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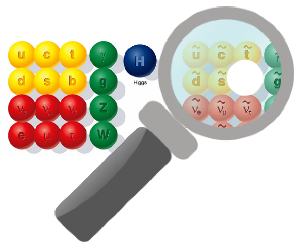
Search for New Physics in the Multijet and Missing Transverse Momentum Final State (CMSDAS 2013@DESY)

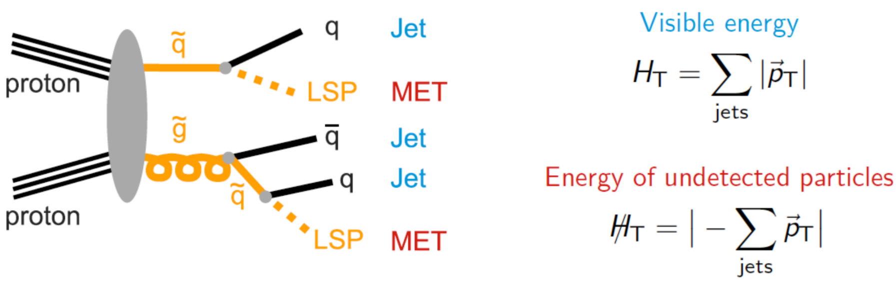


Introduction

A brief introduction to this exercise is given in these introductory slides.

Overview and Analysis Strategy

This analysis is a **generic search for new physics**. It is **motivated by models of R-parity conserving Supersymmetry** (*SUSY*), which predict the production of gluino-gluino, gluino-squark, and squark-squark pairs in the proton-proton collisions at the LHC via the strong interaction. In many models, these reactions have a particularly **large cross section** compared to other SUSY-production channels. The squarks and gluinos will predominantly decay into coloured SM particles and pairs of stable LSPs (*Lightest Supersymmetric Particles*). In realistic models, the LSPs are electrically neutral and only weakly interacting such as neutrinos.

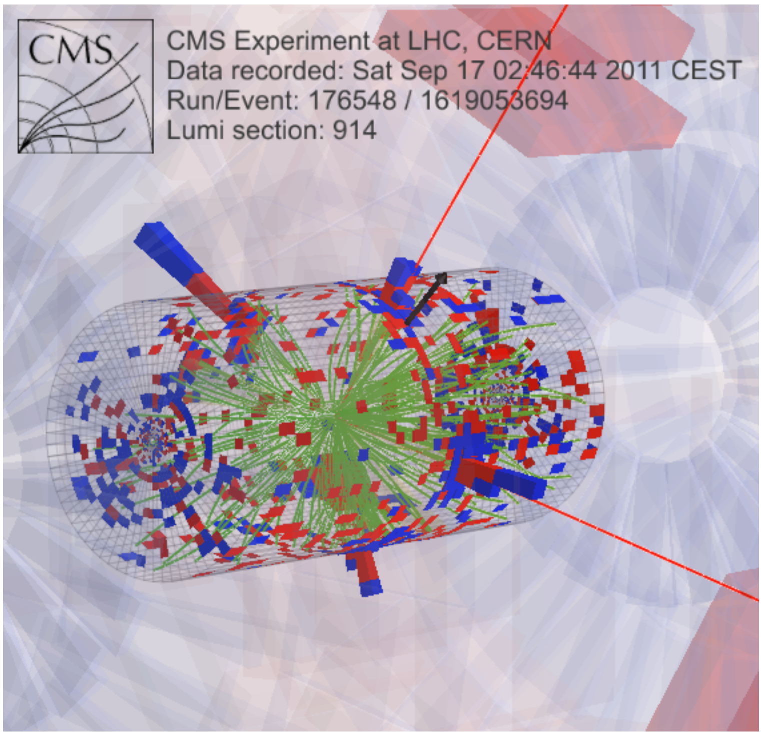


Thus, the SUSY signature we are looking for in the detector consists of **several jets with high p_T, large missing transverse momentum due to the LSPs, and no leptons**. The sensitive variables of the analysis are HT and MHT

- HT, the scalar sum of the p_T of all jets with $p_T > 50$ GeV and | | < 2.5
- MHT, the negative vectorial sum of the p_T of all jets with $p_T > 30$ GeV and | | < 5

However, there are also SM processes with the same signature (*SM background*). Therefore, we can only claim to observe a new process (like SUSY), when the observed number of selected events is significantly larger than the expected number of SM events. Hence, a precise knowledge of the expected SM background is extremely important when searching for new-physics processes. In this analysis, the SM background is determined almost entirely from data. This is beneficial because the reliance on the simulation - and with it the uncertainity on the background rate - is minimised. **The data-based determination of the SM backgrounds is one of the key features of this analysis**.

Below, you see the visualised detector signature of a candidate event found in the 2011 data.



Publications and Documentation

The analysis, internally also termed RA2 (*Reference Analysis 2*), has been performed since the first LHC-data taking. By now, several versions have been published including successively more data and ever-improved analysis methods.

- "Search for New Physics with Jets and Missing Transverse Momentum in *pp* collisions at √s=7 TeV", JHEP **1108** (2011) 155, arXiv:1106.4503 (36/pb)
- "Search for supersymmetry in all-hadronic events with missing energy", CMS-PAS-SUS-11-004 (2011) (1.1/fb)
- "Search for new physics in the multijet and missing transverse momentum final state in proton-proton collisions at √s=7 TeV", Phys. Rev. Lett. **109** (2012) 171803, arXiv:1207.1898 (5/fb)

Detailed information about the analysis techniques can be found in the corresponding public Physics Analysis Summaries (*PAS*) and internal Analysis Notes (*AN*) linked below in the References section.

The CMSDAS Exercise

For this exercise, we will follow the currently ongoing analysis of the 8 TeV data taken in 2012. It is documented in the (evolving) AN-12-350 and SusyRA2NJetsInData2012. We will use the first 5.295/fb of 2012 data. **The focus of the exercise will be on understanding the data-based background determination methods in detail**.

The exercise is performed with a series of simple ROOT-level C++ scripts or plain C++ classes. Some of them are incomplete, and you will be instructed on how to fill them up so that they can be run successfully. You will also be asked some questions meant to gauge your understanding of the topics being discussed. The data you will use have been prepared in a reduced format suitable for easy, interactive access and a fast return (ROOT *ntuple* format). The events store kinematic and other properties of higher-level objects, such as muons, photons, or jets, that have been reconstructed from the detector signals. In case of data, events have been preselected according to certain quality criteria that reject e.g. events affected by detector noise or malfuctioning detector components (*cleaning filters*). (You can find more information about the code and input data used to produce the ntuples below under Information for Facilitators. However, you do not have to read this to perform the exercises.)

Useful Links

The following documents provide information helpful to understand and develop the actual exercise code:

- ROOT reference guide: documentation of all ROOT classes
- C++ Language Library Reference: detailed descriptions of its elements and examples on how to use its functions

Preparation: Setting up the Code

It is assumed that you have successfully performed the Pre-Workshop Exercises and that you have got a `school??` and a CMS computing-account.

Follow the instructions below to prepare the computing environment and the set up the code for this exercise. This needs to be done **only once**.

Show Instructions for First Login Hide Instructions for First Login

- Login to the NAF with your school account

```
ssh -Y school??@nafhh-cms??.desy.de
```

  (You should have gotten an email stating which `nafhh-cms??` machine to use during the school.)
- Setup a CMSSW environment in some directory of your choice. We will use the `CMSSW_5_3_5` release.

```
cd <some directory>
ini cmssw
export SCRAM_ARCH=slc5_amd64_gcc462
scram p CMSSW CMSSW_5_3_5
cd CMSSW_5_3_5/src
cmsenv
```

- Set the cvs credentials

```
kinit <yourcernusername>@CERN.CH
export CVSROOT=":gserver:isscvs.cern.ch/local/reps/CMSSW"
```

- Check out the exercise code from cvs

```
cvs co -r cmsdas2013-DESY-v5 -d RA2Exercises UserCode/mschrode/DAS/RA2Exercises
```

- Compile the code

```
scram b
```

Now you are ready to start with the exercises 🙂

From now on, whenever you want to newly login your working area, you just have to follow the instructions below. This needs to be done **every time you login**.

Show Instructions for Regular Login Hide Instructions for Regular Login

- Login to the NAF with your school account

```
ssh -Y school??@nafhh-cms??.desy.de
```

(You should have gotten an email stating which `nafhh-cms??` machine to use during the school.)
- Set the CMSSW environment

```
ini cmssw
export SCRAM_ARCH=slc5_amd64_gcc462
cd <some directory>/CMSSW_5_3_5/src
cmsenv
```

Now you are ready to start with the exercises

Sample Definition and Composition

In this section of our long exercise, we will learn how to access the data and simulated events and how to apply the selection cuts. We will investigate the data and compare it to the expected properties of the SM backgrounds. You will also get a feeling of how possible SUSY signals look like.

In this analysis, candidate events are selected by requiring:

1. no well-reconstructed and isolated leptons (electrons or muons) with p_T > 10 GeV;
2. N_{jets} >= 3, where only jets with p_T > 50 GeV and | | < 2.5 are considered;
3. HT > 500 GeV, where again only jets with p_T > 50 GeV and | | < 2.5 are considered;
4. MHT > 200 GeV, where jets with p_T > 30 GeV and | | < 5 are considered;
5. Δ ($jet_{1,2}$,MHT) > 0.5 and Δ (jet_3,MHT) > 0.3.

Consider the topology of the selected events.

- **Question 0.1:** Can you list possible SM processes that result in this final state? Considering the event selection, could you roughly rank these processes according to their expected yields? Don't do any calculation now, just use your intuition.

In the following, you will be asked to perform several exercises that will help us better understand the properties of the processes we are investigating. It will also give us some introduction to the technical aspects of how to use the ntuples and perform an analysis with ROOT.

Before you start, make sure you have executed the initial commands shown above at Preparation: Setting up the Code. Then, go to the `General` directory, i.e. from your working area `.../CMSSW_5_3_5/src/RA2Exercises` do

```
cd General
```

SM Background Expectation from Simulation

We will now investigate SM backgrounds using simulated events. There are ntuples available for several different SM as well a potential SUSY-signal process (LM6). The table below lists them together with their cross-sections in units of picobarns (pb) at 8 TeV and the total number of simulated events. **Note the size of the of signal cross-section compared to e.g. W(l)+jets or even ttbar!**

Id	Process	Cross-section [pb]	Total Nr. Events	Comment
1	QCD		9991674	flat sample, no naive cross section

2	ttbar+jets	234	6923750	
3	W(l)+jets	36257.2	57709905	
4	Z( )+jets	6.26	1006928	HT>400 GeV
5	LM6	0.502	1000000	low mass CMSSM m_0 = 85 GeV, $m_{1/2}$ = 400 GeV, tan = 10
6	LM9	9.287	1000000	

We will start with analysing the QCD sample. Please follow the instructions given below.

Show instructions Hide instructions

To analyse the simulated events, execute the script `general1.C` with ROOT by typing

```
root -l -b -q general1.C+\(sampleId\)
```

where *sampleId* should be replaced with the values shown in the first column of the table above. We will start with analysing the QCD sample, so set `sampleId` to 1. (Notice the + after the name of the script in the above command. This will tell ROOT to compile the script before execution which leads to a faster programme.)

The script `general1.C` above will produce a ROOT file `General_QCD.root` that contains various control distributions. Browse the file and investigate its content. You can conveniently plot the distributions with the script `plotGeneral1.C`:

```
root -l plotGeneral1.C\(sampleId\)
```

where `sampleId` is again set to 1. The script also stores the plots as `eps` file in the current directory.

Discuss the distributions. The events are selected if they have no good lepton (electron or muon), i.e. selection step 1 in the list above, and if they have at least 3 jets with p_T > 50 GeV and | | < 2.5, i.e. selection step 2 in the list above. Do the shapes of the distributions meet your expectations?

- **Question 1.1**: What is the reason for the lower cut-off in the N(jet), HT, and MHT distributions?

To exit the ROOT environment, you will have to type at the command prompt `.q` and hit `Enter`. (In case of the first script, the `-q` switch told ROOT to exit after execution of the script. However, since we wanted to look at the plots, we needed to keep the environment open.)

Open now the two scripts we have just run, i.e. `general.C` and `plotGeneral1.C`, in your favourite editor, e.g. `emacs`. Familiarise yourself with the code. Make sure you understand what is being done because the following exercises will build up on this!

- What objects of the event content are being analysed? How are they read from file?
- Where are the histograms declared and filled? Where are they drawn?
- How are the event selection steps 1 and 2 performed?

We will now implement the full event selection of the analysis, i.e. selection steps 1 to 5 in the list above. Add the appropriate code to `general1.C` below the line saying

```
//>>> PLACE OTHER RA2 CUTS HERE
```

You might find the following ROOT functions helpful when implementing the Δ cuts:

- `TMath::ATan2(double y, double x)`, described in http://root.cern.ch/root/html532/TMath.html
- `TVector2::Phi_mpi_pi(Double_t x)`, described in http://root.cern.ch/root/html532/TVector2.html#TVector2:Phi_mpi_pi

Remember to include the approriate header files when using external functions!

At the moment, `general1.C` runs over a small number of simulated events. To analyse the full samples, you will need to replace the current input file name

```
tr->Add("/nfs/dust/test/cmsdas/school61/susy/ntuple/2013-v1/"+fileName(sampleId)+"_0.root");
```

by

```
tr->Add("/nfs/dust/test/cmsdas/school61/susy/ntuple/2013-v1/"+fileName(sampleId)+"_*.root");
```

The wildcard `*` in the file name will tell ROOT to open all files that start with `/nfs/dust/test/cmsdas/school61/susy/ntuple/2013-v1/"+fileName(sampleId)_`. Do you understand what the function call `fileName(sampleId)` does?

Now, run `root -l plotGeneral1.C\(1\)` again and investigate the distributions. How did they change after the full event selection?

- **Question 1.2**: Looking at the impact of the full event selection, can you motivate the cuts? What are features of the potential SUSY events? In order to understand the reason for the Δ cuts, discuss the origin of MHT in QCD events. It is also useful to plot the Δ distribution.

You can find an example implementation that includes the full event selection and runs over the full samples in `general2.C`. But really try for yourself before looking at the given solution.

Now, we will also look at the other samples. Please follow the instructions below.

Show instructions Hide instructions
We want to investigate the kinematic distributions after the full event selection using the full samples, so use your adapted script from the above exercise. (Or, if you prefer, the ready-made `general2.C`.) Execute

```
root -l -b -q general1.C+\(sampleId\)
```

again and again and again for all samples 1 to 5 in the above table. Plot the distributions with the script `plotGeneral1.C` as before:

```
root -l plotGeneral1.C\(sampleId\)
```

Let us first investigate the shape of the distributions. (To compare them between different samples, use e.g. the stored `eps` files.)

- **Question 1.3**: How do the processes differ? Explain the differences of the N(jets) distributions of QCD and ttbar events. Explain the different HT and MHT distributions of the QCD and the Z( )+jets events.

Now, we want to obtain the correct normalisation of each sample, i.e. event yields. The number of simulated events is stated e.g. on the HT distribution.

- **Question 1.4**: Using the cross-section values and the total number of events given in the above table, please compute the expected event yields corresponding to 5.295/fb. (**Ignore the QCD sample for this**. Its normalisation is a little more complicated and it is taken care of automatically. You can simply read of the correct 5.295/fb yields from the HT distribution.) How do the yields compare? Does this match your initial ranking?

Data

We will now study what these distributions look like for the first 5.295/fb of real *pp* collision data collected by CMS in 2012 at √(s) = 8 TeV. Remember, we can only do this since about 10 months! Before, no one has ever seen collisions at such high energies. **So be amazed :)**

Show instructions Hide instructions
Execute the script `general3.C`. This also takes 0 as an argument to run over data:

```
root -l -b -q general3.C+\(0\)
```

Look at the data distributions as before with the script `plotGeneral1.C`:

```
root -l plotGeneral1.C\(0\)
```

What do they look like compared to the simulated SM backgrounds?

Modify `general3.C` and drop the cuts on HT and MHT. Then execute again

```
root -l -b -q general3.C+\(0\)
```

- **Question 2.1**: How do you explain the low-HT and low-MHT behaviour of the data (after having dropped the HT and MHT cuts)?

Reset the HT and MHT cuts so we can use `general3.C` in the next exercise.

Data vs Simulated SM Background

Finally, we want to compare the data distributions with the sum of the background distributions. One goal of this exercise is to implement a plotting script that we want to reuse later when replacing some MC predictions by data-based predictions.

Again, follow the instructions below.

Show instructions Hide instructions
Of course, we need to know the correct normalisation of the simulated distributions for this exercise. We have already computed the expected event yields from the cross sections and could use these numbers to scale the distributions. However, the simulated events require further weighting to correctly describe the impact from pile-up collisions. (Why? Discuss this with one of the tutors!) Therefore, event weights, which take care of the pile-up and the absolute (luminosity) normalisation, have been stored in the ntuples. In the script `general3.C`, these weights are used to scale the histogram entries. Make sure you understand how this is happening!

Thus, execute again

```
root -l -b -q general3.C+\(sampleId\)
```

for data (`sampleId` 0) and all background samples. If you have a look at the event yields now (as printed e.g. on the HT plot), you will see the correct normalisaton has been applied.

- **Question 3.1**: In `plotGeneral1.C`, where the *N(total) = bla* label is printed on the HT plot, the method `TH1::Integral()` is used to obtain the yield. Why? Could you also have used `TH1::GetEntries()`?

As last part of this exercise, implement a script that adds (*stacks*) the background distributions, plots them, and plots the data distributions on top. (The plot shown in the presentation at the beginning of this exercise can be used as a model.) Use `plotGeneral1.C` as a starting point. You might find ROOT's

- `THStack` class http://root.cern.ch/root/html532/THStack.html or
- `TH1::Add` function http://root.cern.ch/root/html532/TH1.html#TH1:Add%1

useful for this task. Ideally, each background gets a different colour so we can distinguis them. Let's produce some nice plots because

- StyleMatters (you could also might find this class helpful);
- we want to re-use this script at the end of the exercise and replace some of the simulated backgrounds by our data-based predictions.

W+Jets and ttbar Background Determination

Introduction

An important SM background, which dominates in most search regions, arises from the production of W bosons in association with jets (*W+jets background*) and from the production of top-antitop quark pairs (*ttbar background*).

Since the t quarks decay almost exclusively to W bosons and b quarks, both processes lead to the presence W bosons and jets. The W bosons decay either into a quark-antiquark pair (*hadronically*) or into a lepton-neutrino pair (*leptonically*). In the first case, there is only very little MHT in the event, produced only from jet mismeasurements. Hence, the events are efficiently rejected by the selection criteria because MHT > 200 GeV is required. In the latter case of leptonically decaying W bosons, the events are to first approximation also rejected because events with isolated leptons are rejected.

However, there are two important cases in which the lepton veto fails, and hence, W+jets and ttbar events are selected:

- *Lost Lepton*: The leptons from the W decay are not reconstructed due to either the limited geometrical acceptance of the detector or the inefficiency of the reconstruction algorithm or the leptons are not isolated because they geometrically overlap with a jet.
- *Hadronic Tau*: The W boson decays into a tau lepton that decays to hadrons that form a jet. In this case, there will be no isolated leptons in the event such that the lepton veto is passed. In addition, there can be sufficient MHT, caused by the neutrinos from the W and subsequent tau decays, to pass the MHT > 200 GeV selection criterion.

In this analysis, the W+jets and ttbar backgrounds are determined simultaneously via two methods which address separately the two stated cases. The lost-lepton method is described in the following but not performed here as an exercise. The hadronic-tau method is decribed afterwards and will be illustrated with an exercise.

Lost-Lepton Method

The procedure starts from a sample (*control sample*) with only one isolated muon and computes event variables (e.g. HT, MHT) including the muon. The yields are renormalized accounting for the isolation efficiency, the reconstruction efficiency and geometrical acceptance. The lepton efficiencies are estimated via Tag-and-Probe method using data, while the geometrical acceptance is determined in simulation.

- **Questions 1:** For the muon channel, what would the renormalization factor look like? Try to express it analytically in terms of muon isolation efficiency ($^{\mu}_{ISO}$), muon reconstruction efficiency ($^{\mu}_{RECO}$)and geometrical acceptance (A^{μ}).

- **Question 2:** Could the same muon channel be used to estimate the contributions from the electron channel? What would be the renormalization factor in this case?

Hadronic-Tau Background

This method aims to determine the number of events in which a W boson decays into a tau lepton that decays further into hadrons. These hadrons (in most cases one or three charged pions and a number of neutral hadrons decaying to photons) form a jet, referred to as *tau jet* in the following. The energy deposited by the hadrons, i.e. the energy of the tau jet, is referred to as *visible tau-energy*.

- **Question 0.1:** The visible tau-energy is in general smaller than the energy of the tau lepton. Why?

The procedure starts with a control sample from data that contains events with exactly one isolated muon, as in the lost-lepton case. The p_T spectrum of the muon from W decay is expected to be similar to that of the tau lepton from W decay.

- **Question 0.2:** Why is the p_T spectrum expected to be similar?

This feature is used to simulate the tau jet by replacing the muon p_T with the p_T expected for a tau jet that originates in a tau lepton with the same p_T as the muon. Essentially, the p_T of the muon is scaled to reproduce the expected tau-jet p_T. The muon with the scaled p_T (the *simulated tau jet*) together with the other jets in the event is used to re-compute the event variables relevant for the analysis, i.e. HT and MHT.

- **Question 0.3**: Why do we use isolated muons?

In the following, you will be asked to perform several exercises that will illustrate this method. Go to the `Wtt_HadTau` directory, i.e. from your working area `.../CMSSW_5_3_5/src/RA2Exercises` do

```
cd Wtt_HadTau
```

Hadronic-Tau 1: Lepton p_T Spectra

We will verify that the p_T spectra of the muons and the tau leptons from the W decay are indeed similar. The instructions below will be used to execute some ROOT scripts that will produce the needed distributions and their comparisons.

Show instructions Hide instructions
Execute the script `hadTau1.C` with ROOT by typing

```
root -l -b -q hadTau1.C+
```

(Notice the + after the name of the script in the above command. This will tell ROOT to compile the script before execution which leads to a faster programme.) The script above will produce a ROOT file `HadTau_WJetMC.root` that contains the p_T distributions of the generator-level muons and tau leptons from W decays in simulated W+jets events. To plot these distributions, execute the script `plotHadTau1.C`:

```
root -l plotHadTau1.C
```

Investigate the distributions.

- **Question 1.1**: Why is the shape of the p_T distributions similar but the normalisation, i.e. the absolute number of events, different?

- **Question 1.2**: What is the ratio of the two p_T distributions? Is this expected? You can determine the size of the ratio more precisely by fitting a constant to the plot: right-click on the ratio plot, choose "Fit Panel", and fit a "pol0" (polynomial of degree 0) to the ratio.

To exit the ROOT environment, you will have to type at the command prompt `.q` and hit `Enter`. (In case of the first script, the `-q` switch told ROOT to exit after execution of the script. However, since we wanted to look at the plots, we need to keep the environment open.)

Open the two scripts we have just run, i.e. `hadTau1.C` and `plotHadTau1.C`, in your favourite editor, e.g. `emacs`. Familiarise yourself with the code. Make sure you understand what is being done because the following exercises will build up on this!

- What objects of the event content are being analysed? How are they read from file?
- Where are the p_T distributions declared and filled? Where is the ratio plot created?
- How is determined whether the W boson decayed into a muon or a tau? And how are the hadronically decaying tau leptons selected?

At the moment, `hadTau1.C` runs over a small number of simulated W+jets events. To analyse the full W+jets sample that was already used [[][above]], you will need to replace the current input file name

```
tr->Add("/nfs/dust/test/cmsdas/school61/susy/ntuple/2013-v1/WJets_0.root")
```

by

```
tr->Add("/nfs/dust/test/cmsdas/school61/susy/ntuple/2013-v1/WJets_*.root")
```

Now, run over the full sample and determine precisely (by fitting the ratio) the branching fraction of the W decaying into hadronically decaying taus and into muons. We will need this ratio later.

Hadronic-Tau 2: Tau Response Template

We will determine the response templates of the tau-jet p_T, i.e. the probability density to measure a certain tau-jet p_T given a fixed tau-lepton p_T. These templates are later used to scale the muon p_T. The templates have of course to be determined from simulated W+jets events.

We will select only W+jets events where the W decayed into hadronically-decaying taus. Then, we will identify the reconstructed jet that originate in the tau-decay products. The identification is done via a geometric matching: we look for a jet that is closer in $\Delta R = \sqrt{(\Delta\ \ ^2 + \Delta\ \ ^2)}$ to the generator-level tau than ΔRmax. In case of an ambigious match, i.e. if there are more than one jets fulfilling this requirement, the event is discarded. ΔRmax is chosen to obtain a matching efficiency above 95%; it is 0.2 for taus with $p_T < 50$ GeV and 0.1 for all other taus.

In addition, we select only events with at leat 2 "HT jets" (jets with $p_T > 50$ GeV and $|\ \ | < 2.5$), where the matched tau jet is not considered for the jet counting. Also, we require the generator-level tau to fall into the kinematic acceptance of reconstructed muons at CMS. This corresponds to the selection applied lateron to select the muon control-sample used in the prediction, and we want to determine the response templates from events resembling the control sample as much as possible. The event selection is discussed further in the next sections.

The tau response template is then simply obtained by plotting the ratio of the tau-jet p_T and the tau-lepton p_T. We will do this in different bins of p_T of the generated tau.

For this exercise, we will again analyse simulated W+jets events. One can also determine them from ttbar+jets events, but we will not learn anything new from that. In real life, the templates are determined from a mixture of both samples corresponding to the expected mixture of W+jets and ttbar events in data. However, for the purpose of this exercise the W+jets sample is sufficient. Please follow the instructions below.

Show instructions Hide instructions
To produce the tau templates, execute the script `hadTau2.C`

```
root -l -b -q hadTau2.C+
```

The script above will update the ROOT file `HadTau_WJetMC.root` from the previous exercise with the response templates. To plot the templates, execute the script `plotHadTau2.C`:

```
root -l plotHadTau2.C
```

To run over the full W+jets sample, please apply the same instructions given in the previous exercise and repeat the steps above.

Again, analyse the code and make sure you understand what is being done.

- Identify the event selection steps described above.
- How is the jet-tau matching being done?

Now, investigate the response templates.

- **Question 2.1**: Why are the mean values in general smaller than 1?
- **Question 2.2**: What is the reason for a response greater than 1?
- **Question 2.3**: Can you explain the shift of the mean of the templates as the p_T of the tau lepton increases?

Hadronic-Tau 3: Prediction on Generator-Level

We will analyse events from the W+jets sample in the muon decay-channel and use the tau templates obtained above to make predictions about the tau decay-channel. You will predict the p_T spectrum of the tau jet as well as the HT and MHT distribution of the W+jets events in the hadronic-tau channel.

As described in the introductory section, we will select the muon to simulate the tau jet. Here, for a first test, we select the generator-level muon lepton, where we are sure that it originates in the W decay. As above with the tau lepton, we use a ΔR matching to find the jet corresponding to the muon and remove it from the jet collection. We select only events with at leat 2 "HT jets" (jets with $p_T > 50$ GeV and $| \; | < 2.5$), where the matched muon jet is not considered for the jet counting.

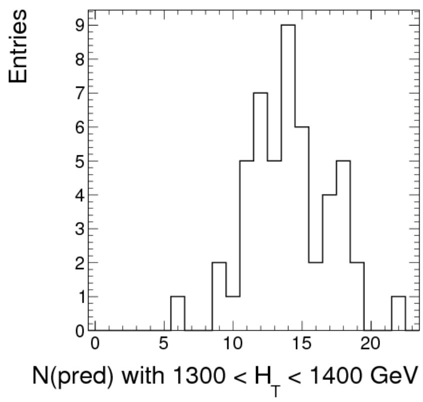
Then, we treat the muon as a tau lepton and scale (*smear*) its p_T by a random factor drawn from the tau-response templates. Remember that several templates were determined in bins of tau-lepton p_T. Hence, depending on the muon p_T, we have to chose the corresponding template. The scaled muon p_T simulates the measured tau-jet p_T. This, together with the other jets in the event, is used to recompute HT and MHT and thus obtain a prediction for these quantities in hadronic-tau events. Here, the predicted distributions are compared to the true distributions, which are known in simulated events, to validate the method.

- **Question 3.1**: Can you motivate the event selection? Why do we require at least 2 HT jets for the control sample (in contrast to the "at least 3 jets" requirement for the final event selection)?

In order to increase the statistical precision of the method, the procedure is repeated several times. Since the scale factor from the response template is drawn randomly, each time the prediction is different. The final prediction is obtained as the mean value of the individual predictions. Since in this way each muon is smeared several times and thus the output is correlated, one has to take care how to define the statistical uncertainty on the predicted number of events. A suitable quantity to define the uncertainty is the standard deviation of the distribution of the individual predictions. This procedure is known as *bootstrap method*.

Let's consider one example. For a given muon control-sample, you perform the muon p_T smearing once for each event. For each event, you compute the simulated HT from all "real" jets (with $p_T > 50$ GeV and | | < 2.5) + the simulated tau-jet, provided it has $p_T > 50$ GeV and | | < 2.5. Then you check whether the simulated HT falls into a particular bin in HT, e.g. 1300 < HT < 1400 GeV. This way, you obtain a prediction for the number of events with 1300 < HT < 1400 GeV.

Now, you can repeat this procedure, say 50 times. Due to the random smearing, you will obtain a slightly different predicted number of events each time. This is shown in the histogram below.



The average of 14.08 of this histogram (obtained by `TH1::GetMean()`) corresponds to the average predicted number of events with 1300 < HT < 1400 GeV. The standard deviation of 3.00 of this histogram (slightly misleadingly obtained by `TH1::GetRMS()`) estimates the statistical uncertainty on that number. Thus, our prediction for the number of events with 1300 < HT < 1400 GeV is 14.08 +/- 3.00.

Follow the instructions below to perform the prediction for yourself.

Show instructions Hide instructions
Execute the script `hadTau3.C` and pass the number of iterations, e.g. 50, as argument `nSimSteps`:

```
root -l -b -q hadTau3.C+\(50\)
```

This will produce a ROOT file `HadTau_WJetMC_PredGen.root`, which contains several histograms:

- The generator-level muon p_T distribution. This is the muon that gets smeared!
- For each bin in tau-jet p_T, HT, and MHT, the above-discussed histogram of predicted event yields. Its mean is the final prediction.
- The resulting predicted tau-jet p_T, HT, and MHT distributions.
- The true tau-jet p_T, HT, and MHT distributions.

You can compare the predicted with the true distributions by executing script `plotHadTau3.C`:

```
root -l plotHadTau3.C
```

(Change the input as before to run over the full W+jets sample.)

Compare the predicted with the true distributions. The shapes should agree well. (Run over the full sample to verify this!)

- **Question 3.2**: Why is the normalisation different?
- **Question 3.3**: With what factor do you have to scale the predicted distributions to obtain the true distributions?

- **Question 3.4**: What is the reason for the the step in the tau-jet p_T distribution at about 50 GeV?

The `plotHadTau3.C` takes a scale factor for the prediction as an optional function argument `scale` (the default value is 1). Hence, you can scale the prediction by e.g. 0.5 in this way:

```
root -l plotHadTau3.C\(0.5\)
```

Now, investigate the code.

- Make sure you understand how the response templates are used and how the random scale-factor is obtained from them.
- Familiarise yourself with the way the bootstrapping is implemented. Can you identify the part of the code that determines the mean value and the uncertainty of the prediction?
- How are the true distributions obtained? Convince yourself that the tau-lepton selection (for the truth) is exactly equivalent to the muon selection (for the prediction).
- What event selection is applied on the predicted jets? Does it agree to the analysis event-selection?

If you would like to understand better the details of the bootstrap method, answering the following optional questions might be of help. But try to finish the other exercises first.

Show questions Hide questions

- **Question 3.5**: What impact does the number `nSimSteps` of iterations have on the final result?
- **Question 3.6**: Say you have a prediction of the HT spectrum in 100 GeV wide bins, i.e. you have predicted the number of events with 0 < HT < 100 GeV, 100 < HT < 200 GeV, and so forth. Can you obtain the predicted number of events with 0 < HT < 200 GeV by adding the predictions in the two bins? Can you obtain the uncertainty on that prediction by adding the uncertainties in quadrature?

Hadronic-Tau 4: Data-Based Prediction with Simulated Events ("Closure Test")

Now, we will omit the usage of generator-level quantities. (Remember that for the prediction above we smeared the generator-level muon!) Rather, we will perform the prediction using the reconstructed muon such that we can apply the method to real collider data. We will still be using simulated events, however, because we want to again compare the prediction to the truth. This kind of test, where the prediction is obtained the same way as it would be obtained on data, is often called a *closure test*.

Follow the instructions below to perform the closure test.

Show instructions Hide instructions
Execute the script `hadTau4.C`. This takes two mandatory arguments

1. `bool isMC`, stating whether we run over MC. If so, the true distributions are also produced.
2. `int nSimSteps`, the number of iterations, as before.

```
root -l -b -q hadTau4.C+\(true,50\)
```

This will produce a ROOT file `HadTau_WJetMC_PredReco.root` with the same content as before. (Change the input as before to run over the full W+jets sample.) You can again use `plotHadTau3.C` to compare the distributions. The script takes a second optional argument `fileName` stating the name of the files containing the histograms (the default name is `HadTau_WJetMC_PredGen.root`). Using the same scale factor as above, execute

```
root -l plotHadTau3.C\(0.64,\"HadTau_WJetMC_PredReco.root\"\)
```

What is the result of the closure test? Does the method work?

In order to predict the expected hadronic-tau background to our analysis, we still need to implement

- the HT and MHT cuts, and
- the Δ cuts,

(cf. Sample Definition and Composition). Δ is computed between MHT and the leading three jets, i.e. the three jets with the highest p_T. The jets are ordered in p_T by default, the jet with index 0 is the jet with the highest p_T. But remember: We have removed the jet matched to the muon and replaced it by the simulated tau jet. Thus, the jet ordering might have changed!

Now, try to implement by yourself these cuts for prediction and truth. An example of how this **can** be done is given in `hadTau5.C` - **but try for yourself first!** This is exactly the same script as `hadTau4.C` but with the additional HT, MHT, and Δ cuts, and it is executed in the same way:

```
root -l -b -q hadTau5.C+\(true,50\)
```

Does this cut affect the quality of the closure?

This method could now be applied to real collision data to predict the HT and MHT distributions.

- **Question 4.1**: Is the normalisation final? What corrections factors do you think are needed to set the correct normalisation of the predicted distributions?
- **Question 4.2**: Due to what effects do you expect systematic uncertainties? How would you determine them?
- **Question 4.3**: Could the presence of possible new-physics processes affect the result? What additional selection cut on the control sample could prevent this?

Hadronic-Tau 5: Prediction on Data

Finally, we will predict the hadronic-tau background from collision data. We will use a control sample that has been collected with the high-level trigger paths `HLT_IsoMu17_eta2p1_DiCentralPFJet30_PFHT350_PFMHT40_v*`, i.e. events with

- at least one isolated muon with $p_T > 17$ GeV and $| \; | < 2.1$
- at least two central PF jets with $p_T > 30$ GeV
- HT > 350 GeV
- MHT > 40 GeV

have been collected. The amount of data corresponds to 5.295 / fb.

To obtain the final result, we will have to implement a few corrections and scale factors. Please follow the instructions below.

Show instructions Hide instructions
We will again use the script `hadTau5.C` and adapt it for usage on data. The data ntuples reside at `/nfs/dust/test/cmsdas/school61/susy/ntuple/2013-v1/MuHad-Run2012AB.root`; change the input file name for the tree accordingly. Then, set the argument `isMC` to false when calling the script:

```
root -l -b -q hadTau5.C+\(false,50\)
```

This will produce a ROOT file `HadTau_WJetData_Pred.root`. Check the predicted distributions with `plotHadTau3.C`. One remark: in the simulation, we found a ratio of 0.64 for the hadronic-tau to the muon decay channel of the W. Since the simulation (incorrectly) assumes equal branching fractions of the W to muons and taus, the actual ratio in data is expected to be slightly different, not 0.64 but 0.69. Hence, use this scale factor when plotting the data prediction:

```
root -l plotHadTau3.C\(0.69,\"HadTau_WJetData_Pred.root\"\)
```

Discuss the predicted distributions.

- **Question 5.1**: What is the reason for the structure of the muon p_T spectrum at low p_T?

In order to obtain the total event yield for the expected number of events after the baseline selection, the predicted number of events need to be scaled to take into account the control-sample selection efficiency (cf. Question 4.1). The overall scale-factor due to the selection efficiency is roughly 2, i.e. scale the data prediction by

```
0.69 * 2
```

to get the final prediction. **But**: The selection efficiency has significant HT and MHT dependencies because in particular the number of isolated muons depends on the event topology and activity. This is not correctly considered when using the constant, overall scale-factor of 2!

QCD Background Determination (R+S Method)

This exercise is intended to familiarize you with the concept of the QCD background determination for the SUSY analysis in the hadronic channel. The QCD multi-jet process has no intrinsic MET, or MHT defined similar as MET but using jets above a certain threshold, except from semi-leptonic b- and c- quark decays. MHT in QCD events can be attributed entirely to the jet energy resolution (JER). The sources that contribute to JER include energy resolution of the calorimeter, detector effects like dead or noise calorimeter cells, physics effects like pile-up or semi-leptonic decays from heavy quarks.

The strategy to determine this QCD background using only the data is twofold: In a first step (The Rebalancing) a clean QCD control-sample is created, that would correspond to a QCD sample measured by a detector with perfect energy resolution, or to the Generator-level of a QCD MC. In a second step (The Smearing) the jets in this QCD control sample are smeared according to the jet energy resolution that already has been measured in the data using photon-jet and di-jet events. The method is therefore termed *Rebalance+Smear* (*R+S*) method.

The intention of this exercise is to understand, develop and study the rebalancing and the smearing algorithm on a subset of the total data using a simplified jet energy resolution. This includes:

QCD R+S Step 1: The code

Get the code from CVS. The code contains the QCD R+S code template in the directory bin/ and code to make comparison plots in the directory plots/. Both can be compiled standalone using `make` or within the CMSSW framework using `scram b` (suggested). Make yourself familiar with the code, compile and test it.

Show Instructions Hide Instructions
Checkout:

DESY:

```
cd RA2Exercises/QCD_RS/bin
cp /nfs/dust/test/cmsdas/school78/data/SUSY/myQCDrs/QCDcontrol_data.root .
cp /nfs/dust/test/cmsdas/school78/data/SUSY/myQCDrs/JetResolution.root .
```

QCD Rebalance and Smearing code (main file QCDrs.cc):

```
cd RA2Exercises/QCDrs/bin
scram b
QCDrs
```

Plotting code (main file Plot.cc):

```
cd RA2Exercises/QCDrs/plot
ln -s ../bin data
make
./Plot
```

QCD R+S Step 2: The Rebalancing

In the file `Rebalance.cc` you find the function `bool Rebalance( const Event* evt, Event* rebalanced,  JetResolution * JetRes)`. The event "evt" should get rebalanced such that the MHT of the resulting event "rebalanced" vanishes. The jet energy resolution for a given jet is accessible by "JetRes". The function returns "true" if the rebalancing was successful. Your task is to develop the rebalancing algorithm. There are different ways to do this:

I. Single jet The simplest case is to assume, that a severe mismeasurement of a jet leading to MHT in QCD events is very rare. In this case, a single mismeasured jet determines MHT. Therefore, choose one jet and rescale its energy, so that MHT becomes zero. Which is the best jet to choose for rebalancing? Will the rebalancing work for every event?

II. Likelihood A more exact way to rebalance the events is to allow all jets to vary, taking into account the average resolution for each jet. In this case a likelihood, i.e. a chi-2 function, can be defined with the additional constraint that MHT=0. The best jet energy scale factors are those, for which the likelihood function is maximal.

$$\chi^2 = \sum_i^{jets} \frac{(measured \quad jet_i - scale_i * jet_i)^2}{\sigma_i^2} \qquad \text{constraint: MHT=0 for the chosen } scale_{1,2,3}$$

Show instructions Hide

- Consider the leading three jets for rebalancing, choose the pT scaling factor scale_2 and scale_3 for the 2nd jet and the 3rd jet and calculate the scale factor scale_1 for the leading jet, such that MHT becomes zero.
- Define a 2-dimensional root histogram, e.g. TH2F, and fill it for each bin defined by scale_2 and scale_3 with the chi2 value defined in the above equation.
- Fit the histogram with a 2D quadratic function, see e.g. this fitting example. The fit determines the best scales.
- Rebalance the jets according to the found scale_2, scale_3, and scale_1. Sort the jets according Pt and return true. If the fit fails, return false.
- Make sure to delete all objects created with 'new' to avoid memory leaks. To debug, test the 2D fit for single events and check the results.

III. KinFitter CMSSW package The full analysis use the CMSSW package KinFitter to rebalance the jets per event. During the exercise this code will be made available, for comparison:

Show instructions Hide

To ckeckout and use the Rebalance code using the KinFitter package do:

```
cd CMSSW_5_3_5/src
cvs co PhysicsTools/KinFitter
```

Make sure to backup your code, as this might get overwritten in the following step:

```
cd RA2Exercises/QCDrs/bin
cp Rebalance.cc Rebalance.cc.bkp
##cvs up -r CMSDAS2012_SolutionRebalance (versioning still not in place)
scram b
```

QCD R+S Step 3: The Smearing

In the file `Smear.cc` you find the function `void Smear( const Event*evt, Event* rs, JetResolution * JetRes )`. It gets an rebalanced event "evt" and the jet energy resolution as input and creates the smeared event "rs" as output. Depending on the rebalancing algorithm used, one or all jets per event should be smeared.

Gaussian JER: In the simplest case the jet energy resolution can be approximated by a Gaussian PDF. The JER depends on the jet transverse momentum. Obtain a Gaussian-distributed random number, where the mean of the Gaussian is 1 and its width corresponds to the pt-dependent jet energy resolution of the current jet, see i.e. JME-10-014. Scale the jet momentum and energy with the random number and sort the jets per event according to their transverse momenta.

Correct JER distribution: In practice the JER distributions have a non-negligible non-Gaussian tail and depend also on the jet's pseudo-rapidity. Use the method `float GetRandom(float pt, float eta, int i_th)` of the `JetResolution` class to get a random value that is distributed according to the true jet energy resolution of the `i_th` leading jet with transverse momentum `pt` and pseudo-rapidity `eta`. How compares a rebalances&smeared sample using this JER to a sample obtained using the Gaussian-only JER?

Consider event weights: Events, regardless if data or MC, might have event weight larger than 1. In data, this is can be due to trigger pre-scales. If these events are smeared by a large random value, i.e. receive a large jet mismeasurement, the event might be in the MHT tail, leading to large statistical uncertainties because of the large event weight. To avoid this, the event can be smeared (int)weight times. These (int)weight events get a reduced event weight close to one, thereby avoiding peaks in the tails and reducing the statistical uncertainties. The statistical uncertainties can be further reduced, by smearing each event, regardless of it's weight, N-times. The resulting events weights have to be scaled by 1/N.

Show solution Hide
To ckeckout and use the code including the solution backup your code and do:

```
cd CMSSW_4_2_5/src/RA2Exercises/QCDrs/bin
cp Rebalance.cc Rebalance.cc.bkp
cp Smear.cc Smear.cc.bkp
##cvs up -r CMSDAS2012_SolutionRebalanceSmear  (versioning still not in place)
scram b
```

QCD R+S Step 4: Studies of the results

Compare the HT, MHT and jet Pt distributions for the original, the rebalanced and the smeared sample. Do they agree? Do they have to agree? Make the same comparison plots after a selection on HT>350 GeV and MHT>100 GeV. Use a control sample containing real MHT, like ttbar production and apply this method. Is the R+S sample ttbar or QCD like?

Invisible Z Background Estimation

The Z+multijet event where the Z boson decays into a pair of neutrinos has the same signtaure as many beyond the SM physics scenarios, especially SUSY models. This background can be measured using Z(dilepton)+jets, W(lepton)+jets and Photon+jets events. Since leptons and photons are measured with high precision at CMS, one can neglect the presence of lepton(s)/photon in the even and interpret its momentum as momentum carried by a neutrino. All these processes are expected to have similar final state event topologies and can be used to estimate Z(nunu)+jets contribution by making use of theoretical correspondence between the various processes. Two methods are covered here. The first one is the Photon+Jets method which uses events with a Photon to estimate the background due to Z(nunu)+jets to multijet events with large missing transverse momentum. The other using dilepton events will be discussed in the following section.

Estimation with Gamma+Jets Events

To estimate the number of events with Z(nunu)+jets from a Photon+Jets sample, we have to proceed in the following steps :

- We start with a set of events containing a well identified photon
- Ignore this photon and calculate HT and MHT using jets
- This number has to be corrected for the detector accetance and identification efficiencies to get the original number of Photon+jets
- Subtract any backgrounds to Photon+jets sample
- Use the ratio of production cross-section of Photon+jets and Z(nunu)+jets to get the number of Z(nunu)+jets

Estimation with Dilepton Events

Estimating the Z(nunu)+Jets background using events including Z decays to dileptons is one of the simplest approaches. This approache exploits the fact that the kinematic characteristics of these events are very similar. The pair of muons can be reinterpreted as missing energy in order to emulate the missing energy in Zvv events.

Final Result

Finally, we want to compare the HT and MHT distributions measured in data with our data-based SM background predictions. Modify the script written in Data vs Simulated SM Background and replace the simulated background distributions with the data-based predictions (where available).

- In case of QCD, this is straight-forward.
- In case of the SM backgrounds from W(l)+jets and ttbar, we only have the hadronic-tau contribution predicted from data. The lost-lepton method has not been performed here. However, the lost-lepton and hadronic-tau contributions have roughly the same size. From the analysis of the 7 TeV data collected in 2011, we get

  ```
  N(lost-lepton) / N(hadronic-tau) = 0.9
  ```

  Hence, we can scale the hadronic-tau prediction by 1.9.
- Thus, only the Z( )+jets background remains from simulation. How reliable do you think the simulation is, e.g. compared to the QCD? Where do you think the major difficulties arise in simulating the Z( )+jets background?

A final question: Are data-based background predictions always preferable to simulation-based predictions?

References

- "Search for New Physics with Jets and Missing Transverse Momentum in *pp* collisions at √s=7 TeV", JHEP **1108** (2011) 155, arXiv:1106.4503
- "Search for supersymmetry in all-hadronic events with missing energy", CMS-PAS-SUS-11-004
- "Search for new physics in the multijet and missing transverse momentum final state in proton-proton collisions at √s=7 TeV", Phys. Rev. Lett. **109** (2012) 171803, arXiv:1207.1898
- The 2012 version AN-12-350, [[https://twiki.cern.ch/twiki/bin/view/CMS/SusyRA2NJetsInData2012][SusyRA2NJetsInData2012]
- ROOT reference guide: documentation of all ROOT classes
- C++ Language Library Reference: detailed descriptions of its elements and examples on how to use its functions
- Bradley Efron, "The Jackknife, the Bootstrap, and Other Resampling Plans", ISBN 0-898-71179-7

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Information for Facilitators

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Ntuple Creation

This recipe has been developed for CMSSW_5_3_5. The code to write the ntuples resides at `UserCode/mschrode/DAS/DASTreeMaker`. It is based on SUSY PAT and some RA2 specific code documented at SusyRA2NJetsInData2012 and RA2Classic. We use the current (30.12.2012) status of the recipes as described in the following.

To run the ntupler, follow these instructions (from the `CMSSW_5_3_5/src` directory):

1. Set up SUSY PAT:

```
addpkg DataFormats/PatCandidates    V06-05-06-03
addpkg PhysicsTools/PatAlgos        V08-09-42
addpkg CommonTools/RecoUtils        V00-00-13
addpkg DataFormats/StdDictionaries  V00-02-14
addpkg RecoParticleFlow/PFProducer  V15-02-06
addpkg JetMETCorrections/Type1MET   V04-06-09
addpkg PhysicsTools/Configuration   V00-12-06
```

2. Set up the RA2-specific filters and objects

```
cvs co -r V00-00-13 RecoMET/METFilters
cvs co -r V01-00-11-01 DPGAnalysis/Skims
cvs co -r V00-11-17 DPGAnalysis/SiStripTools
cvs co -r V00-00-08 DataFormats/TrackerCommon
cvs co -r V01-09-05 RecoLocalTracker/SubCollectionProducers
cvs co -r CutBasedId_V00-00-05 -d EGamma/EGammaAnalysisTools UserCode/EGamma/EGammaAnalysisTools
cvs co -r  RA253XAN_20Dec2012V2  -d SandBox/Skims  UserCode/seema/SandBox/Skims
cvs co -r V04JAN2012_v1 -d UserCode/DataFormats UserCode/lhx/DataFormats
cvs co -r RA2_2012-12-28 -d RA2Classic/AdditionalInputFiles UserCode/kheine/RA2Classic/Additional
cvs co -r RA2_2012-12-28 -d RA2Classic/Utils UserCode/kheine/RA2Classic/Utils
```

```
cvs co -r RA2_2012-12-28 -d RA2Classic/WeightProducer UserCode/kheine/RA2Classic/WeightProducer
```

3. Set up the NtupleMaker

```
cvs co -r cmsdas2013-DESY-v5 -d DAS/DASTreeMaker UserCode/mschrode/DAS/DASTreeMaker
```

4. Copy PU-Reweighting Histograms to local `data` Directory

```
cd RA2Classic/WeightProducer
mkdir data
cd data
cp ../../AdditionalInputFiles/DataPileupHistogram_RA2Summer12_190456-* .
```

This step is necessary because grid-control requires additional input files in the `data` directory.

To produce the ntuples, run `DAS/DASTreeMaker/test/makeDASTree_cfg.py`. Some parameters have to be given as command-line arguments (comma-separated list of 'parameter'='value' pairs), e.g.

```
cmsRun makeDASTree_cfg.py data_set=/HT/Run2012A-13Jul2012-v1/AOD is_mc=false, global_tag=FT_53_V6
```

There is also a grid-control configuration file `DAS/DASTreeMaker/test/dasTreeMaker.conf` to submit jobs to the NAF batch system.

Global Tags

Dataset	Global tag
2012A+B (Jul13 rereco, 53X)	`FT_53_V6C_AN3::All`
2012A (Aug06 rereco, 53X)	`FT_53_V6C_AN3::All`
2012Cv1 (Aug24 rereco, 53X)	`FT53_V10A_AN3::All`
2012Cv2 (prompt reco, 53X)	`FT_P_V42C_AN3::All`
2012D (prompt reco, 53X)	`FT_P_V42_AN3::All`
Summer12_DR53X 53X	`START53_V7G::All`

Existing Ntuples

The ntuples are stored at
`/pnfs/desy.de/cms/tier2/store/user/mschrode/cmsdas/2013-DESY`

Data for Main Analysis

Ntuple	Parent Dataset	Comment
Data*.root	/HT/Run2012A-13Jul2012-v1/AOD, /HT/Run2012A-recover-06Aug2012-v1/AOD, /HTMHT/Run2012B-13Jul2012-v1/AOD	(Sample Definition and Composition)
MuHad-Run2012AB.roo	/MuHad/Run2012A-13Jul2012-v1/AOD, /MuHad/Run2012A-recover-06Aug2012-v1/AOD, /MuHad/Run2012B-13Jul2012-v1/AOD	Muon+Jets Control Sample (Hadronic-Tau Background Prediction)

In order to select the certified sections, use the RA2 analysis JSON files (cvs tag `RA2_2012-12-28`):

- `RA2Classic/AdditionalInputFiles/Cert_190456-196531_AB.txt` for the A and B eras only (5.295/fb)

MC

Ntuple	Parent Dataset
WJets_*.root	/WJetsToLNu_TuneZ2Star_8TeV-madgraph-tarball/Summer12_DR53X-PU_S10_START53_V7A-v2/
QCD_*.root	/QCD_Pt-15to3000_TuneZ2star_Flat_8TeV_pythia6/Summer12_DR53X-PU_S10_START53_V7A-v1
ZInv_*.root	/ZJetsToNuNu_400_HT_inf_TuneZ2Star_8TeV_madgraph/Summer12_DR53X-PU_S10_START53_V
TTJets_*.root	/TTJets_MassiveBinDECAY_TuneZ2star_8TeV-madgraph-tauola/Summer12_DR53X-PU_S10_STAR

Event weights to account for the cross section and PU profile can be produced using the `RA2Classic/WeightProducer`. The PU target distributions are (cvs tag `RA2_2012-12-28`)

- `RA2Classic/AdditionalInputFiles/DataPileupHistogram_RA2Summer12_190456-196` for the A and B eras only (5.295/fb)

-- MatthiasSchroederHH - 30-Dec-2012

This topic: CMS > SWGuideCMSDataAnalysisSchool2013SUSYJetsPlusMHT
Topic revision: r34 - 18-Jan-2013 - MatthiasSchroederHH