DESY Summer Student Program 2009

Report

Trigger studies for GMSB events with high-pt photons

Vera Stalter

Universität Freiburg - Institut für Physik

DESY ATLAS group
Supervisor Wolfgang Ehrenfeld

11th September 2009

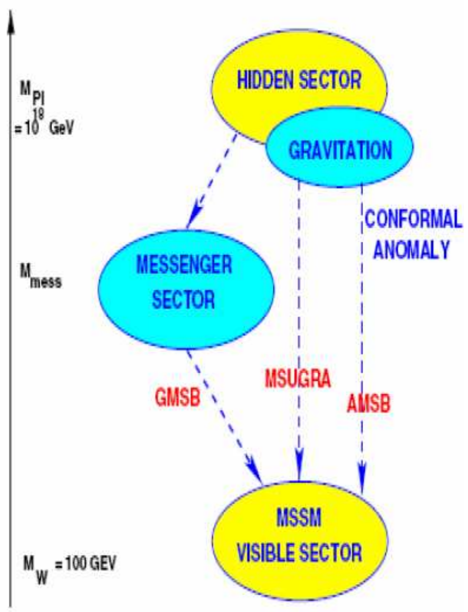
Abstract

In certain Gauge Mediated Supersymmetry Breaking (GMSB) models the next-to-lightest supersymmetric particle is the lightest neutralino. It decays into a high-p_T photon and a gravitino that is always the lightest supersymmetric particle in GMSB models. An event selection was developed and optimized using Monte Carlo data from the ATLAS experiment for the so called GMSB1 benchmark model. Further the trigger efficiency for different triggers was studied within this model.

1 Introduction

Supersymmetry (SUSY) provides an elegant way to solve many problems of the current Standard Model (SM) of particle physics. It postulates for every fermion in the SM a supersymmetrical bosonic partner and vice versa, that in general are called sparticles. It resolves the hierarchy problem in which the Higgs mass corrections due to loop effects leads to divergencies. Contributions of possible SUSY particles are in the same magnitude but with an opposite sign, hence the divergency cancels. Furthermore the unification of the fundamental forces apart from gravitation is possible. If R-parity is conserved, the lightest supersymmetrical particle (LSP), a weakly interacting particle, is stable. This might be the cause of dark matter in our universe. But only considering the minimal supersymmetrical model (MSSM) already 105 free new parameters have to be introduced.

SUSY can not be an exact symmetry as it predicts the same quantum numbers for sparticles, especially same mass. This has not been observed. Hence it must be broken. There are several theories that explain the symmetry breaking in the MSSM, that occurs in the hidden sector on the Planck scale. From there it must be transmitted to the visible MSSM sector (figure 1). GMSB is one possible breaking scenario. It introduces a messenger sector that mediates the breaking via loop effects. The minimal Supergravity (mSUGRA) model refers to a mediation through gravity, while in the Anomaly Mediated Supersymmetry Breaking (AMSB) model the breaking is not directly communicated through gravity.



In the physic program of the ATLAS group searches for signatures for physics beyond the SM (BSM), especially SUSY play a crucial role. Because SUSY processes often have a cross section in the order of a few picobarn (pb), high event rates are vital for discoveries. The Large Hadron Collider (LHC) at Cern with a center-of-mass energy up to 10 TeV and a design luminosity of

$10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ offers therefore a huge potential for BSM discoveries.
The dominant processes at the LHC is the production of jets due to strong interactions, as it is typical for proton-proton colliders. To be able to find signals for interesting physics a reliable trigger system is indispensable. Therefore clear signatures of special event searches must be given.

This project is concentrated on GMSB events, in which the gravitino ($\tilde{\mathrm{G}}$) is the LSP and the neutralino $\tilde{\chi}_1^0$ the NLSP. The event topology consists of two photons with high transverse momentum ($\mathrm{p_T}$ and multiple high-energy jets in the final state with additional high missing transverse energy due to the undetectable $\tilde{\mathrm{G}}$.
The next section is about GMSB theory in more detail, especially with a focus on the GMSB1 benchmark with a following event selection. The third section deals with studies on trigger decisions according to GMSB1 events.

2 Overview over GMSB SUSY

2.1 GMSB SUSY

GMSB is one of the most popular theories to describe the spontaneous soft SUSY breaking in the MSSM. The breaking occurs in the hidden sector and is transmitted to the low energy scale due to ordinary flavor-blind gauge interactions, through so called messengers. This is illustrated in figure 1. The messengers' mass scale $\mathrm{M_m}$ is far below the Planck scale but of a few 100 TeV also much higher than the visible SM mass scale.

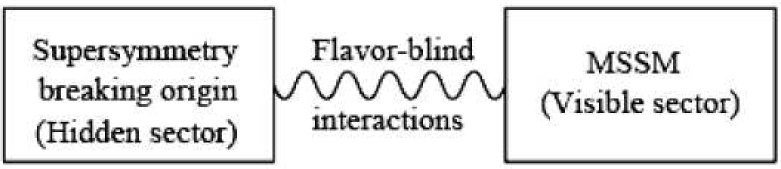


Figure 1: GMSB: SUSY breaking is mediated to visible MSSM through messenger fields

In the GMSB scenario the 105 new MSSM parameters are reduced by using assumptions on exact flavor and CP conversation to only six parameters. These are the effective SUSY breaking scale Λ, the mass scale of the messengers M_{m}, the number of messenger generations N_5, the ratio of the Higgs

	Λ [TeV]	$N_5 = 1$	M_m [TeV]	$\tan\beta$	sign(μ)	C_{grav}
GMSB1	90	1	500	5	+	1.0
GMSB2	90	1	500	5	+	30
GMSB3	90	1	500	5	+	55
GMSB6	40	3	250	30	+	1

Table 1: ATLAS specific benchmark subset

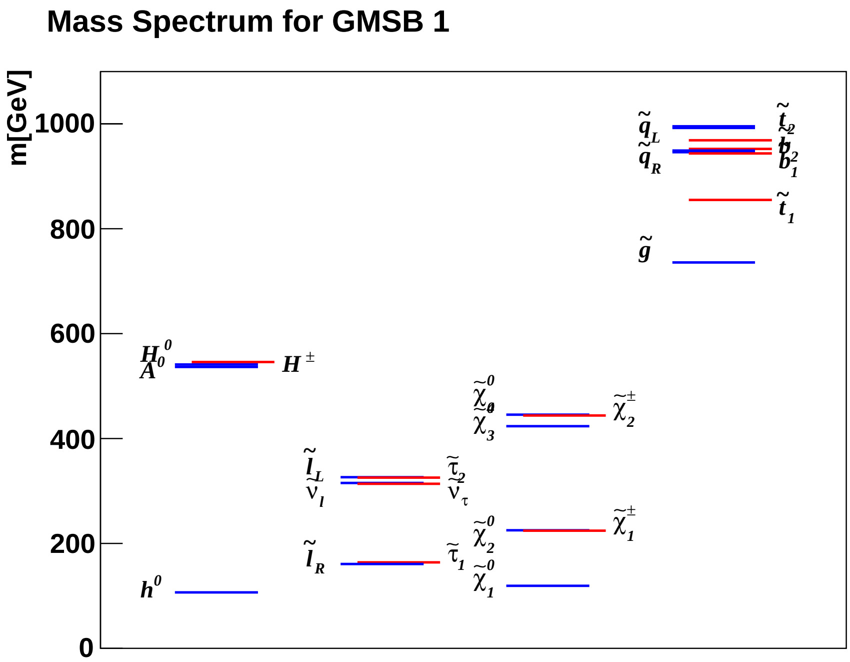


Figure 2: Masses of SUSY particle in the GMSB1 benchmark

vacuum expectation value $\tan\beta$, the sign of the higgsino mass μ and the scale factor of the gravitino coupling C_{grav}, that is related to the NLSP lifetime. The index 5 in N_5 appears because the messenger fields form a SU(5) super-multiplet.

Depending on the parameter different scenarios are possible. This report is focused on the GMSB1 benchmark. This is one of the ATLAS specific benchmark scenarios (see table 1). Here the NLSP has a very short lifetime because of $C_{\mathrm{grav}} = 1$. This leads to a promt photon decay. The masses of the sparticles with this parameter setting are shown in figure 2. Other ATLAS specific benchmarks are GMSB2 or GMSB3 in which the NLSP lifetime is longer. Due to a higher value of C_{grav} the NLSP decays outside the primary vertex. Stable heavy charged sleptons appear in the final state by increasing either N_5 or $\tan\beta$. An example therefore is the GMSB6 model with a stau as NLSP. The exact benchmarks for the different mentioned GMSB scenarios are given in table 1. A more in-depth discussion of ATLAS specific GMSB benchmarks is given in [ATL1].

2.2 GMSB1 SUSY with photon signatures

This work concentrates exclusively on the GMSB1 benchmark (see table 1). Here the lightest neutralino mass is 118.8 GeV. The photon originates very close to the primary vertex with a decay length of 1.1 mm.

At LHC there are two production mechanisms possible. On the one hand squarks or gluinos can be produced via strong interactions with a branching ratio BR) of about 75%. On the other hand there is also the production of sleptons, charginos or neutralinos possible with BR of 25% . The associated cascade decay of produced squarks or gluinos is shown in figure 3. Depending on the branching ratios decays into various SUSY particles are possible. The Feynman graph shows the standard SUSY decay chain. Because R-Parity is conserved this has to be considered twice. Therefore the typical signature is a photon pair production with high-p_T in the final states, multiple jets and high missing transverse energy due to the production of the gravitinos. There are also leptons in the final states, but they are not necessarily taken

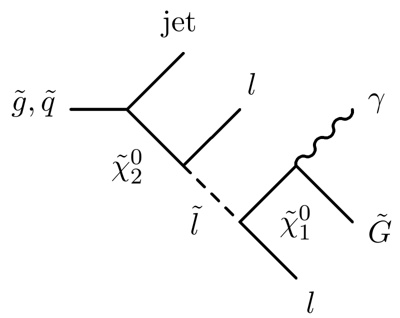


Figure 3: Main decay channel of GMSB1 events

into account because as studies already have shown [Terw3] additional lepton cuts does not really improve the search for GMSB1 SUSY events.
The neutralino decays into a $\tilde{\mathrm{G}}$ and a photon, Z boson or a electron-positron pair with a BR of 97%, 2%, 1% respectively. The total cross section for the main process is 7.8 pb in next-to-leading-order (NLO) calculations.

2.3 GMSB1 event selection

As explained in the previous section the event topology consists of high-p_T photons, high-p_T jets and high missing transverse energy E_T^{mis}. Hence the event selection is based on these objects.
The analyzed sample consists of 9986 events generated by the Monte Carlo generator HERWIG.

2.3.1 Photon preselection

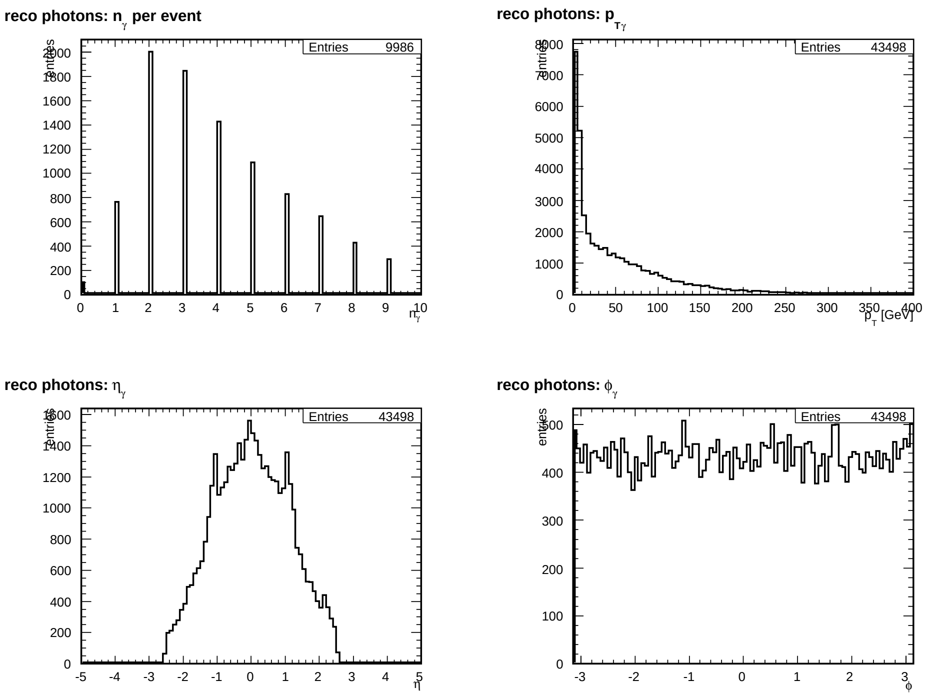


Figure 4: Distributions of the reconstructed GMSB1 photons

The p_T, η, ϕ and energy distributions of all reconstructed photons including conversions are shown in figure 4. The average number per event is 4.3.

In order to get a selection on photons only those with a p_T higher than 20 GeV are required which are within a η region less than 2.5. and outside the crack region of $1.37 \leq |\eta| \leq 1.52$. After applying these cuts the total number of photons is reduced to 45.3%. The part of conversions into a $e^- e^+$-pair from them is 10.8 % .

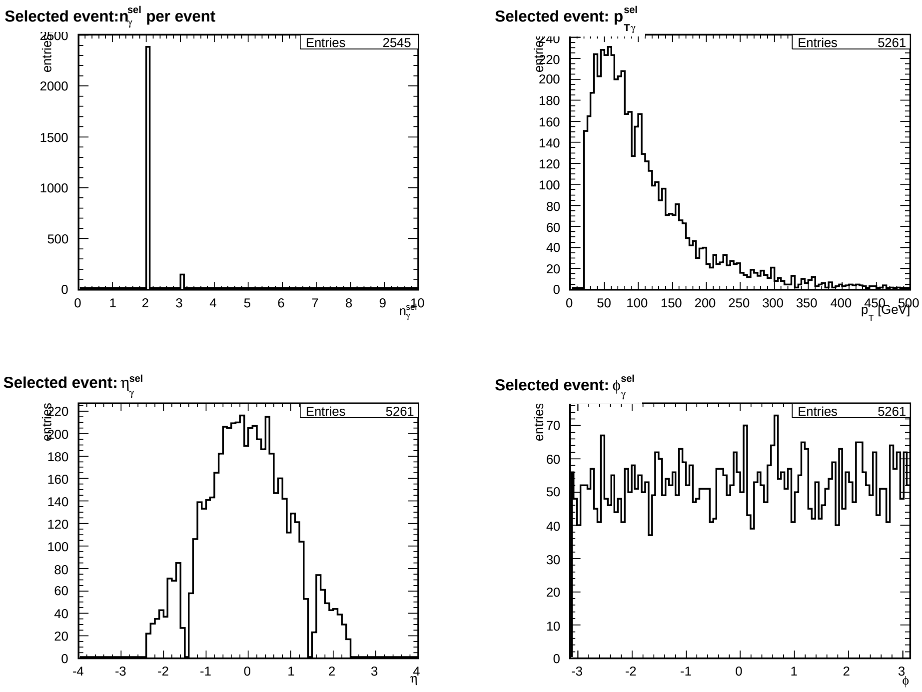


Figure 5: Distributions of GMSB1 photons after the event selection

Before, this part of conversions was with about 45% quiete huge due to among conversions happening in the crack region that consists mostly of supporting material. Hence, this range is excluded within the additional cut in η. The distributions after the photon cuts are given in figure 13 in the appendix. It shows that the p_T cut already reduces the number of photons to a maximum of three and to an average value of 2.
In figure 5 the photon distributions after the event selection is given. The final efficiency of selected versus reconstructed photons yields 12.1%.

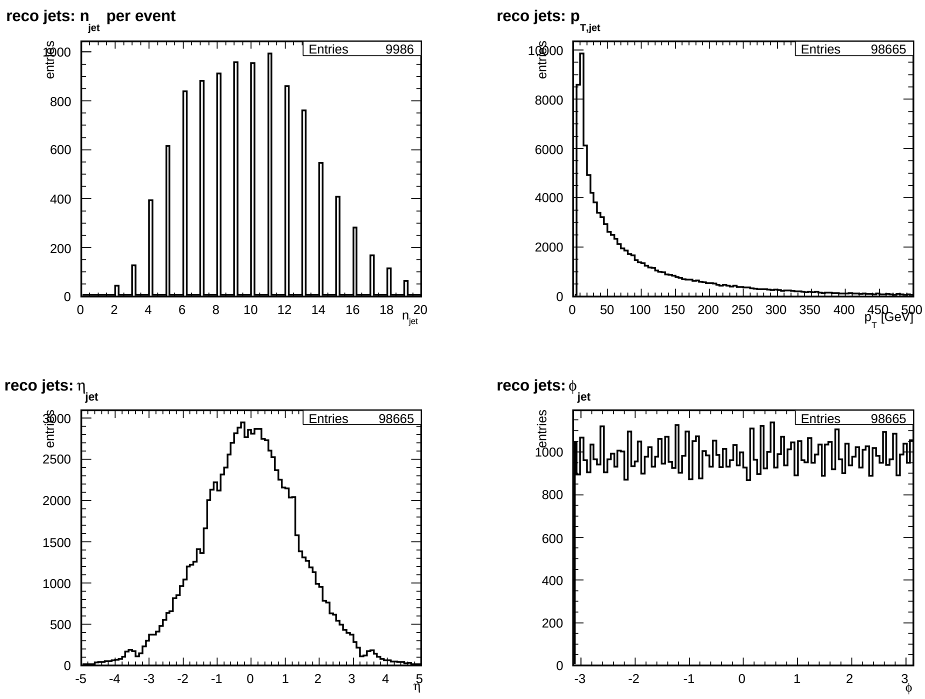


Figure 6: Distributions of the reconstructed GMSB1 jets

2.3.2 Jet preselection

The p_{T}, η, ϕ and energy distributions for all the reconstructed jets are given in figure 6. The average number here is about 10 per event with the maximum of about 20 per event. The cuts for a selection are also chosen in respect on high transverse momentum (high-$\mathrm{p_T}$ 50 GeV) jets within the central barrel region of η less than 2.5.

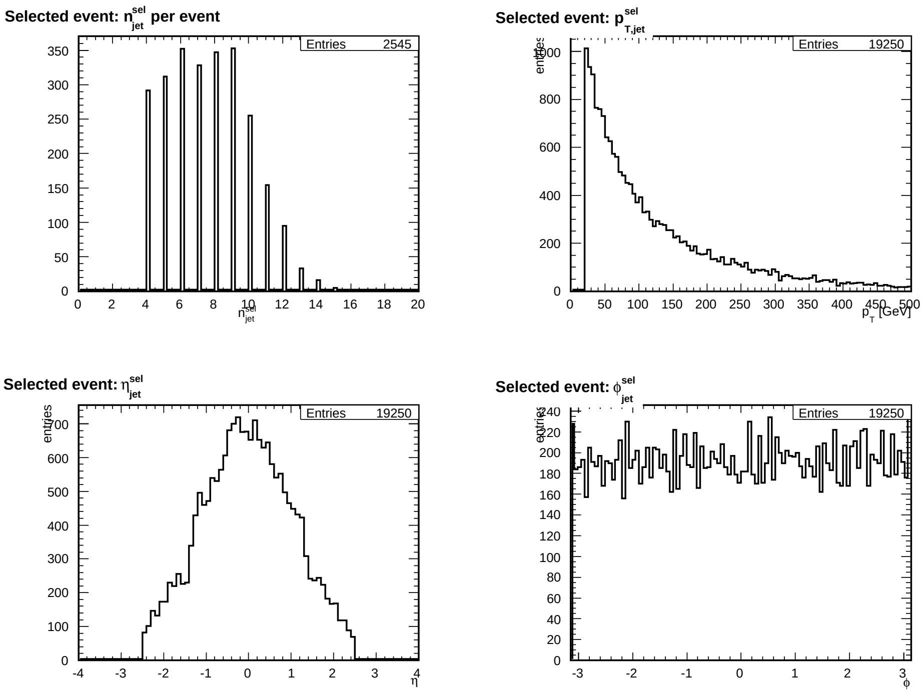


Figure 7: Distributions of GMSB1 jets after the event selection

In contrast to the photons, here it is possible to get the truth information about all MC generated jets. The correspondending distributions in p_{T}, η, ϕ are given in figure 15. The reconstruction efficiency yields 89.6%, calculated as the ratio of the number of reconstructed versus true jets. Applying the jet cuts the average number of jets per event is reduced to 7. Those distributions are given in figure 14 in the appendix. The ratio between 'good' to reconstructed is with 72.2 % much better than the correspondending photon ratio with 45.3%.

Figure 7 shows the jet distributions after applying also the event selection, that leads to a efficiency of selected to reconstructed jets of 19.5%.

2.3.3 Selection on missing transverse energy

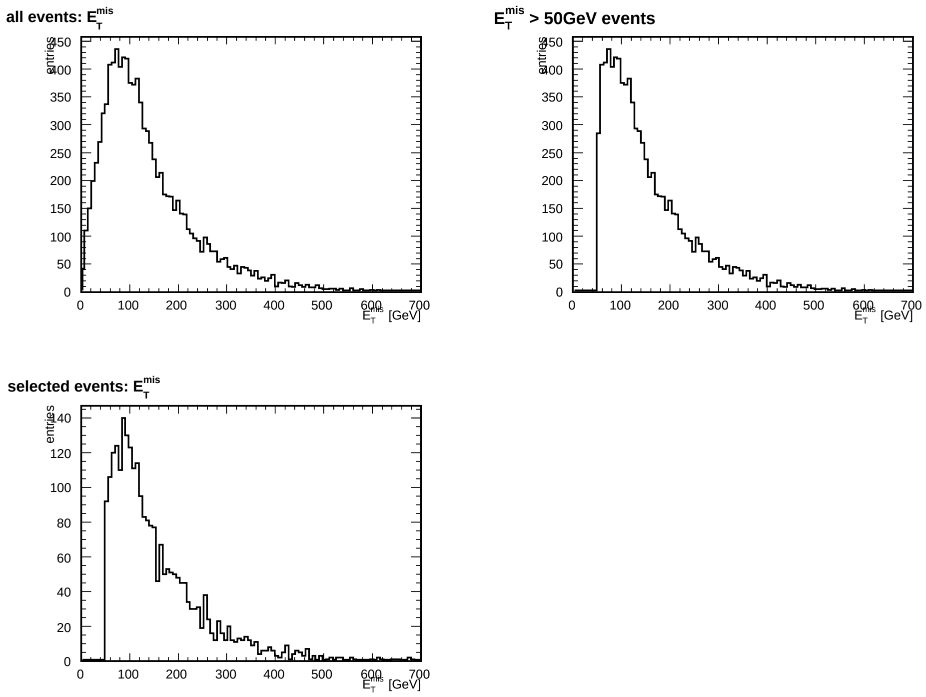


Figure 8: Distribution of the missing transverse energy before the selection (up l), after the 50 GeV cut (up r) and after all cuts (down l)

The distribution of the missing transverse energy is demonstrated in figure 8. In all histograms is shown the number of events in dependency of p_T. The first one on the left is filled with all events, the one on the right only contains entries after applying the E_T^{mis} 50 GeV cut and the one below shows the distribution after the complete event selection. The efficiency after the E_T^{mis} cut still is 86.2% and after all cuts 25.5% that is described in-depth in the next subsection.

2.3.4 Event selection

The following event selection is based on cuts on photon and jet number per event as well as on missing transverse energy. Here more than 1 photons and more than 3 jet are required. The threshold for E_T^{mis} is as already mentioned before at 50 GeV.

The efficiency yields 25.5 %. That is a acceptable value, although background considerations were excluded. These of cause have to be taken into account for further studies.
The selection efficiencies resulting from applying the different cuts are given in table 2. It shows that the 2γ cut already leads to a reduction of 67.2 %, while the others,the typical SUSY cuts, only yield an additional contribution of 7.3%.

cut	abs. in %	rel in %
2γ	32.8	
+ 4 jets	29.7	90.2
+ E_T^{mis}	25.5	86.1

Table 2: Selection efficiencies

Having a look on the leading jets in p_T in figure 9, there are obviously two peaks visible in the p_T plot. The physical background for this is the fact that at the LHC there are two main SUSY production mechanisms. On the one hand there is the production of squarks or gluinos via strong interactions, that of course will dominate, and on the other hand the generation of charginos and neutralinos via weak processes. A possibility a get information about the branching ratio is to intergrate over each peak, what is applied.

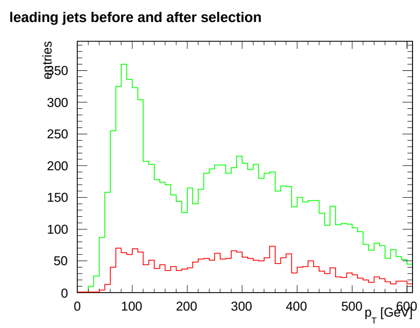


Figure 9: Comparing the leading jets before (green) and after the event selection (red)

A cut between the first and second peak is set at 180 GeV. And in order to take the overlapping area into account, a linear slope is fitted by hand. Then the yield value received from integration of the first peak is reduced by this overlapping that instead is added to the other side. The overlapping is determined by integrating from the root of the linear slope at 100 GeV till the cut at 180 GeV. These calculations give a BR for $\chi_2^{\pm/0}$ of 24.8 % and for $\tilde{q}$ and $\tilde{g}$ of 75.2% considering a estimated error of 10%. However, the results are in good agreement with the theoretical expectation. Plots which illustrats and compares the distibution of the first three leading photons and respectively the jets are given in the appendix (figure 16 and figure 17).

3 Trigger

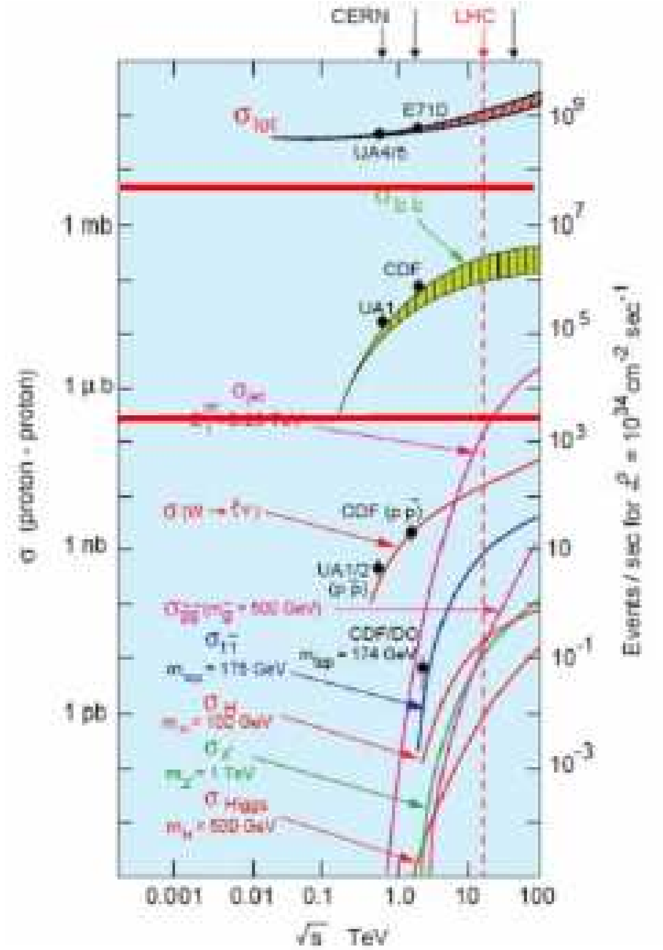


Figure 10: Cross sections of different SM and BSM processes

The LHC overall interaction rate is in the order of 1 GHz. The bunch crossing rate is of about 40MHz. However, the possible storage rate is only 200 Hz. This means a online reduction of 99.9995% is necessary. Figure 10 illustrates the cross section of SM and beyond SM processes. The productions due to strong interactions will completly dominate compared to the electroweak, Higgs or SUSY production. In order to reject the uninteresting QCD background and accept as much as possible interesting events a an efficient and reliable trigger sytem is required. At first it is important to understand the detector. Hence, the focus is on electroweak processes that are already known and understood. Then the interesting search for new physics and the Higgs boson starts. Important signatures are always high missing transverse energy, objects with high-p_T and such from electroweak interactions in general. The following subsection will describe the ATLAS trigger system, followed by a trigger efficiency study of the GMSB1 benchmark.

3.1 ATLAS trigger system

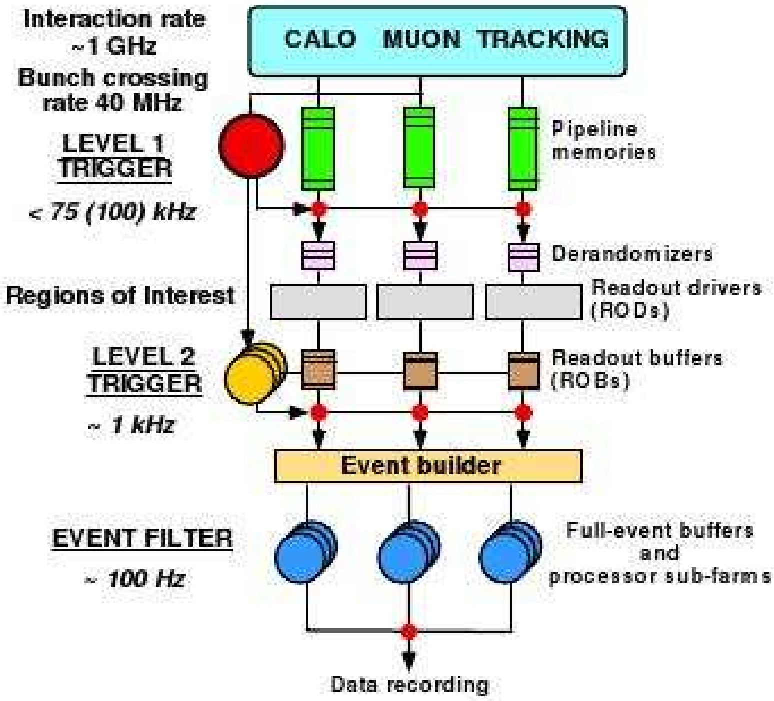


Figure 11: ATLAS trigger system: Level 1 (L1), Level 2 (L2), Event Filter (EF)

The ATLAS trigger system, shown in figure 11, consists of three levels. level 1 is hardware-based, while the high level trigger (HLT) composed of level 2 and the event filter is software-based.

- **Level 1** (L1) receives the complete bandwidth of data at a bunch crossing rate of 40MHz. This must be reduced to an output rate to less than 75 kHz. A decision, whether a event is accepted or rejected must not take more than 2.5 μs. For fast processsing L1 only uses access to the calorimeter and two muonsystems. A trigger decision depends on energy thresholds and multiplicities of electromagnetic clusters (EM), taus and jets, missing transverse energy, and the scalar sum of the transverse energy deposition in the calorimeter and the total E_T deposition of jets. Analogue the muon system thresholds are based on high-p_T values and multiplicities. When an event has passed one of these thresholds a so called region-of-interest (RoI) is created with a L1 item either e.g. EM18 for electromagnetic objects or MU20 for muons. The number indicates the passed threshold in GeV. For L1 item capital letters are used, for HLT chains small letters. There also EM is specified, either photon (g) or electron (e).

- The **Level 2** (L2) selection is based on the analysis of the regions-of-interest (RoI) that are identified by Level 1. The input thus is the L1 item, a so called seed. The L2 selection algorithms that are running on a computer farm, create then a small window around the seed position and construct a small RoI window. L2 has access to all detector information with full granularity around the RoI for a local analysis. For a certain input there are L2 chains that consist of several algorithms that specify the input information. The principle is illustrated in figure 12. The maxmum of time for a decision is around 10 ms. After a positive decision the event is passed to the event builder and then to the event filter. The limit of accepted events is about 1 kHz.

- **Event Filter** (EF) is a farm of 1800 dual core processors. Here happens the final online selection based on software algorithms that have access to the full detector information. Now there is capacity and time enough, about 1 second, to reconstruct the whole event and to take all important selection criteria into account for a decision. The online data rate now has to be reduced to about 200 Hz corresponding to 300 MB/s. Due to today's storage capacity it is not possible to accept more events. Here is also a seed used, that is given from the L2 output. Depending on this seed a certain sequence of algorithms, the EF chain, starts. Typically the EF uses the same methods as the 'offline' analysis.

More information about the ATLAS trigger is given in [ATL2].

3.2 Trigger analysis

For a analysis on trigger efficiencies with regard to GMSB1 events the interesting trigger chains are those with thresholds in p_T, E_T^{mis} and the multiplic-

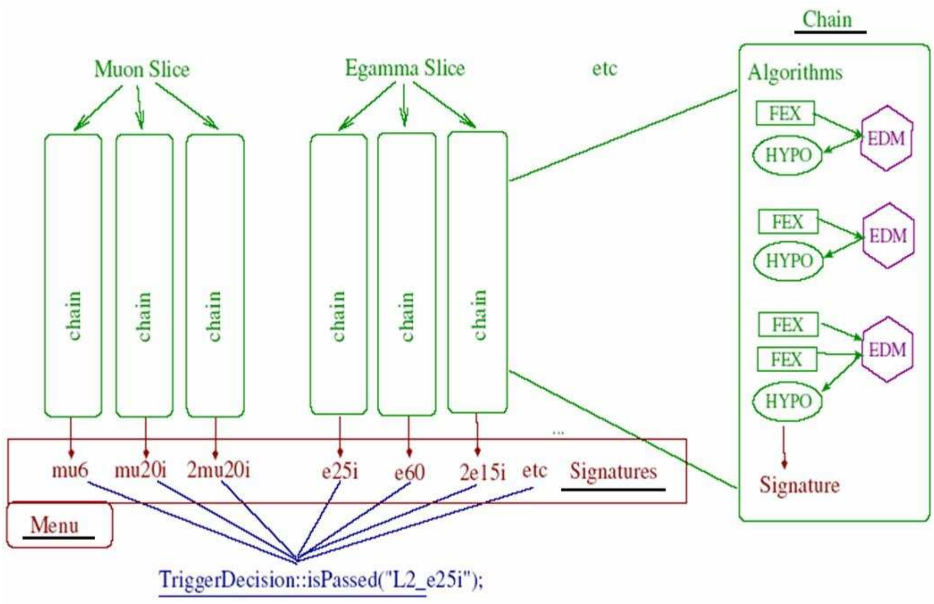


Figure 12: Trigger principle

ities of jets and photons.
Via an interface the standard ATLAS trigger software, the TrigDecisionTool (TDT), it is possible to have access to various chaingroups, trigger decisions and other trigger information. In table 3 the studied triggers are itemized. There are also given the full path of these triggers from L1 over L2 to EF with the yield efficiencies of passed events.
The trigger on photons with a p_T higher than 20 GeV (g20) is the one with the highest efficiency of 95%. The abbrevation xe describes a HLT trigger on E_T^{mis}.
The number of events that have passed the trigger that requires at least two photons with minimal p_T of 10 GeV is with 69% far below the g20 efficiency. The reason is that some photons can not get detected because of being to close to the beampipe.
The fact, that there are no passed events after the L2 for the 4j50 trigger indicates that there might be still a bug in the software. It is not very probable, that in the generated GMSB1 events there are no ones with more than 3 jets with a p_T above 50 GeV.

EF chain	passed	L2 chain	passed	L1 item	passed
g20	0.95	g20	0.98	EM18	1
g20i	0.91	g20i	0.94	EM18I	0.96
2g10	0.69	2g10	0.88	2EM7	0.99
4j95	0.0	4j50	0.0	4J23	0.84
xe70	0.64	xe70	0.74	XE70	0.77
j70_xe30	0.85	j70_xe30	0.88	J70_XE30	0.89
2j42_xe30	0.85	2j42_xe30	0.88	2J42_XE30	0.89

Table 3: Studied chaingroups and yield efficiencies of passed GMSB1 events

4 Summary

Gauge Mediated Supersymmetry Breaking (GMSB) is one possibility to explain the soft SUSY breaking in the minimal supersymmetrical model in which the NLSP decays into a high-p_T photon and a gravitino. This work, focused on the GMSB1 benchmark includes an event selection of 9986 generated GMSB events. A developed event selection using the typical GMSB1 topology, such as high-p_T photons, multiple high-p_T jets and missing transverse energy yield a selection efficiency of 25.5 %. This is quite a good value, although background processes are not considered. In further studies of course they have to be taken into account.
The analysis of suitable triggers such as trigger on single or several photons or jets or on E_T^{mis} results, that the photon trigger with a minimal threshold on p_T of 20 GeV gives the highest efficiency with 95%.
The next step would be a comparison between the analysis and the trigger decisions.

References

[ATL1] ATLAS collaboration, *Supersymmetry Signatures with High-p_T Photons or Long-Lived Heavy Particles*, ATL-PHYS-PUB-2009-069.

[ATL2] ATLAS collaboration, *Expected performance of the ATLAS experiment : detector, trigger and physics*, CERN-OPEN-2008-020.

[Terw1] Mark Terwort *Searches for GMSB at the LHC*, www.sciwipub.com/proceedings/DIS2008/110_terwort_mark.pdf.

[Terw2] Mark Terwort, *GMSB SUSY searches with the ATLAS detector*, http://maria-laach.physik.uni-siegen.de/2007/participants/files/E-13_Terwort.pdf.

[Terw3] Mark Terwort, *Searches for GMSB with LHC*, http://cdsweb.cern.ch/record/1101031/files/slide-2008-032.pdf?version=1.

[Dingf] Jochen Dingfelder, *lecture on 'Higgs Physik und Physik jenseits des Standardmodells'*, chapter 2: Supersymmetry, part 1 to 4, http://terascale.physik.uni-freiburg.de/?Lehre:Sommersemester_2009:Higgs-Physik.%0Aund_Physik_jenseits_des_Standardmodells.

Thanks to my supervisor Wolfgang Ehrenfeld and the whole DESY ATLAS group.

A Additional GMSB1 plots

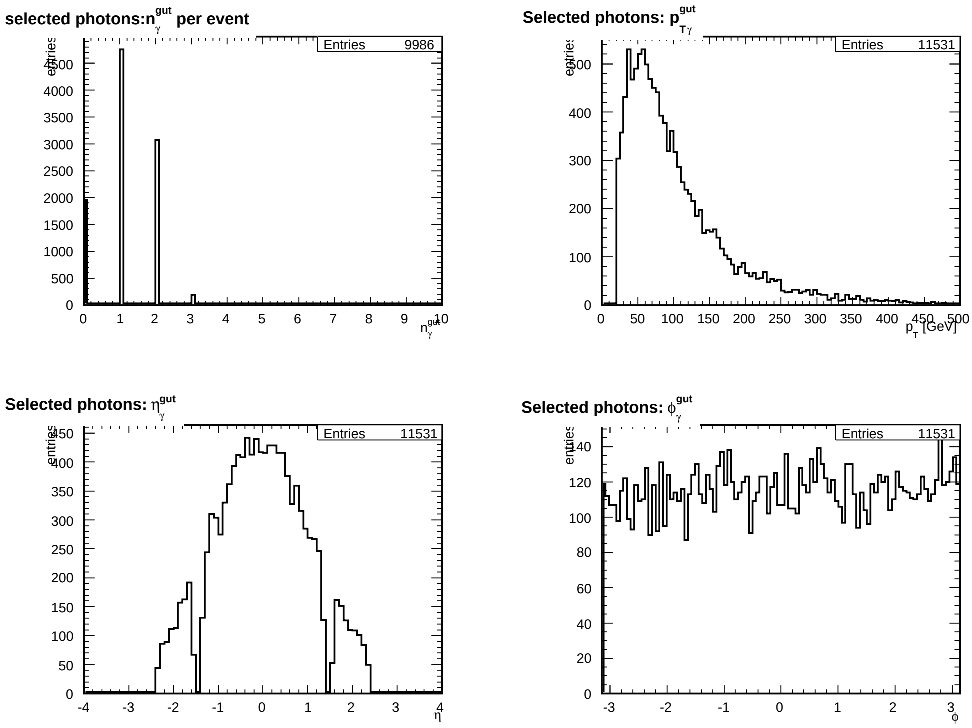


Figure 13: Photon distributions after p_T and η cuts

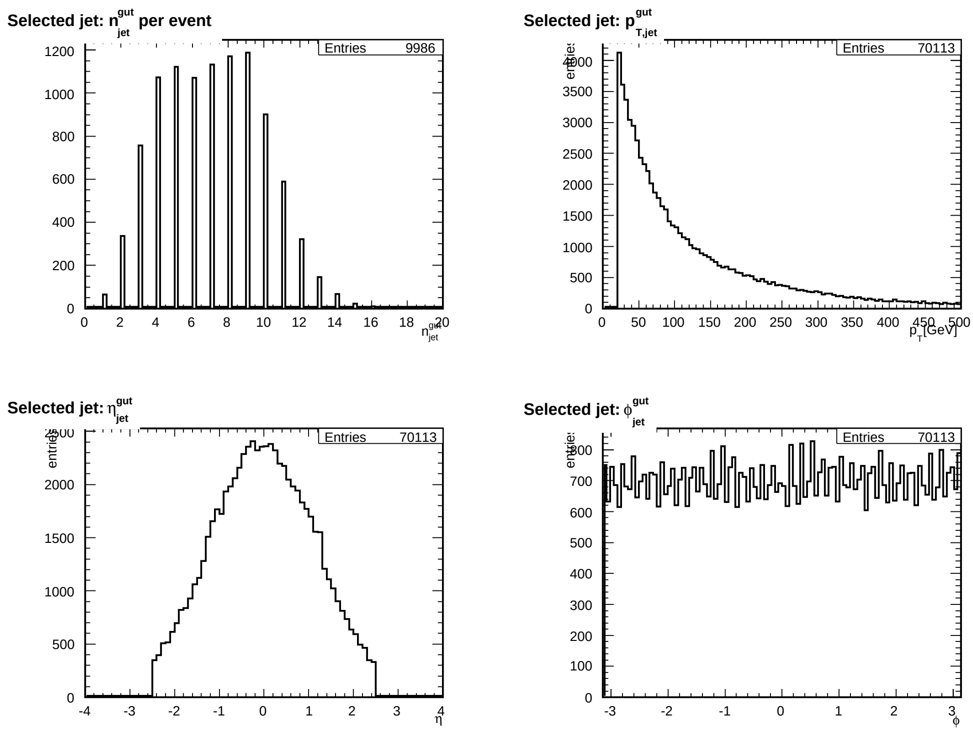


Figure 14: Jet distributions after p_T and η cuts

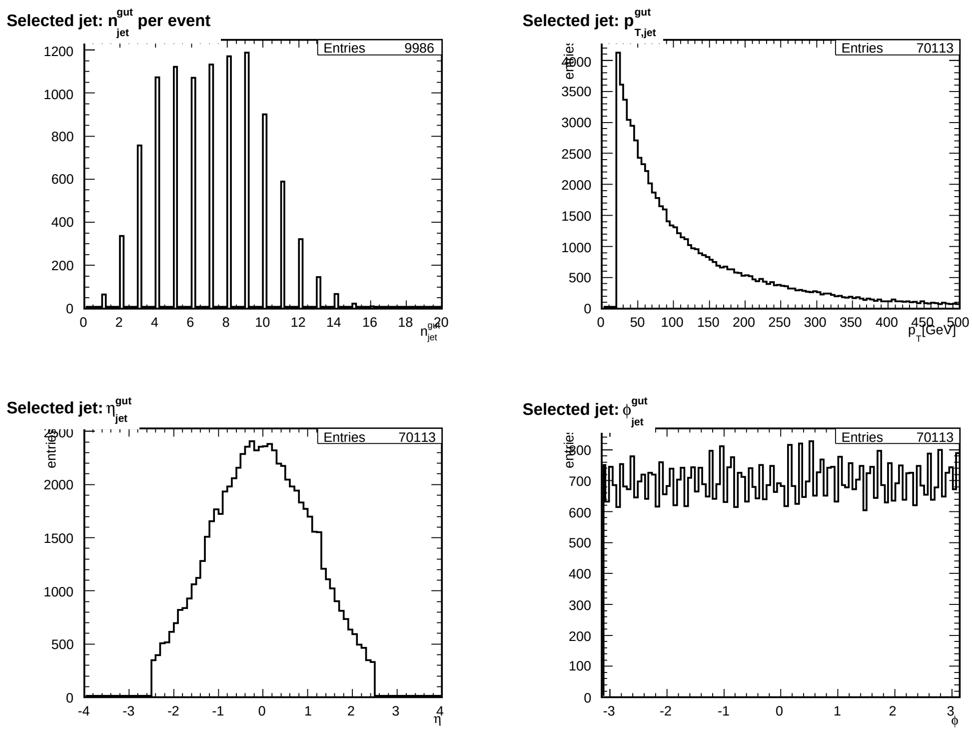


Figure 15: Truth jet distributions after p_T and η cuts

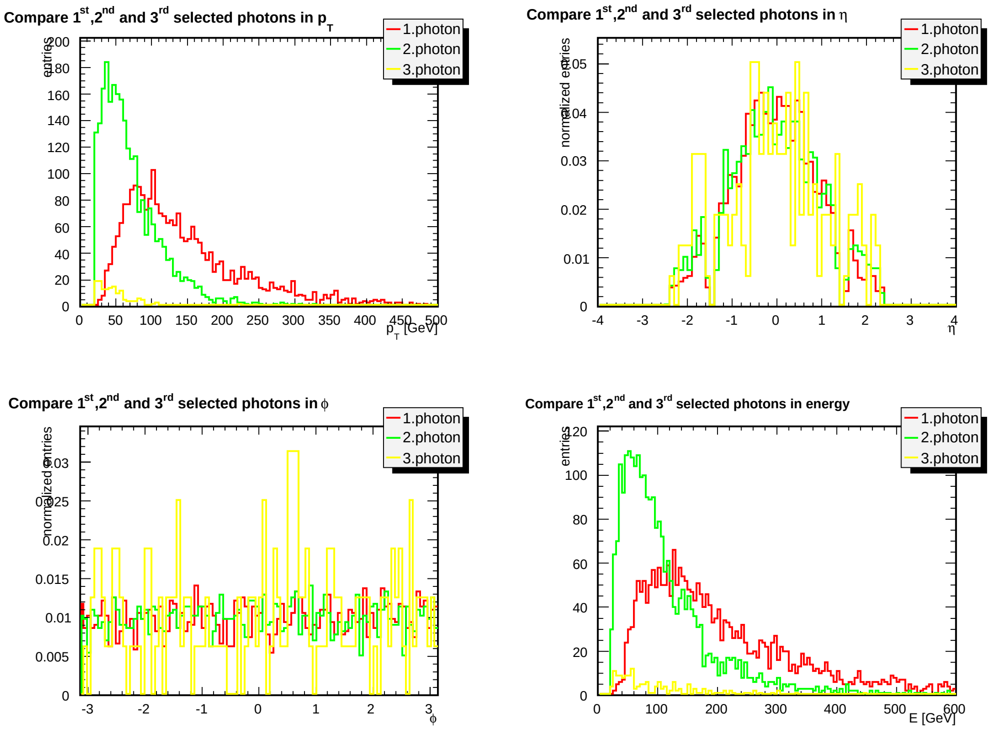


Figure 16: Comparing the first three leading photons after the event selection

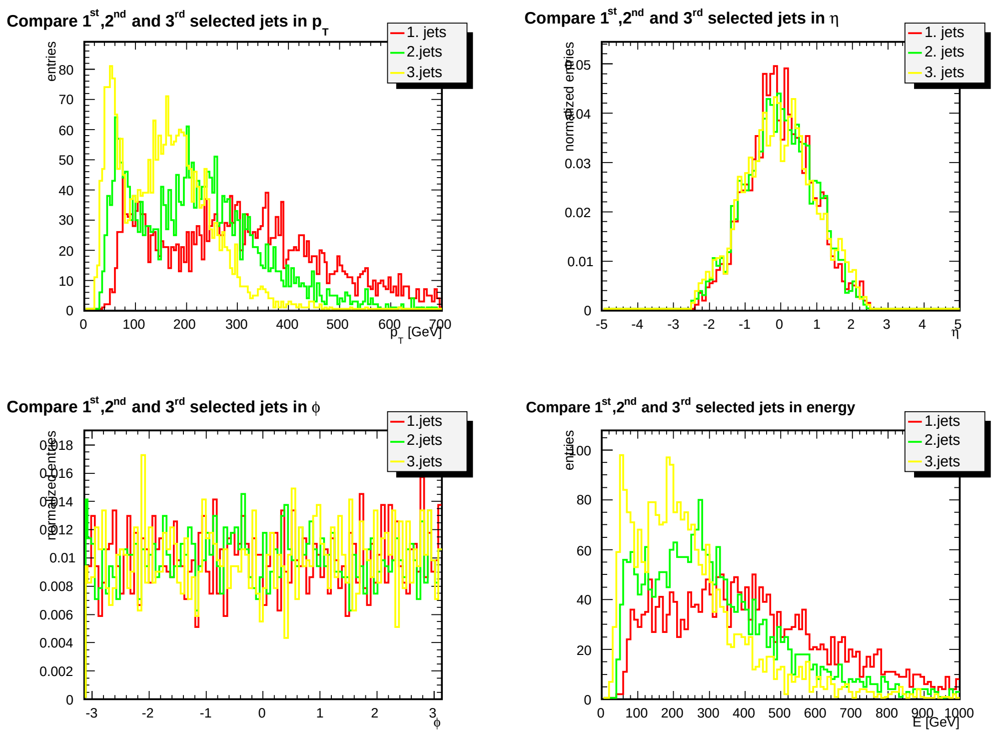


Figure 17: Comparing the first three leading jets after the event selection