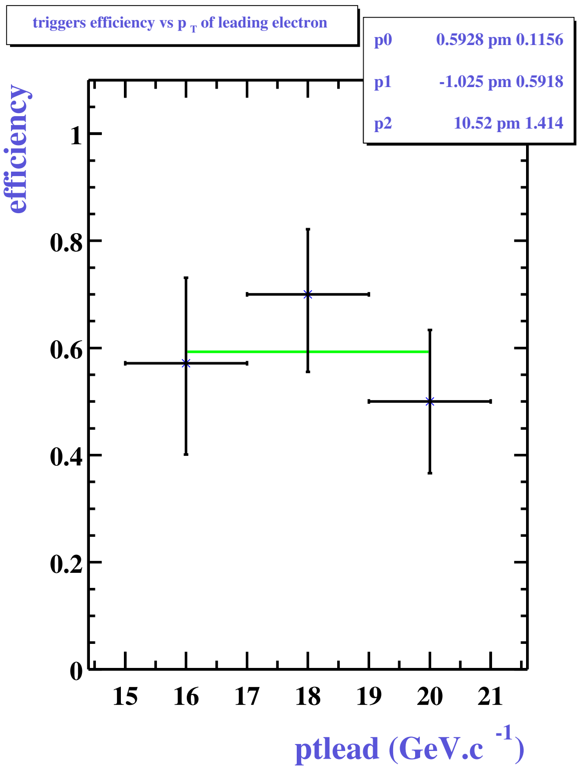

Figure 5: PRELIMINARY: Di-EM trigger efficiency as a function of the p_T of the leading electron candidate.

5 MC samples : SM physics processes and SUSY signal

Standard Model processes have been generated with PYTHIA 6.202 [13] (Table 3) .

SM process	$\sigma\times$ Br (pb)	Nb events	$\mathcal{L}_{equivalent}$ (pb^{-1})
$\gamma^*/Z \to ee$ (2 – 15)	27884 ± 300	10250	0.58 ± 0.01
$\gamma^*/Z \to ee$ (20 – 60)	244 ± 30	25000	102 ± 10
$\gamma^*/Z \to ee$ (60 – 130)	266 ± 32	52000	195 ± 20
$\gamma^*/Z \to ee$ (130 – 250)	1.37 ± 0.01	10500	7664 ± 77
$\gamma^*/Z \to \tau\tau$ (2 – 15)	31370 ± 300	10000	0.51 ± 0.01
$\gamma^*/Z \to \tau\tau$ (60 – 130)	266 ± 32	52500	215 ± 2
$\gamma^*/Z \to \tau\tau$ (130 – 250)	1.37 ± 0.01	10000	7299 ± 73
$WW \to e\nu e\nu$	0.095 ± 0.001	21500	226315 ± 2260
$WZ \to e\nu ee$	0.052 ± 0.001	5750	110577 ± 2210
$W\gamma$ incl	161.7 ± 1.7	11000	68.0 ± 0.7
$Z\gamma$ incl	124.9 ± 1.2	10250	82.1 ± 0.8
$W \to e\nu$	1899 ± 28	49500	26.0 ± 0.4
$t\bar{t}$ incl	5.93 ± 0.13	52000	8769.0 ± 192

Table 3: PRELIMINARY: MC samples analyzed in the tri-EM search. The Drell-Yan cross sections for the mass ranges 2-15 and 20-60 GeV has been multiplied by a factor K= 1.6 [11].

Signal events have been generated with SUSYGEN [1] using the CTEQ5L parton distribution functions and combined with an average of 0.8 minimum-bias events . For each SUSY point 4000 events have been generated. Table 4 shows the masses of $\tilde{\chi}_1^0$ and $\tilde{\chi}_1^+$ and total neutralino or chargino pair production cross section for some points in the parameter space. The two dominant processes are neutralino-chargino and chargino-chargino pair production.

All MC events have been processed through the full detector simulation and reconstructed with d0reco (p13.06.01).

The trigger efficiency has been applied to all MC events (SM processes and SUSY) according to the following procedure :

- for each EM candidate of the event with $p_T > 15$ GeV the single-EM turn-on is applied. More precisely a random number between 0 and 1 is chosen and if it is below the turn-on value for this p_T, the event is considered as "triggered";
- if after this loop on EM candidates none has "triggered" and if the event contains at least 2 EM candidates (p_T >15 and p_T >10) the di-EM turn-on is applied as a

function of the leading p_T (using the same technic of the random number compared to turn-on value).

m_0	$m_{1/2}$	μ	$tan\beta$	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{\chi}_1^+}$	σ_{NN} (pb)	σ_{CC} (pb)	σ_{NC} (pb)	σ_{tot} (pb
150	150	<0	5	61.3	115.1	0.022	0.329	0.504	0.855
150	150	>0	5	51.4	90.1	0.035	0.936	1.653	2.624
150	175	>0	5	63.3	112.4	0.014	0.374	0.607	0.995
150	200	<0	5	81.7	156.3	0.006	0.085	0.120	0.211
150	200	>0	5	74.7	134.5	0.007	0.172	0.267	0.446
250	150	<0	5	62.0	117.3	0.017	0.321	0.498	0.836
250	150	>0	5	52.4	92.6	0.027	0.871	1.537	2.435
250	250	<0	5	103.0	199.6	0.001	0.026	0.034	0.061
250	250	>0	5	97.3	179.9	0.002	0.045	0.064	0.111
500	100	<0	5	42.9	84.2	0.040	1.534	2.616	4.190
500	150	<0	5	63.2	123.3	0.007	0.306	0.482	0.795
500	150	>0	5	55.1	100.5	0.011	0.709	1.215	1.935
750	150	<0	5	64.0	128.2	0.002	0.289	0.458	0.749
750	150	>0	5	57.3	107.9	0.004	0.585	0.981	1.570
1000	150	<0	5	64.7	131.3	0.001	0.275	0.430	0.706
1000	150	>0	5	58.9	113.6	0.001	0.509	0.836	1.346
1000	200	<0	5	85.6	172.9	0.004	0.077	0.113	0.190
1000	200	>0	5	80.3	155.2	0.001	0.128	0.193	0.322
2000	150	<0	5	66.2	139.0	0.001	0.234	0.362	0.595
2000	150	>0	5	61.5	124.5	0.001	0.381	0.614	0.995

Table 4: PRELIMINARY: Masses and cross sections for fully simulated events generated with SUSYGEN in the mSUGRA framework. (N stands for any of the four neutralinos and C for any of the two charginos)

6 QCD background

The contribution of QCD multi-jet processes fluctuating to fake electrons is determined from data by inverting the cut on the HMatrix for selection of the electron candidate [12].

Starting from the selection of events with two EM candidates with one and only one matched to a track, the QCD sample is obtained by selecting the events in which both EM candidates have their HMx8>25 (the resulting number of events is called QCD_{sample} in the following). This sample is scaled to the number of events satisfying the same criteria except the HMx8 which is required to be <20. Z and Drell-Yan expected contributions are subtracted from the data using MC events scaled at the same luminosity (the corresponding number of events is called (Data-Z-DY)$_{sample}$ in the following). Scaling factors defined as the ratio of (Data-Z-DY)$_{sample}$ over QCD$_{sample}$ have been determined for two categories of EM pairs : CCCC (0.204± 0.013) and CCEC (0.377 ± 0.028). For each category the contribution of background coming from QCD is defined as : QCD$_{bkg}$=scaling factor× QCD$_{sample}$. In this analysis, the reltive error on QCD$_{bkg}$ has been set to 7.5%, the maximal relative error in the two regions.

Figures 6, 7 8 and 9 presents, for the CCCC region, some distributions : "di-EM" invariant mass, MET, p$_T$ and η of the "EM-candidates" for Data (HMX8 < 20) and QCD$_{bkg}$. The agreement is good even if some simulated SM processes lack of statistics (in particular $W \to e\nu$, Wγ and Zγ).

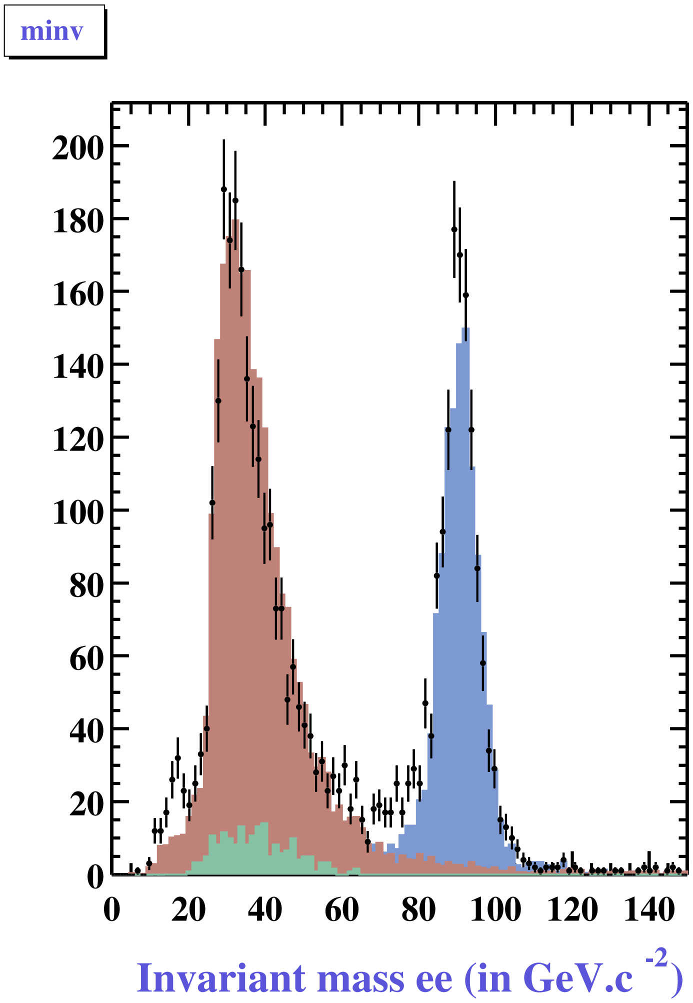

Figure 6: PRELIMINARY : QCD background study in CCCC. Distributions of "di-EM" invariant mass. Data points : data HMx8 < 20 and one matched electron only. Histogram : Drell-Yan (green), Z (blue) and QCD$_{bkg}$($brown$). The excess of events around 15 < m$_{ee}$ < 20 GeV is due to Υ production which has not been included yet in the simulation.

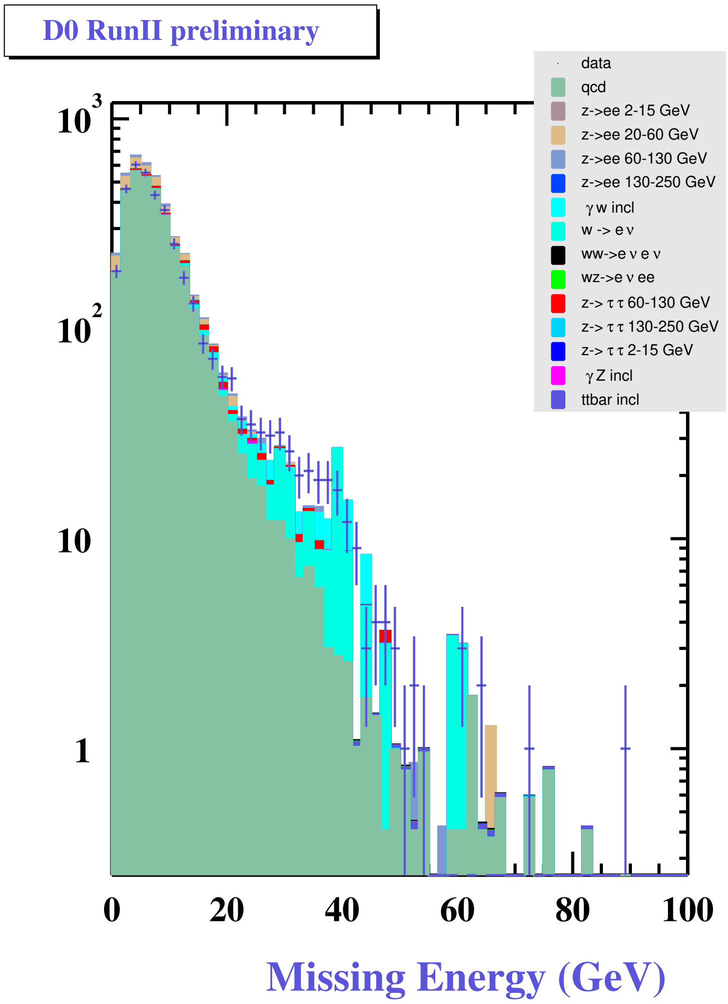

Figure 7: PRELIMINARY : QCD background study in CCCC. Distributions of MET of the "di-EM-candidates" events with a di-EM invariant mass < 70 GeV. Data points : data selection with HMx8 < 20 and one matched electron only. Histogram : sum of the backgrounds including the $\mathrm{QCD}_{bkg}(darkgreen)$.

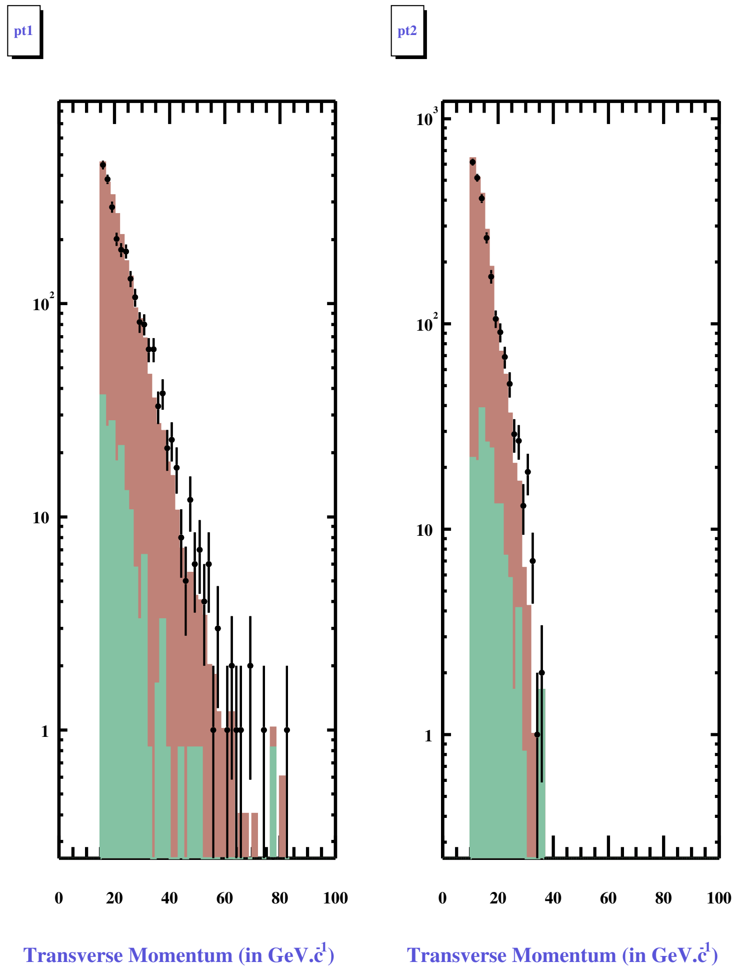

Figure 8: PRELIMINARY : QCD background study in CCCC. P$_T$ distributions of the "EM-candidates" of the "di-EM-candidates" events with a di-EM invariant mass $<$ 70 GeV. Data points : data selection with HMx8 $<$ 20 and one matched electron only. Histogram : sum Drell-Yan (green) and QCD$_{bkg}(brown)$.

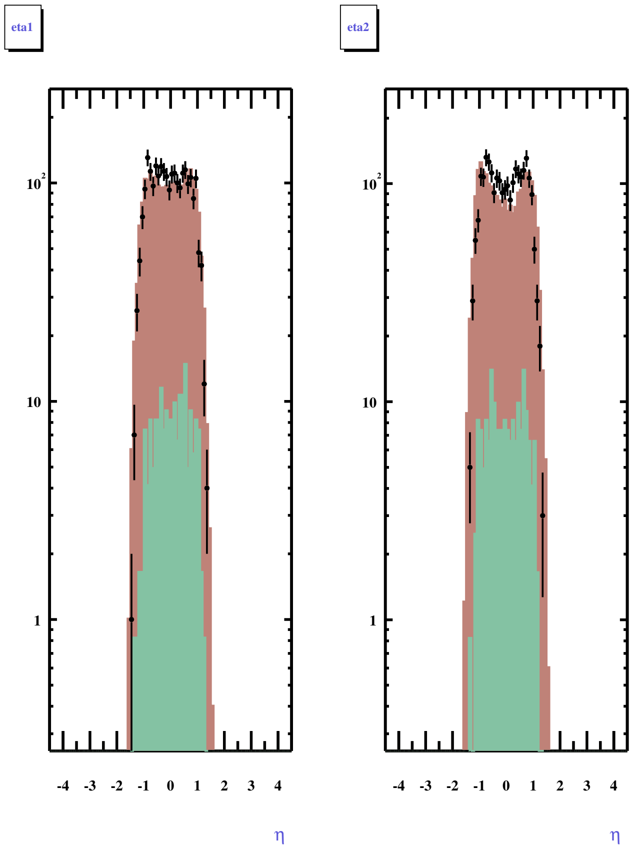

Figure 9: PRELIMINARY : QCD background study in CCCC. η distributions of the "EM-candidates" of the "di-EM-candidates" events with a di-EM invariant mass < 70 GeV. Data points : data selection with HMx8 < 20. Histogram : sum of Drell Yan and QCD$_{bkg}$.

7 Tri-electron analysis

7.1 Di-electron selection cuts

To control that the data are well understood, first a di-electron selection is applied and the properties of the selected events are compared to SM expectation and instrumental background.

The following cuts have been applied :

- at least 2 EM-candidate ID = 10 OR |ID| = 11 (section 3).
- both should satisfy the condition "is_in_eta_fiducial" of the EM ID group [7]. This implies that the energy lost in phi crack is corrected and that the EM candidates near the cryostat edges are removed ($|z| < 115$ cm in the CC and r < 85 cm in the EC);

- EM candidate should be outside ICD region (abs(η) between 1.1 and 1.5)
- EM with abs(η)>4 are not considered. It has been observed that when a matching with a track is required, no EM candidates are found for abs(η)>3;
- the EM candidate should be isolated from jets (d > 0.7);
- p_T(leading EM-candidate) > 15 GeV/c;
- p_T(next to leading EM-candidate) > 10 GeV/c;
- $|\eta$(leading EM-candidate)$|$ < 1.1.

Figure 10 shows the di-EM invariant mass at the condition that only one EM candidate is matched with a track.

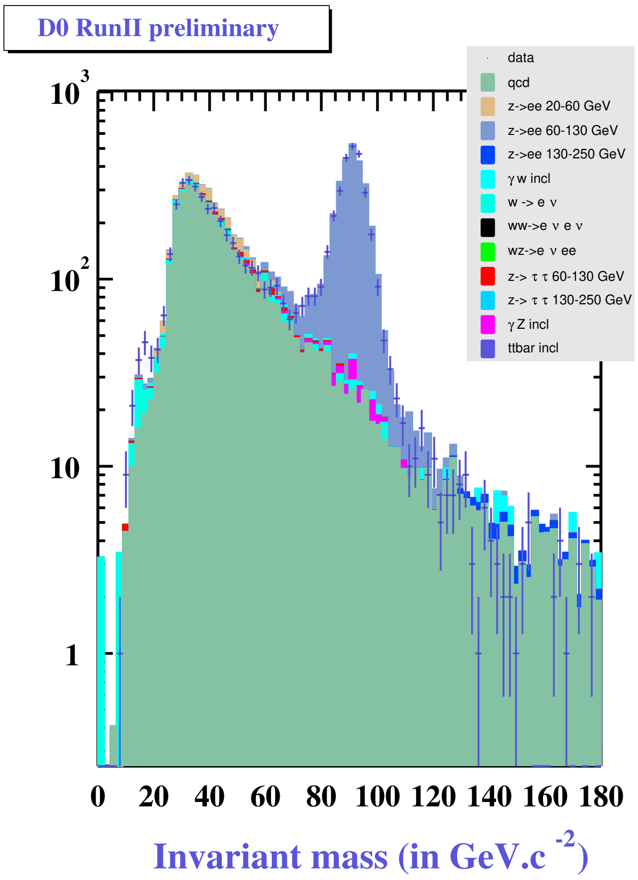

Figure 10: PRELIMINARY : Di-EM invariant mass distribution. The two EM candidates are isolated from jets, leading EM in CC, p_T leading > 15 GeV, p_T next to leading > 10 GeV and at least one candidate is matched with a track. Υ production is not included in the simulation.

Figure 11 shows the di-EM invariant mass at the condition that the two EM candidates are matched with a track.

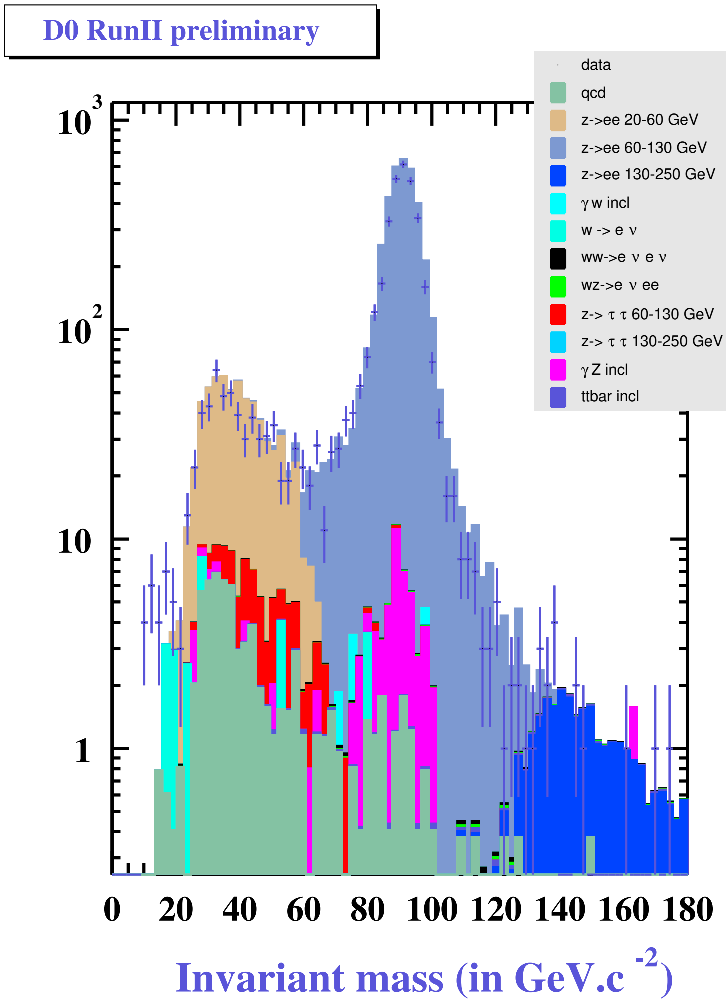

Figure 11: PRELIMINARY : Di-EM invariant mass distribution. The two EM candidates are isolated from jets, leading EM in CC, p_T leading > 15 GeV, p_T next to leading > 10 GeV and the two candidates are matched with a track. Υ production is not included in the simulation.

Numbers of data and expected events are given in Table 5. In this Table, processes giving no contribution at the level of the condition "2 matched EM" are not mentioned (i.e : $\gamma^*/Z \rightarrow ee$ (2 – 15), $\gamma^*/Z \rightarrow \tau\tau$ (2 – 15) and $\gamma^*/Z \rightarrow \tau\tau$ (130 - 250)). For SM processes, the quoted error includes the systematic errors on the cross section, the trigger, the matching, the EMID and the luminosity and is computed as :

$$(d\epsilon/\epsilon)^2 =$$
$$(d\epsilon_{sel}/\epsilon_{sel})^2 + (d\epsilon_{lumi}/\epsilon_{lumi})^2 + (d\epsilon_{\sigma}/\epsilon_{\sigma})^2 + (d\epsilon_{trig}/\epsilon_{trig})^2 + (d\epsilon_{match}/\epsilon_{match})^2 + (d\epsilon_{emid}/\epsilon_{emid})^2$$

7.2 Tri-electron selection cuts

A third EM candidate (satisfying the criteria of subsection 3.1) is searched for in the di-electron sample (both electrons are matched with a track).
Figure 12 shows the p_T of this 3rd EM candidate.Numbers of data and expected events are given in Table 5.

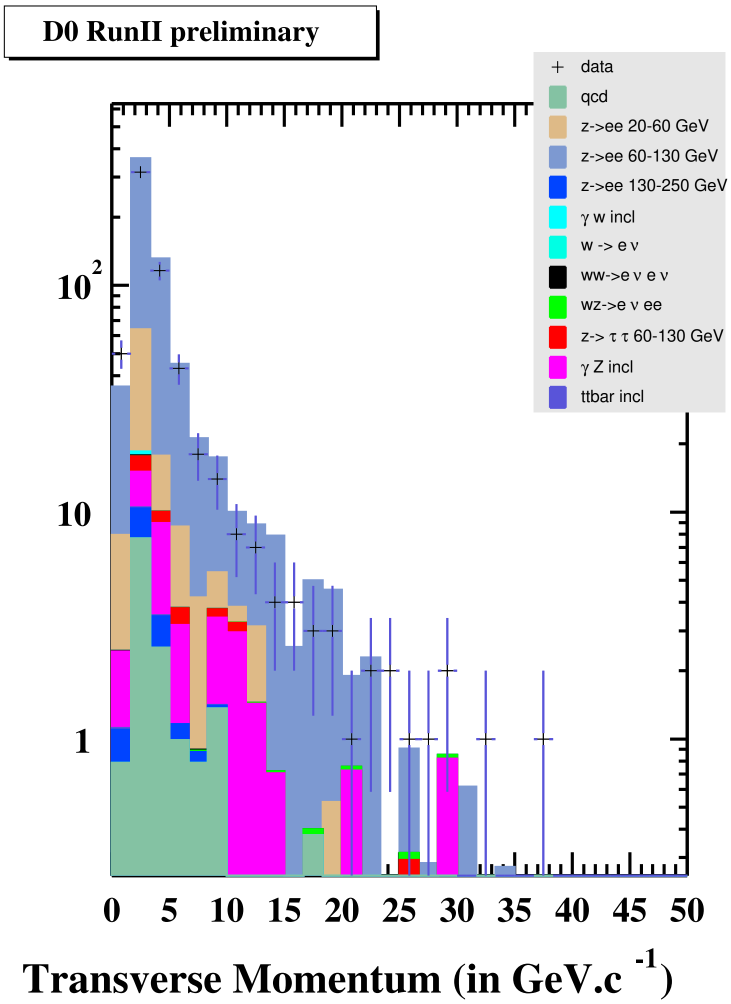

Figure 12: PRELIMINARY : P_T of all 3rd EM candidate in the di-electron selection . The two leading EM candidated are isolated from jets, leading EM in CC, p_T leading > 15 GeV, p_T next to leading > 10 GeV, the two candidates are matched with a track.

Further cuts are applied to improve the quality of the 3rd electron candidate :

- p_T(EM-candidate) > 5 GeV/c ;
- $\Delta R > 0.7$ from any jet;

- satisfy the condition "is_in_eta_fiducial" of the EM ID group [7] ;

Figure 13 shows the p_T of this 3rd EM candidate satisfying those criteria.

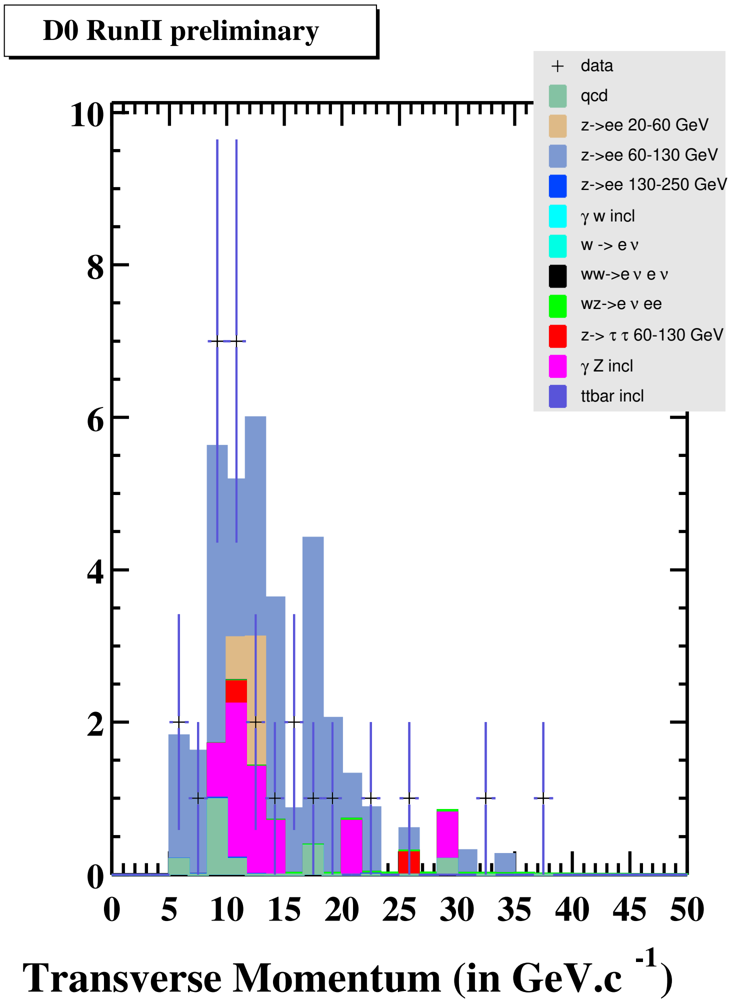

Figure 13: PRELIMINARY : P_T of the 3rd selected EM candidate in the di-electron selection . The two leading EM candidated are isolated from jets, leading EM in CC, p_T leading $>$ 15 GeV, p_T next to leading $>$ 10 GeV, the two candidates are matched with a track.

An additional requirement is made to improve the quality of the third electron:

- the 3rd EM candidate should be matched with a track

3 events remain after those cuts and 3.0 ± 1.5 are expected from background (see Table 5).

Figure 14 shows invariant mass of the two leading EM-candidates of the 3 selected tri-electron events and Figure 15 the p_T distribution of the matched 3rd electron..

As the dominant backgrounds are coming from SM processes implying Z ($\gamma^*/Z \to ee$ (60 – 130), WZ and $Z\gamma$ *incl*), a further cut on the invariant mass of the two leading electrons is applied :

- $m_{ee} < 70$ GeV

1 event remains in data for 1.2 ± 0.8 expected from background (Table 5).

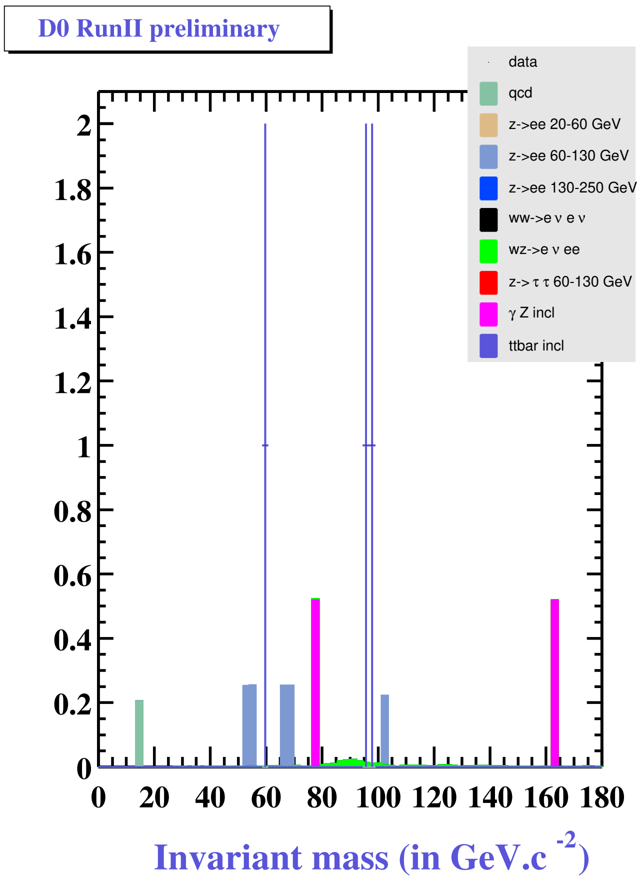

Figure 14: PRELIMINARY : invariant mass distribution of the two leading EM-candidates in the 3 selected tri-electron events

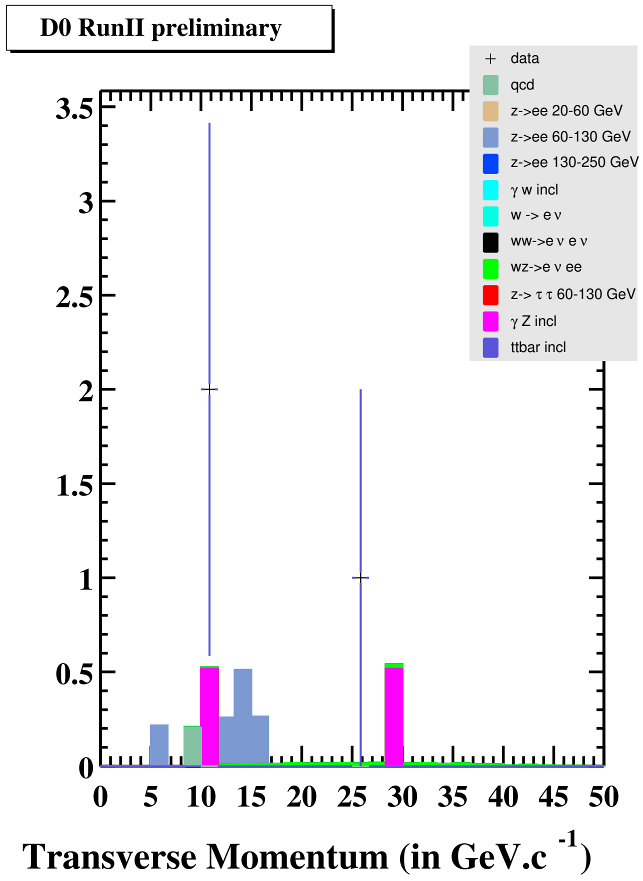

Figure 15: PRELIMINARY : p_T distribution of the 3rd EM-candidate in the 3 selected tri-electron events

The main characteristics of those events are given in the Table 6.

SM process	2 matched EM	leading EM in CC	3rd EM candidate	matched 3rd EM	$m_{ee} < 70$ GeV
$\gamma^*/Z \to ee$ (20 – 60)	1095 ± 301	526 ± 145	2.3 ± 1.0	0 ± 0.0001	0 ± 0.0001
$\gamma^*/Z \to ee$ (60 – 130)	6067 ± 1657	3845 ± 1050	25.2 ± 7.9	1.26 ± 0.08	1.0 ± 0.08
$\gamma^*/Z \to ee$ (130 – 250)	38.8 ± 9.5	32.2 ± 7.9	0.06 ± 0.03	0 ± 0.0001	0 ± 0.0001
$\gamma^*/Z \to \tau\tau$ (60 – 130)	58.7 ± 16.7	38.9 ± 11.3	0.58 ± 0.68	0 ± 0.0001	0 ± 0.0001
WW	2.20 ± 0.54	1.80 ± 0.44	0.008 ± 0.003	0.0002 ± 0.0001	0.0002 ± 0.0001
WZ	1.52 ± 0.38	1.13 ± 0.28	0.44 ± 0.12	0.31 ± 0.08	0.025 ± 0.007
$W\gamma$ *incl*	5.6 ± 3.2	3.7 ± 2.6	0 ± 0.0001	0 ± 0.0001	$0 \pm .0001$
$Z\gamma$ *incl*	73.7 ± 19.7	46.8 ± 13.1	6.3 ± 3.0	1.20 ± 1.24	0 ± 0.0001
$W \to e\nu$	24.2 ± 10.8	16.9 ± 8.5	0 ± 0.0001	0 ± 0.0001	0 ± 0.0001
$t\bar{t}$ *incl*	1.81 ± 0.46	1.67 ± 0.43	0.02 ± 0.02	0 ± 0.0001	0 ± 0.0001
QCD	169 ± 11	93 ± 6	2.0 ± 0.1	0.2 ± 0.01	0.2 ± 0.01
total bkg	7538 ± 1680	4608 ± 1060	39.9 ± 8.6	3.0 ± 1.5	1.2 ± 0.08
DATA	5988	3907	28	3	1

Table 5: PRELIMINARY: Number of Data events and of expected background events after each cut of the tri-electron selection. The errors include trigger, cross section and luminosity sytematic errors

	event 1	event 2	event 3
selected if $m_{ee} < 70$ GeV ?	yes	no	no
Runnum	175 869	169 774	166 782
Eventnum	30 979 360	7 277 943	125 150 615
p_T 3rd EM (GeV)	10.9	26	10.5
η	-2.02	1.46	0.76
Φ	0.793	1.95	6.02
3rd lepton matched ?	yes	yes	yes
charges	$+-+$	$-+-$	$+--$
$M_{e_1e_2}$ (Gev c^{-2})	61	96	98
$M_{e_2e_3}$ (Gev c^{-2})	43	82	42
$M_{e_3e_1}$ (Gev c^{-2})	58	45	27
$M_{e_1e_2e_3}$ (Gev c^{-2})	95	134	110

Table 6: PRELIMINARY: Main characteristics of the selected tri-electron candidates.

8 Systematic errors

8.1 Systematic error due to the luminosity

The relative error on the luminosity is estimated at 10% and has been included in the errors of Table 5.

8.2 Systematic error due to Trigger

The parameters of the single-EM turn-on curve have been changed by one σ and the resulting relative variation of the efficiency is shown in Table 7 for some values of p_T. For the di-EM trigger, the relative systematic error is 11/60= 0.18 (section 4). As the mean p_T of the electrons we are dealing with is of the order of 25-30 GeV, we have set the systematic error due to trigger turn-on at 20%. This error has been included in the errors of Table 5.

p_T = 20 GeV	0.76
p_T = 30 GeV	0.33
p_T = 40 GeV	0.14

Table 7: PRELIMINARY: Relative systematic error on the single-EM trigger turn-on.

8.3 Systematic error due to MC cross sections

The relative systematic errors due to cross section are for SM processes deduced from Table 3 and included in the errors of Table 5.

9 Results : exclusion limits

9.1 Cross sections limits at 95% CL

In order to estimate the sensitivity of the present analysis to RpV SUSY with λ_{121}, efficiencies of the cuts were studied and are presented Table 8 for $m_{1/2} = 150$ and tan$\beta = 5$. The final efficiency $\times$ acceptance is obtained by multiplying this efficiency by the offline EMID reconstruction and track matching factors mentioned in subsection 3.2.

	$m_0 = 750$ $\mu < 0$	$m_0 = 750$ $\mu > 0$	$m_0 = 1000$ $\mu < 0$	$m_0 = 1000$ $\mu > 0$	$m_0 = 2000$ $\mu < 0$	$m_0 = 2000$ $\mu > 0$
triggered	0.963 ± 0.006	0.948 ± 0.007	0.961 ± 0.006	0.956 ± 0.006	0.953 ± 0.006	0.945 ± 0.007
nb EM > 2	0.801 ± 0.012	0.793 ± 0.012	0.805 ± 0.013	0.802 ± 0.012	0.799 ± 0.012	0.797 ± 0.012
in_fiducial	0.798 ± 0.012	0.789 ± 0.012	0.802 ± 0.013	0.798 ± 0.012	0.793 ± 0.012	0.792 ± 0.012
jet isolation	0.643 ± 0.015	0.623 ± 0.015	0.647 ± 0.015	0.623 ± 0.015	0.644 ± 0.015	0.615 ± 0.015
HMx8 < 20	0.527 ± 0.015	0.522 ± 0.015	0.529 ± 0.016	0.522 ± 0.015	0.529 ± 0.015	0.513 ± 0.015
$P_{T1} > 15$ $P_{T2} > 10$	0.499 ± 0.015	0.471 ± 0.015	0.495 ± 0.016	0.480 ± 0.015	0.497 ± 0.016	0.463 ± 0.015
2 matched EM	0.397 ± 0.007	0.382 ± 0.007	0.396 ± 0.007	0.392 ± 0.007	0.398 ± 0.007	0.379 ± 0.007
leading EM in CC	0.359 ± 0.007	0.332 ± 0.007	0.357 ± 0.007	0.343 ± 0.007	0.357 ± 0.007	0.332 ± 0.007
3rd EM candidate	0.147 ± 0.005	0.133 ± 0.005	0.146 ± 0.005	0.132 ± 0.005	0.146 ± 0.005	0.129 ± 0.005
matched 3rd EM	0.130 ± 0.004	0.117 ± 0.004	0.130 ± 0.004	0.117 ± 0.004	0.124 ± 0.004	0.112 ± 0.004
$m_{ee} < 70$ GeV	0.082 ± 0.004	0.090 ± 0.004	0.088 ± 0.004	0.083 ± 0.004	0.081 ± 0.004	0.087 ± 0.004

Table 8: PRELIMINARY: Efficiencies and their statistical error after each cut for the SUSY points generated with $m_{1/2} = 150$ tan$\beta = 5$.

A Bayesian 95 % CL limit has been computed using the root macro written by G. Landsberg [14]. For each fully simulated point at tanβ=5, the efficiency $\times$ acc and its error as well as the limit on σ at 95 % CL are given given in :

- Table 9 for $\mu < 0$ and Table 10 for $\mu > 0$;

- Table 11 for $\mu < 0$ and Table 12 for $\mu > 0$ (with the additional requirement that the invariant mass of the two leading electrons is : $m_{ee} < 70$ GeV).

The relative uncertainty on the efficiency $\times$ acceptance (including the luminosity error and the systematic errors due to cross section, trigger turn-on ,matching and emid) is computed as :

$$(d\epsilon/\epsilon)^2 = \\ (d\epsilon_{sel}/\epsilon_{sel})^2 + (d\epsilon_{match1}/\epsilon_{match1})^2 + (d\epsilon_{emid1}/\epsilon_{emid1})^2 + (d\epsilon_{match2}/\epsilon_{match2})^2 + (d\epsilon_{emid2}/\epsilon_{emid2})^2 + \\ (d\epsilon_{match3}/\epsilon_{match3})^2 + (d\epsilon_{emid3}/\epsilon_{emid3})^2 + (d\epsilon_{lumi}/\epsilon_{lumi})^2 + (d\epsilon_{\sigma}/\epsilon_{\sigma})^2 + (d\epsilon_{trig}/\epsilon_{trig})^2$$

where ϵ_{sel}, ϵ_{eid}, ϵ_{match} and ϵ_{lumi} are the selection, matching and emid efficiencies respectively.

	$m_0 = 150$ $m_{1/2} = 150$	$m_0 = 250$ $m_{1/2} = 150$	$m_0 = 500$ $m_{1/2} = 150$	$m_0 = 750$ $m_{1/2} = 150$	$m_0 = 1000$ $m_{1/2} = 150$	$m_0 = 2000$ $m_{1/2} = 150$
excluded ?	yes D0	yes D0	yes D0			
$\sigma_{NN+CC+NC}$ (pb)	0.855	0.836	0.795	0.749	0.706	0.595
eff $\times acc$	0.054 ± 0.013	0.038 ± 0.010	0.053 ± 0.013	0.054 ± 0.013	0.053 ± 0.013	0.051 ± 0.013
evts expected	5.5 ± 0.8	3.8 ± 0.6	5.0 ± 0.7	4.7 ± 0.7	4.4 ± 0.7	3.6 ± 0.5
$\sigma_{95}(pb)$	1.191	1.850	1.227	1.227	1.227	1.324
exclusion ?	no	no	no	no	no	no

	$m_0 = 150$ $m_{1/2} = 200$	$m_0 = 250$ $m_{1/2} = 250$	$m_0 = 500$ $m_{1/2} = 100$	$m_0 = 1000$ $m_{1/2} = 200$		
excluded ?			yes LEP yes D0			
$\sigma_{NN+CC+NC}$ (pb)	0.211	0.061	4.190	0.190		
eff $\times acc$	0.078 ± 0.019	0.069 ± 0.017	0.029 ± 0.007	0.065 ± 0.016		
evts expected	1.9 ± 0.3	0.5 ± 0.1	14.5 ± 2.3	1.4 ± 0.2		
σ_{95} (pb)	0.833	0.940	2.219	1.009		
exclusion ?	no	no	yes	no		

Table 9: PRELIMINARY: Tests of exclusion on the SUSY points generated with $\mu < 0$ and $\tan\beta = 5$. Table shows cross sections for neutralino-neutralino (NN), chargino-chargino (CC), neutralino-chargino (NC), efficiencies and errors and the σ_{95}. LEP limits are $m_{\tilde{\chi}_1^0} > 40$ GeV and $m_{\tilde{\chi}_1^+} > 103$ GeV [16]. D0 Run I results are published in ref [15]. The number of expected events is for an integrated luminosity of 117.5 pb^{-1}.

	$m_0 = 150$ $\mathrm{m}_{1/2} = 150$	$m_0 = 250$ $\mathrm{m}_{1/2} = 150$	$m_0 = 500$ $\mathrm{m}_{1/2} = 150$	$m_0 = 750$ $\mathrm{m}_{1/2} = 150$	$m_0 = 1000$ $\mathrm{m}_{1/2} = 150$	$m_0 = 2000$ $\mathrm{m}_{1/2} = 150$
excluded ?	yes LEP yes D0	yes LEP yes D0	yes LEP yes D0			
$\sigma_{NN+CC+NC}$ (pb)	2.624	2.435	1.935	1.570	1.346	0.995
eff $\times acc$	0.048 ± 0.012	0.044 ± 0.011	0.046 ± 0.011	0.048 ± 0.012	0.048 ± 0.012	0.047 ± 0.012
evts expected	15.7 ± 2.3	12.6 ± 1.9	10.5 ± 1.6	8.9 ± 1.4	7.6 ± 1.2	5.5 ± 0.8
$\sigma_{95}(pb)$	1.382	1.509	1.390	1.382	1.382	1.443
exclusion ?	yes	yes	yes	yes	no	no
	$m_0 = 150$ $\mathrm{m}_{1/2} = 175$	$m_0 = 150$ $\mathrm{m}_{1/2} = 200$	$m_0 = 250$ $\mathrm{m}_{1/2} = 250$	$m_0 = 1000$ $\mathrm{m}_{1/2} = 200$		
excluded ?	yes D0	yes D0				
$\sigma_{NN+CC+NC}$ (pb)	0.995	0.446	0.111	0.322		
eff $\times acc$	0.065 ± 0.016	0.073 ± 0.018	0.063 ± 0.016	0.064 ± 0.016		
evts expected	7.5 ± 1.2	3.8 ± 0.6	0.8 ± 0.1	2.4 ± 0.4		
σ_{95} (pb)	1.009	0.883	1.025	1.039		
exclusion ?	no	no	no	no		

Table 10: PRELIMINARY: Tests of exclusion on the SUSY points generated with $\mu > 0$ and tan$\beta = 5$. Table shows cross sections for neutralino-neutralino (NN), chargino-chargino (CC), neutralino-chargino (NC), efficiencies and errors including the error on the luminosity and the σ_{95}. LEP limits are $\mathrm{m}_{\tilde{\chi}_1^0} > 40$ GeV and $\mathrm{m}_{\tilde{\chi}_1^+} > 103$ GeV [16]. D0 Run I results are published in ref [15]. The number of expected events is for an integrated luminosity of 117.5 pb^{-1}.

	$m_0 = 150$ $\mathrm{m}_{1/2} = 150$	$m_0 = 250$ $\mathrm{m}_{1/2} = 150$	$m_0 = 500$ $\mathrm{m}_{1/2} = 150$	$m_0 = 750$ $\mathrm{m}_{1/2} = 150$	$m_0 = 1000$ $\mathrm{m}_{1/2} = 150$	$m_0 = 2000$ $\mathrm{m}_{1/2} = 150$
excluded ?	yes D0	yes D0	yes D0			
$\sigma_{NN+CC+NC}$ (pb)	0.855	0.836	0.795	0.749	0.706	0.595
cut Z eff $\times acc$	0.035 ± 0.009	0.025 ± 0.006	0.034 ± 0.009	0.034 ± 0.009	0.036 ± 0.009	0.033 ± 0.008
cut Z evts expected	3.5 ± 0.5	2.4 ± 0.4	3.2 ± 0.5	3.0 ± 0.5	3.0 ± 0.5	2.3 ± 0.4
cut Z $\sigma_{95}(pb)$	1.350	1.772	1.442	1.442	1.276	1.349
cut Z exclusion ?	no	no	no	no	no	no
	$m_0 = 150$ $\mathrm{m}_{1/2} = 200$	$m_0 = 250$ $\mathrm{m}_{1/2} = 250$	$m_0 = 500$ $\mathrm{m}_{1/2} = 100$	$m_0 = 1000$ $\mathrm{m}_{1/2} = 200$		
excluded ?			yes LEP yes D0			
$\sigma_{NN+CC+NC}$ (pb)	0.211	0.061	4.190	0.190		
cut Z eff $\times acc$	0.035 ± 0.009	0.022 ± 0.006	0.025 ± 0.006	0.035 ± 0.009		
cut Z evts expected	0.9 ± 0.1	0.16 ± 0.03	12.1 ± 1.9	0.8 ± 0.1		
cut Z $\sigma_{95}(pb)$	1.350	2.311	1.772	1.350		
cut Z exclusion ?	no	no	yes	no		

Table 11: PRELIMINARY: Tests of exclusion on the SUSY points generated with $\mu < 0$ and tan$\beta = 5$. Table shows cross sections for neutralino-neutralino (NN), chargino-chargino (CC), neutralino-chargino (NC), efficiencies and errors and the σ_{95}. LEP limits are $\mathrm{m}_{\tilde{\chi}_1^0} > 40$ GeV and $\mathrm{m}_{\tilde{\chi}_1^+} > 103$ GeV [16]. D0 Run I results are published in ref [15]. The number of expected events is for an integrated luminosity of 117.5 pb^{-1}.
Cut Z stands for the additional condition : invariant mass pair of the two leading $\mathrm{m}_{ee} < 70$ GeV.

	$m_0 = 150$ $m_{1/2} = 150$	$m_0 = 250$ $m_{1/2} = 150$	$m_0 = 500$ $m_{1/2} = 150$	$m_0 = 750$ $m_{1/2} = 150$	$m_0 = 1000$ $m_{1/2} = 150$	$m_0 = 2000$ $m_{1/2} = 150$
excluded ?	yes LEP yes D0	yes LEP yes D0	yes LEP yes D0			
$\sigma_{NN+CC+NC}$ (pb)	2.624	2.435	1.935	1.570	1.346	0.995
cut Z eff $\times acc$	0.035 ± 0.009	0.031 ± 0.009	0.035 ± 0.009	0.037 ± 0.009	0.034 ± 0.009	0.036 ± 0.009
cut Z evts expected	10.7 ± 1.7	9.6 ± 1.5	7.9 ± 1.2	6.9 ± 1.1	5.4 ± 0.8	4.2 ± 0.7
cut Z σ_{95} (pb)	1.350	1.870	1.350	1.212	1.442	1.276
cut Z exclusion ?	yes	yes	yes	yes	no	no
	$m_0 = 150$ $m_{1/2} = 175$	$m_0 = 150$ $m_{1/2} = 200$	$m_0 = 250$ $m_{1/2} = 250$	$m_0 = 1000$ $m_{1/2} = 200$		
excluded ?	yes D0	yes D0				
$\sigma_{NN+CC+NC}$ (pb)	0.995	0.446	0.111	0.322		
cut Z eff $\times acc$	0.040 ± 0.010	0.040 ± 0.010	0.025 ± 0.006	0.034 ± 0.009		
cut Z evts expected	4.7 ± 0.7	2.0 ± 0.3	0.32 ± 0.05	1.3 ± 0.2		
cut Z σ_{95} (pb)	1.149	1.149	1.771	1.442		
cut Z exclusion ?	no	no	no	no		

Table 12: PRELIMINARY: Tests of exclusion on the SUSY points generated with $\mu > 0$ and $\tan\beta = 5$. Table shows cross sections for neutralino-neutralino (NN), chargino-chargino (CC), neutralino-chargino (NC), efficiencies and errors including the error on the luminosity and the σ_{95}. LEP limits are $m_{\tilde{\chi}_1^0} > 40$ GeV and $m_{\tilde{\chi}_1^+} > 103$ GeV [16]. D0 Run I results are published in ref [15]. The number of expected events is for an integrated luminosity of 117.5 pb^{-1}. Cut Z stands for the additional condition : invariant mass pair of the two leading $m_{ee} < 70$ GeV.

9.2 Discussion of the results

For $\tan\beta = 5$ and no cut of the invariant mass of the leading ee pair, one can draw the following main conclusions:

- for $\mu < 0$ $\sigma_{95} > 1.3$ pb are excluded for $m_0 > 500$ GeV and $m_{1/2} = 150$ GeV and $\sigma_{95} > 1$ pb for $m_{1/2} \geq 200$ GeV ;
- for $\mu > 0$ $\sigma_{95} > 1.4$ pb are excluded for $m_0 > 500$ GeV and $m_{1/2} = 150$ GeV and $\sigma_{95} > 1$ pb for $m_{1/2} \geq 200$ GeV.

In almost all cases studied, limits without the mass condition ($m_{ee} < 70$ GeV) are presently better because :

- for regions where the gauginos are heavy this condition reduces the efficiency. This effect can be seen on Figure 16 (m_0= 500, $m_{1/2}$ = 100, $\mu < 0$: "light" gauginos) and Figure 17 (m_0= 750, $m_{1/2}$ = 150, $\mu < 0$: "heavy" gaugino). Those figures show also the tri-EM invariant mass. A cut on this mass could reduce events in which one electron of the Z radiates a hard photon. The remaining data event (see Table 6) can be interpreted this way. This hypothesis is corroborated with the number of expected Z events (Table 5). Cut on di-EM and tri-EM invariant mass which can improve the ratio signal/sqrt(background) will be studied in the future.
- the error on the MC efficiency signal is presently relatively high due to the limited statistics of the MC samples for the signal (4000 events).

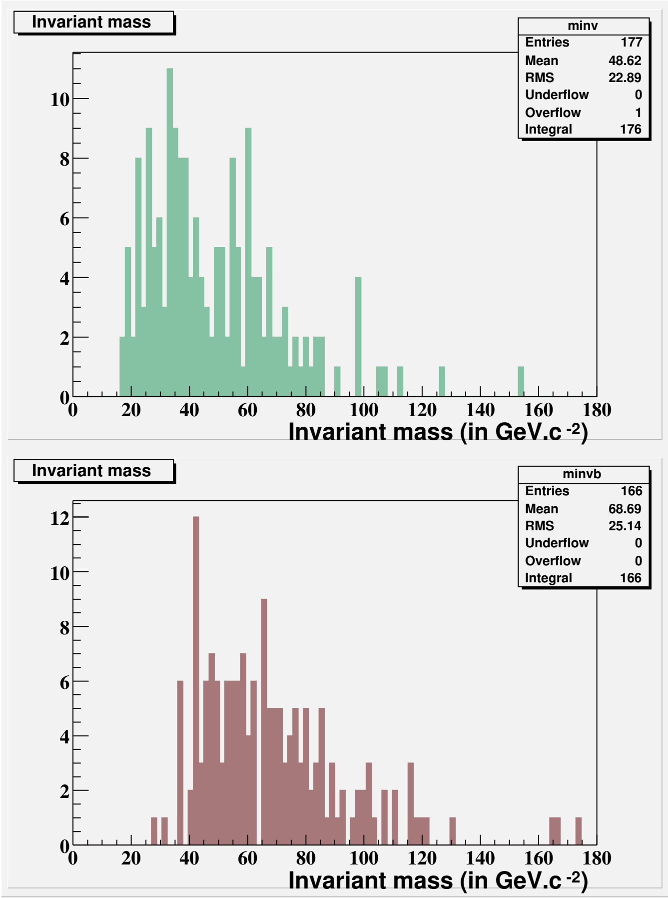

Figure 16: PRELIMINARY : invariant mass distributions of the two leading EM-candidates (top figure) and of the three leading EM candidates (bottom figure) for signal : m_0= 500, $m_{1/2}$ = 100 and $\mu < 0$.

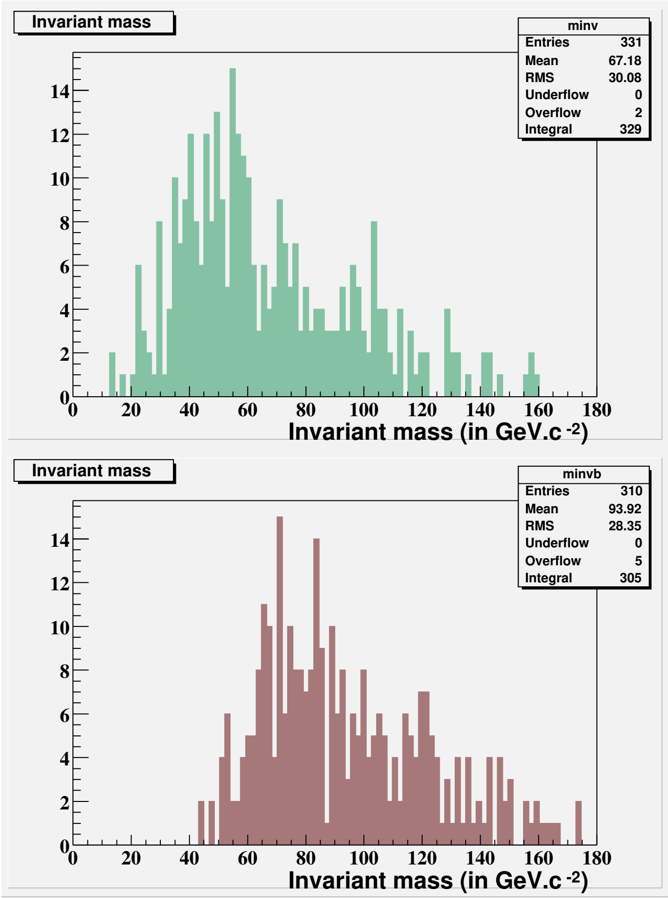

Figure 17: PRELIMINARY : invariant mass distributions of the two leading EM-candidates (top figure) and of the three leading EM candidates (bottom figure) for signal : m_0= 750, $m_{1/2}$ = 150 and $\mu < 0$.

Considering muon triggers and including searches with muons in the final state should improve those limits and extend the domain already excluded by RunI D0 analysis [15]. Limits can already be confronted with the present constraints on the minimal supergravity model [17] in particular at $m_0 > 500$ GeV.

10 Conclusions

A preliminary search for tri-electron events in 117.5 pb^{-1} of data recorded by D0 from september 2002 to mid-june 2003 has been performed in the framework of RpV SUSY in the hypothesis of a λ_{121} coupling. 3 events have been selected for 3.0 ± 1.5 expected from SM physics processes and instrumental background. 1 event is found for 1.2 ± 0.8 expected if one requires that the invariant mass of the 2 leading electron is below 70 Gev. Preliminary study of the exclusion domain in the mSUGRA parameter space shows that for $\mu < 0$ $m_0 >$ 500 GeV and $m_{1/2} = 150$ GeV, $\sigma_{95} > 1.3$ pb are excluded and for $\mu > 0$, $m_0 > 500$ GeV and

$m_{1/2}$ = 150 GeV , $\sigma_{95} > 1.4$ pb are excluded.

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