Z' RECONSTRUCTION AT THE LHC

Overview of the Tutorial

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Introduction to Terascale Physics
24 February 2011

THE Z' BOSON

And the relevant final states

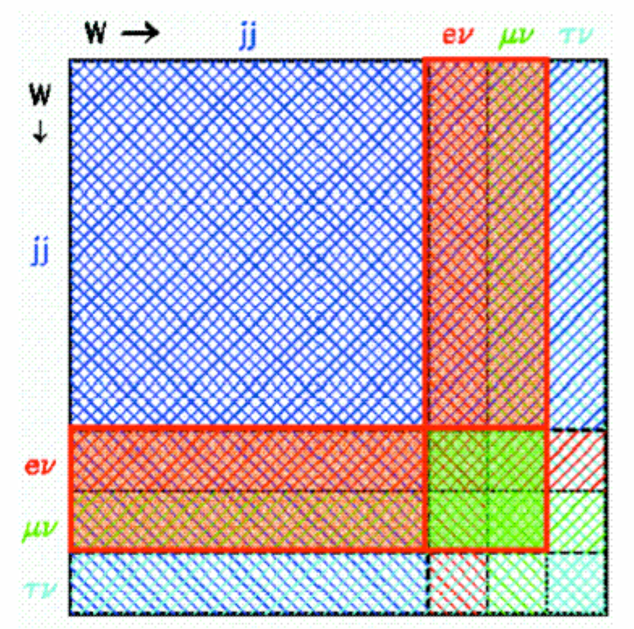
Z': massive, electrically neutral resonance.
Potentially in extended gauge groups like $SU(2)_{EW} \times U(1)_Y \times U(1)_{Z'}$

- Can mix with the SM Z.
- Supposed to be heavier than 500 GeV.
- Preferred decay mode: to top quark pair with subsequent decays to Wb pairs:

$$Z' \rightarrow t\bar{t} \rightarrow W^+ b W^- \bar{b}$$

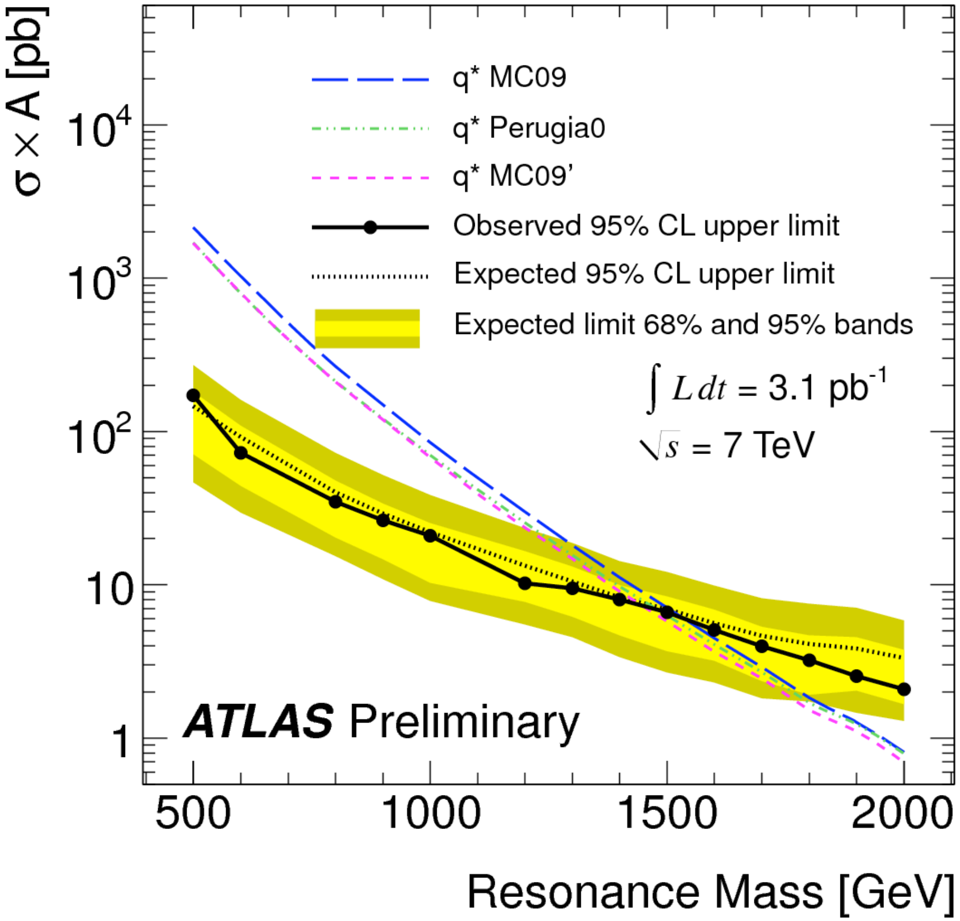
Top final states and W boson decays:

- W bosons can decay leptonically or hadronically
- fully hadronic, semi-leptonic and fully leptonic final states.
- Here concentrate on semi-leptonic final state (moderate background, good branching ratio)

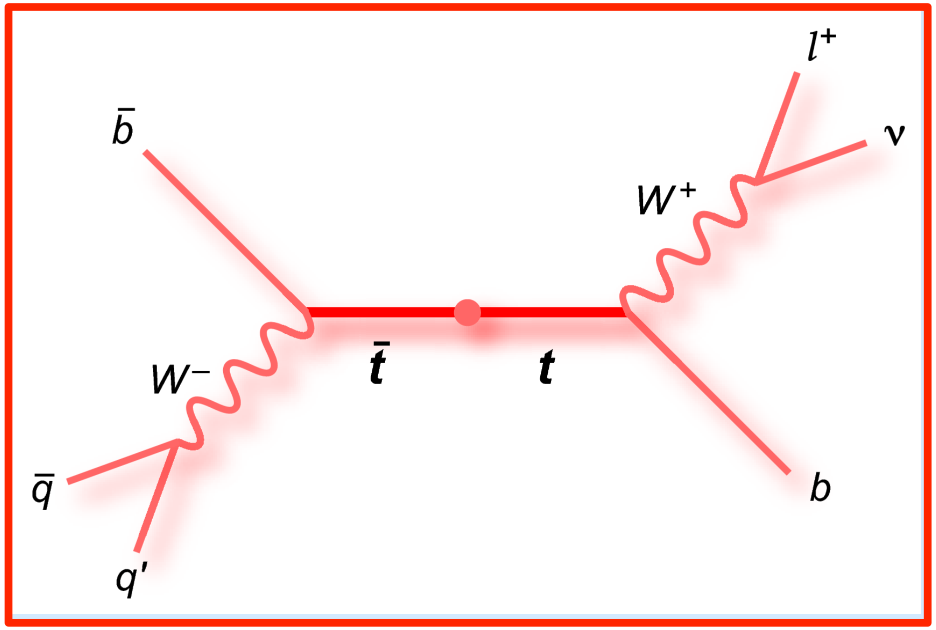


EXISTING LIMITS ON THE Z' BOSON

From LEP, HERA, Tevatron, LHC



THE PROJECT: FINDING THE Z'



- At least 4 jets with $|\eta| < 2.5$ and $p_T > 40\,\mathrm{GeV}$
- Exactly one isolated lepton with $p_T > 20$, GeV for the electrons and $p_T > 25\,\mathrm{GeV}$ for the muons; excluded crack region $1.37 < |\eta| < 1.52$ [1].
  The isolation cuts are $E_T^{\mathrm{cone20}} < C1 + C2 \cdot E_T$ ($C1 = 4.0\,\mathrm{GeV}$, $C2 = 0.023$) for the electrons and $E_T^{\mathrm{cone20}}/p_T < 0.1$ for the muons
- Exactly two b–tagged jets (tag weight > 6.0)
- Missing transverse energy $\not{E}_T > 20\,\mathrm{GeV}$

ANALYSIS FRAMEWORK AND FLOW

In only a few cc files … data samples

```
#include <...>
...
// for debugging purposes: set to -1 if all events should be read
int maxReadEventsPerFile = -1;

// Sample file names
const char* zPrime_file="data/zprime_sample.root";

// Raw data NTuple declaration
Data *zprimeData,*ttbarData,*zeeData,*zmumuData,*wenuData,*wmunuDat

// Reco data declaration
RecoData *zprimeRecoData ...

// Now include all exercise files
#include "exercise1.cc"
...

// main() routine
int main(int argnum,char** args)
{
  // Read sample NTuples
  zprimeData=readNTuple(zPrime_file);
  ...
  // Perform Z' reconstruction on samples
  zprimeRecoData=getReconstructedData(zprimeData);
  ...
  // Open a text file to log important results
  report.open("analysis_report.txt",std::ios_base::out);
  ...
  // And now it's your turn...
  exercise1();
  ...
}
```

ANALYSIS FRAMEWORK AND FLOW

In only a few cc files … data samples

```
#include <...>
...
// for debugging purposes: se
int maxReadEventsPerFile = -1

// Sample file names
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// Raw data NTuple declaration
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  ...
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  ...
}
```

```
//*********************************************************************************
// RecoData* getReconstructedData(Data* data):
//
// Reconstruct the top quarks, calculate Z' mass and return pointer to reconstructed
// data
//*********************************************************************************
RecoData* getReconstructedData(Data* data)
```

ANALYSIS FRAMEWORK AND FLOW

In only a few cc files … data samples

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#include <...>
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  // Open a text file to log important results
  report.open("analysis_report.txt",std::ios_bas
  ...
  // And now it's your turn...
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  ...
}
```

```
//*************************************************************************
// RecoData* getReconstructedData(Data* data):
//
// Reconstruct the top quarks, calculate Z' mass and return pointer to reconstructed
// data
//*************************************************************************

RecoData* getReconstructedData(Data* data)
```

```
// How many events to read?
unsigned int maxEvents=data->size();

for (unsigned int i=0;i<maxEvents;i++)
{
        // Event has passed all cuts?
        if (isGoodEvent(data->at(i)))
        {
                Event event=data->at(i);

                RecoObject tmpObj;

                tmpObj.event=event;

                HadronicWBoson hadW=getBestHadronicWFit(event);
                LeptonicWBoson lepW=getBestLeptonicWFit(event);

                HadronicTop hadTop=getBestHadronicTopFit(event,hadW);
                LeptonicTop lepTop=getBestLeptonicTopFit(event,lepW,hadTop);

                tmpObj.hadTop=hadTop;
                tmpObj.lepTop=lepTop;

                tmpObj.ZprimeMass=getZprimeMass(hadTop,lepTop);

                ret->push_back(tmpObj);

                goodEvents++;

        }
```

RUNNING THE ANALYSIS

… for the various exercises …

```
Terminal — ssh — 63×34
[desy-cms004] ~/tutorial $ ls
Makefile             exercise4.cc   readNTuple.cc
analysis_report.txt  exercise5.cc   reconstruction.cc
cuts.cc              exercise6.cc   save
data                 exercise7.cc   solutions
doc                  exercise8.cc   stripped
exercise1.cc         exercise9.cc   test.cc
exercise10.cc        kinematics.cc  typedefs.cc
exercise2.cc         main.cc
exercise3.cc         plots
[desy-cms004] ~/tutorial $ make
g++ -g -O2 -Wall -pthread -m32 -I/opt/products/root/5.26.00/inc
lude main.cc -I/opt/products/root/5.26.00/include -L/opt/produc
ts/root/5.26.00/lib -L./ -L/opt/products/root/5.26.00/lib -lCor
e -lCint -lRIO -lNet -lHist -lGraf -lGraf3d -lGpad -lTree -lRin
t -lPostscript -lMatrix -lPhysics -lMathCore -lThread -pthread
-lm -ldl -rdynamic -o main -lMathCore
[desy-cms004] ~/tutorial $ ls
Makefile             exercise4.cc   plots
analysis_report.txt  exercise5.cc   readNTuple.cc
cuts.cc              exercise6.cc   reconstruction.cc
data                 exercise7.cc   save
doc                  exercise8.cc   solutions
exercise1.cc         exercise9.cc   stripped
exercise10.cc        kinematics.cc  test.cc
exercise2.cc         main           typedefs.cc
exercise3.cc         main.cc
[desy-cms004] ~/tutorial $ ./main
+++ NTuple file: data/zprime_sample.root:
 => 19020 entries found
+++ NTuple file: data/ttbar_sample.root:
 => 58475 entries found

[desy-cms004] ~/tutorial $
```

THE DATA STRUCTURES
used for the analysis, defined in typedefs.cc

`struct RecoObject`

- `Event event`: the raw event associated to the reconstruction
- `HadronicTop hadTop`: the reconstructed hadronic top quark
- `LeptonicTop lepTop`: the reconstructed leptonic top quark
- `double ZprimeMass`: the reconstructed invariant Z' mass

THE DATA STRUCTURES
used for the analysis, defined in typedefs.cc

`struct HadronicTop`

- `Jet bJet`: b–tagged jet closest in ΔR to the previously reconstructed hadronic W boson
- `HadronicWBoson wBoson`: the hadronic W boson
- `double mass`: reconstructed invariant hadronic top mass
- `double deltaR`: ΔR between the b jet and the hadronic W

`struct LeptonicTop`

- `Jet bJet`: b–tagged jet closest in ΔR to the previously reconstructed leptonic W boson
- `LeptonicWBoson wBoson`: the leptonic W boson
- `double mass`: reconstructed invariant leptonic top mass (best agreement of the two leptonic W solutions with hadronic top mass)
- `double deltaR`: ΔR between the b jet and the leptonic W

THE DATA STRUCTURES
used for the analysis, defined in typedefs.cc

`struct LeptonicWBoson`

- `double El,pxl,pyl,pzl`: energy and 3-momentum components of the charged lepton constituent of the W boson
- `double ptnu`: transverse momentum of the recovered neutrino
- `double pxnu,pynu`: x and y 3-momentum components of the recovered neutrino
- `std::pair<double,double> pznu`: the two soluintions of the p_z^ν recovery (see 4.4)
- `std::pair<double,double> Enu`: the two energies calculated from the p_z^ν solutions of the recovered neutrino
- `std::pair<double,double> mass`: the two invariant W masses calculated from the p_z^ν solutions
- `double Enu_final`: E_ν for the best W fit
- `double pznu_final`: p_z^ν for the best W fit
- `double mass_final`: invariant W mass for the best W fit

`struct HadronicWBoson`

- `Jet jet1,jet2`: light jet constituents of the hadronic W boson
- `double mass`: reconstructed invariant W mass

THE DATA STRUCTURES

used for the analysis, defined in typedefs.cc

`struct Electron`

- `E` : electron energy
- `Et` : electron transverse energy
- `p` : norm of electron 3-momentum
- `pt`: electron p_T
- `px,py,pz` : vector components of electron 3-momentum
- `double eta,phi`: electron η, φ
- `charge` : charge of the electron
- `etCone20` : energy deposition in a $\Delta R = 0.2$ cone around the electron track

`struct Jet`

- `E` : jet energy
- `Et` : jet transverse energy
- `p` : norm of jet 3-momentum
- `pt`: jet p_T
- `px,py,pz` : vector components of jet 3-momentum
- `double eta,phi`: jet η, φ
- `tag_weight` : statistical weight of b tagging
- `bjet_prob` : b tag weight converted to a probability

THE DATA STRUCTURES

used for the analysis, defined in typedefs.cc

struct Event

- std::vector<Jet>: all jets of the event
- std::vector<Electron>: all electrons of the event
- std::vector<Muon>: all muons of the event
- double missingET: missing transverse energy $\not\!\!E_T$
- double missingET_phi: azimuthal direction of $\not\!\!E_T$ (angle in x, y–plane)
- weight: the event weight (only important when scaling samples up to a mixed data sample, is 1.0 in the prefabricated samples)

struct Muon

- double E : muon energy
- double Et : muon transverse energy
- double p : norm of muon 3-momentum
- double pt: muon p_T
- double px,py,pz : vector components of muon 3-momentum
- double eta,phi: muon η, φ
- double tag_weight : statistical weight of b tagging
- double charge : charge of the muon
- double etCone20 : energy deposition in a $\Delta R = 0.2$ cone around the muon track

THE DATA STRUCTURES

Example of usage

From typedefs.cc:

```
struct RecoObject
{
        Event event;
        HadronicTop hadTop;
        LeptonicTop lepTop;
        double ZprimeMass;
};
```

Reconstructed for each in event in each data sample

```
struct Event
{
        std::vector<Jet> jets;
        std::vector<Electron> electron
        std::vector<Muon> muons;
        double missingET;
        double missingET_phi;
        double weight;
};
```

```
struct Jet
{
        double E;
        double Et;
        double pt;
        double p;
        double px;
        double py;
        double pz;
        double eta;
        double phi;
        double tag_weight;
        double bjet_prob;
};
```

```
TH1F zprimeJetMultiHisto2("zprimeJetMultiHisto2","",16,-0.5,15.5);

for (unsigned int i=0;i<zprimeRecoData->size();i++)
        zprimeJetMultiHisto2.Fill(zprimeRecoData->at(i).event.jets.size());

if (event.jets[i].bjet_prob>prob)
```

DATA SAMPLES

for ttbar and Z' signals, and for backgrounds

We have generated simple ROOT NTuples for signal and the most important background processes containing only the most relevant information you need for this exercise. They have been produced from official ATLAS MonteCarlo production data sets.

file name	contained data	σ [pb]	$\int \mathcal{L}\, dt$ [pb^{-1}]
`zee_jets.root`	$Z \to e^+e^- + n$ jets	28.81	1000
`zmumu_jets.root`	$Z \to \mu^+\mu^- + n$ jets	29.41	1000
`wenu_jets.root`	$W \to e\nu + n$ jets	160.57	200
`wmunu_jets.root`	$W \to \mu\nu + n$ jets	90.77	200
`wbb_jets.root`	$Wb\bar{b} + n$ jets	14.64	1000
`ttbar_sample.root`	$t\bar{t}$, semi–lep	220.66	250
`zprime_sample.root`	$Z' \to t\bar{t}$, $M_{Z'} = 1000$ GeV	0.634	30000
`data_sample.root`	mixed $Z'/t\bar{t}$ sample	—	300

The luminosities of the samples were chosen in a way to end up with similar number of events in each sample.

EXERCISE 1: SELECTION

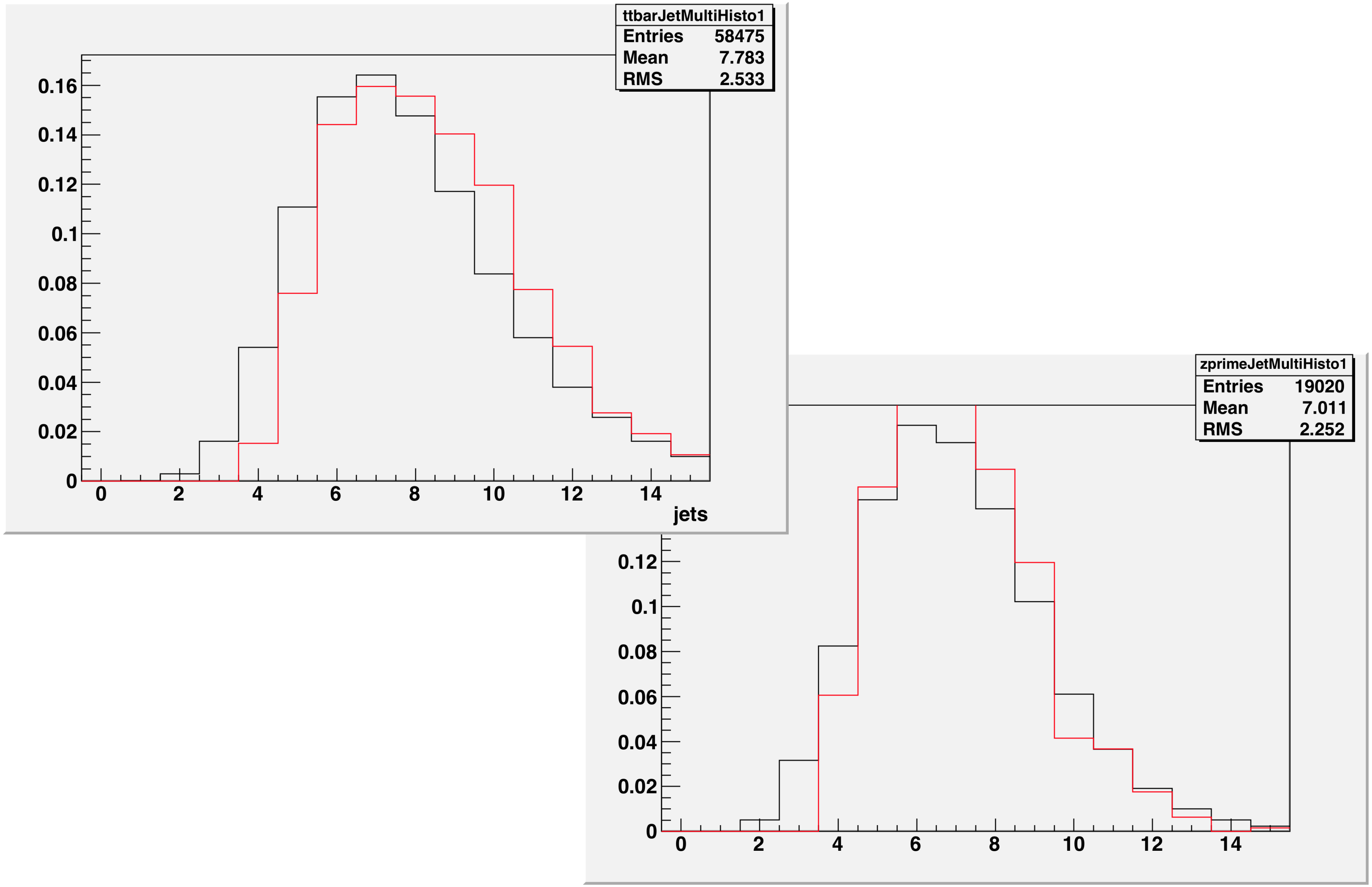
- At least 4 jets with $|\eta| < 2.5$ and $p_T > 40\,\mathrm{GeV}$
- Exactly one isolated lepton with $p_T > 20$, GeV for the electrons and $p_T > 25\,\mathrm{GeV}$ for the muons; excluded crack region $1.37 < |\eta| < 1.52$ [1].
  The isolation cuts are $E_T^{\mathrm{cone20}} < C1 + C2 \cdot E_T$ ($C1 = 4.0\,\mathrm{GeV}$, $C2 = 0.023$) for the electrons and $E_T^{\mathrm{cone20}}/p_T < 0.1$ for the muons
- Exactly two b–tagged jets (tag weight > 6.0)
- Missing transverse energy $\not{E}_T > 20\,\mathrm{GeV}$

Exercise 1

Make two plots for the jet multiplicities of the $t\bar{t}$ and the Z' sample out of two overlaid histograms: One histogram filled with the jet mutliplicity before and one after applying the cuts. Normalize the histograms to their integrals.

Calculate the event selection efficiencies $\epsilon_{t\bar{t}}^{\mathrm{C1}}$ and $\epsilon_{Z'}^{\mathrm{C1}}$ for the $t\bar{t}$ and the Z' sample. From the efficiencies of all the background samples (except $t\bar{t}$) calculate an average background suppression factor $\langle b \rangle = 1 - \langle \epsilon \rangle$.

EXERCISE 1: RESULT



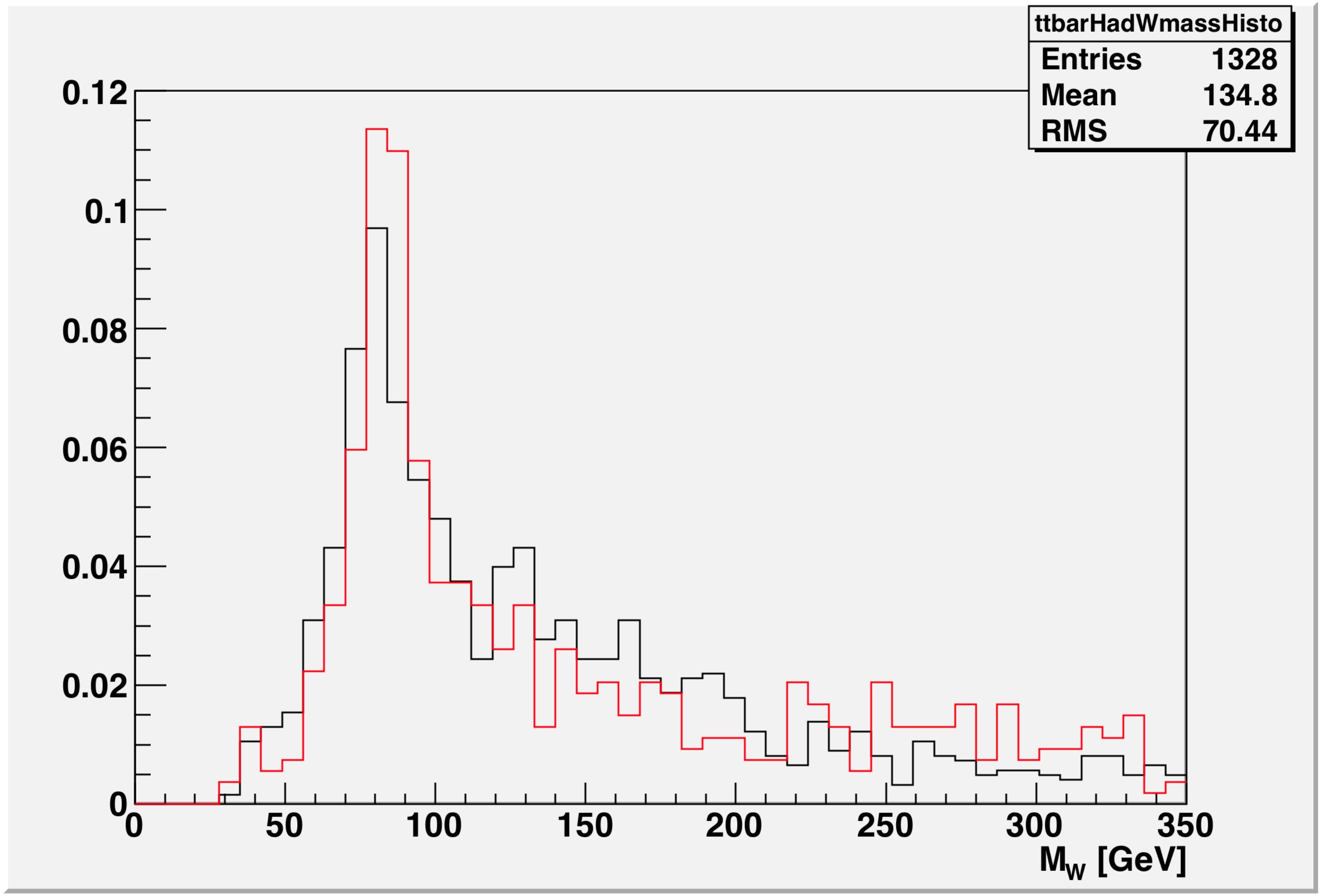
EXERCISE 2: RECONSTRUCTED HAD. W

The hadronic W boson in a semi–leptonic top quark event is the W boson that decays into two light flavor (LF) jets. LF jets are all jets that have not been b–tagged (tag weight < 6.0). Among all LF jets, the two ones are used for the kinematic W reconstruction that build up the W mass fitting the best ($M_W = 80.4\,\mathrm{GeV}$).

Exercise 2

Combine the hadronic W mass spectra of the $t\bar{t}$ and the Z' samples in one plot. Normalize both histograms to their integrals.

EXERCISE 2: RESULT



EXERCISE 3: COMBINATORIAL BG

The most important background in this process is the so–called "combinatorical background": If you have n LF jets in your event, there are $n(n-1)$ possibilities to combine them two the W boson. For $n = 5$ LF jets, there are $5 \cdot 4 = 20$ combinations, only one of them is true.

The combinatorical background of the W reconstruction can be described by a 4th degree Tschebyschow polynomial, the correctly combined jets can be assumed to be Gaussian distributed around the W mass. The first four orders of

$$T_0 = 1 \qquad T_1 = x \qquad T_2 = 2x^2 - 1$$

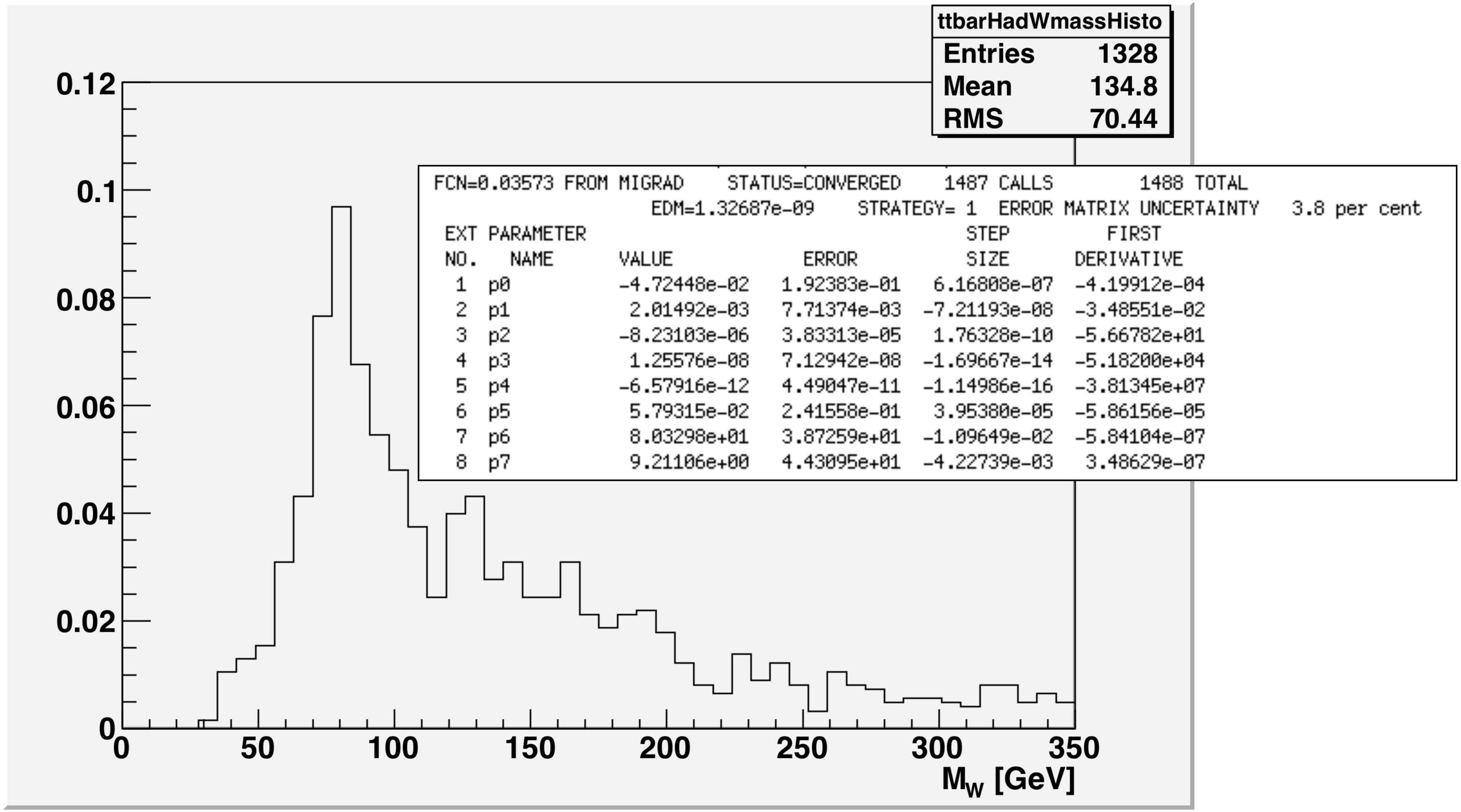
$$T_3 = 4x^3 - 3x \qquad T_4 = 8x^4 - 8x^2 + 1$$

Exercise 3

Fit the sum of a 4th degree Tschebyschow and a Gaussian distribution to your hadronic W mass spectrum of the $t\bar{t}$ sample and extract the W mass and width from the mean and the RMS of the Gaussian.

Hint: First define five `TF1`'s representing your Tschebyschoff polynomials $T_0 \ldots T_4$ and one `TF1` for the Gauss. In a sixth `TF1`, add the five polynomials, each one provided with a free fit parameter for scaling, and the Gaussian `TF1`. Use the standard `TH1::Fit(...)` method. Maybe you have to set start parameters for the Gauss to bring the fit to converge.

EXERCISE 3: RESULT



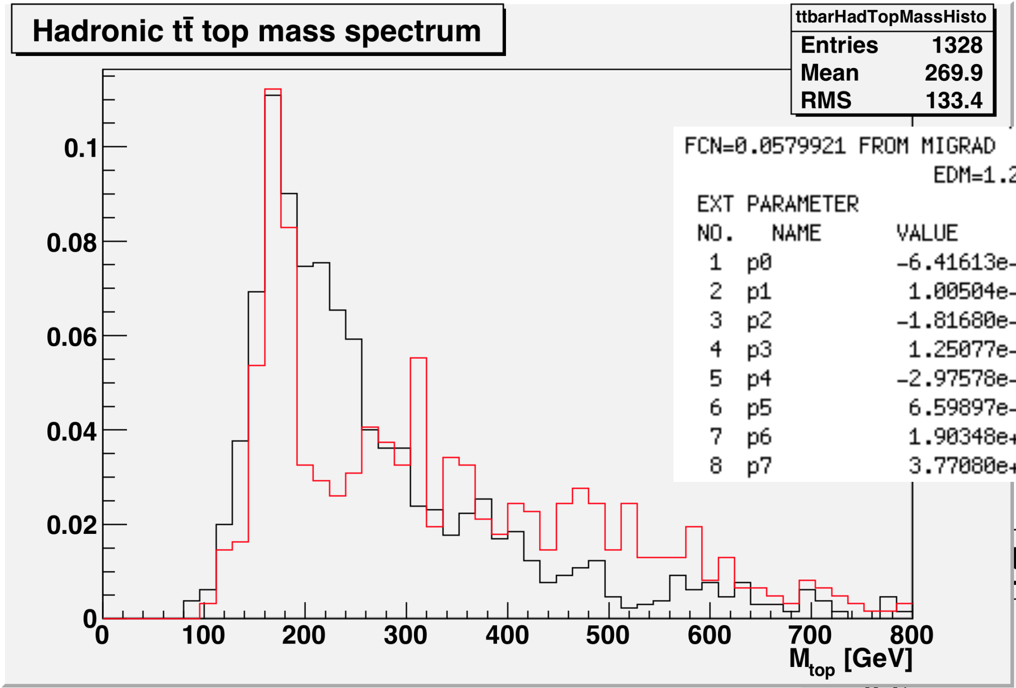
EXERCISE 4: THE HADRONIC TOP

After the hadronic W is reconstructed, the b jet that is closest in ΔR to the hadronic W boson is chosen to reconstruct the hadronic top quark.

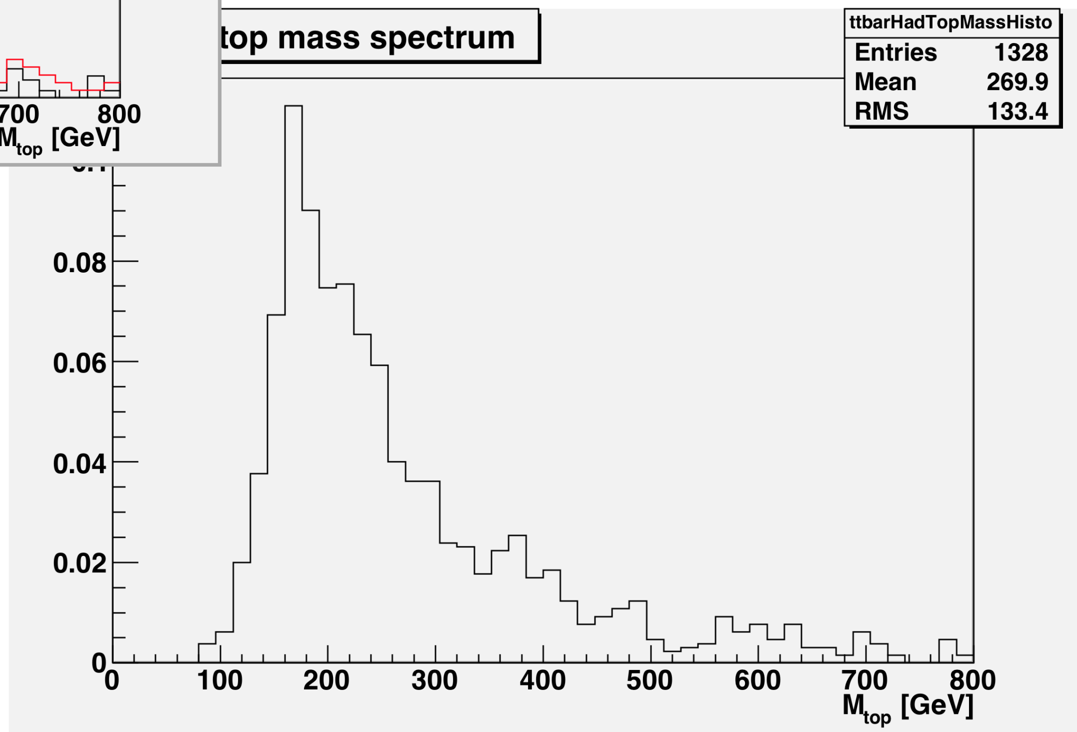
Exercise 4

Plot the hadronic top mass spectrum for the $t\bar{t}$ and the Z' sample (normalized to their integrals).
Perform the previous exercise with the Tschebyschoff fit to obtain the top mass and width of the $t\bar{t}$ sample.

EXERCISE 4: RESULT




```
FCN=0.0579921 FROM MIGRAD    STATUS=CONVERGED     1075 CALLS        1076 TOTAL
                    EDM=1.21812e-09    STRATEGY= 1  ERROR MATRIX UNCERTAINTY   2.4 per cent
 EXT PARAMETER                                    STEP         FIRST
 NO.   NAME        VALUE            ERROR          SIZE       DERIVATIVE
  1  p0          -6.41613e-02   2.72460e-01  -2.84366e-05  -9.11846e-04
  2  p1           1.00504e-03   4.29134e-03   4.00030e-07  -5.58354e-01
  3  p2          -1.81680e-06   8.70376e-06  -7.83692e-10  -5.27887e+02
  4  p3           1.25077e-09   6.66319e-09   5.86449e-13  -4.36484e+05
  5  p4          -2.97578e-13   1.74065e-12  -1.49638e-16  -2.92856e+08
  6  p5           6.59897e-02   1.60674e-01  -9.07578e-07   3.32315e-04
  7  p6           1.90348e+02   1.10184e+02   5.55517e-04  -5.74393e-07
  8  p7           3.77080e+01   1.23383e+02  -5.72140e-03   6.22411e-07
```



EXERCISE 5: THE "LEPTONIC" W

The difficulty of reconstructing the W that decays into two leptons is the unknown neutrino momentum vector. The only observable that can be measured in a hadron collider is the missing transverse energy $\not{E}_T$; besides, the direction of $\not{E}_T$ in the x, y–plane can be reconstructed. In good approximation, $\not{E}_T$ can be considered to be the transverse energy of the neutrino.

Taking the W boson mass as a fixed value, one can obtain a quadratic equation in p_z^ν:

$$M_W{}^2 = m_\ell{}^2 - 2(p_x^\ell p_x^\nu + p_y^\ell p_y^\nu) + 2E_\ell\sqrt{\not{E}_T{}^2 + p_z^{\nu\,2}} - 2(p_z^\ell p_z^\nu) \qquad (1)$$

p_x^ν and p_y^ν can be calculated from $\not{E}_T$ and $\varphi(\not{E}_T)$:

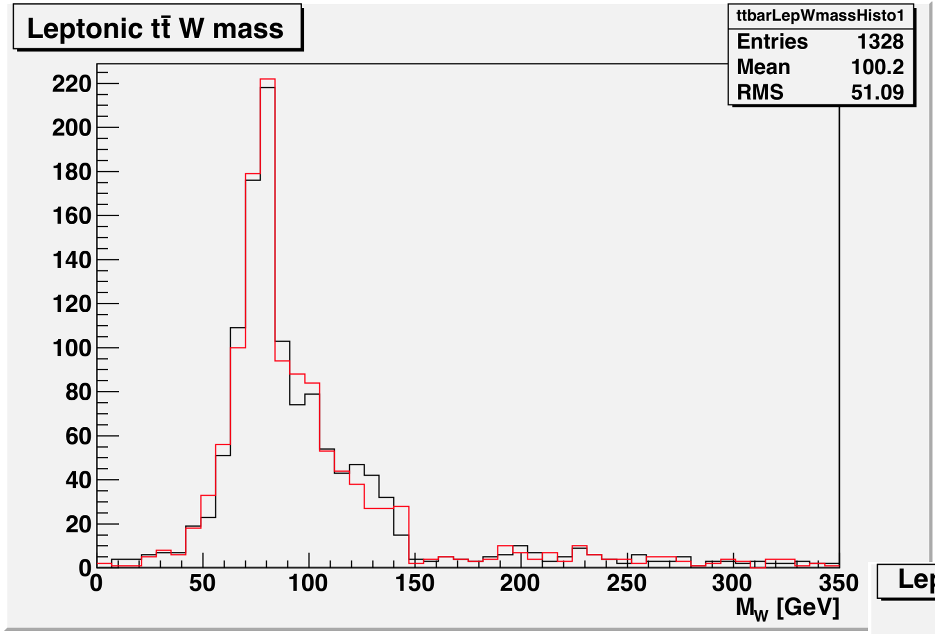
$$p_x^\nu = \not{E}_T \cdot \cos(\varphi(\not{E}_T)) \qquad p_y^\nu = \not{E}_T \cdot \sin(\varphi(\not{E}_T))$$

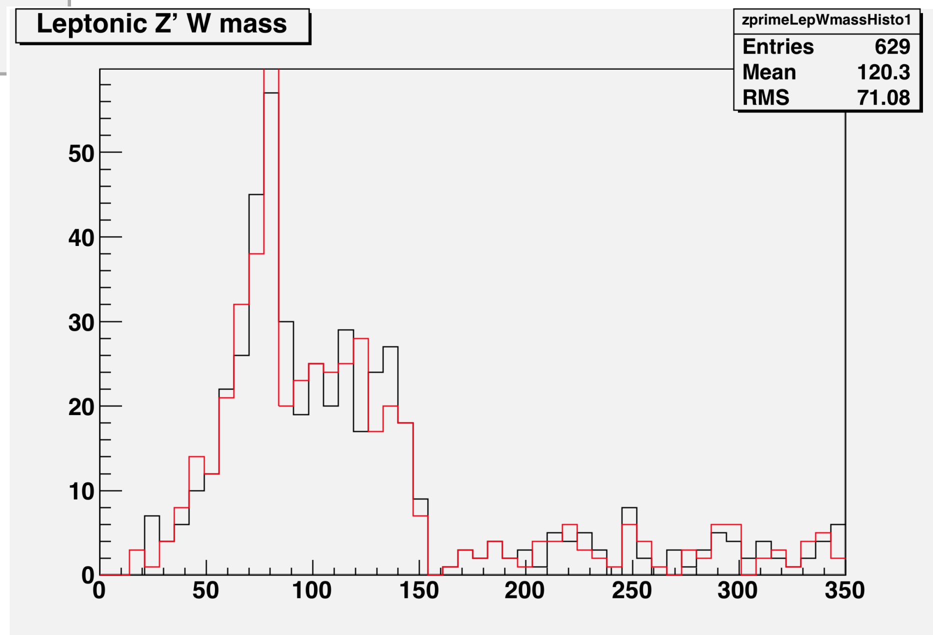
(1) has either two solutions or none. If it has none, p_T^ν is iterativelly decreased until the equation has two solutions. Later on, the leptonic top mass will be reconstructed with the leptonic W from both solutions. The leptonic top mass that agrees best with the hadronic top mass will be kept.

Exercise 5

Combine the histograms of the leptonic W mass for both p_z^ν solutions in one plot. Make one plot for each the $t\bar{t}$ and the Z' sample.

EXERCISE 5: RESULT





EXERCISE 6: Z' RECONSTRUCTION

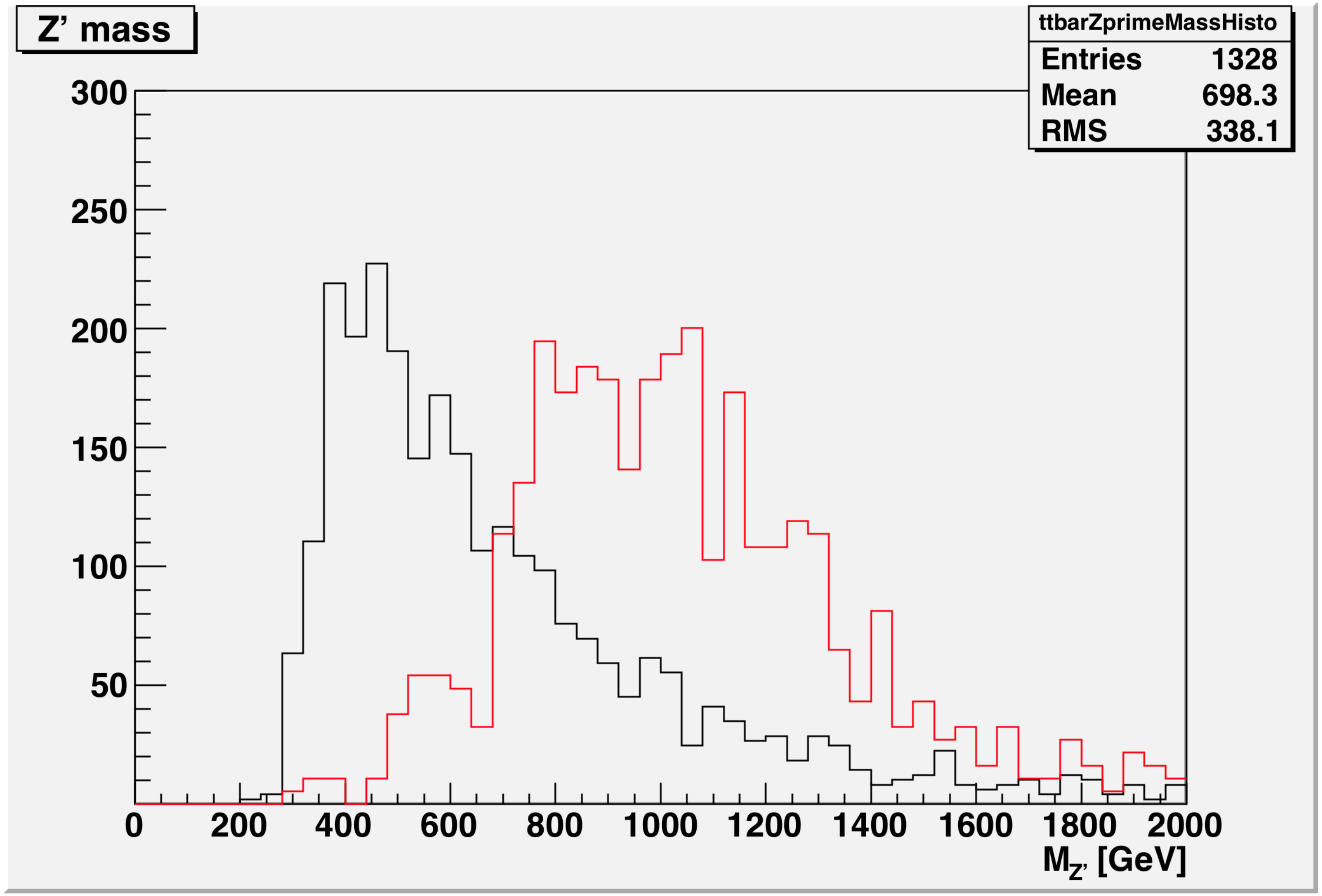
Finally, the Z' invariant mass can be calculated from the reconstructed tops. Since the cross section for SM $t\bar{t}$ production is about a factor 370 higher than $\sigma(Z' \to t\bar{t})$, one has to think about a way to distinguish the production channels.

$t\bar{t}$ production from a Z' is a resonant decay, i. e. the top quarks will be more boosted in average. As consequence, the opening angle of the cone of the decay products from the top quarks will be more narrow. This should be seen as a clear signature in the ΔR distributions of the b jet and the corresponding W boson.

Exercise 6

Fill two histograms with the invariant Z' mass spectrum from the Z' and $t\bar{t}$ samples and combine them in one plot. Choose logarithmic y scaling.

EXERCISE 6: RESULT



EXERCISE 7:

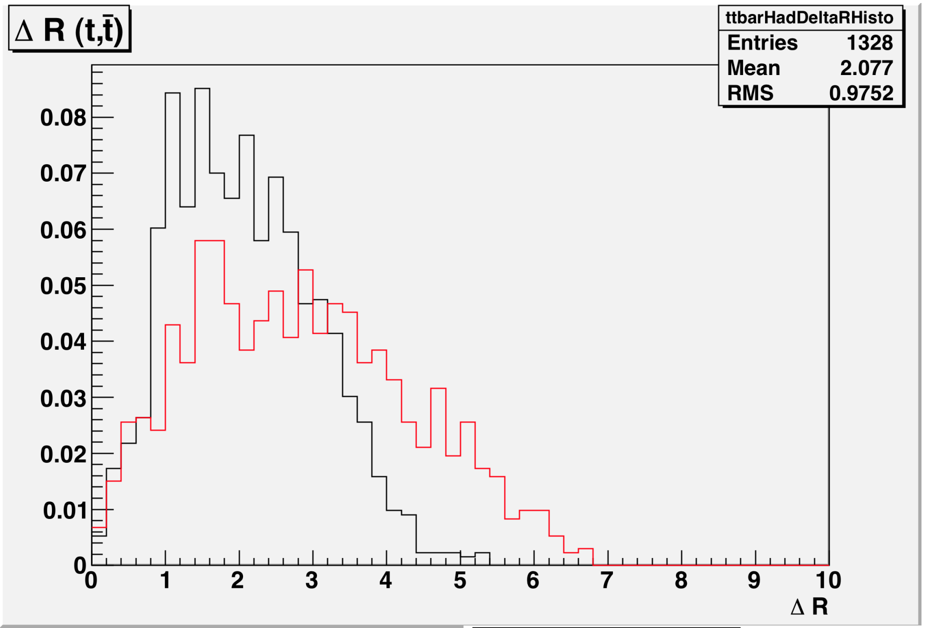
Exercise 7

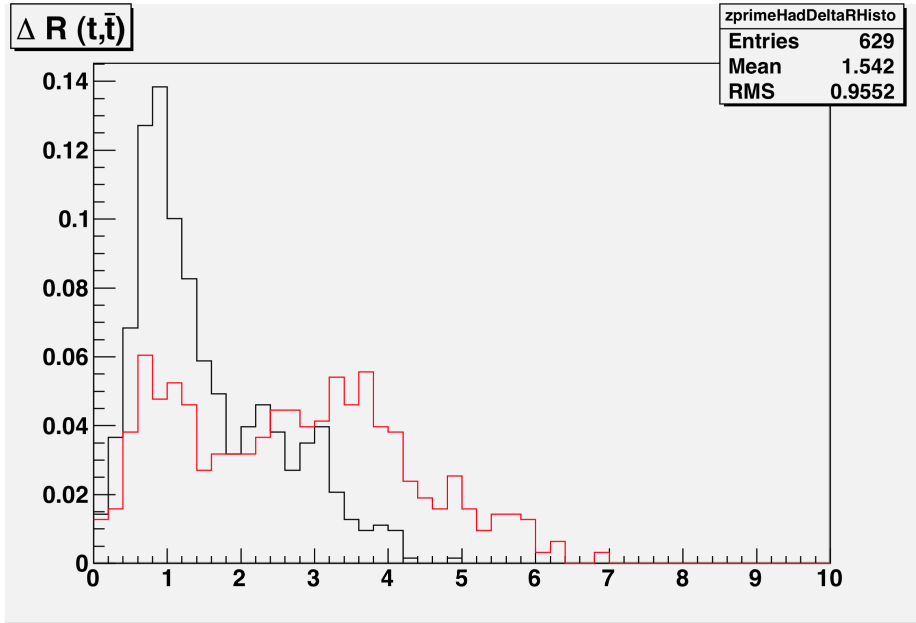
For each the hadronic and the leptonic top quark, fill two histograms with the ΔR spectrum of the Z' and $t\bar{t}$ samples. Make two plots out of them (e. g. "hadronic_top_deltaR.eps" and "leptonic_top_deltaR.eps"). Normalize the two histograms in each plot to their integrals.

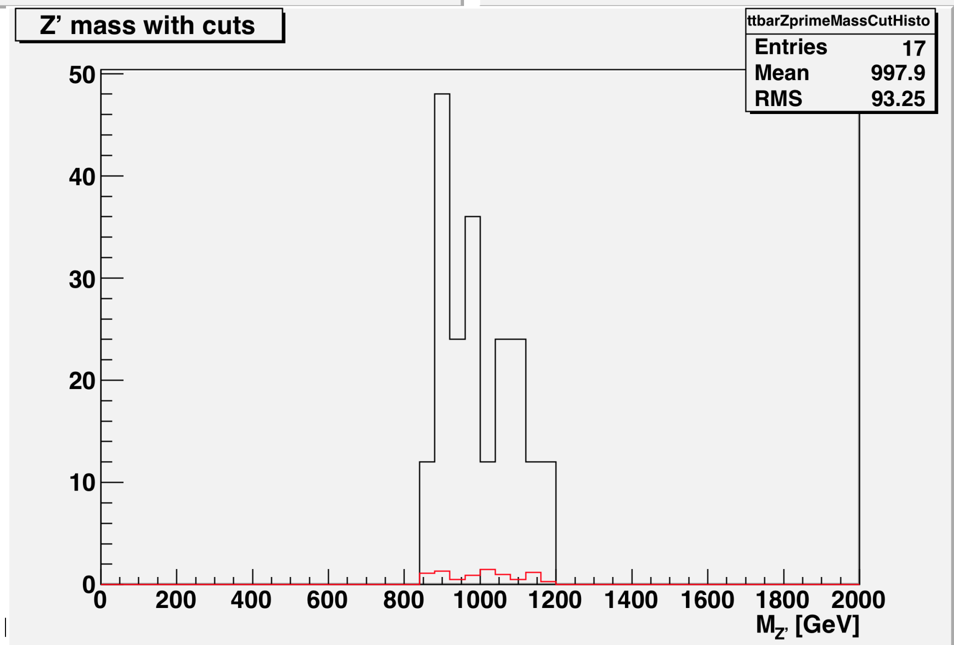
Choose a cut in ΔR in a way to maximize purity on the on hand, but not cutting away too many events on the other hand. Apply an additional, appropriate cut on the invariant Z' mass; choose a quite naarow window around $1000\,\mathrm{GeV}$

With these additional cuts, again fill two histograms with the invariant Z' mass, this time with linear y scaling. Normalize the histograms to $3\,\mathrm{fb}^{-1}$ now.
Calculate the efficiencies $\epsilon_{t\bar{t}}^{\mathrm{C2}}$ und $\epsilon_{Z'}^{\mathrm{C2}}$ for the additional cuts.

EXERCISE 7: RESULT







EXERCISE 8: DISCOVERY POTENTIAL

Let's assume there was no Z' at all (the *null hypothesis*). Then, the number of expected $t\bar{t}$ is $N_{\text{exp}} = \epsilon_{t\bar{t}} \cdot N_{t\bar{t}}$. N_{exp} will fluctuate according to a Poisson distribution. For large numbers the uncertainty is given by:

$$\Delta N_{\text{exp}} = \sqrt{N_{\text{exp}}}$$

We can ask now the question how many events we may count additionally to an expected number N_{exp} of $t\bar{t}$ events after Z' reconstruction and still trust the null hypothesis. Obviously, the number of $t\bar{t}$ we really observe is given by

$$N_{\text{obs}} = N_{\text{exp}} + \eta \cdot \Delta N_{\text{exp}} = N_{\text{exp}} + \eta \cdot \sqrt{N_{\text{exp}}} \Rightarrow \eta = \frac{N_{\text{obs}} - N_{\text{exp}}}{\sqrt{N_{\text{exp}}}}$$

η is called the *discovery potential*, it tells you the number of standard deviations the observed number of events is lying above the expected number of events.

- The number of expected (and observed) events depends on the integrated luminosity. The relative deviation becomes smaller with the number of events

- Produce a graph of eta as a function of integrated luminosity
  - For each value of luminosity calculate $N_{\text{obs}},\ N_{\text{exp}},\ \eta$ taking the efficiencies into account:

$$N = \sigma \cdot \mathcal{L} \cdot \epsilon$$

EXERCISE 8: DISCOVERY POTENTIAL

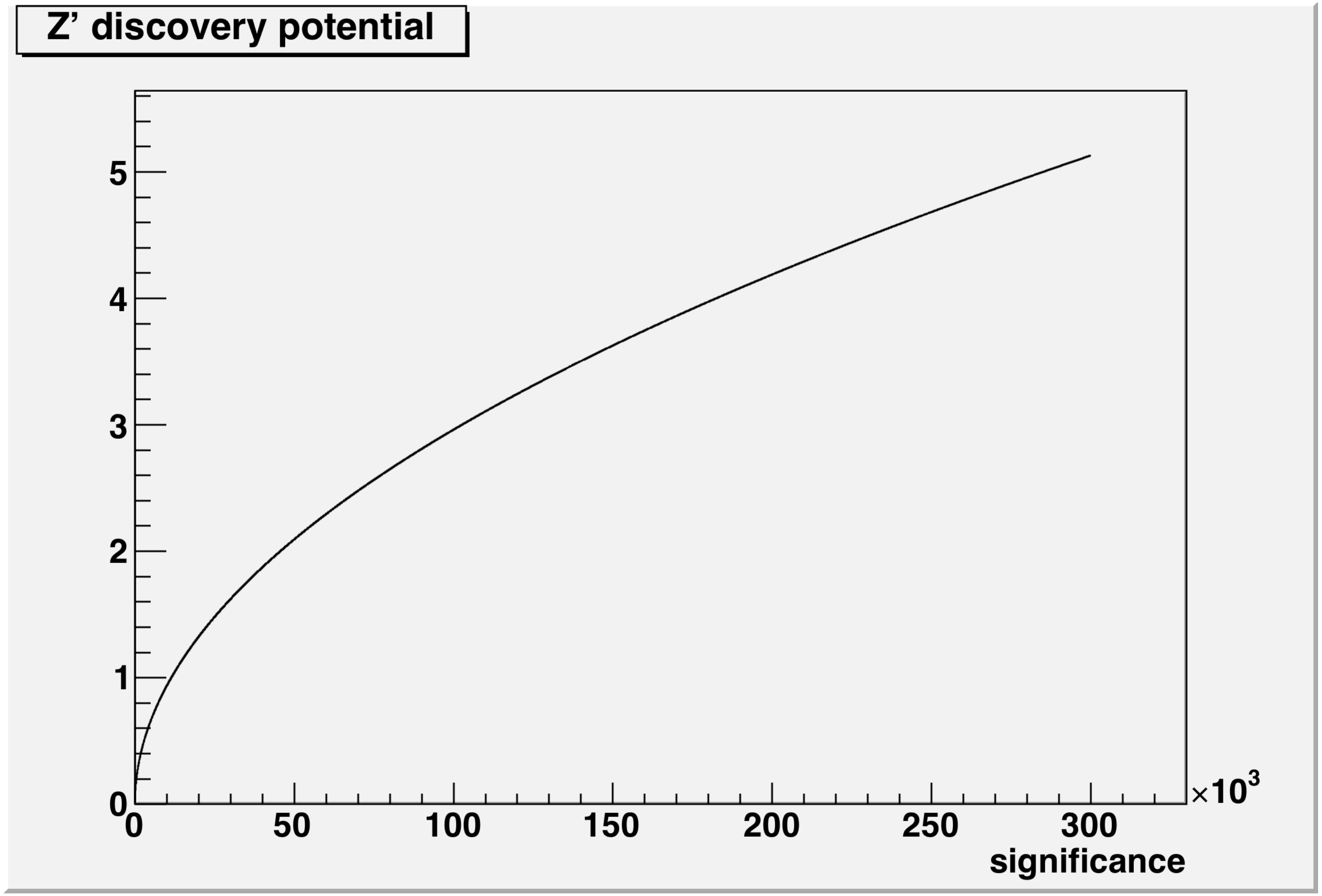
Exercise 8

Extract N_{obs} and N_{exp} from your analysis and calculate the discovery potential for a $1000\,\text{GeV}$ Z' at an integrated luminosity of $3\,\text{fb}^{-1}$.

Plot the function "discovery portential vs. integrated luminosity". Estimate your value for N_{exp} and N_{obs} from $\sigma_{t\bar{t}}$ and the reconstruction efficiency. Use a `TF1` with draw option `"AL"`.

Hint: The overall efficiencies for sequential cuts always factorize, i. e. $\epsilon = \epsilon^{\text{C1}} \cdot \epsilon^{\text{C2}}$.

EXERCISE 8: RESULT



EXERCISE 9: LIMIT DERIVATION

- From the measured number of events, knowing the contribution from backgrounds, efficiencies and luminosity, an upper limit on the possible Z' cross section can be given

$$\sigma = \frac{N_{\text{obs}}}{\epsilon \cdot L}$$

- N_{obs} is composed of $N_{\text{obs}} = N_{\text{obs},t\bar{t}} + N_{\text{obs},Z'}$ and has a statistical uncertainty
- Assuming again that N_{obs} comes entirely from tt, i.e. $N_{obs} = N_{exp,tt}$, the upper limit $N_{max,Z}$ can be determined and expressed in units of the standard deviation of N_{obs}

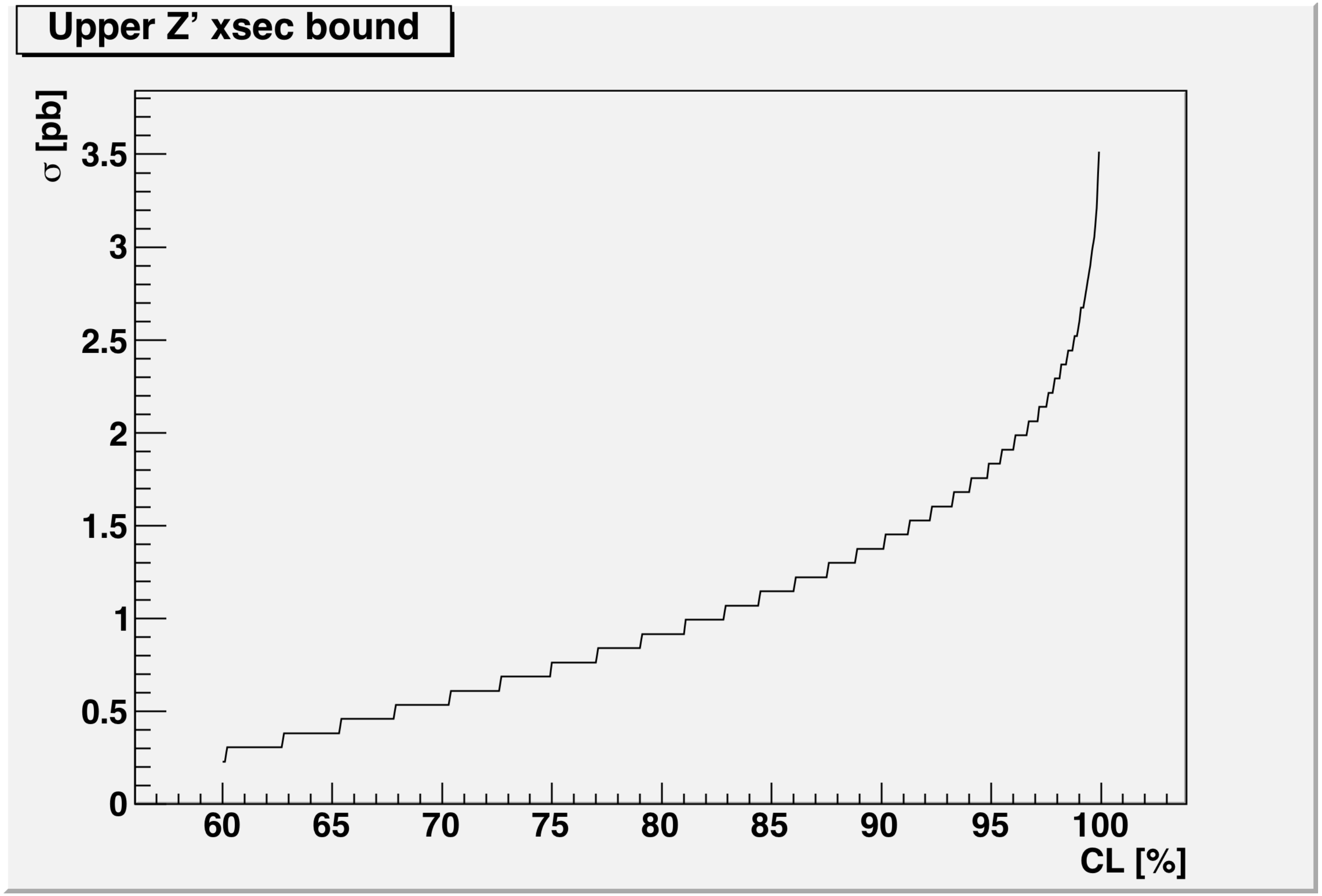
$$N_{\text{max},Z'} = N_{\text{obs}} - N_{\text{exp},t\bar{t}}$$

- The upper limit of the cross section at …. % C.L. is calculated from $N_{max,Z}$ for the corresponding point of the (Gaussian) distribution $N_{\text{obs}}(\mu, \text{CL})$ where $\mu = N_{\text{exp},t\bar{t}}$
- Make a graph of $N_{max,Z}$ as a function of C.L. using the results for N_{obs} obtained in exercise 7.

Exercise 9

Plot a function "CL vs. upper bound cross section" in the range of CL $= [60 \ldots 99\,\%]$. Use a `TGraph` and add x, y–values in a `for` loop. Use the draw option `"AL"`.

EXERCISE 9: RESULT



EXERCISE 10: CROSS SECTION DETERM.

Exercise 10

Make a histogram of the invariant Z' mass of the $t\bar{t}$ sample. Fit a Landau distribution to the histogram.

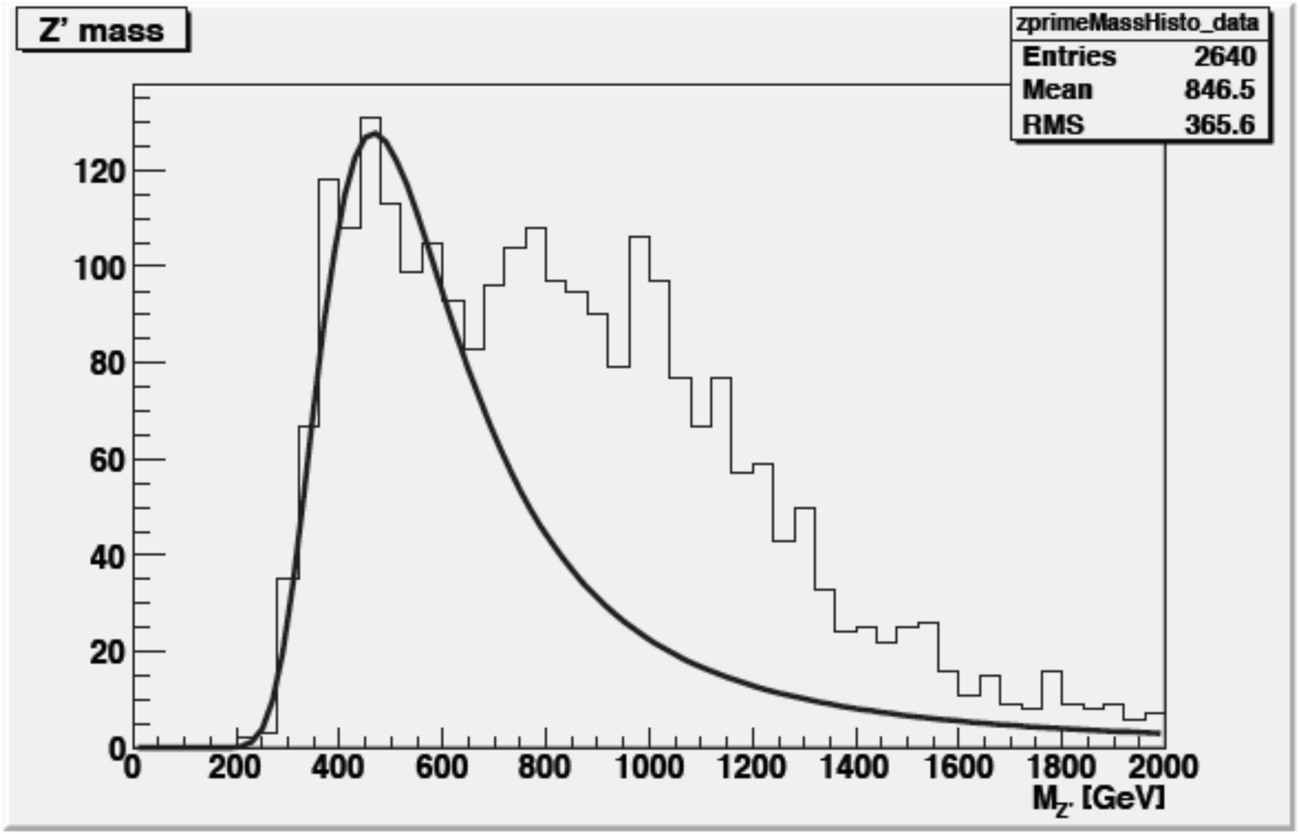
Make a histogram of the invariant Z' mass spectrum of `data_sample.root`. Scale the Landau fit by the ratio of luminosities.

With the scaled Landau fit, go through the data histogram bin by bin and subtract the function value at the bin center from the bin content. Fill a new histogram with that difference bin by bin. Take care that you set equal bin numbers for all histograms!

Calculate the cross section of the "unknown" resonance and its uncertainty.

EXERCISE 10: CROSS SECTION DETERM.

- Determine and fit background shape from simulation
- Normalize and overlay background shape on data



- Subtract background from data

EXERCISE 10: RESULT