Backgrounds in charm and beauty secondary vertex analysis

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Abstract

The analysis of charm and beauty secondary vertices is based on the asymmetry in the significance of the decay length. After data selection up, down and strange composite particles are still contributing to this asymmetry. Monte-Carlo samples for up, down and strange events are used to investigate this background. The significance of K_s^0, Λ, $\pi^{+,-}$, $K^{+,-}$ and particles coming from hadronic interactions are calculated and compared with the significance of all recorded secondary vertices.

Contents

1 Introduction

This report is a dedicated summary of my work during the summer student program 2011 at DESY in Hamburg. I worked on data analysis at HERA in the ZEUS group. For a paper correlated with this study, see [1].

1.1 HERA and ZEUS

The Hadron-Elektron-Ring-Anlage (*HERA*) is a circular accelerator located at DESY. It was operating from 1992 to 2007 with an temporal interruption in 2000 and 2001 for modifications. Nevertheless data analysis is still being done. Electrons and protons with energies about $27.5 GeV$ and $920 GeV$ respectively have been collided, that is the center of mass energy is $320 GeV$ [1]. This value is below the threshold for top-antitop pair production. Thus the beauty quark is the heaviest particle produced at HERA [2]. Four different kinds of detectors have been used to record the collisions. One of them was ZEUS. The purpose of the ZEUS (and in collaboration with the H1) experiment is to investigate the structure of the proton, to prove quantum chromodynamics (*QCD*) which is the theory describing the strong interaction and to search for new physics. They have shown the electroweak unification and measured the strong force over a broad range of energies, for example.

1.2 Analysis of charm and beauty production

In deep inelastic scattering (*DIS*) processes charm and beauty quarks are mainly produced by photon gluon fusion (*PGF*), shown in Figure 1 [3].

[1] The HERMES experiment was a fixed target experiment, working in a slightly different way. More details on different kinds of experiments and most topics covered in this report in general can be found in the lectures of the summer student programme, see [2].

[2] I will use the term 'beauty' in preference to 'bottom'.

[3] We will consider inclusive processes.

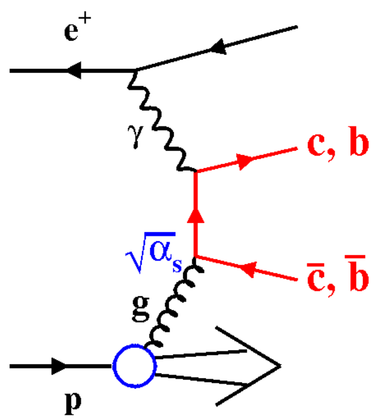

Figure 1: Photon gluon fusion in electron-proton collisions results in pairs of charm-anticharm and beauty-antibeauty quarks [3]. This Feynman-diagram is described by QCD and therefore directly sensitive to the gluon density in the proton.

Up, down and strange quarks can be produced by the same process [4]. Additionally they may be directly scattered, shown in Figure 2.

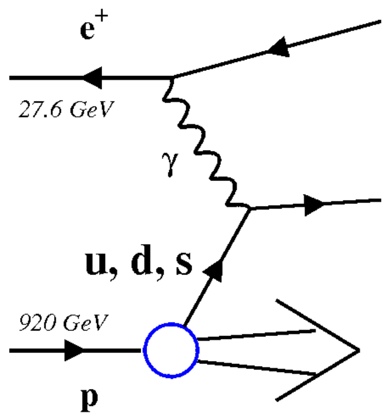

Figure 2: Quark parton model for light flavor sea and valence quarks in electron-proton collisions at HERA [3]. This is described by quantum electrodynamics which is the theory describing the electromagnetic interaction.

Charm and beauty composite particles have a high lifetime $c\tau$ compared to light flavor quarks [5]. Consequently their vertices are displaced from the primary vertex. Thus,

[4] I will refer to them as 'light flavor'.
[5] See the particle data group [4].

we can separate the charm and beauty composite particles from the light flavor ones, theoretically. Experimentally a light flavor particle background is measured. We may distinguish between charm and beauty composite particles by a mass threshold of the vertex of $2GeV$.
The separation of the vertices is technically done by calculating the so-called 'significance' of the decay length, shown in Figure 3. At first, we calculate the length from the secondary vertex to a vertex derived from the beam spot and the reduced primary vertex. Thereafter we project this length onto the associated jet axis. The significance is the result of this projected decay length divided by the error of the decay length.

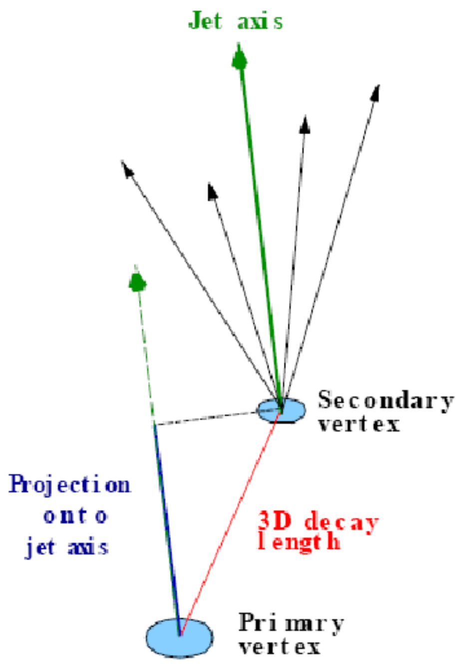

Figure 3: Decay length of the secondary vertex and the projection of the decay length of the secondary vertex on the associated jet axis [5].

In this study the significance is calculated in the plane transversed to the beam axis as the beam spot along the beam axis has large errors compared to that of the transversed plane. The significance may be negative, traced back to the limited resolution of the detector. If we consider charm and beauty events this effect is of less weight and we will find an asymmetric significance distribution, see Figure 4 [6].

[6]We will consider significances from -20 to 20.

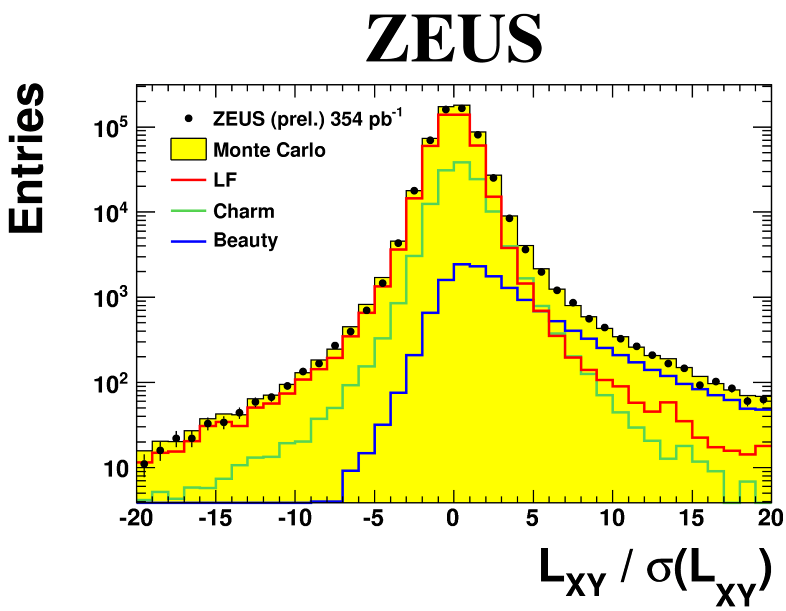

Figure 4: The significance of the projected transversed decay length for charm, beauty and light flavor composite particles [5]. Note that this plot is dominated by beauty composite particles due to a higher cut on the mass of the secondary vertex.

Let us have a closer look at the 'mirrored significance', the difference of the value of positive significance and its corresponding negative value.

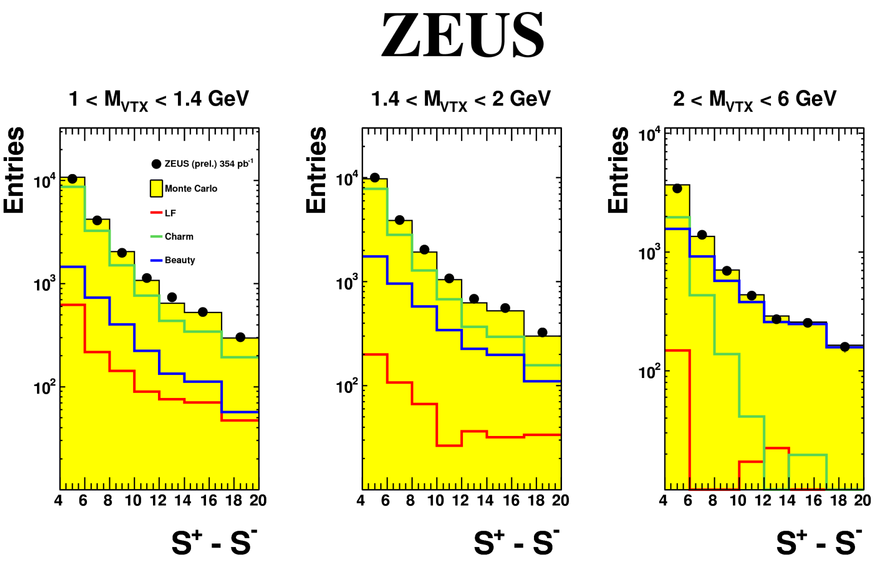

Figure 5: The mirrored significance of the projected transversed decay length for charm, beauty and light flavor composite particles for different mass ranges [5]. The right plot corresponds to Figure 4.

In Figure 5 we can identify a background significance distribution of light flavor particles. In this study we try to understand and control this background in charm and beauty secondary vertices.

2 Data selection

To do the analysis of the asymmetric light flavor significance the data have to be selected by the following aspects for charm and beauty events [7].

Secondary vertex selection

- $1GeV < M < 6GeV$
- $\chi^2/ndf < 4$
- $|Z| < 30cm$
- $c\tau < 1cm$

Jet selection

- $E_t < 4.2GeV$
- $-1.6 < \eta < 2.2$ [8]

For an argumentation for the limits, see [5].

[7]For the trigger and the deep inelastic scattering selection, see 6.
[8]The pseudo-rapidity η is defined as $\eta = -ln(tan(\theta/2))$.

3 Analysis

The study of the asymmetric light flavor significance is purely based on Monte-Carlo (*MC*) samples. Furthermore charm and beauty events have been discarded for this analysis.

3.1 Possible sources for the asymmetric light flavor significance

Possible sources for the asymmetric light flavor significance are particles with a sufficiently high decay length, yielding to vertices displaced from the primary vertex [9]. These are mainly K, Λ and charged π [10]. Additionally, particles from hadronic interactions may contribute to the significance asymmetry as they could be matched to a secondary vertex. Hence, we are selecting the following decay channels and their corresponding antiparticles from the MC samples [11]

- $K_s^0 \rightarrow \pi^+ + \pi^-$ [12]
- $\Lambda \rightarrow p + \pi^-$
- $\Lambda \rightarrow n + \pi^0$
- $\pi^+ \rightarrow \mu^+ + \nu_\mu$ [13]
- $K^+ \rightarrow \mu^+ + \nu_\mu$
- $K^+ \rightarrow \pi^+ + \pi^0$

3.2 Computation

The main ROOT-code for the computation is appended in 6 [14]. The MC samples have been created by ARIADNE for 03/04p, 05e, 06e and 06/07p [15]. They contain about 98,000,000 events describing inclusive collisions with $Q^2 > 4$ for light flavor composite particles. The selection of the true particles in the MC samples is done according to 3.1. Thereafter, the selected true tracks of the daughter particles are tried to be matched to corresponding recorded tracks, see Figure 6 and 7 for a distribution of the distances [16].

[9] The limited resolution of the detector should contribute in a symmetric significance distribution.
[10] Charged π with a decay length of several meters are contributing to the asymmetric significance owing to the high number of processes they are produced by.
[11] We are looking for particles which could be traced by the tracker. Photon conversion may be another source for the significance asymmetry. However, photons are not traced in the MC samples.
[12] We have to look for the decay of the weak eigenstate of the neutral Kaon.
[13] We are not looking for ν technically as they are barely detectable.
[14] I haven't appended the entire file and the header file. The header file was created by the MakeClass method in ROOT, see [6].
[15] The samples are stored in Common Ntuples v02e, see [7] (authentication is required).
[16] This could as well be done starting on the recorded level, matching true tracks and selecting the events. Be aware that the number of entries in Figure 7 doesn't begin at zero.

A track is called 'matched' if its distance to a recorded track is smaller than $0.1cm$. It is distinguished between '1' and '2' times matched vertices [17]. In the case that both true tracks could be matched they have to come from the same vertex to be selected [18].
Afterwards, the cuts on these vertices and tracks are done according to 2. The corresponding quantities without and with these cuts are shown in the Figures 8 to 12.
At the end of the calculation we have a look at the significance and the mirrored significance, shown in Figure 13 and 14.
Thereafter we will have a look at the significance and the mirrored significance for different mass ranges, shown in the Figures 15 to 18 [19].

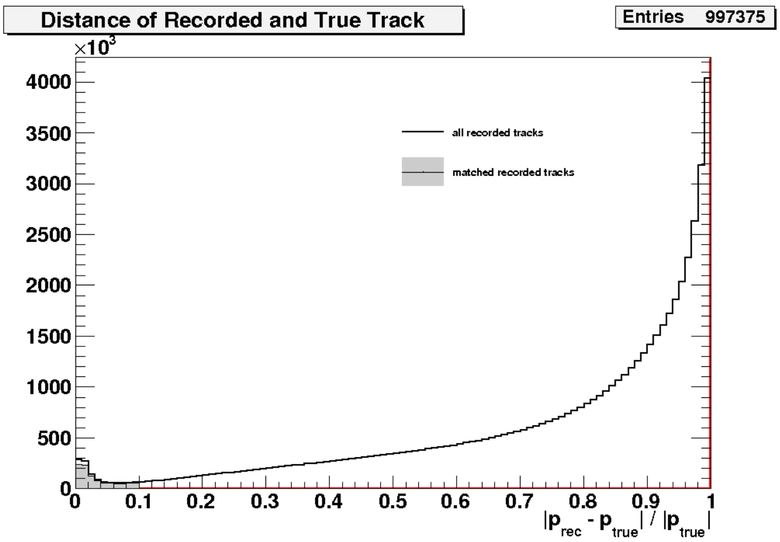

Figure 6: Distribution of the distance of recorded tracks and true tracks in the Monte Carlo samples. The threshold for matched tracks is $0.1cm$. The maximum close to zero indicates the true tracks.

[17] Charged π and particles from hadronic interactions can not be matched twice. The ratio of two daughter particles being matched to one daughter particle being matched was computed to 0.103924.

[18] The ratio of two daughter particles being matched to the same vertex to two daughter particles being matched was computed to 0.995727.

[19] The mass cut at $1.4Gev$ is arbitrary.

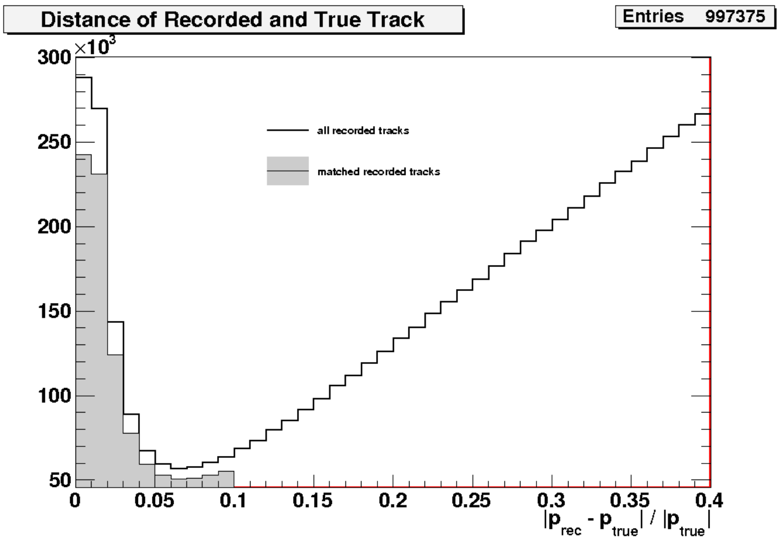

Figure 7: Scaled distribution of the distance of recorded tracks and true tracks in the Monte Carlo samples, taken from Figure 6. The threshold for matched tracks is $0.1cm$.

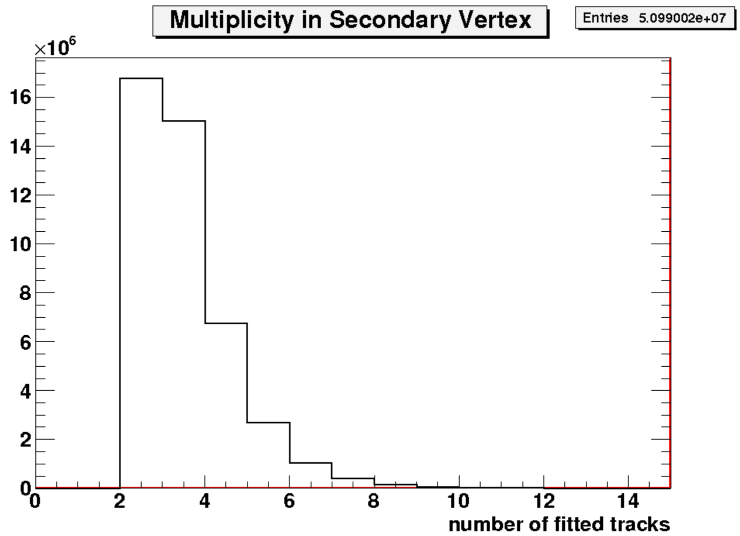

Figure 8: Distribution of the multiplicity in the secondary vertex on recorded level. This quantity may be used for further studies.

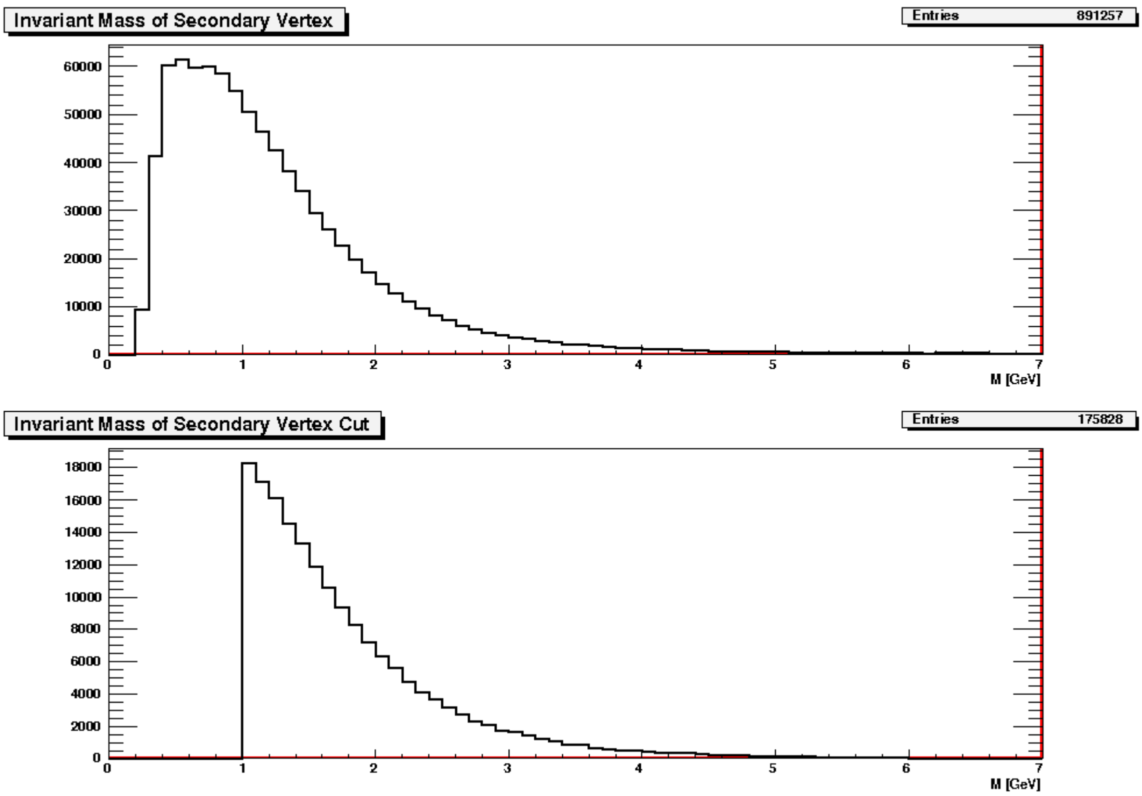

Figure 9: Distribution of the invariant mass of the secondary vertex on recorded level without and with cuts. The low mass range is dominating for light flavor Monte-Carlo samples.

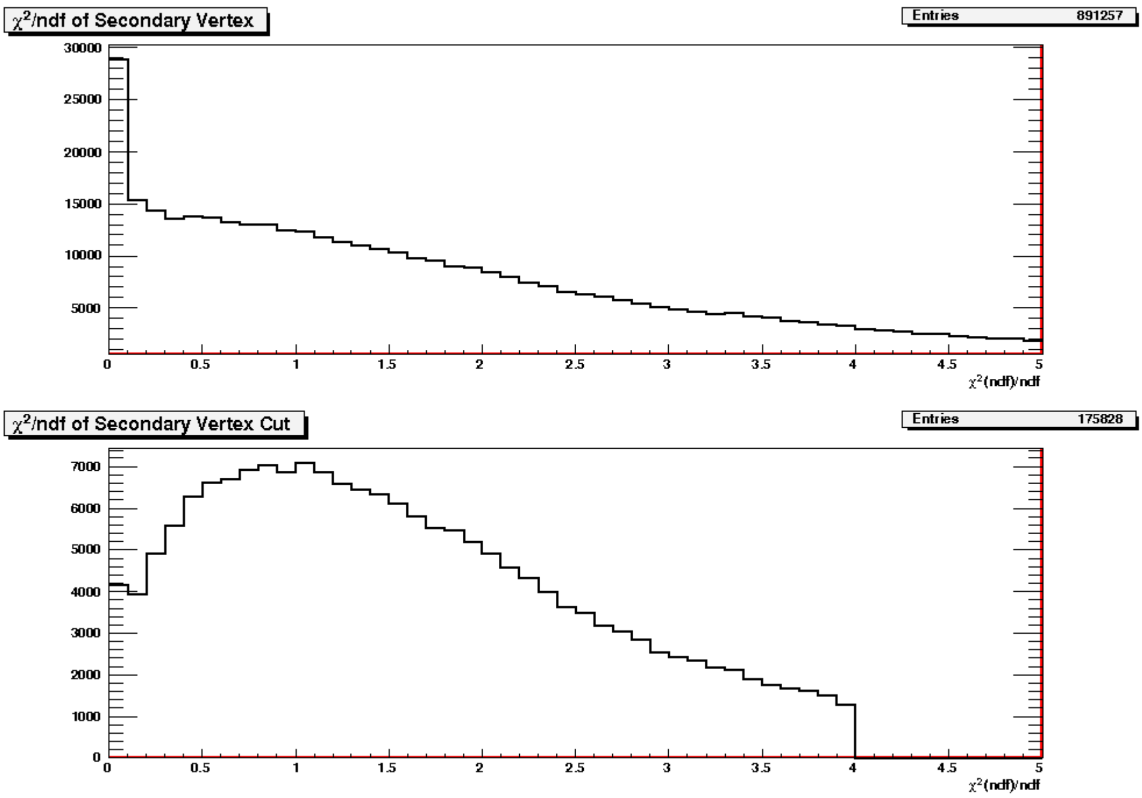

Figure 10: χ^2/ndf distribution of the secondary vertex on recorded level without and with cuts. With cuts it is distributed around a significance of one.

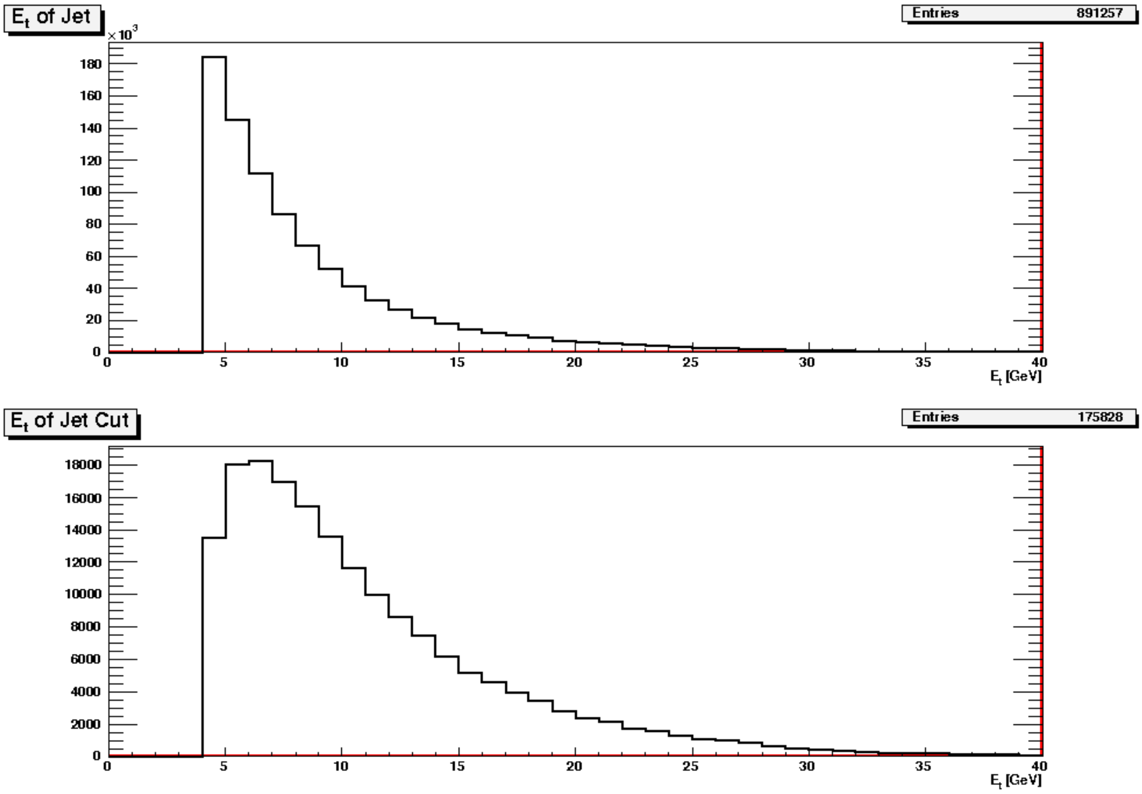

Figure 11: E_t distribution of the jets of the secondary vertex on recorded level without and with cuts. This distribution is typical for HERA experiments.

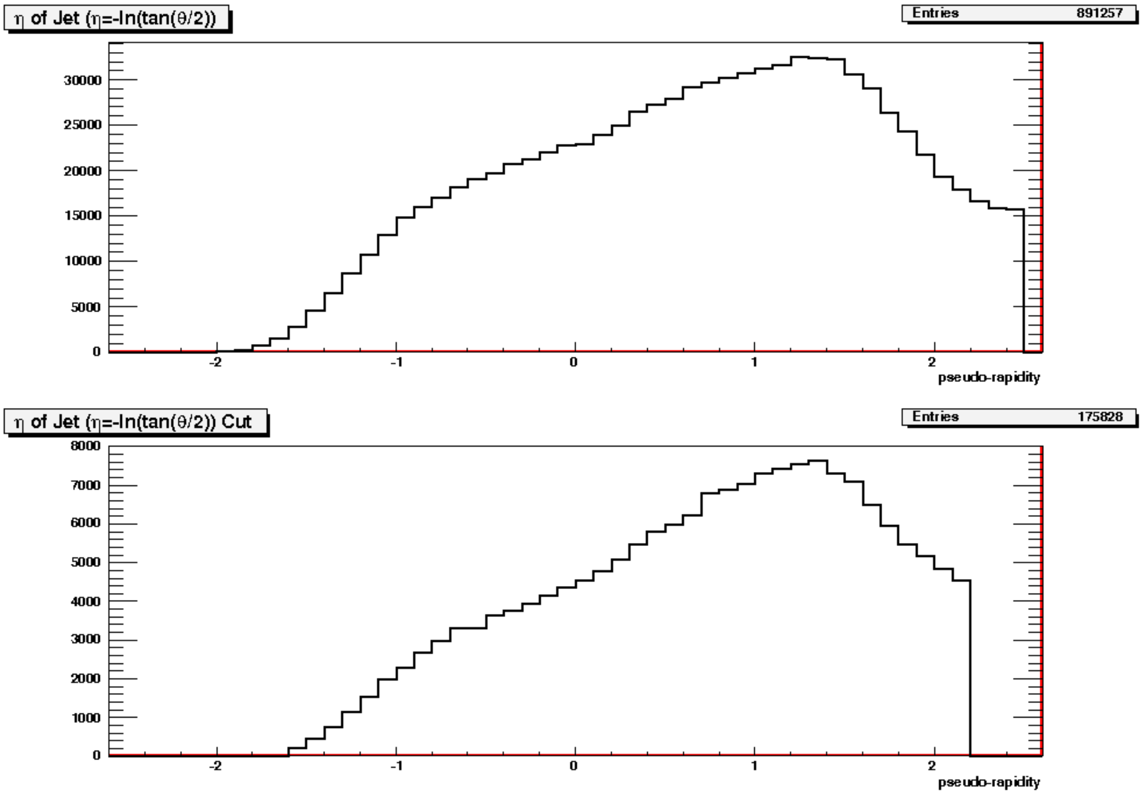

Figure 12: η distribution of the jets of the secondary vertex on recorded level without and with cuts. Most jets are pointing in the forward direction of the proton.

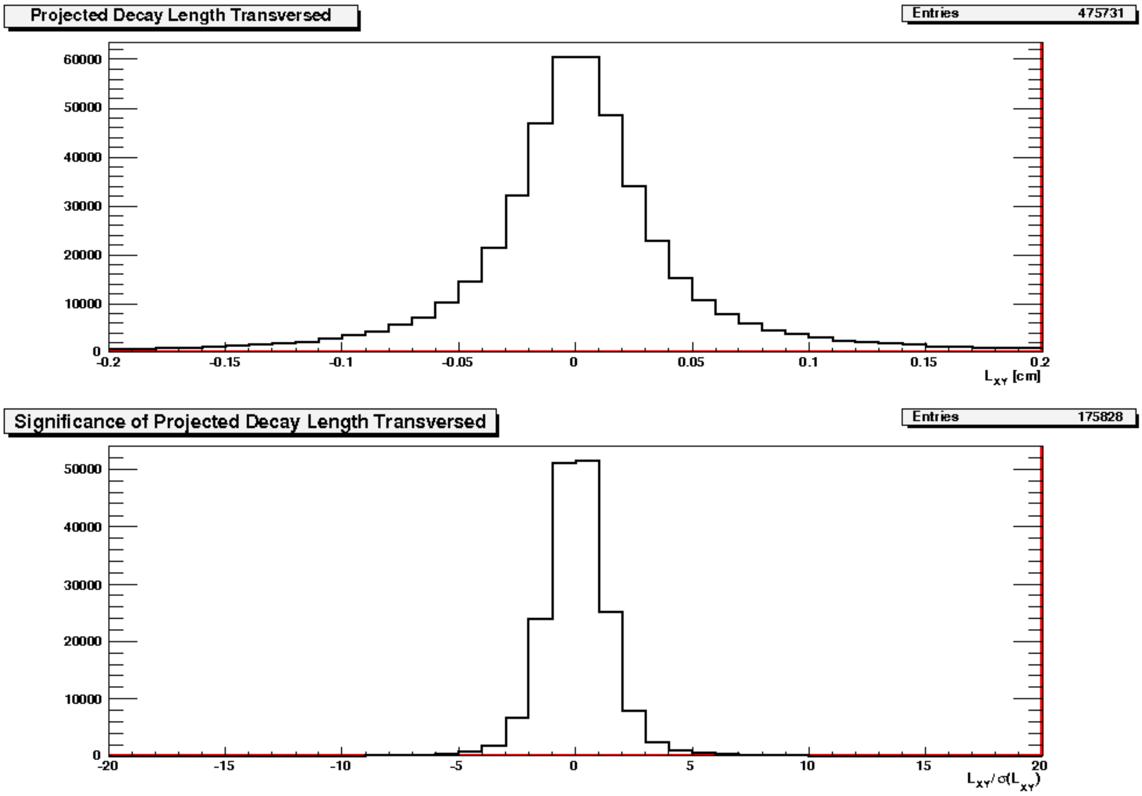

Figure 13: Transversed decay length of the secondary vertex projected onto the associated jet axis and the significance of the transversed decay length of the secondary vertex projected onto the associated jet axis. The decay length distribution corresponds to a the resolution of the detector of around $100\mu m$ to $350\mu m$. The significance should be a Gaussian with σ equals to one.

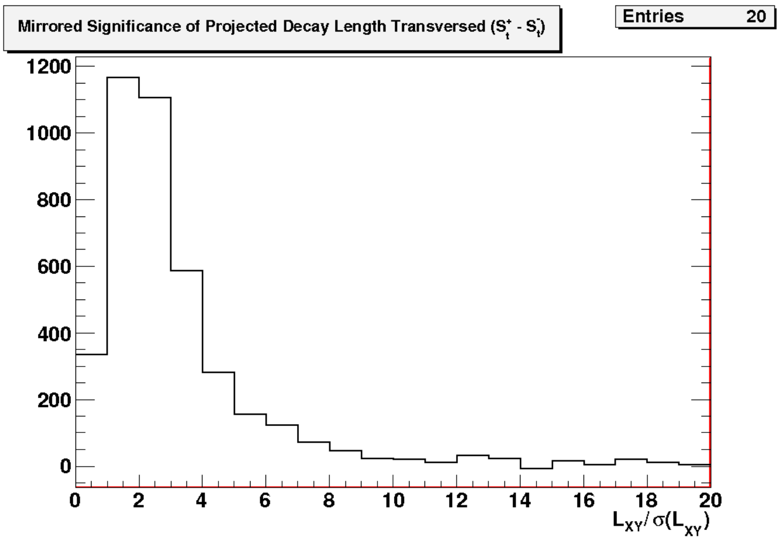

Figure 14: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis. The asymmetric significance distribution falls with the significance around zero. It behaves different for small significances.

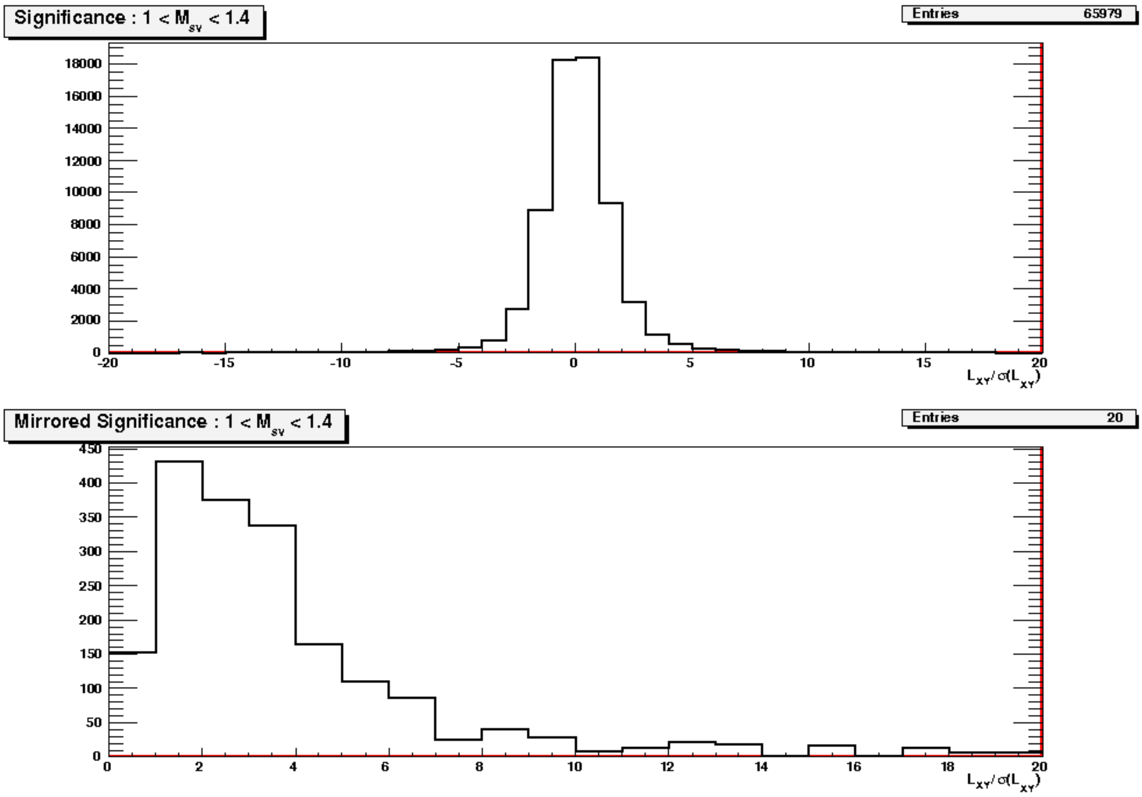

Figure 15: Significance and mirrored significance for the mass range $1 < M_{sv} < 1.4$. The events are dominated by charm composite particles.

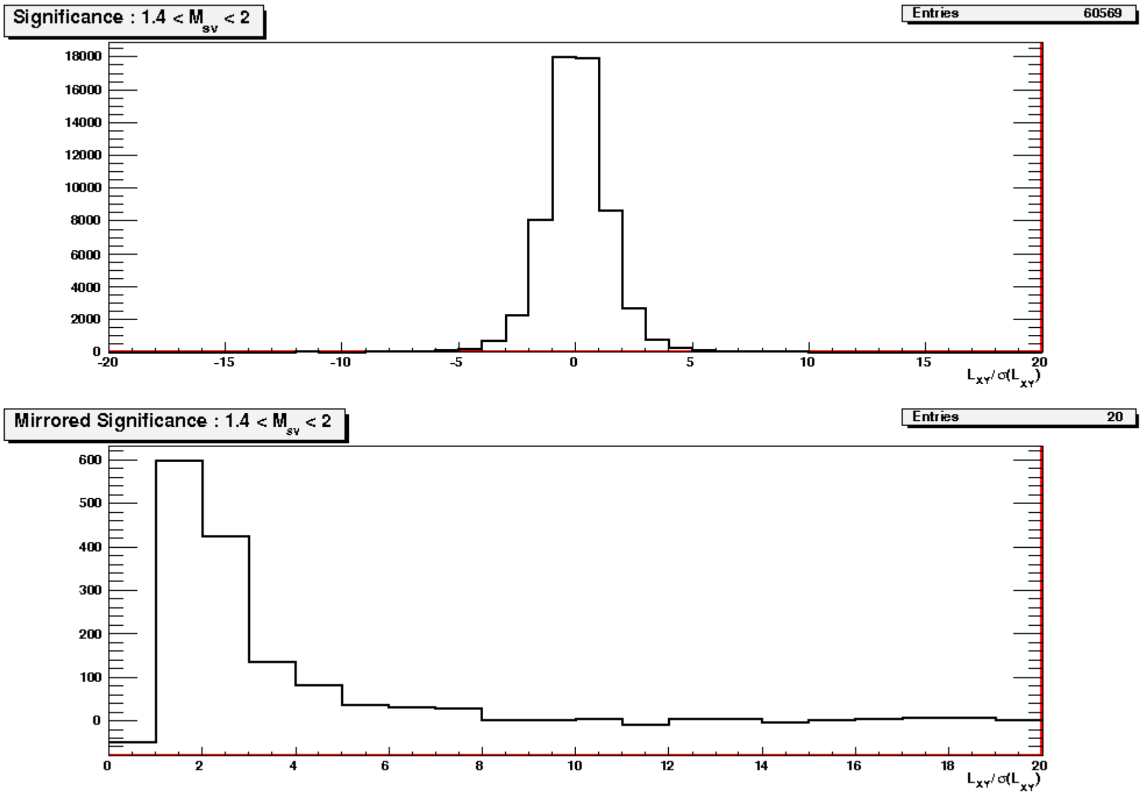

Figure 16: Significance and mirrored significance for the mass range $1.4 < M_{sv} < 2$. The mirrored significance is negative for small significances. The events are dominated by charm composite particles.

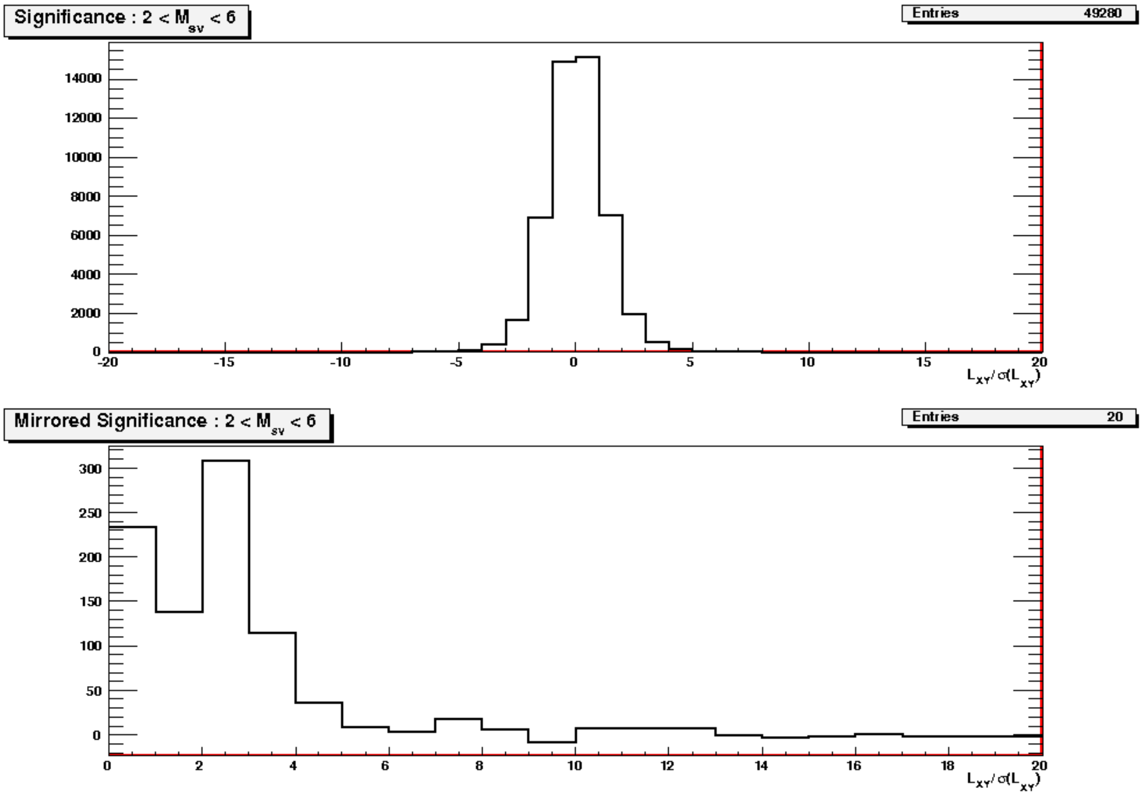

Figure 17: Significance and mirrored significance for the mass range $2 < M_{sv} < 6$. The different bahyvior in for small significances is valid for a larger range. The events are dominated by beauty composite particles.

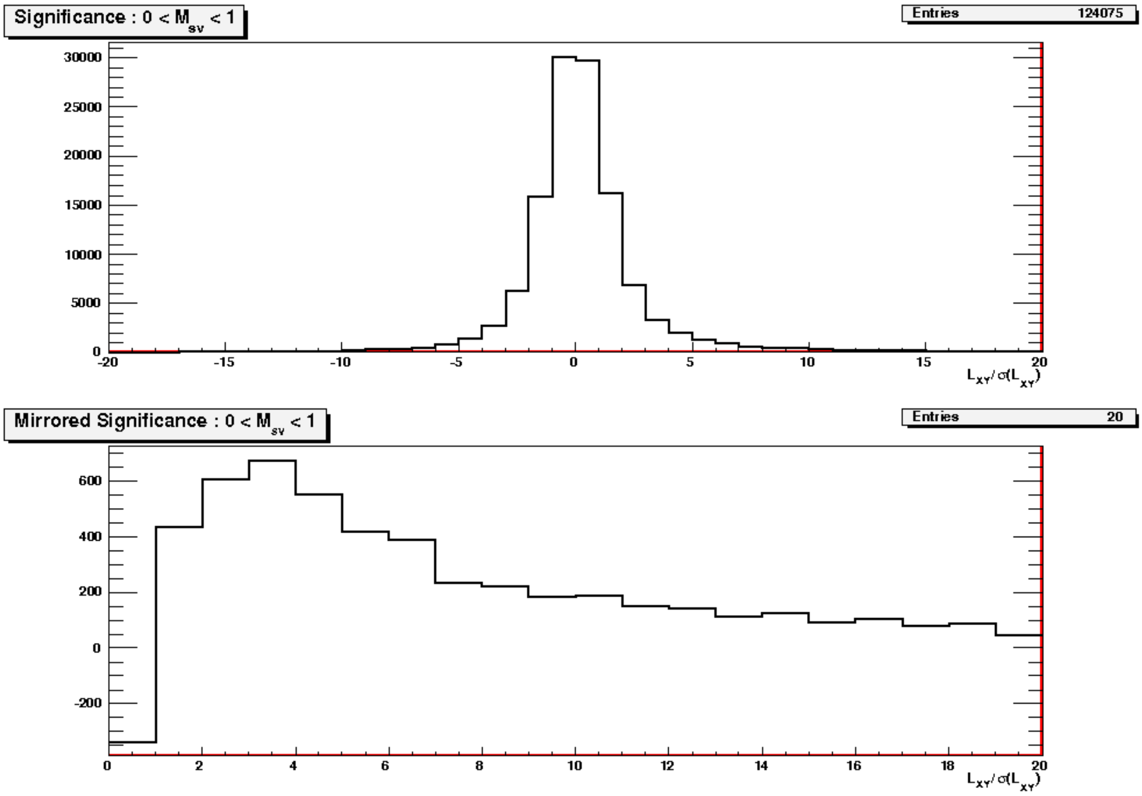

Figure 18: Significance and mirrored significance for the mass range $0 < M_{sv} < 1$. This control plot is for a different mass range. The significance asymmetry is higher for light flavor dominated events.

4 Results

The results are shown in the Figures 19 to 24. Additionally the results for the mass range $1 < M_{sv} < 1.4$, $1.4 < M_{sv} < 2$, $2 < M_{sv} < 6$ for different flavor dominated events and $0 < M_{sv} < 1$ as control plots are shown in Figures 25 to 30, 31 to 36, 37 to 42 and 43 to 47, respectively [20]. The mirrored significances are additionally shown for significances from 2 to 20 due to the fluctuations in the low significance range as well in the range from 4 to 20 for a common cut on the significance for charm and beauty secondary vertices.

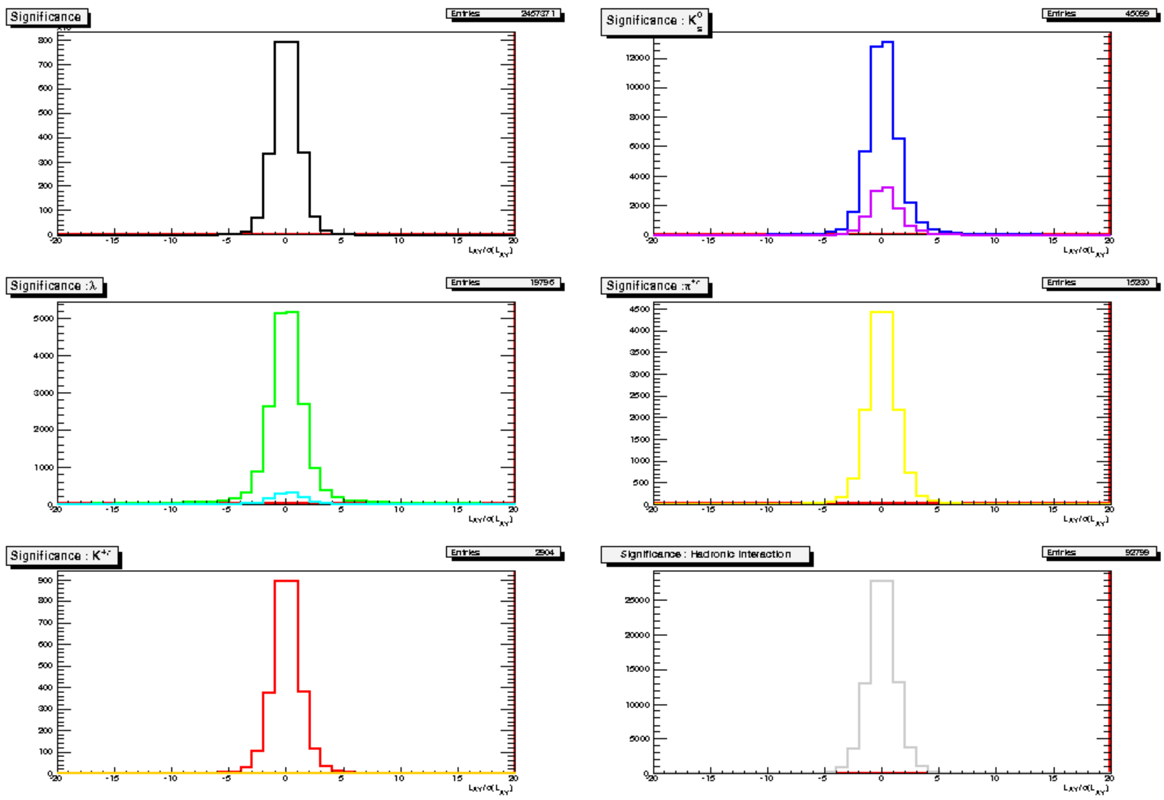

Figure 19: Significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels. The colors blue, green and red represent 1 matched vertices and the colors purple, cyan and orange represent 2 matched vertices.

[20]Unfortunately the plot for the mirrored significance of light flavor composite particles for the mass range $0 < M_{sv} < 1$ is gone.

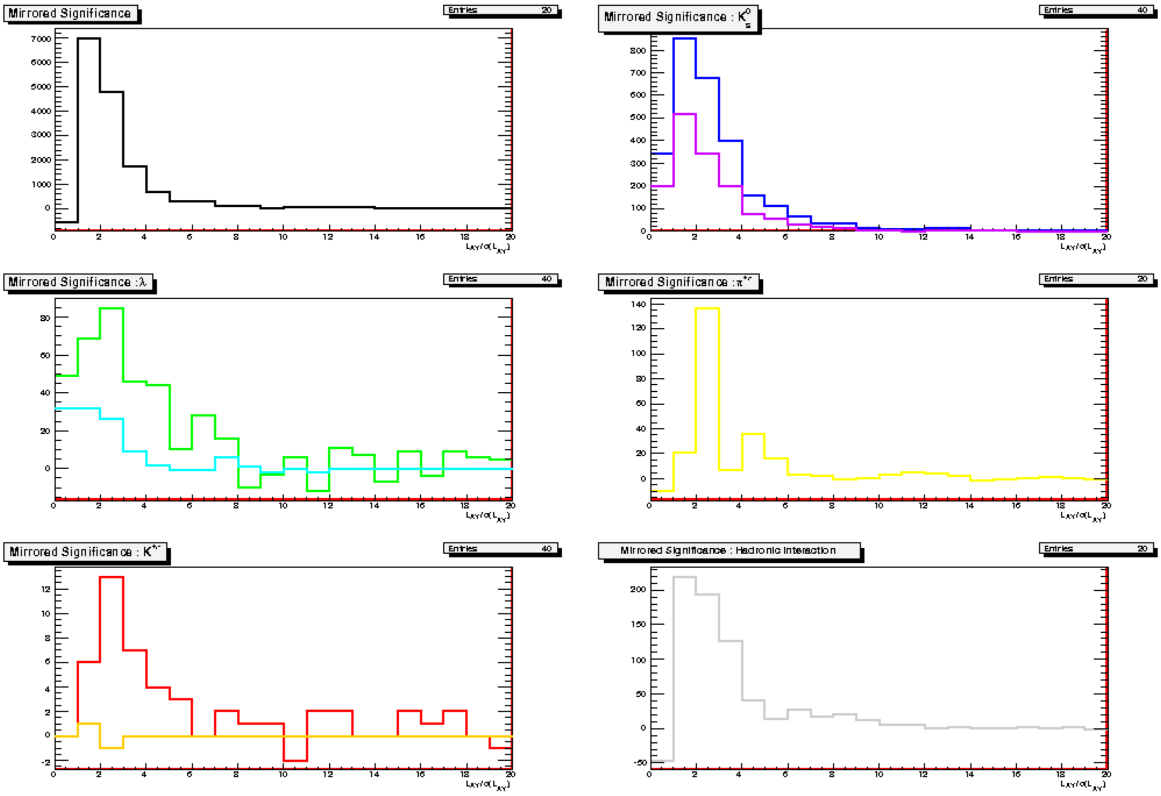

Figure 20: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels. The colors blue, green and red represent 1 matched vertices and the colors purple, cyan and orange represent 2 matched vertices.

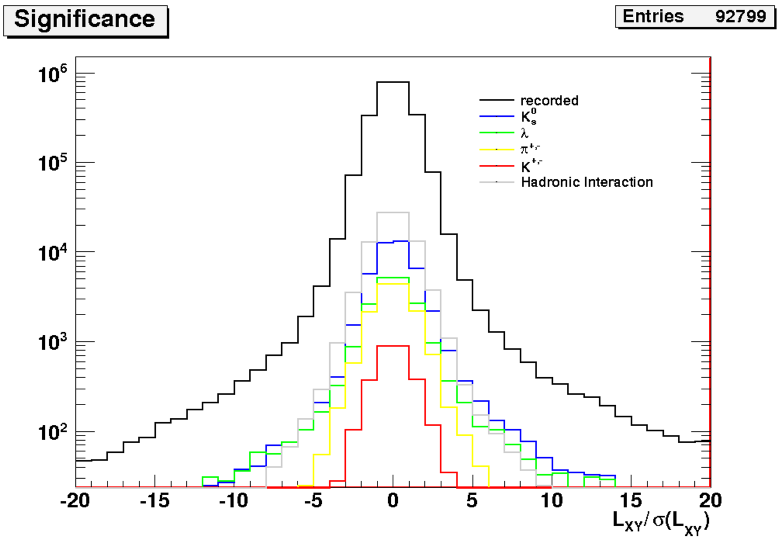

Figure 21: Significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels. The axis for the entries is scaled logarithmically.

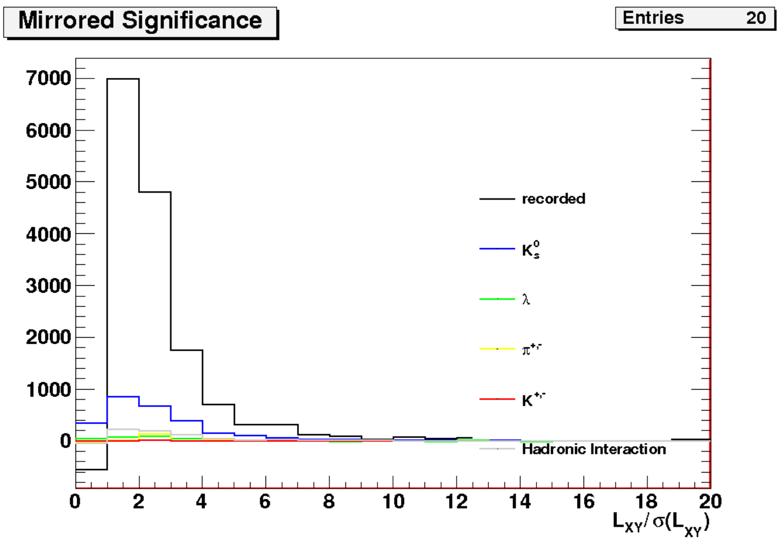

Figure 22: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels. K_s^0 is contributing significantly to the mirrored significance

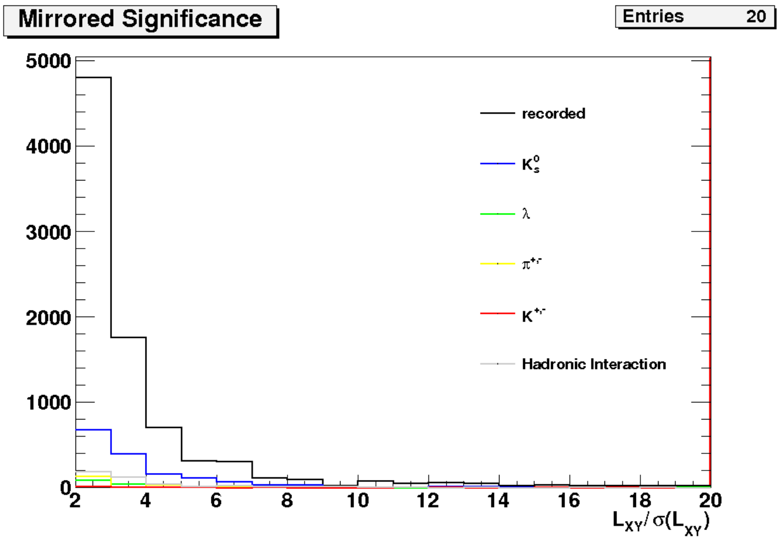

Figure 23: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis > 2 for different decay channels.

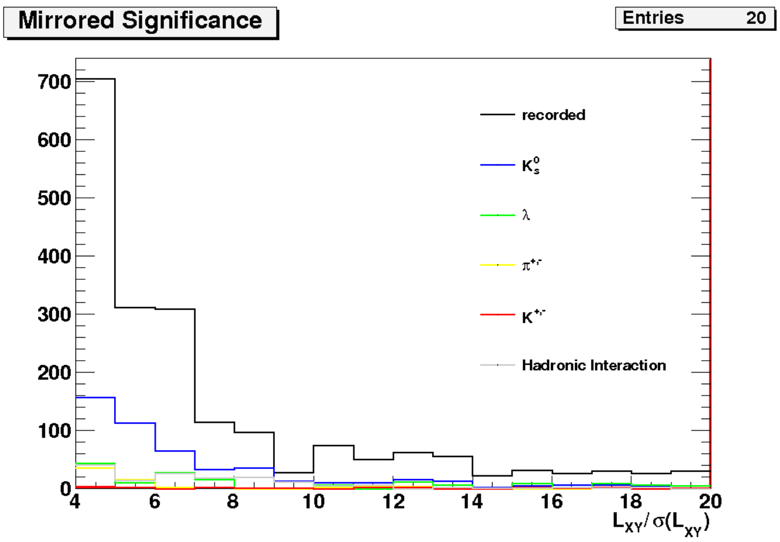

Figure 24: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis > 4 for different decay channels. We can see a local maximum for higher significances.

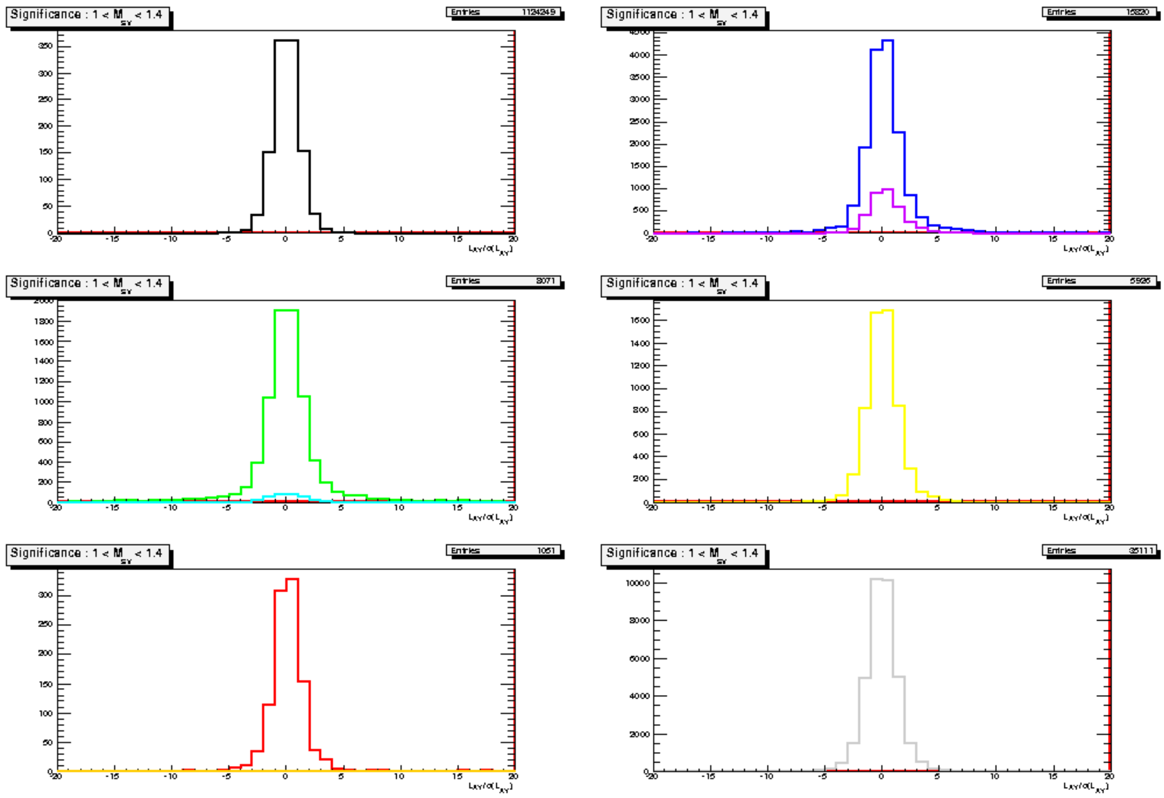

Figure 25: Significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels for the mass range $1 < M_{sv} < 1.4$. The colors blue, green and red represent 1 matched vertices and the colors purple, cyan and orange represent 2 matched vertices.

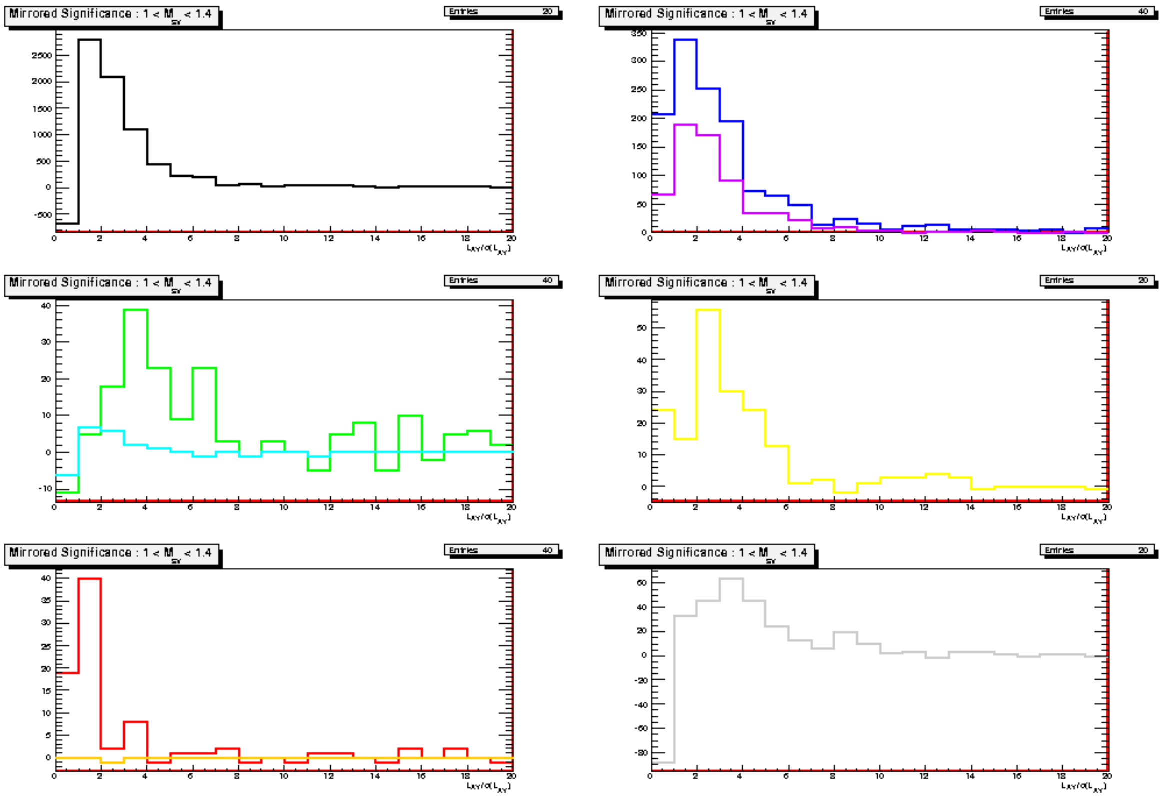

Figure 26: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels for the mass range $1 < M_{sv} < 1.4$. The colors blue, green and red represent 1 matched vertices and the colors purple, cyan and orange represent 2 matched vertices.

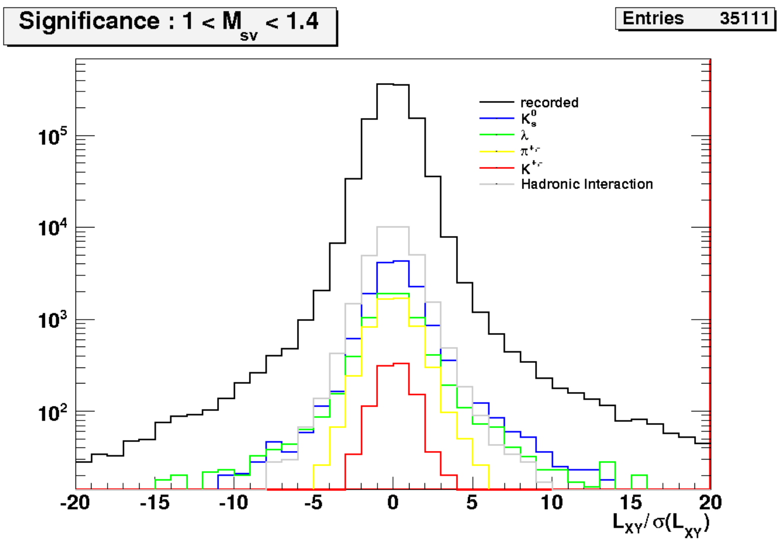

Figure 27: Significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels for the mass range $1 < M_{sv} < 1.4$.

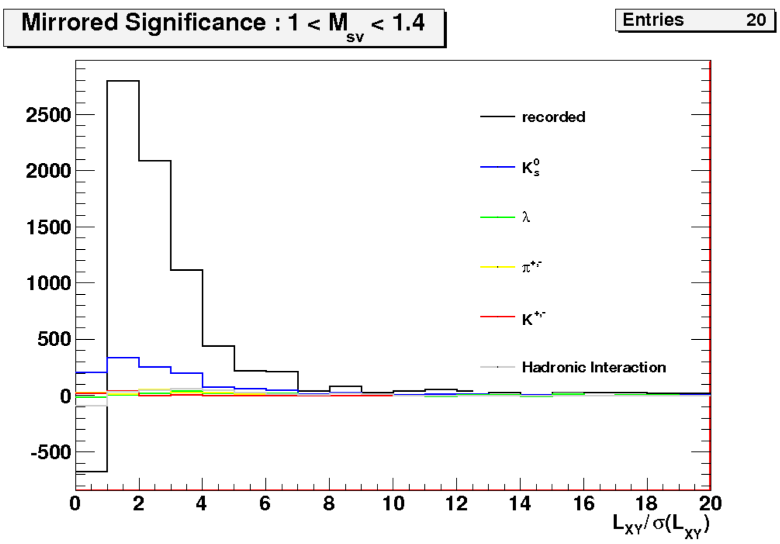

Figure 28: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels for the mass range $1 < M_{sv} < 1.4$.

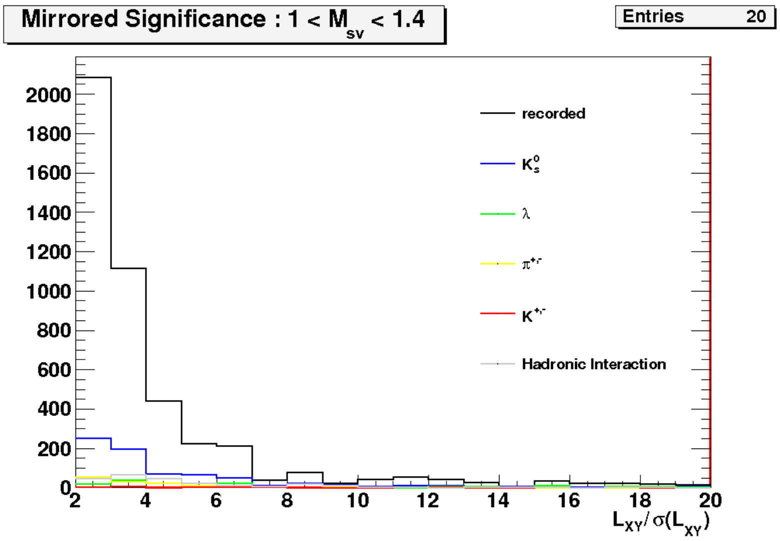

Figure 29: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis > 2 for different decay channels for the mass range $1 < M_{sv} < 1.4$.

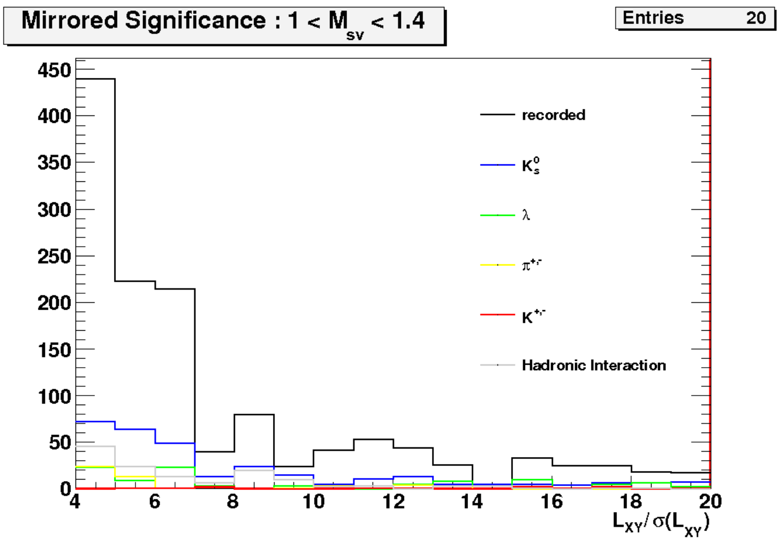

Figure 30: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis > 4 for different decay channels for the mass range $1 < M_{sv} < 1.4$.

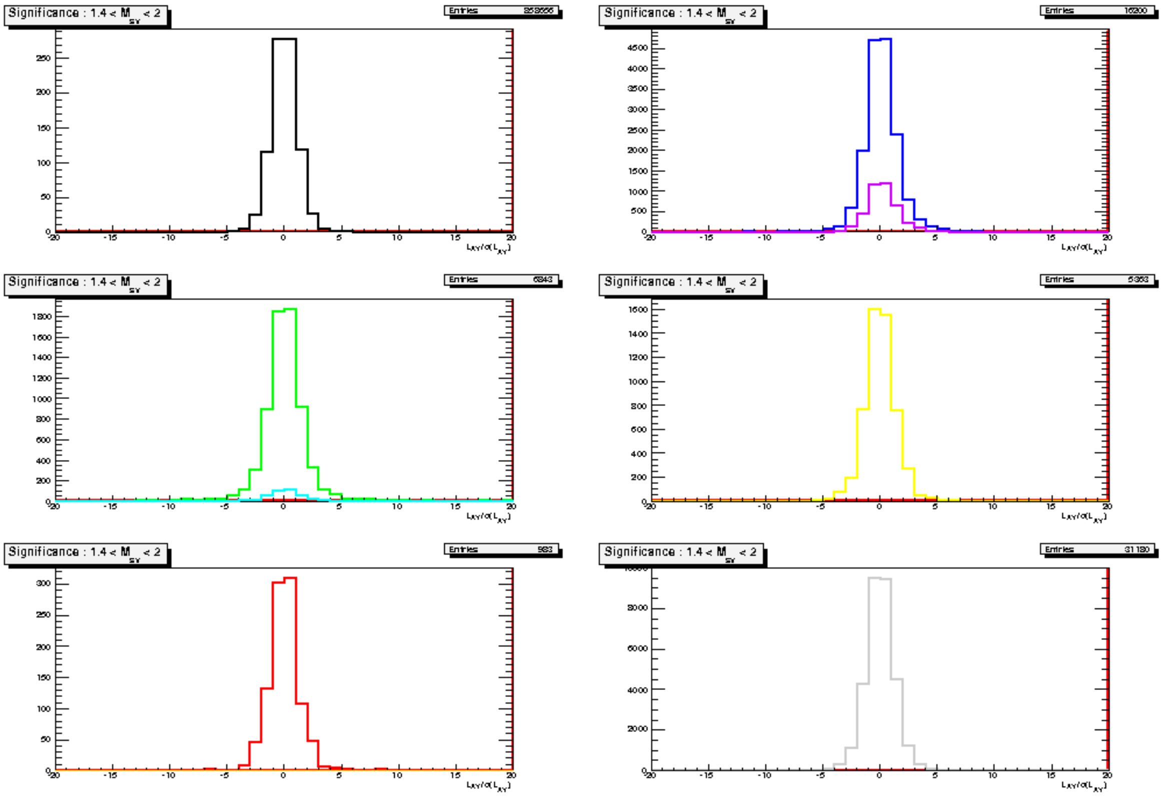

Figure 31: Significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels for the mass range $1.4 < M_{sv} < 2$. The colors blue, green and red represent 1 matched vertices and the colors purple, cyan and orange represent 2 matched vertices.

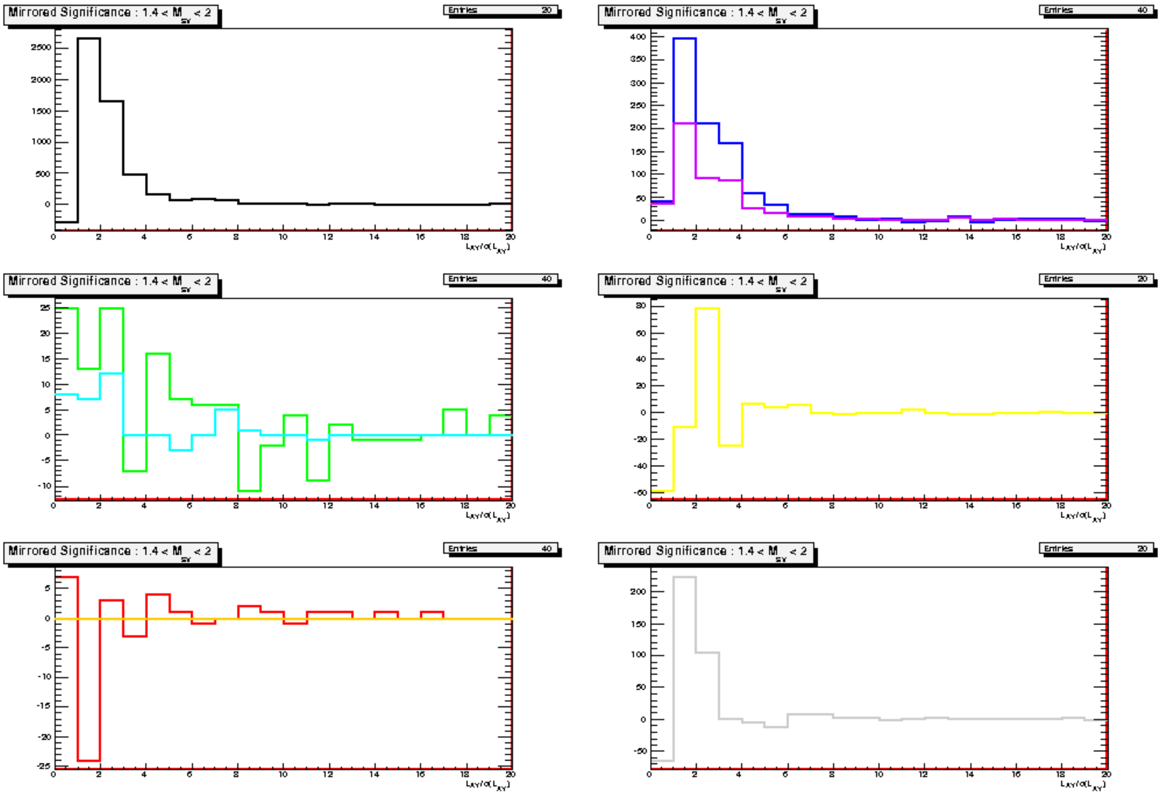

Figure 32: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels for the mass range $1.4 < M_{sv} < 2$. The colors blue, green and red represent 1 matched vertices and the colors purple, cyan and orange represent 2 matched vertices.

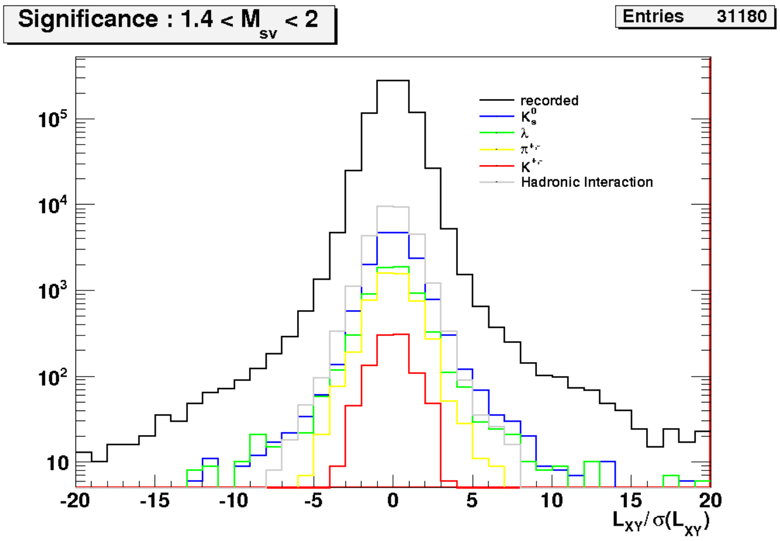

Figure 33: Significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels for the mass range $1.4 < M_{sv} < 2$.

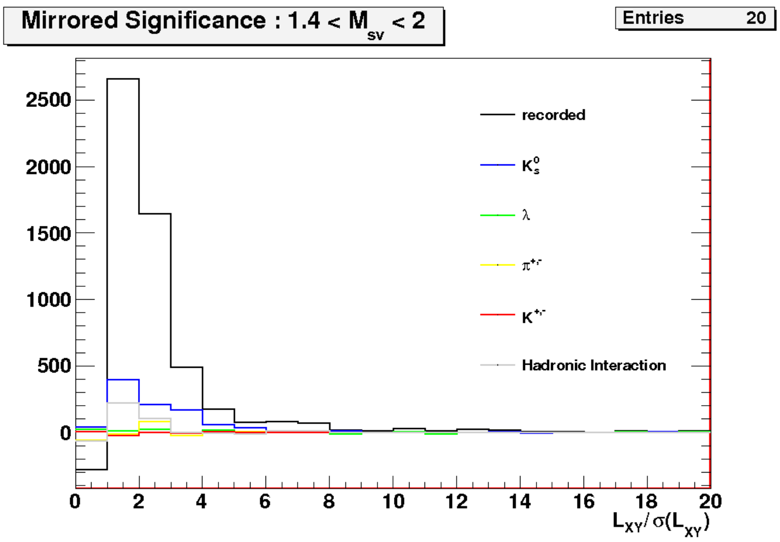

Figure 34: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels for the mass range $1.4 < M_{sv} < 2$.

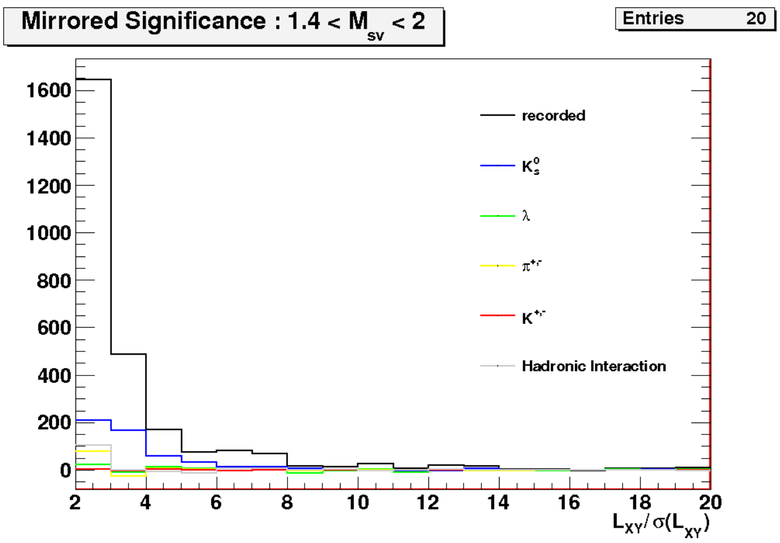

Figure 35: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis > 2 for different decay channels for the mass range $1.2 < M_{sv} < 2$.

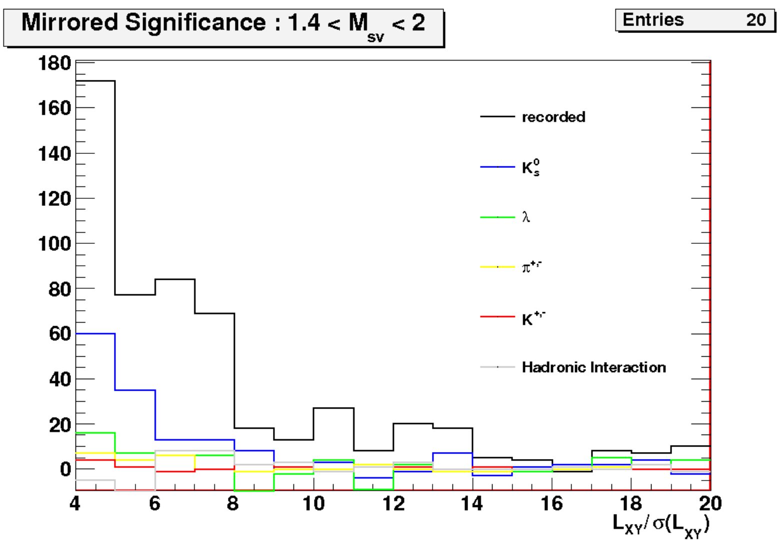

Figure 36: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis > 4 for different decay channels for the mass range $1.4 < M_{sv} < 2$.

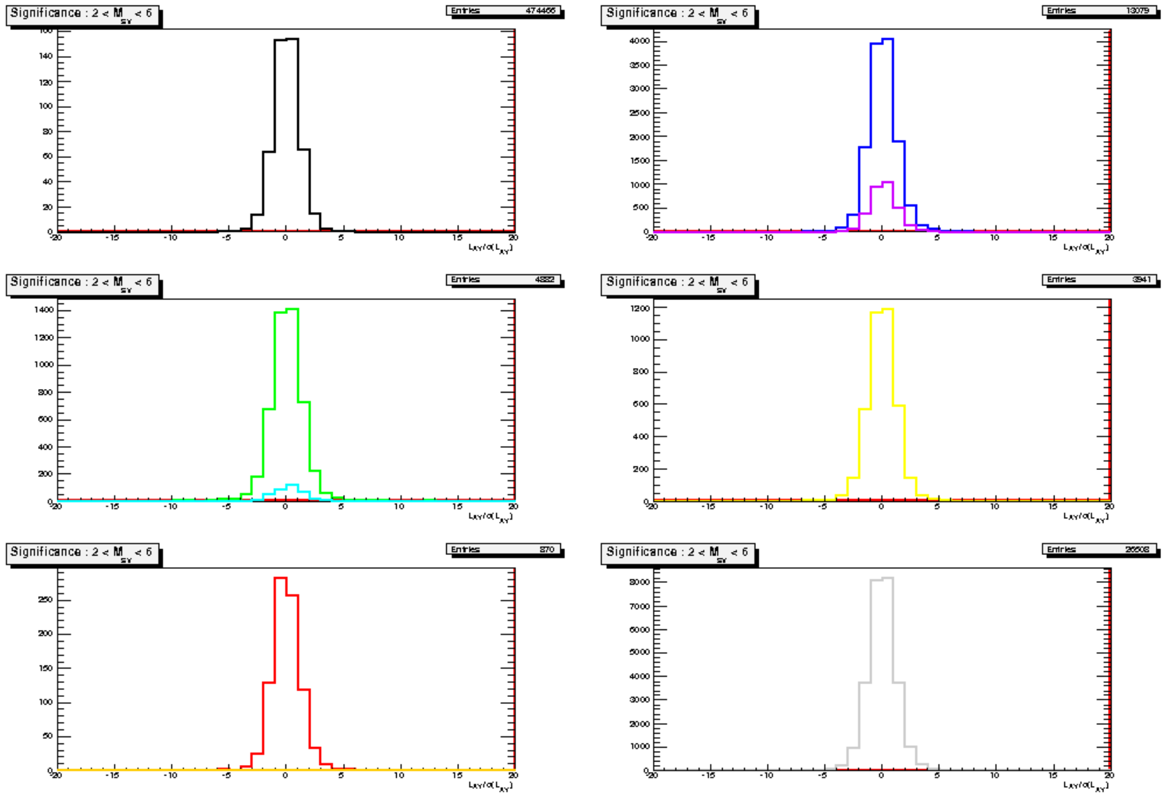

Figure 37: Significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels for the mass range $2 < M_{sv} < 6$. The colors blue, green and red represent 1 matched vertices and the colors purple, cyan and orange represent 2 matched vertices.

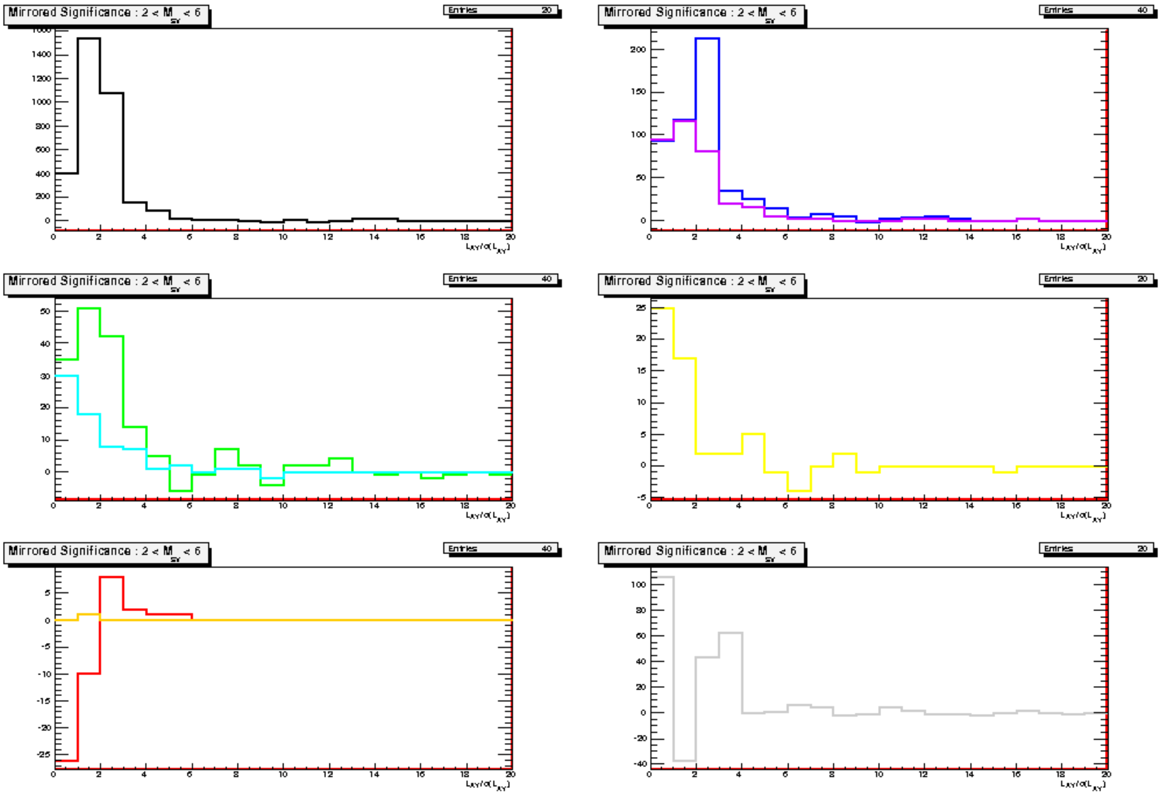

Figure 38: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels for the mass range $2 < M_{sv} < 6$. The colors blue, green and red represent 1 matched vertices and the colors purple, cyan and orange represent 2 matched vertices.

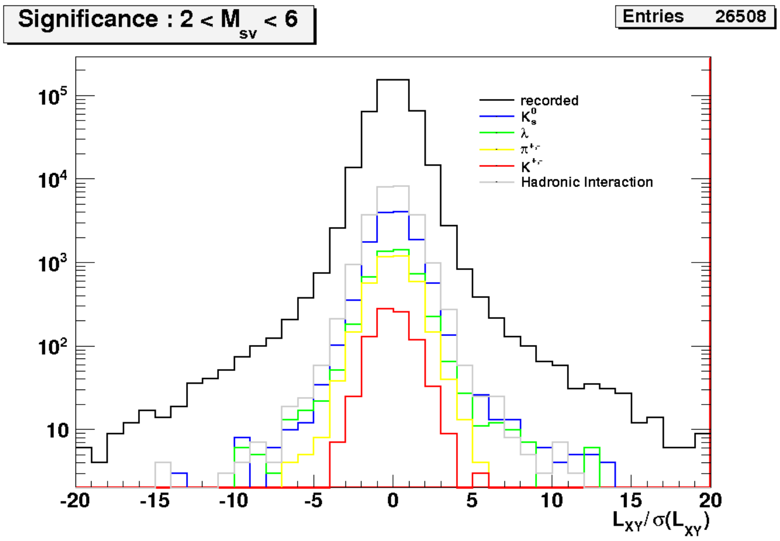

Figure 39: Significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels for the mass range $2 < M_{sv} < 6$.

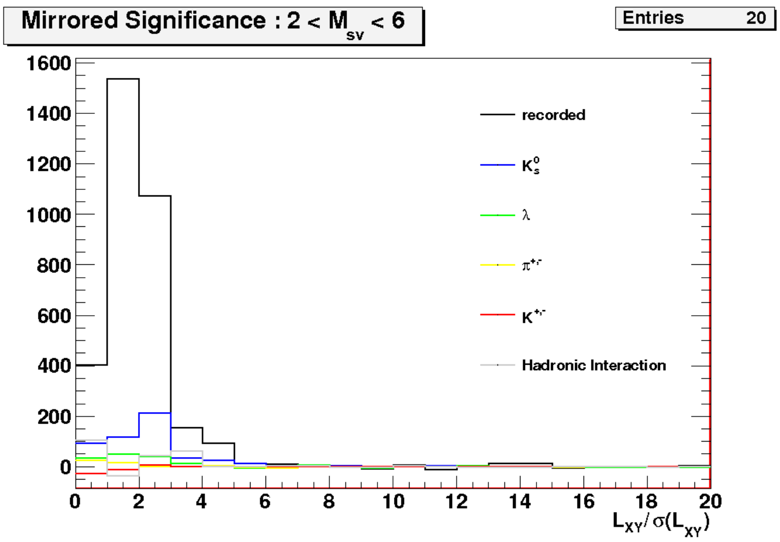

Figure 40: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels for the mass range $2 < M_{sv} < 6$.

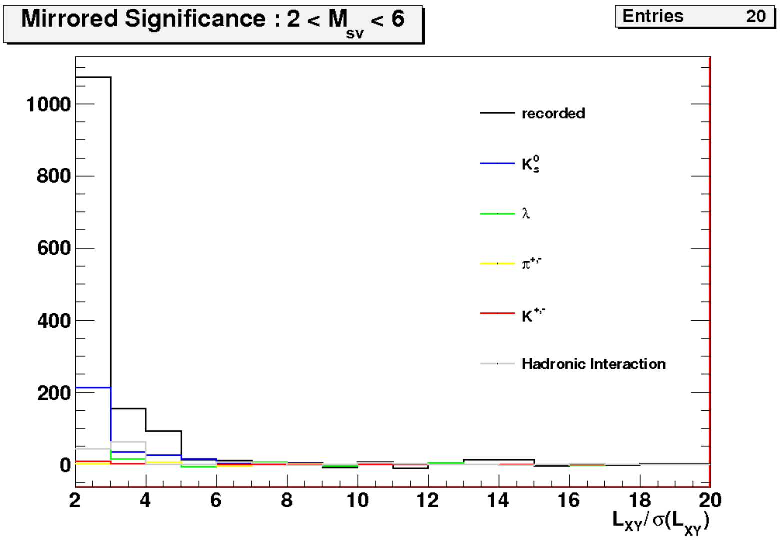

Figure 41: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis > 2 for different decay channels for the mass range $2 < M_{sv} < 6$.

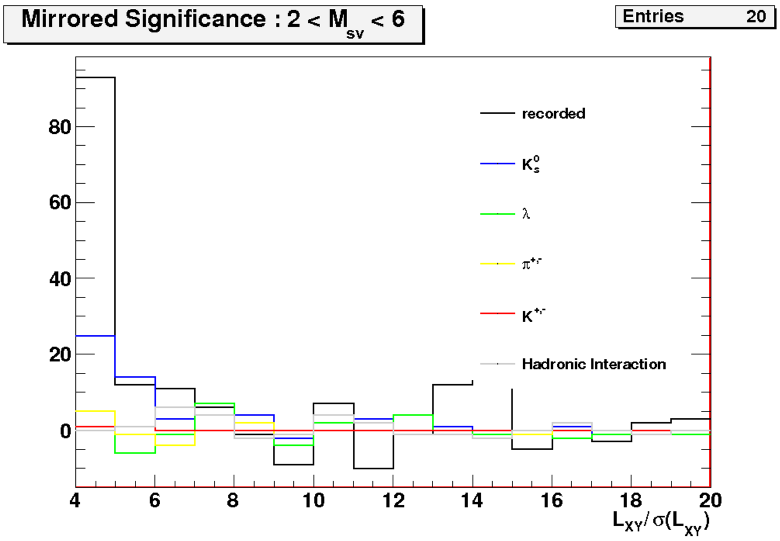

Figure 42: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis > 4 for different decay channels for the mass range $2 < M_{sv} < 6$. The contribution of K_s^0 to the mirrored significance is higher than the of all recorded tracks.

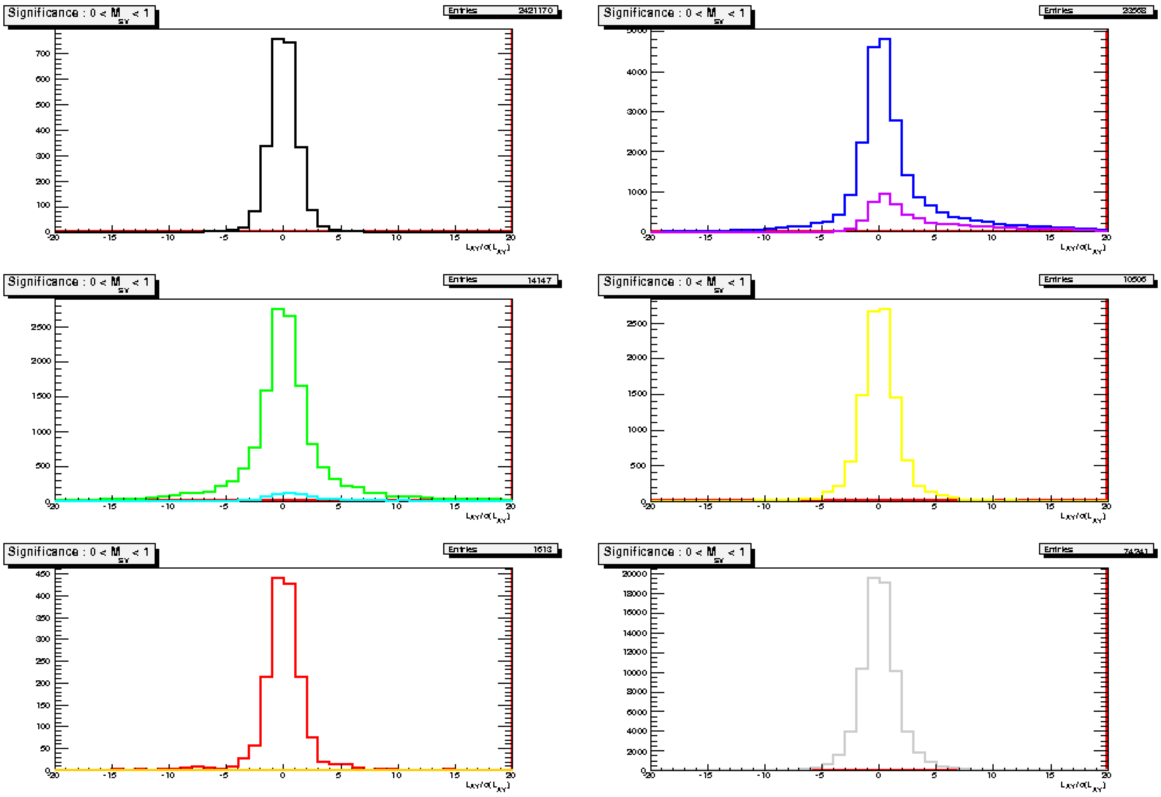

Figure 43: Significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels for the mass range $0 < M_{sv} < 1$. The colors blue, green and red represent 1 matched vertices and the colors purple, cyan and orange represent 2 matched vertices.

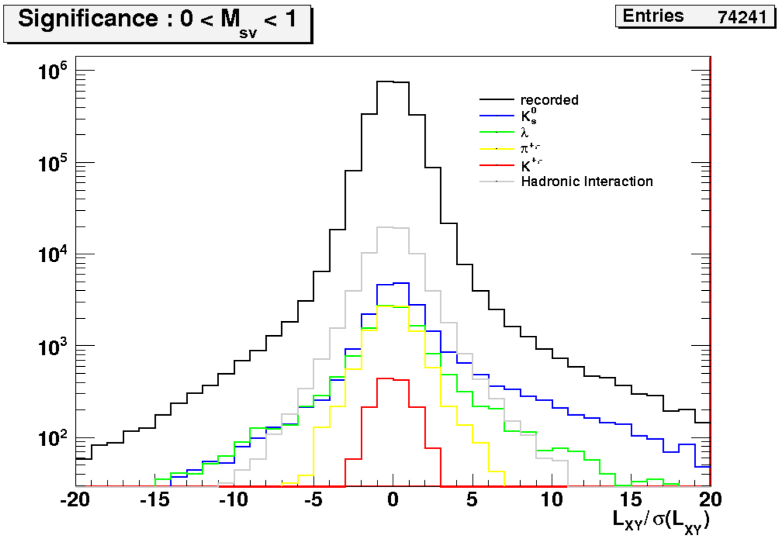

Figure 44: Significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels for the mass range $0 < M_{sv} < 1$.

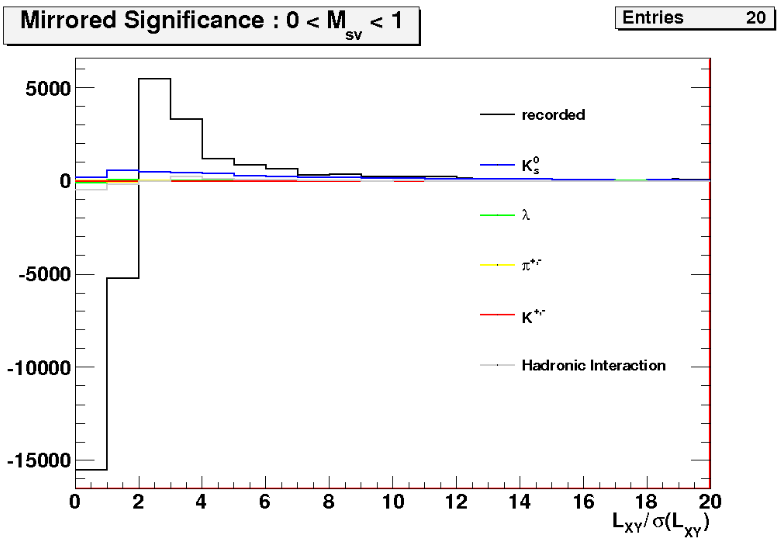

Figure 45: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis for different decay channels for the mass range $0 < M_{sv} < 1$.

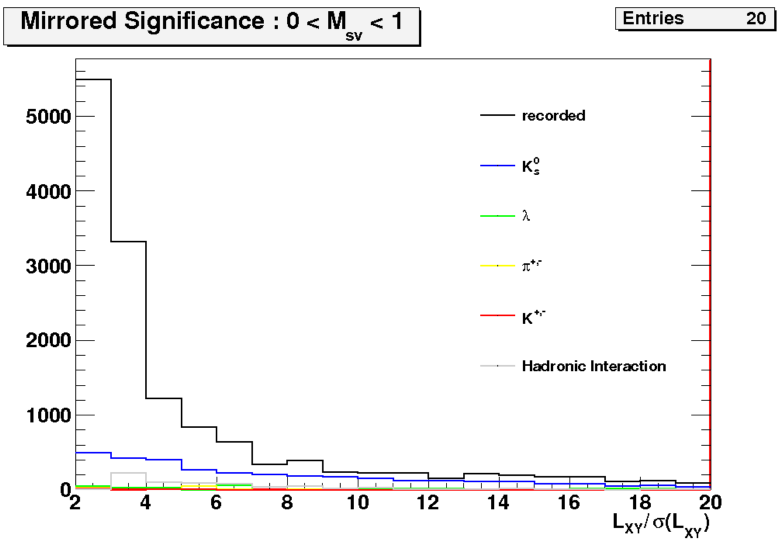

Figure 46: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis > 2 for different decay channels for the mass range $0 < M_{sv} < 1$.

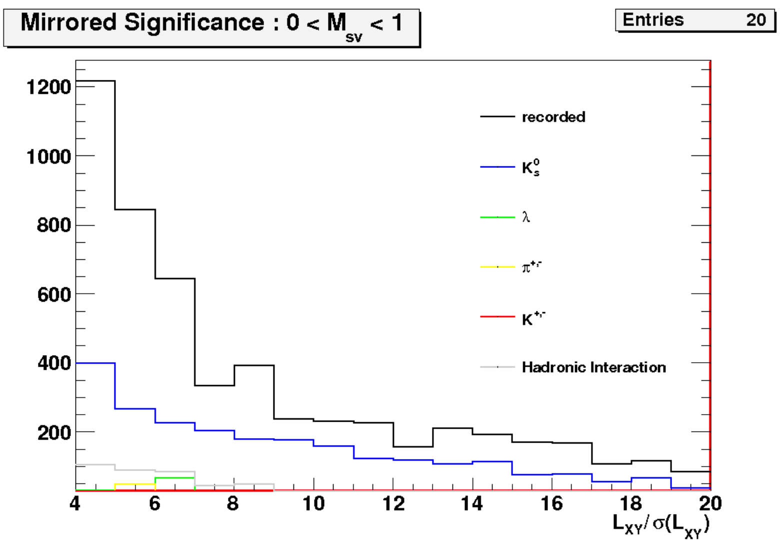

Figure 47: Mirrored significance of the transversed decay length of the secondary vertex projected onto the associated jet axis > 4 for different decay channels for the mass range $0 < M_{sv} < 1$. The mirrored significance is dominated by K_s^0.

The following tables are a summary of the contribution of K_s^0, Λ, $\pi^{+,-}$, $K^{+,-}$ and particles coming from hadronic interactions to the asymmetric significance of all recorded light flavor composite particles.

Table 1: Fraction of the recorded mirrored significance > 4

recorded	1
K_s^0 1	0.141557
K_s^0 2	0.109201
Λ 1	0.0566229
Λ 2	0.00151668
$\pi^{+,-}$ 1	0.0338726
$K^{+,-}$ 1	0.00859454
$K^{+,-}$ 2	0
Hadronic Interaction 1	0.0758342

Table 2: Fraction of the recorded mirrored significance > 4 for the mass range $1GeV < M_{sv} < 1.4GeV$

recorded	1
K_s^0 1	0.135425
K_s^0 2	0.0925784
Λ 1	0.0657995
Λ 2	-0.00153022
$\pi^{+,-}$ 1	0.0382555
$K^{+,-}$ 1	0.00382555
$K^{+,-}$ 2	0
Hadronic Interaction 1	0.0986993

Table 3: Fraction of the recorded mirrored significance > 4 for the mass range $1.4GeV < M_{sv} < 2GeV$

recorded	1
K_s^0 1	0.124304
K_s^0 2	0.131725
Λ 1	0.0426716
Λ 2	0.00371058
$\pi^{+,-}$ 1	0.0315399
$K^{+,-}$ 1	0.0185529
$K^{+,-}$ 2	0
Hadronic Interaction 1	0.0185529

Table 4: Fraction of the recorded mirrored significance > 4 for the mass range $2GeV < M_{sv} < 6GeV$.

recorded	1
K_s^0 1	0.272727
K_s^0 2	0.181818
Λ 1	0.0227273
Λ 2	0.0227273
$\pi^{+,-}$ 1	0
$K^{+,-}$ 1	0.0151515
$K^{+,-}$ 2	0
Hadronic Interaction 1	0.0833333

Table 5: Fraction of the recorded mirrored significance > 4 for the mass range $0GeV < M_{sv} < 1GeV$

recorded	1
K_s^0 1	0.109261
K_s^0 2	0.338447
Λ 1	0.00710945
Λ 2	0.0241347
$\pi^{+,-}$ 1	0.0166511
$K^{+,-}$ 1	0.00187091
$K^{+,-}$ 2	0.000187091
Hadronic Interaction 1	0.0868101

5 Conclusion

K_s^0 are contributing $1/4$ to the significance asymmetry. Λ and charged π are contributing more than $7/100$ and $3/100$, respectively. Charged Kaons are barely contributing. As a summarized result we can say that more $1/3$ of the significance asymmetry is coming from light flavor particle decays. The contribution Hadronic Interactions is not clarified yet as the matching for these tracks may be different but seems to be interesting.
For the mass range $0GeV < M_{sv} < 1GeV$ this contribution differs little. For the mass range $1.4GeV < M_{sv} < 2GeV$ charged Kaons are contributing more and particles from Hadronic Interactions less. The mass range $2GeV < M_{sv} < 6GeV$ is dominated by K_s^0. Charged π are not contributing anymore.

6 Appendix - ROOT-code

```
#define orange_cxx
#include "orange.h"

...

using namespace std;

void orange::Loop()
{

...

   // define cut constants

   Float_t   cutChi2NdfSecVtx = 4.;
   Float_t   cutDisRecTrueTrk = 0.1;
   Float_t   cutEtJet = 4.2;
   Float_t   cutEtaJetLow = -1.6;
   Float_t   cutEtaJetUp = 2.2;
   Float_t   cutMassSecVtxLow = 1.;
   Float_t   cutMassSecVtxUp = 6.;
   Float_t   cutMassSecVtx1 = 1.4;
   Float_t   cutMassSecVtx2 = 2.;



// define histograms

...

   // define here the number of entries to analyze
   Long64_t   nentries = fChain->GetEntriesFast();

   Long64_t   nbytes = 0, nb = 0;

   UInt_t   fLf = 0;
   UInt_t   fDis = 0;
   UInt_t   true_trk_mat = 0;
   UInt_t   both_true_trk_mat = 0;
   UInt_t   both_true_trk_mat_vtx = 0;

   for ( Long64_t   jentry = 0; jentry < nentries; jentry++ ) {
```

```
      // show progress while computing, about 20000 entries are stored in a
ntuple
      if ( !(jentry % 20000) ) cout << "... processing event " << jentry <<
" ..." << endl;

      Long64_t ientry = LoadTree(jentry);
      if ( ientry < 0 ) break;

      nb = fChain->GetEntry(jentry);   nbytes += nb;


      // consider entries on true level
      // consider light flavor
      if ( Ncb > 0 ) continue;

      fLf++;
      if ( !( this->IsDIS() ) ) continue;
      fDis++;

      // get mother
      for ( Int_t   k = 0; k < Fmck_nstor; k++ ) {

         UInt_t   prtM = Fmck_prt[k];
         UInt_t   daugP = Fmck_daug[k];
         if ( ( prtM != 54 ) && ( prtM != 55 ) && ( prtM != 58 ) &&
( prtM != 59 ) && ( prtM != 62 ) && ( prtM != 194 ) && ( prtM != 195 ) &&
( daugP != 2147483647 ) ) continue;
         Int_t   idM = Fmck_id[k];
         Int_t   fmckinP = -1 ;
         Int_t   fmckinPP = -1 ;

         // check for hadronic interaction
         if ( daugP == 2147483647 ) {
            fmckinP = k;
            fmckinPP = k;
         }

         // search for first daughter particle
         for ( Int_t   p = 0; p < Fmck_nstor; p++ ) {
            if ( daugP == 2147483647 ) break;
            if ( Fmck_daug[p] != idM ) continue;
            UInt_t   prtP = Fmck_prt[p];
```

```
            // check for Pion^{+} -> Muon^{+} + X and corresponding
anti-particle decay
            if ( ( ( prtM == 54 ) && ( prtP == 26 ) ) || ( ( prtM == 55 )
&& ( prtP == 25 ) ) ) {
               fmckinP = p;
               fmckinPP = p;
               break;
            }

            // check for K^{+} -> Muon^{+} + X and corresponding
anti-particle decay
            if ( ( ( prtM == 58 ) && ( prtP == 26 ) ) || ( ( prtM == 59 )
&& ( prtP == 25 ) ) ) {
               fmckinP = p;
               fmckinPP = p;
               break;
            }

            // search for second daughter particle
            for ( Int_t   pp = p; pp < Fmck_nstor; pp++ ) {
               if ( pp == p ) continue;
               if ( Fmck_daug[pp] != idM ) continue;
               UInt_t   prtPP = Fmck_prt[pp];

               // check for K^{0}_{s} (weak interaction eigenstate) ->
Pion^{+} + Pion^{-} and corresponding anti-particle decay
               if ( ( prtM == 62 ) && ( ( ( prtP == 54 ) && ( prtPP == 55 ) )
|| ( ( prtP == 55 ) && ( prtPP == 54 ) ) ) ) {
                  fmckinP = p;
                  fmckinPP = pp;
                  break;
               }

               // check for Lambda -> Proton + Pion^{-} and Lambda -> Neutron
+ Pion^{0} and corresponding anti-particle decays
               if ( ( ( ( prtM == 194 ) && ( ( ( prtP == 55 ) &&
( prtPP == 190 ) ) || ( ( prtP == 190 ) && ( prtPP == 55 ) ) ) ||
( ( ( prtP == 56 ) && ( prtPP == 192 ) ) || ( ( prtP == 192 ) &&
( prtPP == 56) ) ) ) ) || ( ( ( prtM == 195 ) && ( ( ( prtP == 54 ) &&
( prtPP == 191 ) ) || ( ( prtP == 191 ) && ( prtPP == 54 ) ) ) ||
( ( ( prtP == 56 ) && ( prtPP == 193 ) ) || ( ( prtP == 193 ) &&
( prtPP == 56) ) ) ) ) ) {
                  fmckinP = p;
                  fmckinPP = pp;
```

```
               break;
            }

            // check for K^{+} -> Pion^{+} + Pion^{0} and corresponding
anti-particle decay
            if ( ( ( prtM == 58 ) && ( ( ( prtP == 54 ) &&
( prtPP == 56 ) ) || ( ( prtP == 56 ) && ( prtPP == 54 ) ) ) ) ||
( ( prtM == 59 ) && ( ( ( prtP == 55 ) && ( prtPP == 56 ) ) ||
( ( prtP == 56 ) && ( prtPP == 55 ) ) ) ) ) {
               fmckinP = p;
               fmckinPP = pp;
            }

            break;
         }
         break;
      }
      if ( fmckinP == -1 ) continue;



      // consider secondary vertices on recorded level
      Float_t   min_dis_rec_true_trkP = 1.;
      Float_t   min_dis_rec_true_trkPP = 1.;
      Int_t   vertexP = -1;
      Int_t   vertexPP = -1;
      UInt_t   matP = 0;
      UInt_t   matPP = 0;
   for ( Int_t   vertex = 0; vertex < Nr_secvtx; vertex++ ) {

         // consider tracks from the secondary vertex
         Int_t   sec_vtx_mul = Vtxsec_multi[vertex];
         // check whether secondary vertex is defined
         if ( sec_vtx_mul == 666 ) continue;
         hVtxsecMulti->Fill(sec_vtx_mul);
 for ( Int_t   track = 0; track < sec_vtx_mul; track++) {
    // try to find this track in the tracking block
    Int_t   trk = -1;
    for ( Int_t   t = 0; t < Trk_ntracks; t++ ) {
       if ( Trk_id[t] == Vtxsec_zttid[vertex][track] ) {
  trk = t;
  break;
}
          }
```

```
              // check whether it was successful
          if ( trk == -1 ) {
              cout << "Secondary vertex track could not be found in the
tracking table. Abort" << endl;
          abort();
       }

              // try to match this recorded track to one of the true tracks
       Float_t   dis_rec_true_trkP =
CalculateDisRecTrueTrk(trk, fmckinP);
              hDisRecTrueTrk->Fill(dis_rec_true_trkP);
              // check whether this recorded track could be matched to the
true tracks
           if ( dis_rec_true_trkP < min_dis_rec_true_trkP ) {
                 // define this difference as the new reference difference
                 min_dis_rec_true_trkP = dis_rec_true_trkP;
                 vertexP = vertex;
                 matP++;
              }
              if ( fmckinP != fmckinPP ) {
                 Float_t   dis_rec_true_trkPP =
CalculateDisRecTrueTrk(trk, fmckinPP);
                 hDisRecTrueTrk->Fill(dis_rec_true_trkPP);
                 if ( dis_rec_true_trkPP < min_dis_rec_true_trkPP ) {
                    // define this difference as the new reference
difference
                    min_dis_rec_true_trkPP = dis_rec_true_trkPP;
                    vertexPP = vertex;
                    matPP++;
                 }
              }
            }
         }



         // check whether true track could be matched by a corresponding
recorded track
         if ( ( min_dis_rec_true_trkP > cutDisRecTrueTrk ) &&
( min_dis_rec_true_trkPP > cutDisRecTrueTrk ) ) continue;
         true_trk_mat++;
         // in case that both true tracks could be matched by corresponding
recorded tracks check whether both recorded tracks are from same vertex
         Bool_t   both = kFALSE;
```

```
        if ( ( fmckinP != fmckinPP ) &&
( min_dis_rec_true_trkP < cutDisRecTrueTrk ) &&
( min_dis_rec_true_trkPP < cutDisRecTrueTrk ) ) {
           both_true_trk_mat++;
           if ( vertexP != vertexPP ) continue;
           both_true_trk_mat_vtx++;
           both = kTRUE;
        }

        // try to match this (block-A-) jet to one of the jets in block B
(for v02)
 Int_t   jetP = -1;
   // loop over jets in block B
     for (Int_t   jet = 0; jet < Kt_njet_b; jet++) {
    // check whether eta, et and phi are the same for both jets
    Float_t   deta = Kt_etajet_a[vertexP] - Kt_etajet_b[jet];
    Float_t   dphi = Kt_phijet_a[vertexP] - Kt_phijet_b[jet];
    Float_t   dEt = Kt_etjet_a[vertexP] - Kt_etjet_b[jet];
    if ( ( deta == 0 ) && ( dphi == 0 ) &&  ( dEt == 0 ) ) {
       jetP = jet;
              break;
    }
 }
 if ( jetP == -1 ) continue;

        // fill histograms
        Float_t   mass_sec_vtx = Vtxsec_mass[vertexP];
        hVtxsecMass->Fill(mass_sec_vtx);
        Float_t   chi2ndf_sec_vtx = Vtxsec_chi2[vertexP] /
Vtxsec_ndf[vertexP];
        hVtxsecChi2Ndf->Fill(chi2ndf_sec_vtx);
        Float_t   et_jet = Kt_etjet_b[jetP];
        hKtEtjetB->Fill(et_jet);
        Float_t   eta_jet = Kt_etajet_b[jetP];
        hKtEtajetB->Fill(eta_jet);

        // select secondary vertex corresponding to recorded tracks matched
to true tracks
        if ( ( fmckinP != fmckinPP ) &&
( min_dis_rec_true_trkPP < cutDisRecTrueTrk ) ) {
           hDisMatRecTrueTrk->Fill(min_dis_rec_true_trkPP);
        }
        if ( min_dis_rec_true_trkP < cutDisRecTrueTrk ) {
           hDisMatRecTrueTrk->Fill(min_dis_rec_true_trkP);
```

```
         } else {
            vertexP = vertexPP;
            fmckinP = fmckinPP;
         }

         // cut on chi2/ndf secondary vertex
 if ( chi2ndf_sec_vtx > cutChi2NdfSecVtx ) continue;

         // upper cut on mass secondary vertex
     if ( mass_sec_vtx > cutMassSecVtxUp ) continue;

         // cut on Et jet
 if ( et_jet < cutEtJet ) continue;

         // cut on eta jet
 if ( ( eta_jet < cutEtaJetLow ) || ( eta_jet > cutEtaJetUp ) ) continue;

         // try to calculate projected decay length transversed
 Float_t   pro_dec_len_t = CalculateProDecLenT(vertexP);
         // check whether it was successful
 if ( pro_dec_len_t == -999 ) continue;
         if ( pro_dec_len_t == -998 ) continue;
 // calculate projected decay length transversed error
 Float_t   pro_dec_len_t_err = CalculateProDecLenTerr(vertexP);
         // check whether it is non-zero for calculation of significance of
projected decay length transversed
         if ( pro_dec_len_t_err == 0 ) continue;
         hProDecLenT->Fill(pro_dec_len_t);
         Float_t   sig_pro_dec_len_t = pro_dec_len_t / pro_dec_len_t_err;



         // fill histograms
         if ( mass_sec_vtx >= cutMassSecVtxLow ) {
            hVtxsecMassCut->Fill(mass_sec_vtx);
            hVtxsecChi2NdfCut->Fill(chi2ndf_sec_vtx);
            hKtEtjetBcut->Fill(et_jet);
            hKtEtajetBcut->Fill(eta_jet);
            hProDecLenT->Fill(pro_dec_len_t);
            hSigProDecLenT->Fill(sig_pro_dec_len_t);
            if ( mass_sec_vtx < cutMassSecVtx1 )
hSig114->Fill(sig_pro_dec_len_t);
            if ( ( mass_sec_vtx >= cutMassSecVtx1 ) &&
( mass_sec_vtx < cutMassSecVtx2 ) ) hSig142->Fill(sig_pro_dec_len_t);
```

```
            if ( mass_sec_vtx >= cutMassSecVtx2 )
hSig26->Fill(sig_pro_dec_len_t);
            if ( prtM == 62 ) {
               if ( both ) {
                  hSigK0s2->Fill(sig_pro_dec_len_t);
                  if ( ( mass_sec_vtx >= cutMassSecVtxLow ) &&
( mass_sec_vtx < cutMassSecVtx1 ) ) hSig114K0s2->Fill(sig_pro_dec_len_t);
                  if ( ( mass_sec_vtx >= cutMassSecVtx1 ) &&
( mass_sec_vtx < cutMassSecVtx2 ) ) hSig142K0s2->Fill(sig_pro_dec_len_t);
                  if ( mass_sec_vtx >= cutMassSecVtx2 )
hSig26K0s2->Fill(sig_pro_dec_len_t);
               } else {
                  hSigK0s1->Fill(sig_pro_dec_len_t);
                  if ( ( mass_sec_vtx >= cutMassSecVtxLow ) &&
( mass_sec_vtx < cutMassSecVtx1 ) ) hSig114K0s1->Fill(sig_pro_dec_len_t);
                  if ( ( mass_sec_vtx >= cutMassSecVtx1 ) &&
( mass_sec_vtx < cutMassSecVtx2 ) ) hSig142K0s1->Fill(sig_pro_dec_len_t);
                  if ( mass_sec_vtx >= cutMassSecVtx2 )
hSig26K0s1->Fill(sig_pro_dec_len_t);
               }
               continue;
            }
            if ( ( prtM == 194 ) || ( prtM == 195 ) ) {
               if ( both ) {
                  hSigLambda2->Fill(sig_pro_dec_len_t);
                  if ( ( mass_sec_vtx >= cutMassSecVtxLow ) &&
( mass_sec_vtx < cutMassSecVtx1 ) ) hSig114Lambda2->Fill(sig_pro_dec_len_t);
                  if ( ( mass_sec_vtx >= cutMassSecVtx1 ) &&
( mass_sec_vtx < cutMassSecVtx2 ) ) hSig142Lambda2->Fill(sig_pro_dec_len_t);
                  if ( mass_sec_vtx >= cutMassSecVtx2 )
hSig26Lambda2->Fill(sig_pro_dec_len_t);
               } else {
                  hSigLambda1->Fill(sig_pro_dec_len_t);
                  if ( ( mass_sec_vtx >= cutMassSecVtxLow ) &&
( mass_sec_vtx < cutMassSecVtx1 ) ) hSig114Lambda1->Fill(sig_pro_dec_len_t);
                  if ( ( mass_sec_vtx >= cutMassSecVtx1 ) &&
( mass_sec_vtx < cutMassSecVtx2 ) ) hSig142Lambda1->Fill(sig_pro_dec_len_t);
                  if ( mass_sec_vtx >= cutMassSecVtx2 )
hSig26Lambda1->Fill(sig_pro_dec_len_t);
               }
               continue;
            }
            if ( ( prtM == 54 ) || ( prtM == 55 ) ) {
               hSigPion1->Fill(sig_pro_dec_len_t);
```

```
               if ( ( mass_sec_vtx >= cutMassSecVtxLow ) &&
( mass_sec_vtx < cutMassSecVtx1 ) ) hSig114Pion1->Fill(sig_pro_dec_len_t);
               if ( ( mass_sec_vtx >= cutMassSecVtx1 ) &&
( mass_sec_vtx < cutMassSecVtx2 ) ) hSig142Pion1->Fill(sig_pro_dec_len_t);
               if ( mass_sec_vtx >= cutMassSecVtx2 )
hSig26Pion1->Fill(sig_pro_dec_len_t);
               continue;
            }
            if ( ( prtM == 58 ) || ( prtM == 59 ) ) {
               if ( both ) {
                  hSigKaon2->Fill(sig_pro_dec_len_t);
                  if ( ( mass_sec_vtx >= cutMassSecVtxLow ) &&
( mass_sec_vtx < cutMassSecVtx1 ) ) hSig114Kaon2->Fill(sig_pro_dec_len_t);
                  if ( ( mass_sec_vtx >= cutMassSecVtx1 ) &&
( mass_sec_vtx < cutMassSecVtx2 ) ) hSig142Kaon2->Fill(sig_pro_dec_len_t);
                  if ( mass_sec_vtx >= cutMassSecVtx2 )
hSig26Kaon2->Fill(sig_pro_dec_len_t);
               } else {
                  hSigKaon1->Fill(sig_pro_dec_len_t);
                  if ( ( mass_sec_vtx >= cutMassSecVtxLow ) &&
( mass_sec_vtx < cutMassSecVtx1 ) ) hSig114Kaon1->Fill(sig_pro_dec_len_t);
                  if ( ( mass_sec_vtx >= cutMassSecVtx1 ) &&
( mass_sec_vtx < cutMassSecVtx2 ) ) hSig142Kaon1->Fill(sig_pro_dec_len_t);
                  if ( mass_sec_vtx >= cutMassSecVtx2 )
hSig26Kaon1->Fill(sig_pro_dec_len_t);
               }
               continue;
            }
            if ( daugP == 2147483647 ) {
               hSigHaIn1->Fill(sig_pro_dec_len_t);
               if ( ( mass_sec_vtx >= cutMassSecVtxLow ) &&
( mass_sec_vtx < cutMassSecVtx1 ) ) hSig114HaIn1->Fill(sig_pro_dec_len_t);
               if ( ( mass_sec_vtx >= cutMassSecVtx1 ) &&
( mass_sec_vtx < cutMassSecVtx2 ) ) hSig142HaIn1->Fill(sig_pro_dec_len_t);
               if ( mass_sec_vtx >= cutMassSecVtx2 )
hSig26HaIn1->Fill(sig_pro_dec_len_t);
            }
         } else {
            hSig01->Fill(sig_pro_dec_len_t);
            if ( prtM == 62 ) {
               if ( both ) hSig01K0s2->Fill(sig_pro_dec_len_t);
               else hSig01K0s1->Fill(sig_pro_dec_len_t);
               continue;
            }
```

```
            if ( ( prtM == 194 ) || ( prtM == 195 ) ) {
               if ( both ) hSig01Lambda2->Fill(sig_pro_dec_len_t);
               else hSig01Lambda1->Fill(sig_pro_dec_len_t);
               continue;
            }
            if ( ( prtM == 54 ) || ( prtM == 55 ) ) {
               hSig01Pion1->Fill(sig_pro_dec_len_t);
               continue;
            }
            if ( ( prtM == 58 ) || ( prtM == 59 ) ) {
               if ( both ) hSig01Kaon2->Fill(sig_pro_dec_len_t);
               else hSig01Kaon1->Fill(sig_pro_dec_len_t);
               continue;
            }
            if ( daugP == 2147483647 ) hSig01HaIn1->Fill(sig_pro_dec_len_t);
         }
      }



      // calculate significance of projected decay length transversed recorded
      for ( Int_t   vertex = 0; vertex < Nr_secvtx; vertex++ ) {
         Float_t   sec_vtx_multi = Vtxsec_multi[vertex];
         if ( sec_vtx_multi == 666 ) continue;
         if ( Vtxsec_chi2[vertex] / Vtxsec_ndf[vertex] > cutChi2NdfSecVtx )
continue;
         Int_t   jetB = -1;
        for (Int_t   jet = 0; jet < Kt_njet_b; jet++) {
       Float_t   deta = Kt_etajet_a[vertex] - Kt_etajet_b[jet];
       Float_t   dphi = Kt_phijet_a[vertex] - Kt_phijet_b[jet];
       Float_t   dEt = Kt_etjet_a[vertex] - Kt_etjet_b[jet];
       if ((deta == 0) && (dphi == 0) &&  (dEt == 0)) {
       jetB = jet;
               break;
    }
 }
 if ( jetB == -1 ) continue;
         if ( Kt_etjet_b[jetB] < cutEtJet ) continue;
         Float_t   eta_jet = Kt_etajet_b[jetB];
 if ( ( eta_jet < cutEtaJetLow ) || ( eta_jet > cutEtaJetUp ) ) continue;
         Float_t   mass_sec_vtx = Vtxsec_mass[vertex];
         if ( mass_sec_vtx > cutMassSecVtxUp ) continue;
         Float_t   pro_dec_len_t = CalculateProDecLenT(vertex);
         if ( pro_dec_len_t == -999 ) continue;
```

```
         if ( pro_dec_len_t == -998 ) continue;
         Float_t   pro_dec_len_t_err = CalculateProDecLenTerr(vertex);
         if ( pro_dec_len_t_err == 0 ) continue;
         Float_t   sig_pro_dec_len_t = pro_dec_len_t / pro_dec_len_t_err;
         if ( mass_sec_vtx >= cutMassSecVtxLow ) {
            hSigRec->Fill(sig_pro_dec_len_t);
            if ( mass_sec_vtx < cutMassSecVtx1 )
hSig114Rec->Fill(sig_pro_dec_len_t);
            if ( ( mass_sec_vtx >= cutMassSecVtx1 ) &&
( mass_sec_vtx < cutMassSecVtx2 ) ) hSig142Rec->Fill(sig_pro_dec_len_t);
            if ( mass_sec_vtx >= cutMassSecVtx2 )
hSig26Rec->Fill(sig_pro_dec_len_t);
         } else hSig01Rec->Fill(sig_pro_dec_len_t);
      }

   // if ( Cut(ientry) < 0 ) continue;
   }




   // calculate mirrored significance of projected decay length transversed

...

// output on shell

...

// calculate fraction of mirrored significance of projected decay length
transversed recorded

...

// draw histograms

...

}
```

```
Float_t   orange::CalculateProDecLenT(Int_t   vertex) {

   // define cut constants
   Float_t   cutAbsZsv = 30.;
   Float_t   cutDecLenT = 1.;

   // get position of secondary vertex
   Float_t   xsv = Vtxsec_x[vertex];
   Float_t   ysv = Vtxsec_y[vertex];
   Float_t   zsv = Vtxsec_z[vertex];

   // get position of beam spot transversed
   Float_t   xbspt = Bspt_x + Bspt_dxdz * (Vtxredprm_z - Bspt_z);
   Float_t   ybspt = Bspt_y + Bspt_dydz * (Vtxredprm_z - Bspt_z);

   // calculate decay length transversed
   Float_t   dx = xsv - xbspt;
   Float_t   dy = ysv - ybspt;
   Float_t   dec_len_t = TMath::Sqrt(dx * dx + dy * dy);

   // cut on z position secondary vertex
   if ( TMath::Abs(zsv) > cutAbsZsv ) return -999;
   // cut on decay length transversed
   if ( dec_len_t > cutDecLenT ) return -998;

   // calculate jet topology
   Float_t   jet_phi = Kt_phijet_a[vertex];
   Float_t   sin_phi = TMath::Sin(jet_phi);
   Float_t   cos_phi = TMath::Cos(jet_phi);

   // calculate projected decay length transversed
   Float_t   ProDecLenT = dx * cos_phi + dy * sin_phi;
   return ProDecLenT;
}


Float_t   orange::CalculateProDecLenTerr(Int_t   vertex) {

   // define beam spot position error by average value
   Float_t   Bspt_xerConst = 0.0088;
   Float_t   Bspt_yerConst = 0.0024;

   // calculate jet topology
   Float_t   jet_phi = Kt_phijet_a[vertex];
```

```
   Float_t   sin_phi = TMath::Sin(jet_phi);
   Float_t   cos_phi = TMath::Cos(jet_phi);

   // get error of secondary vertex position
   Float_t   sigma_x = TMath::Sqrt(Vtxsec_cov[vertex][0]);
   Float_t   sigma_y = TMath::Sqrt(Vtxsec_cov[vertex][2]);

   // calculate projected decay length transversed error by propagation of
uncertainty (correlated)
   Float_t   ProDecLenTerr;
   ProDecLenTerr = TMath::Sqrt(cos_phi * cos_phi * (sigma_x * sigma_x +
Bspt_xerConst * Bspt_xerConst) + sin_phi * sin_phi * (sigma_y * sigma_y +
Bspt_yerConst * Bspt_yerConst) + 2 * cos_phi * sin_phi *
Vtxsec_cov[vertex][1]);
   return ProDecLenTerr;



Float_t   orange::CalculateDisRecTrueTrk(Int_t   rec_trk, Int_t   true_trk) {

   // get momemtum of true track
   Float_t   true_trk_px = Fmck_px[true_trk];
   Float_t   true_trk_py = Fmck_py[true_trk];
   Float_t   true_trk_pz = Fmck_pz[true_trk];

   // calculate magnitude of true track momentum
   Float_t   rec_trk_mom_mag = TMath::Sqrt(true_trk_px * true_trk_px +
true_trk_py * true_trk_py + true_trk_pz * true_trk_pz);

   // calculate differences of momenta
   Float_t   dpx = true_trk_px - Trk_px[rec_trk];
   Float_t   dpy = true_trk_py - Trk_py[rec_trk];
   Float_t   dpz = true_trk_pz - Trk_pz[rec_trk];

   // calculate distance of recorded and true track momentum
   Float_t   DisRecTrueTrk = TMath::Sqrt(dpx * dpx + dpy * dpy + dpz * dpz)
/ rec_trk_mom_mag;
   return DisRecTrueTrk;
}


Bool_t   orange::IsDIS() {

   Bool_t   fIsMC = true;
```

```
   // trigger
   Bool_t   SPP02 = (Bool_t)( ( Tltw[2] >> ( 1 + 16 ) ) & 1 );
   Bool_t   SPP09 = (Bool_t)( ( Tltw[2] >> ( 8 + 16 ) ) & 1 );
   Bool_t   HFL17 = (Bool_t)( ( Tltw[13] >> ( 0 + 16 ) ) & 1 );
   Bool_t   HPP31 = (Bool_t)( ( Tltw[11] >> ( 14 + 16 ) ) & 1 );

   // trigger selection
   // 0607p
   if ( ( Simrun >= 60005 ) && ( Simrun <= 62636 ) ) if ( !( SPP09 ||
HFL17 || HPP31 ) ) return false;
   // 06e
   if ( ( Simrun >= 58207 ) && ( Simrun <= 59947 ) ) if ( !( SPP09 ||
HFL17 || HPP31 ) ) return false;
   // 05e
   if ( ( Simrun >= 52258 ) && ( Simrun <= 57123 ) ) if ( !SPP02 )
return false;
   // 0304p
   if ( ( Simrun >= 45783 ) && ( Simrun <= 51245 ) ) if ( !SPP02 )
return false;

   // SINISTRA electron
   if ( Sincand < 1 ) return false;

   // propability for the first electron
   if ( Siprob[0] < 0.9 ) return false;

   // Q^{2}_{double angle}
   if ( Siq2da[0] < 5 ) return false;
   if ( Siq2da[0] > 1000 ) return false;

   // fraction of the electron carried by the photon
   if ( Siyel[0] > 0.7 ) return false;
   if ( Siyjb[0] < 0.02 ) return false;

   // electron position
   Float_t   x_el = Sipos[0][0];
   Float_t   y_el = Sipos[0][1];
   Float_t   x_el_abs = TMath::Abs(x_el);
   Float_t   y_el_abs = TMath::Abs(y_el);
   if ( ( x_el_abs < 13. ) && ( y_el_abs < 13. ) ) return false;

   // energy of the elctron
   if ( Siecorr[0][2] < 10. ) return false;
```

```
   if ( TMath::Abs(Zvtx) > 30. ) return false;

   // energy - momentum along the beam axis
   Float_t   e_pz_zufos = V_h_e_zu - V_h_pz_zu;
   if ( ( e_pz_zufos < 44 ) || ( e_pz_zufos > 65 ) ) return false;

   // number of reconstructed primary vertices
   if ( Ntrkvtx == 0 ) return false;
   if ( !fIsMC ) {
      if ( Evtake <= 0 ) return false;
   }

   if ( !fIsMC ) {
      if ( Mvdtake <= 0 ) return false;
   }

   // bad cell cut: x,y position cuts are the same as Ramoona's but no zel
requirement as well as certain run range. Taken from Philipp
   Int_t   cRunnr = Runnr;
   if ( fIsMC ) cRunnr = Simrun;

   if ( ( ( cRunnr > 59600 ) && ( cRunnr < 60780 ) ) || ( ( cRunnr > 61350 )
&& ( cRunnr < 61580 ) ) || ( ( cRunnr > 61800 ) && ( cRunnr < 63000 ) ) ) {
      if ( ( x_el >= 7.515 ) && ( x_el <= 31.845 ) && ( y_el >= 7.90 ) &&
( y_el <= 31.90 ) ) return false;
   }

   return true;
}



// notes
// looking for vertices with a jet from block B as a reference
(Vtxsec_type[vertex] = 2) may not work for v06
// daughter and mother may be associated with the same id in the fmvtx table
(secondary vertex selection includes particles with the same id in fmvtx
table as the one of the string)
// photons are not traced in fmckin table
// K^{0}, K^{0}b and K^{0}_{s}, K^{0}_{l} are related by daug in the fmckin
table
// fmckin table of v02 does not include the complete event (it is a part of
the fmckin table of v06)
```

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References

[1] H. Abramowicz *et al.* [ZEUS Collaboration], "Measurement of heavy-quark jet photoproduction at HERA," Eur. Phys. J. **C71** (2011) 1659. [arXiv:1104.5444 [hep-ex]].

[2] *http://www.desy.de/f/students/summer_lectures.2011.html*

[3] O. Behnke, "Production of charm and beauty quarks at HERA,"

[4] *http://pdg.lbl.gov/*

[5] P. Roloff, "Measurement of charm and beauty production in deep inelastic scattering at HERA,"

[6] *http://root.cern.ch/drupal/*

[7] *http://www-zeus.desy.de/components/offline/#analysis*