Search for long lived decays of new massive particles in the CMS experiment at the LHC

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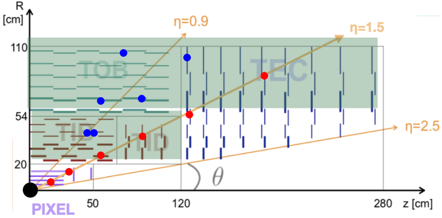
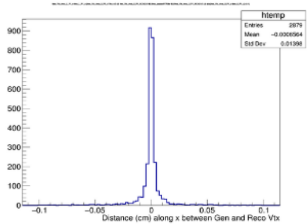
Internship's goals

Search for Displaced Tracks



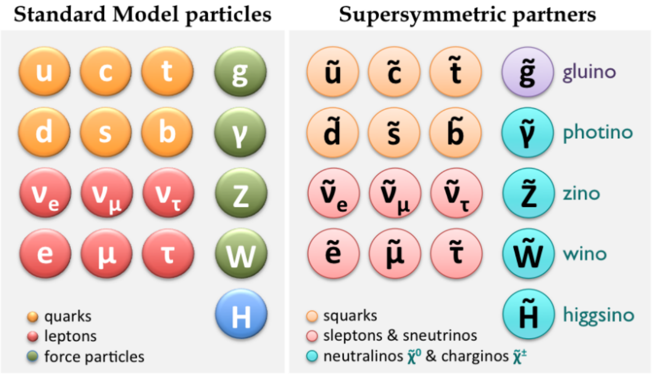
- Characterize the Signal
- Multivariate Analysis
- Select Displaced Tracks

Reconstruct the vertices of the decay of the long-lived particles



- Apply Kalman Vertex Filter
- Evaluate Resolution and Reconstruction efficiency

SuperSymmetry



SM particles => Superpartners + Neutralinos and charginos (mixing of photino, zino, wino and higgsino)

R-Parity Violation Minimal SUSY Model

$P_R = (-1)^{3(B-L)+2s}$ where B and L are respectively the Baryonic and Leptonic numbers, s being the spin of the particle

$P_R = +1$ for SM particles

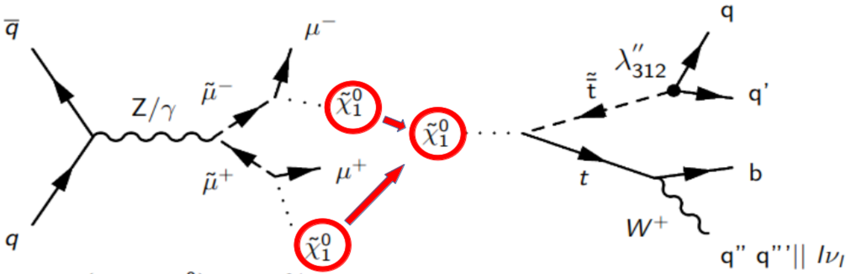
$P_R =$ -1 for SUSY particles

R-Parity Violation

- Non-conservation of the leptonic and/or the baryonic number
- Decay of the LSP into SUSY and/or SM Particles
- **Displaced tracks** can appear in the tracker
- **Displacement** is a function of the lifetime of the LSP

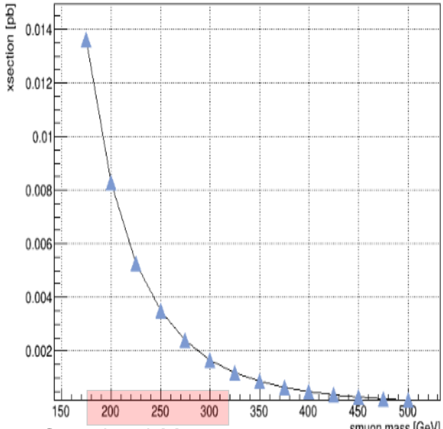
RPV process studied

- p-p interaction :
- Neutralino decay :

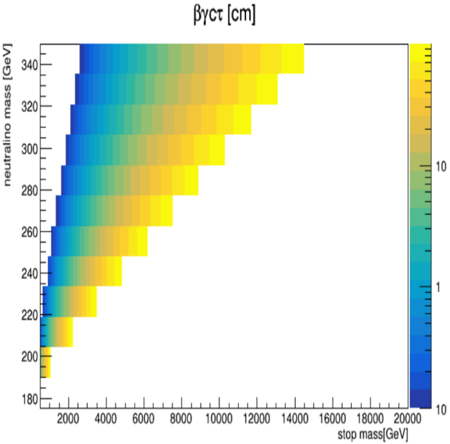


- $Br(\tilde{\mu} \rightarrow \mu\chi_1^0) = 100\%$
- Two neutralinos with a long lifetime
- Trigger : Pair of Muons
- 6 to 10 jets
- λ''_{312} RPV coupling
- displaced top + stop->quarks
- Neutralino is a Majorana particle

Parameters of the flight distance of the neutralino



Considered Mass range



- $\lambda'' = 10^{-3}$
- σ : ~1 fb (10^3 lower than Higgs production)
- ~100 events in the Run2 (2015-2018)

Monte-Carlo Samples

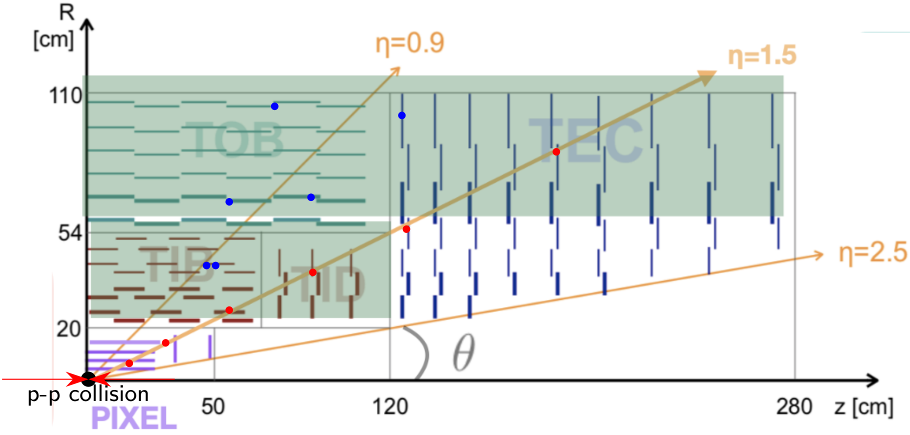
4 Monte-Carlo samples of 10 000 events were generated, simulated and reconstructed for 4 different distances of flight:

$\beta\tilde{\gamma}c\tau$(cm)	Mass $\tilde{\mu}$ (GeV)	Mass $\tilde{\chi}_1^0$ (GeV)	Mass $\tilde{t}$ (GeV)	Coupling $\lambda^{''}$
10	250	200	7200	10^{-1}
30	300	250	10300	10^{-2}
50	275	225	2350	10^{-3}
70	250	200	3700	10^{-2}

Table: Masses of the SUSY particles for each distance of flight as well as for the coupling $\lambda^{''}$

- Compromise between the cross sections, masses of the SUSY particles and the coupling
- Decay in the tracker volume of ∼1.1m radius in the transverse plane (min. 3 cm)

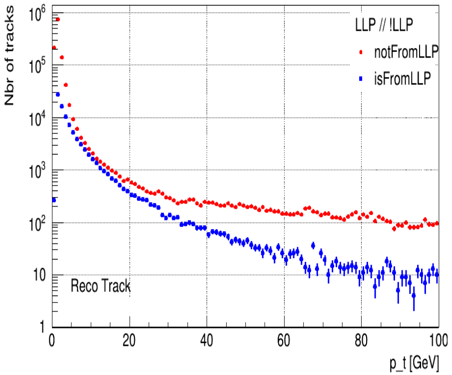
CMS Tracker



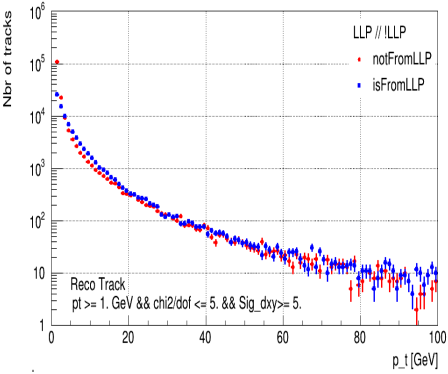
Search for Displaced Tracks

Pre-selection of the tracks

Before pre-selection



After pre-selection



$p_t > 1$ GeV **AND** $\chi^2/dof < 5$ **AND** $Sig_{dxy} > 5$

=> 90% Background reduction & ~1% Signal loss

Signal -> All the displaced tracks & Bkg -> the other tracks

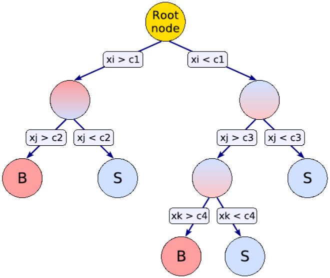
<S>~13 & <B>~27 tracks per event

Boosted Decision Tree

Goal

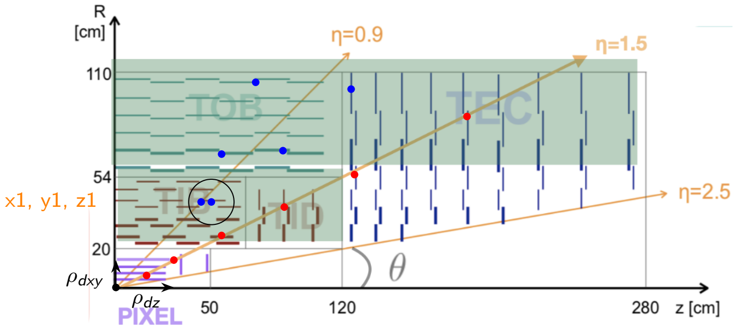
- Select the displaced tracks coming from the neutralino decay

Classifier : Binary Tree



- Selection of the most discriminant variables between Signal and Background
- Cut to optimise $\frac{S}{S+B}$
- 1 tree => 1 forest : Multiple trees
- Stabilize BDT response with respect to fluctuations
- Increase the performance

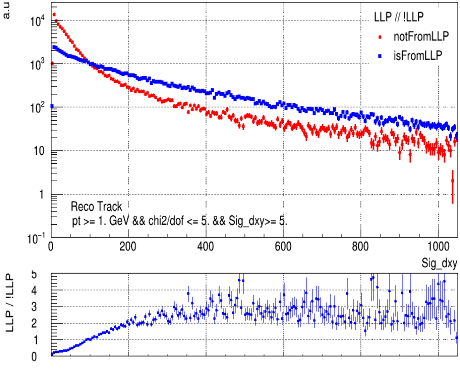
Variable List

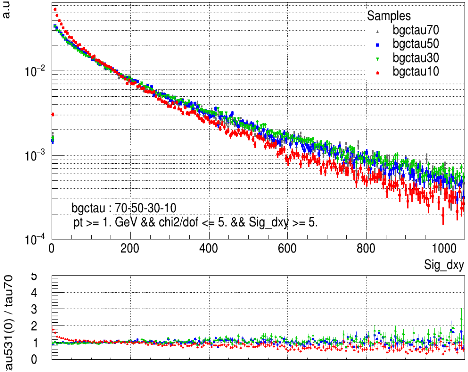


- For a given track with first hit (x1, y1, z1), count the **number of other tracks with their first hit at less than** 10 cm (n_d10), 20 cm (n_d20), . . . or within 10-20 cm (n_10d20), 20-30 cm (n_20d30),. . .
- **Impact Parameters** : ρ_{dxy}, σ_{dxy}, ρ_{dz}, σ_{dz}, $Sig_{dxy} = \frac{\rho_{dxy}}{\sigma_{dxy}}$, $Sig_{dz} = \frac{\rho_{dz}}{\sigma_{dz}}$, Sig_{dd}
- **Number of Hits in each region** : n_{TIB}, n_{TOB}, n_{PixBar}, n_{TEC}
- **Others** : algo, p_t, η, χ^2/dof, n_{hits}, $isinjet_{AK4PF}$

For each variable, a comparison between the Signal and the Bkg is made for each sample:

with S=89580 and B=173677, **$<S>\sim 13$ & $<B>\sim 27$ tracks per event**

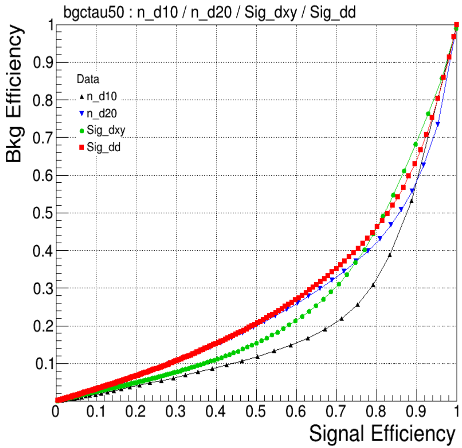




On the left, Signal/Bkg comparison for Sig_{dxy} for the sample $\beta\gamma c\tau 50$.
On the right, Signal comparison between the 4 samples for Sig_{dxy}.

Receiver Operating Characteristic (ROC) curve : Evaluate the discriminating power of the variables for the $\beta\gamma c\tau$ 50 cm sample

Signal Efficiency: % of Signal Tracks selected
Bkg Efficiency : % of Bkg Tracks selected
ROC Integral : Area Under Curve (AUC) Performance



- For a given track with first hit (x1, y1, z1), count the number of other tracks with their first hit at less than 10 cm (n_d10), 20 cm (n_d20),
- $Sig_{dxy} = \frac{\rho_{xy}}{\sigma_{xy}}$
- $Sig_{dd} = \sqrt{Sig^2_{dxy} + Sig^2_{dz}}$

Lists of variables

Conditions on the 27 variables:

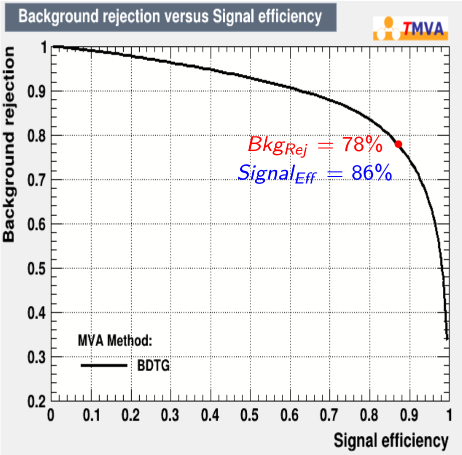
- Remove variables causing information redundancy e.g : **n_10d20** is the combination **n_d10** and **n_d20**, Sig_{dxy} is the combination of ρ_{dxy} and σ_{dxy} (27 -> 16 Variables)
- Variables **a priori dependant on the distance of flight of the neutralino are removed** to limit the dependence on the Training sample (16 -> 7 Variables)
- algo : tracking iteration used
- *isinjet* : if the track is in a jet or not

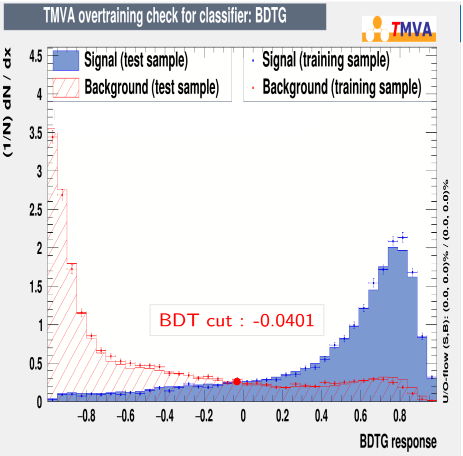
List of variables used for the BDT

η χ^2/dof n_d10 algo Sig_{dxy} p_t *isinjet*

ROC results:

- ROC curve (Background Rejection vs. Signal Efficiency)
- Training and Test distributions with BDT cut





Validity of Training

Validity of Training

- Look for any dependence on the Training sample for the AUC Performance
- Determine if one Training sample is better than the other to describe any distance of flight of the neutralino
- Check if any information is missed in the removed variables

Test/Training	$\beta\tilde{\gamma}c\tau$ 10	$\beta\tilde{\gamma}c\tau$ 30	$\beta\tilde{\gamma}c\tau$ 50	$\beta\tilde{\gamma}c\tau$ 70
$\beta\tilde{\gamma}c\tau$ 10	0.86	0.85	0.85	0.85
$\beta\tilde{\gamma}c\tau$ 30	0.87	0.87	0.87	0.87
$\beta\tilde{\gamma}c\tau$ 50	0.88	0.88	0.89	0.88
$\beta\tilde{\gamma}c\tau$ 70	0.88	0.89	0.89	0.89
Average (7V)	**0.87**	**0.87**	**0.87**	**0.87**

Table: *7V* are the 7 variables mentioned earlier

Validity of training with respect to test samples

Test/Training	$\beta\tilde{\gamma}c\tau$ 10	$\beta\tilde{\gamma}c\tau$ 30	$\beta\tilde{\gamma}c\tau$ 50	$\beta\tilde{\gamma}c\tau$ 70
$\beta\tilde{\gamma}c\tau$ 10	0.86	0.85	0.85	0.85
$\beta\tilde{\gamma}c\tau$ 30	0.87	0.87	0.88	0.87
$\beta\tilde{\gamma}c\tau$ 50	0.88	0.89	0.89	0.89
$\beta\tilde{\gamma}c\tau$ 70	0.88	0.89	0.89	0.89
Average (n_{hit})	**0.87**	**0.87**	**0.88**	**0.88**
Average (all)	**0.87**	**0.87**	**0.88**	**0.88**

Table: 7V + n_{hits} are the 7 variables + the number of hits in the tracker
all are the 7 variables + all the variables supposed to be dependant on the distance of flight

Validity of training

1. No dependence on the Training sample (distance of flight of the neutralino)
2. All samples could be used for the final BDT
3. Few information added by previously removed variables
4. Final Training Sample : $\beta\gamma c\tau$ 50 cm

Kalman Vertex Filter

Kalman Vertex filtering steps

1. Vertex Finding with Pure Signal
   - At least 2 tracks
   - Convergence criteria
     1. Nbr. of iterations (can be number of tracks or lower)
     2. Distance in the transverse plane between two iterations
2. Vertex Fitting
   - Obtain best estimation of the position of the vertex

Reconstruction of Displaced Vertices using only Signal Tracks to test the Reconstruction method

Efficiency and Resolution of the reconstructed vertices

For the sample of $\beta\gamma c\tau$ of 50 cm, for 6694 events filtered:

- Without using the BDT : 2*5153 reconstructed vertices (77% efficiency)
- Using the BDT : 2*4654 reconstructed vertices (70% efficiency)

Adding a restriction on the χ^2 ($\chi^2<5$) on the reconstructed vertices

- Without using the BDT : 2*2796 reconstructed vertices (42% efficiency)
- Using the BDT : 2*2955 reconstructed vertices (44% efficiency)

The resolution obtained with the BDT in the transverse plane is at the order of 0.14 mm

The resolution obtained with the BDT in the z axis is at the order of 0.17 mm

Reconstruction and Selection of displaced Vertices

Requirement : $\chi^2 < 5$ for the generated and reconstructed vertices (not optimised)

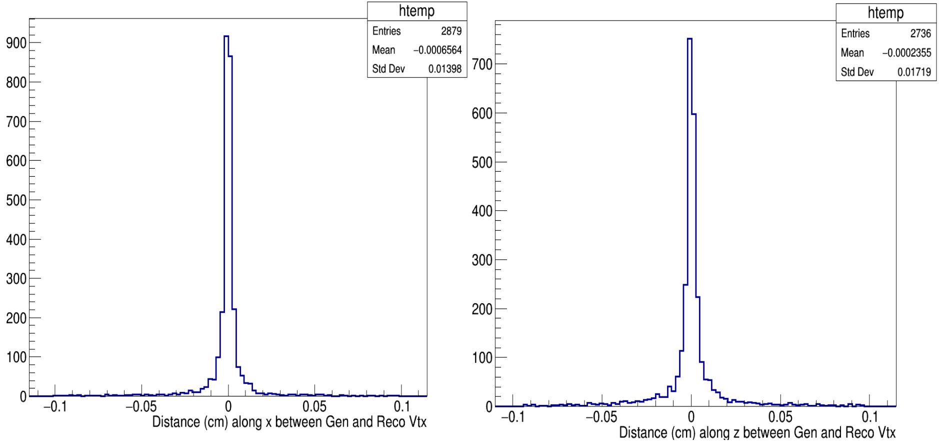


Figure: Distribution of the difference in cm between the generated vertex and the reconstructed vertex along the x axis (on the left) and along the z axis (on the right)

Conclusion

For the BDT :

1. Choice of training sample does not matter

For the Reconstruction of Secondary Vertices:

1. 44% vertex reconstruction efficiency with a good resolution
2. Still need optimisation on the tracks used to build the vertices

Future planned development:

Add Background tracks to the vertex reconstruction
Test the vertex reconstruction on Λ baryons and K^0 mesons
Apply the track selection an vertex reconstruction to the Data of Run2
Possibility to use a neural network (instead of a BDT) for the track selection

Thanks !!

Back-up

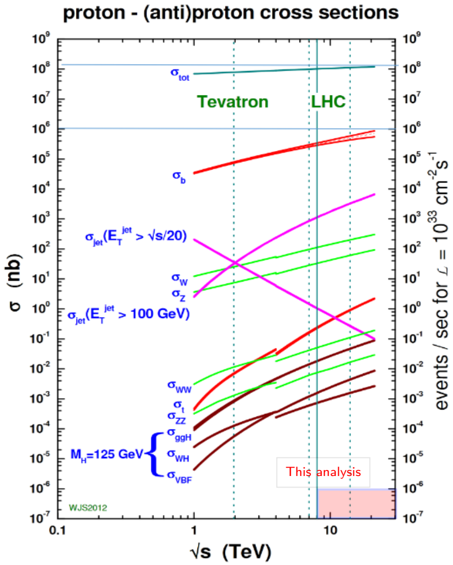
Back-up

BDT parameters used:

$dataloader->PrepareTrainingAndTestTree(mycuts, mycutb, "nTrain\_Signal = 10000 : nTrain\_Background = 10000 : SplitMode = Random : NormMode = NumEvents :!V");$
$factory->BookMethod(dataloader, TMVA :: Types :: kBDT, "BDTG", "!H :!V : NTrees = 1000 : MinNodeSize = 2.5\% : MaxDepth = 3 : BoostType = Grad : UseBaggedBoost = True : GradBaggingFraction = 0.6 : Shrinkage = 0.1 : SeparationType = GiniIndex : nCuts = 20 : UseYesNoLeaf = True : UseRandomisedTrees = False : DoBoostMonitor = True");$

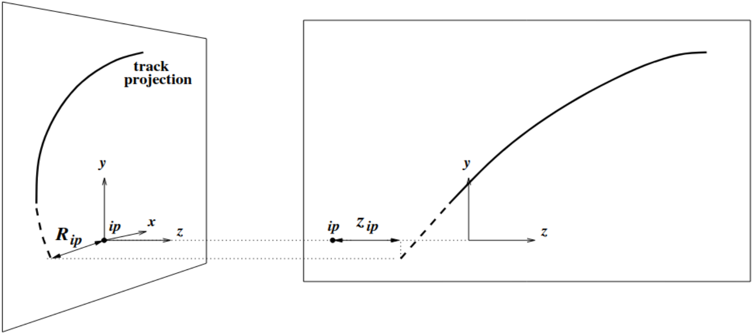
- *mycuts, mycutsb* : Possibilty to add cuts inside the TMVA (not done in our analysis) $abs(eta) \lesssim 1.5$
- The number of Test events can also be given
- *BDTG*: "G" stands for Gradient.
- *NTrees*: Number of trees
- *MinNodeSize, GradBraggingFraction, Shrinkage, nCuts, SeparationType, UseYesNoLeaf, UseRandomisedTrees, DoBoostMonitor*: Good default value.
- *MaxDepth*: Keep it between 3 and 5 (according to TMVA guide user)

Cross section region



Impact parameters

Impact parameters definition :



1. Extrapolation of the track and projection in the transverse plane
2. d_{xy} is defined as the distance between the nearest point of the extrapolated track from the interaction vertex
3. d_z is the distance along the beam axis for the given d_{xy}

Filters

ZMu filter :
(1) Estimate the efficiency of reconstruction for muons from a Z boson
(2) Calibrate the reconstruction of muons using real data

Tag muon

- Muon from reconstructed muons collection
- $p_t > 28$ GeV
- $|\eta| < 2.4$

Probe muon

- Track from general Track collection (has to be a muon in our analysis)
- $p_t > 10$ GeV
- $|\eta| < 2.4$
- Opposite charge from the tag muon

+ Invariant Mass $>$ 60 GeV

H_T filter on jets

$H_T = \sum_{jets} p_t$ with H_T>180 GeV being required

$\sim$65% of the initial events are selected

Classification of the variables according to their ROC integral (AUC Performance)

Parameter	bgctau10	Parameter	bgctau30	bgctau50	bgctau70
n_d10	0.227	n_d10	0.239	0.236	0.249
Sig_{dd}	0.263	Sig_{dxy}	0.261	0.252	0.248
n_{PixBar}	0.271	Sig_{dd}	0.263	0.276	0.292
n_d20	0.277	n_d20	0.293	0.295	0.306
Sig_{dz}	0.295	n_{TIB}	0.308	0.322	0.332
n_{Pix}	0.312	$isinjet_{AK4PF}$	0.309	0.296	0.297
n_{Pix}	0.312	pt	0.317	0.306	0.310
n_d30	0.312	n_d30	0.325	0.329	0.336
Sig_{dxy}	0.318	Sig_{dz}	0.337	0.340	0.360
n_{TIB}	0.323	n_{TOB}	0.346	0.346	0.351
$isinjet_{AK4PF}$	0.342	n_d40	0.352	0.356	0.360
n_{hit}	0.346	n_{PixBar}	0.358	0.397	0.419

From the list above:

- A dozen of the variables in the list are *supposed* to be correlated with the flight distance of the LLP (i.e: of the sample)
- No correlation are taken into account : information redundancy is expected for the BDT

List of variables for which the sample $\beta\gamma c\tau 10$ is different from the other:

Signal

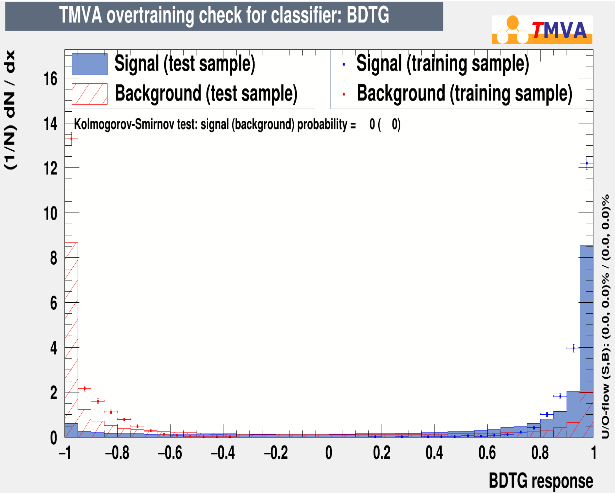
- 3D distance between first hits (cm) (n_d10, n_d20,..)
- ρ_{dd}
- ρ_{dxy}
- ρ_{dz}
- pix
- $r1_{\eta<1.5}$
- $z1_{\eta>1.5}$

Background

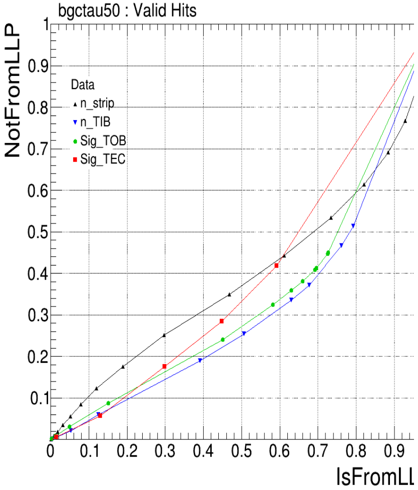
- 3D distance between first hits (cm) (n_d10, n_d20,..)
- $r1_{\eta<1.5}$
- $z1_{\eta>1.5}$

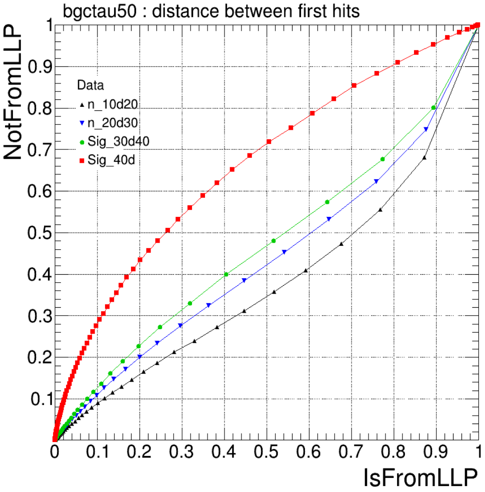
Overtraining example

- Less events in the Training sample (10k->3k)
- Increase the depth of the tree (3->10)

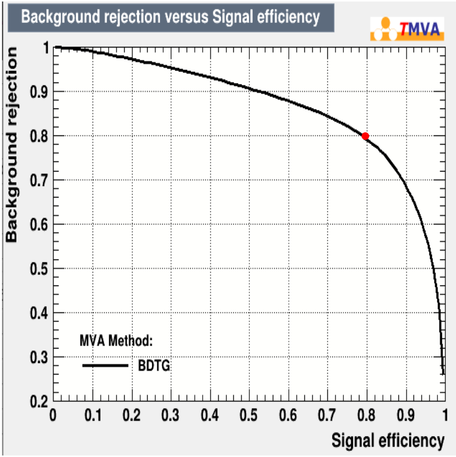


others :

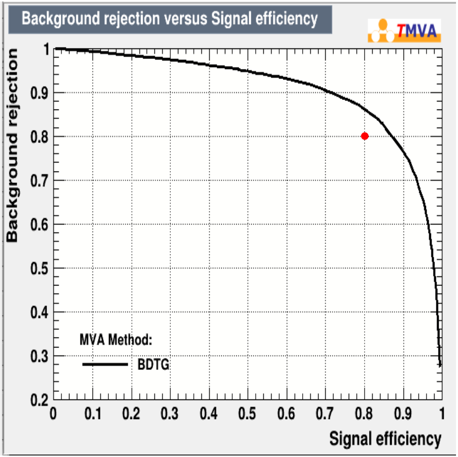

bgctau50 : Valid Hits
NotFromLLP
IsFromLL
Data
n_strip
n_TIB
Sig_TOB
Sig_TEC
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


bgctau50 : distance between first hits
NotFromLLP
IsFromLLP
Data
n_10d20
n_20d30
Sig_30d40
Sig_40d
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

ROC as a function of η for 9 variables



ROC for abs(η)<1.5 (AUC = 86.5%)



ROC for abs(η)>1.5 (AUC = 90.6 %)

Table Performances AUC pour Training 10 et 30

Test/Training	bgctau10 (7V)	bgctau10 (nhits)	bgctau10 (all)
bgctau10	0.856	0.859	0.859
bgctau30	0.866	0.871	0.869
bgctau50	0.876	0.882	0.881
bgctau70	0.876	0.883	0.881
Average	0.8685	0.87375	0.8725

X	bgctau30 (7V)	bgctau30 (n_{hit})	bgctau30 (all)
bgctau10	0.846	0.85	0.849
bgctau30	0.872	0.873	0.874
bgctau50	0.883	0.885	0.886
bgctau70	0.885	0.886	0.888
Average	0.8715	0.8735	0.87425

AUC Performances for Training samples 50 and 70

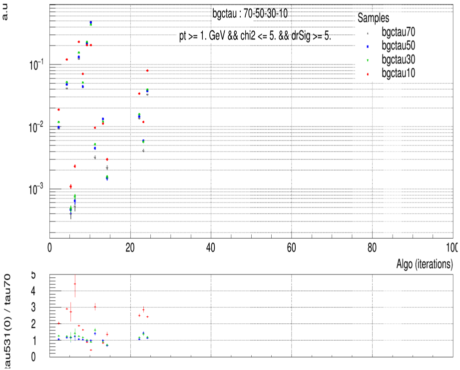
X	bgctau50 (7V)	bgctau50 (n_{hit})	bgctau50 (all)
bgctau10	0.847	0.853	0.851
bgctau30	0.872	0.876	0.875
bgctau50	0.887	0.889	0.89
bgctau70	0.888	0.89	0.89
Average	0.8735	0.877	0.8765

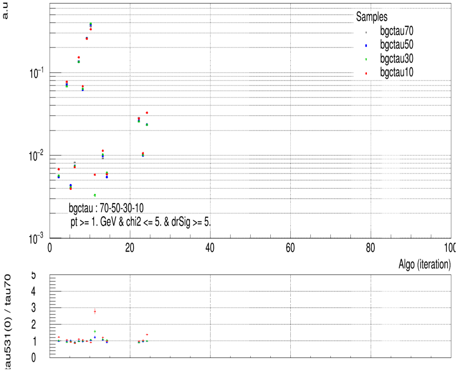
X	bgctau70 (7V)	bgctau70 (n_{hit})	bgctau70 (all)
bgctau10	0.845	0.852	0.851
bgctau30	0.869	0.874	0.874
bgctau50	0.884	0.887	0.888
bgctau70	0.89	0.892	0.894
Average	0.872	0.87625	0.87675

X	bgctauX0 (7V)	bgctauX0 (n_{hit})	bgctauX0 (all)
Global average	0.871375	0.875125	0.875

Variables dépendantes de la distance de vol

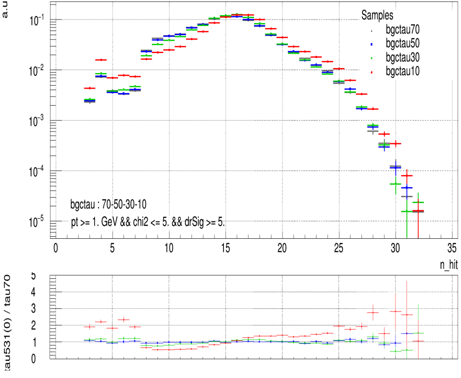
Algo Signal and Bkg

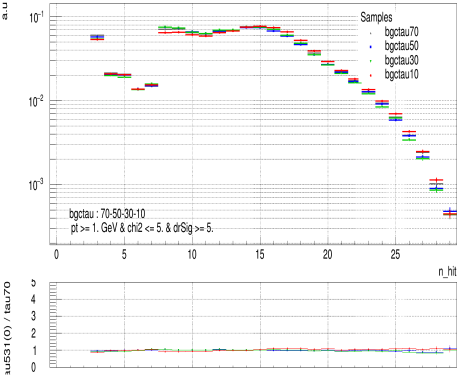




Variables dépendantes de la distance de vol

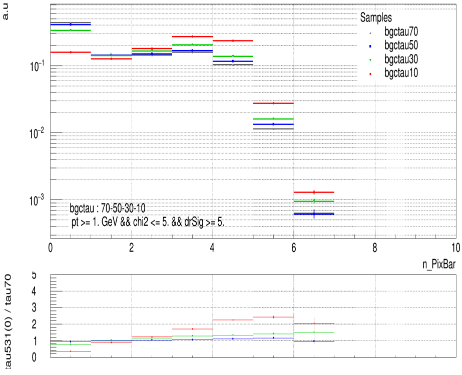
n_{hit} Signal and Bkg

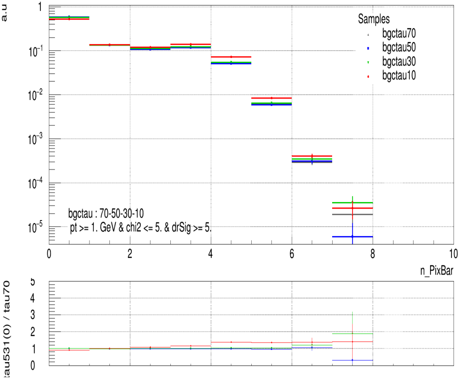




Variables dépendantes de la distance de vol

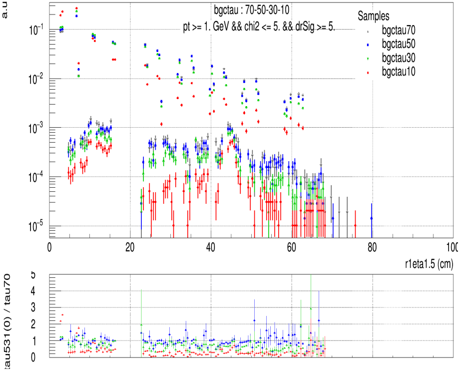
n_{PixBar} Signal and Bkg

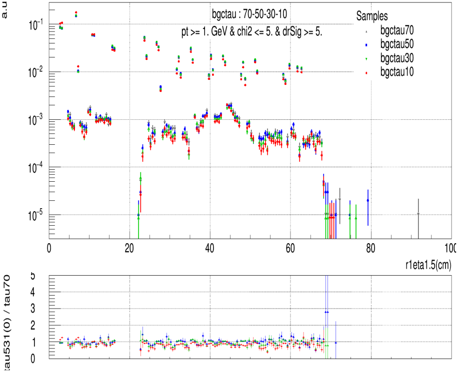




Variables dépendantes de la distance de vol

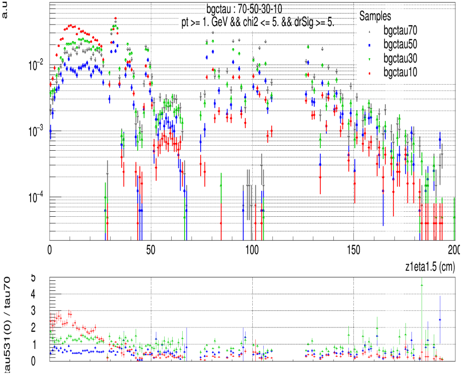
$r1_{\eta<1.5}$ Signal and Bkg

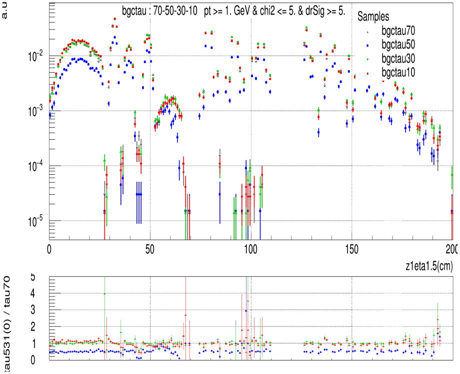




Variables dépendantes de la distance de vol

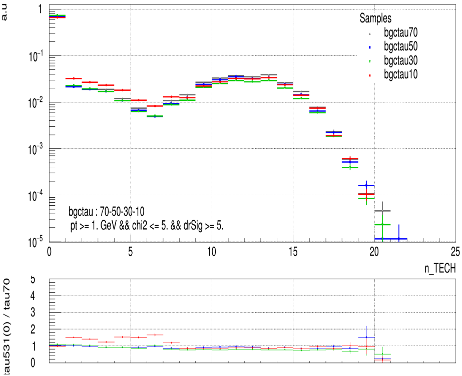
$z1_{\eta>1.5}$ Signal and Bkg

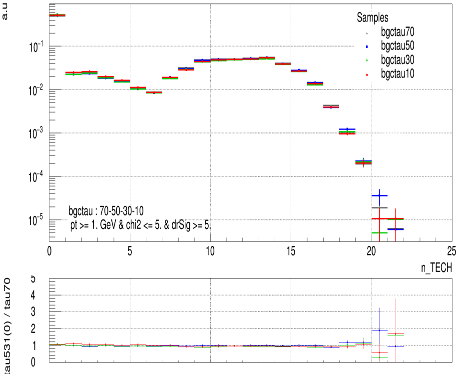




Variables dépendantes de la distance de vol

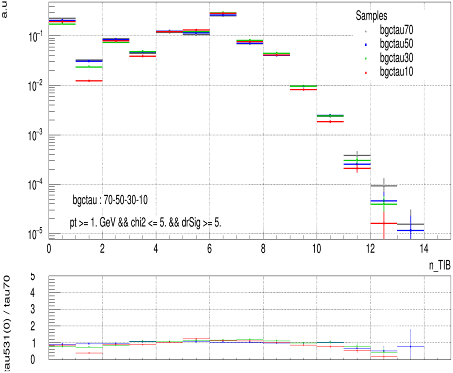
n_{TECH} Signal and Bkg

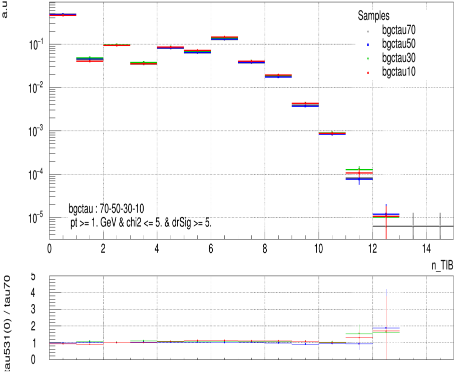




Variables dépendantes de la distance de vol

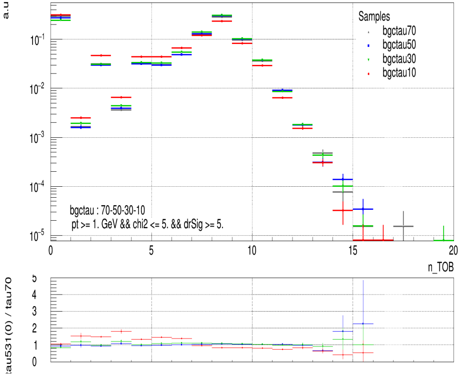
n_{TIB} Signal and Bkg

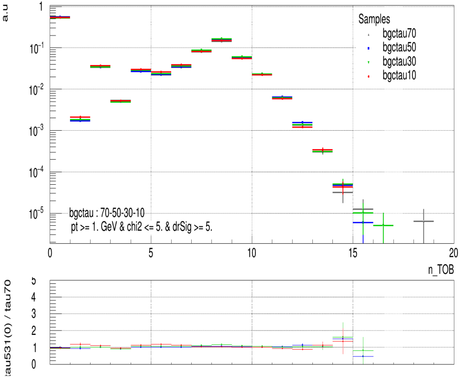




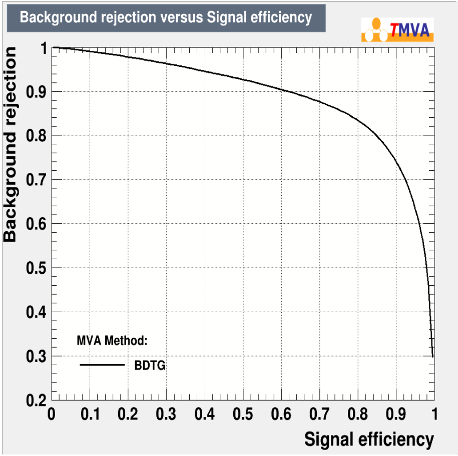
Variables dépendantes de la distance de vol

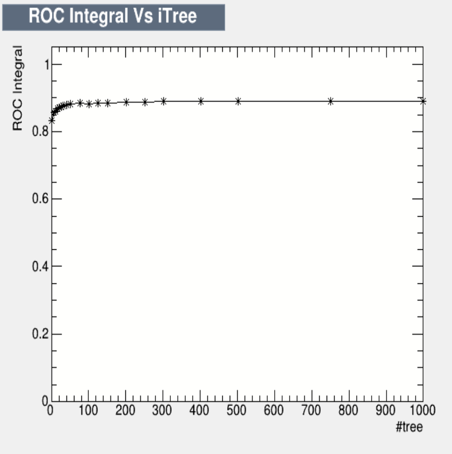
n_{TOB} Signal and Bkg



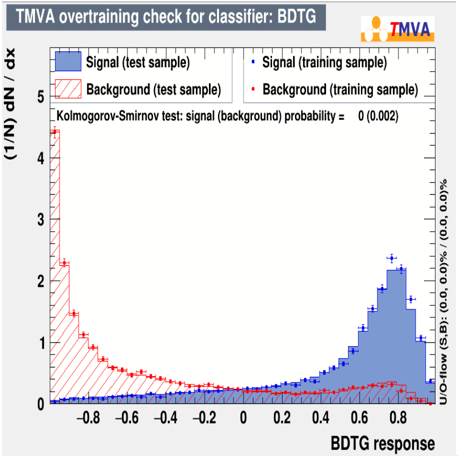


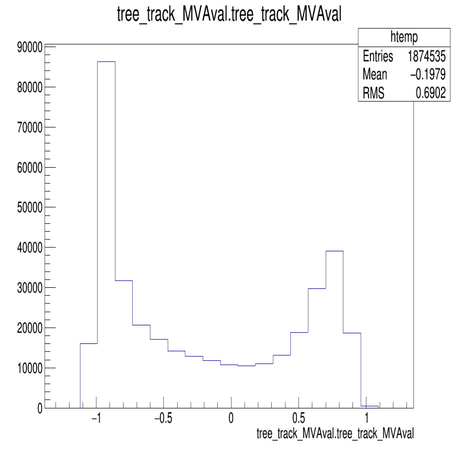
$\beta\gamma c\tau 50$: 1000 Arbres, 10k Training Signal events, 10k Training Bkg events





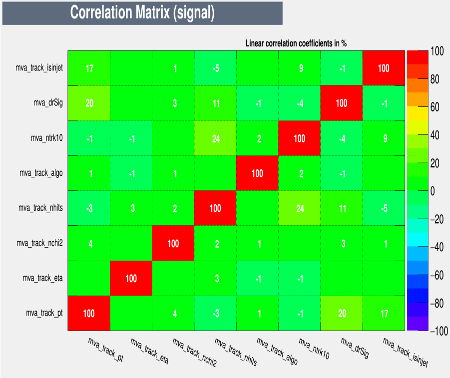
Overtraining

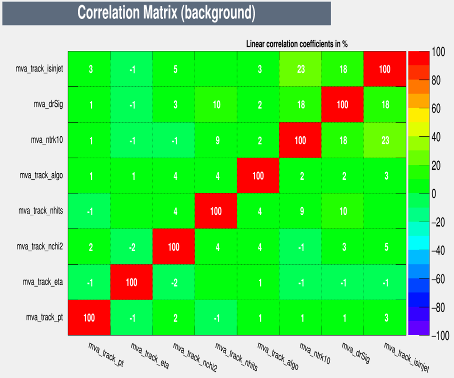




- Training and Test samples are similar : small ovetraining https://root-forum.cern.ch/t/kolmogorov-smirnov-test-values/32868/3

Correlation Matrices between the 8 final variables

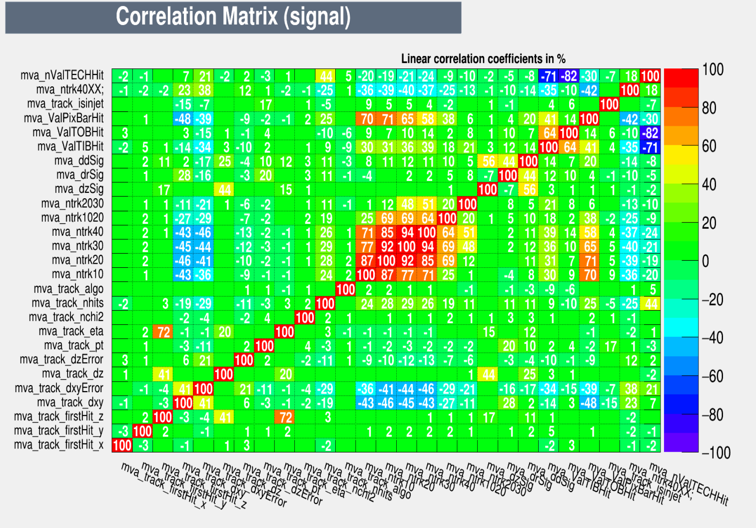




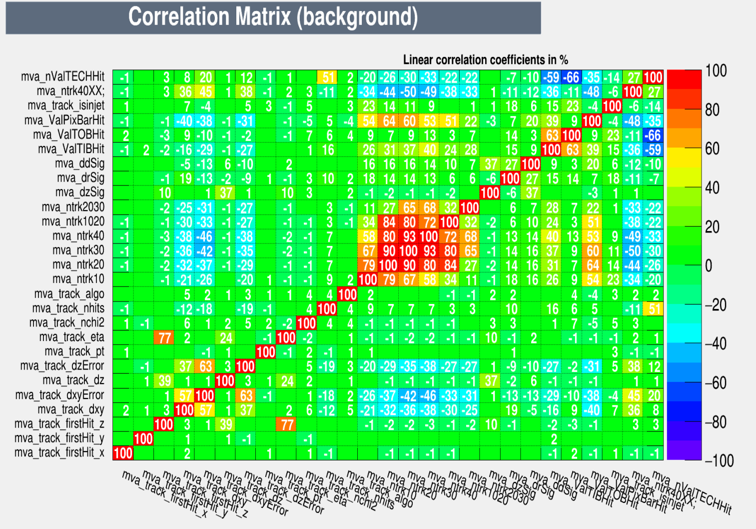
Paramètre	bgctau10	Paramètre	bgctau30	Paramètre	bgctau50	Paramètre	bgctau70
n_d10	0.227	n_d10	0.239	Sig_{dd}	0.276	Sig_{dd}	0.292
Sig_{dd}	0.263	Sig_{dxy}	0.261	n_d10	0.236	Sig_{dxy}	0.248
n_{PixBar}	0.271	Sig_{dd}	0.263	Sig_{dxy}	0.252	n_d10	0.249
n_d20	0.277	n_d20	0.293	n_d20	0.295	isinjet	0.297
Sig_{dz}	0.295	n_{TIB}	0.308	isinjet	0.296	n_d20	0.306
n_{Pix}	0.312	isinjet	0.309	p_t	0.306	p_t	0.310
n_{Pix}	0.312	p_t	0.317	n_{TIB}	0.322	n_{TIB}	0.332
n_d30	0.312	n_d30	0.325	Sig_{dz}	0.340	n_{TOB}	0.351
Sig_{dxy}	0.318	Sig_{dz}	0.337	n_d30	0.329	n_d30	0.336
n_{TIB}	0.323	n_{TOB}	0.346	n_{TOB}	0.346	Sig_{dz}	0.360
isinjet	0.342	n_d40	0.352	n_d40	0.356	n_d40	0.360
n_{hit}	0.346	n_{PixBar}	0.358	n_{hit}	0.373	n_{hit}	0.380
p_t	0.348	n_{hit}	0.361	n_{Strip}	0.393	n_{Strip}	0.394
n_d40	0.350	n_{Strip}	0.392	n_{PixBar}	0.397	n_{PixBar}	0.419
n_10d20	0.379	n_10d20	0.397	n_10d20	0.417	ρ_{dxy}	0.422
n_{TOB}	0.385	n_{Pix}	0.410	ρ_{dz}	0.428	ρ_{dz}	0.422
n_{Strip}	0.412	n_{Pix}	0.410	n_{Pix}	0.446	n_10d20	0.422
n_20d30	0.464	n_20d30	0.456	n_{Pix}	0.446	ρ_{dd}	0.459
n_30d40	0.508	ρ_{dz}	0.462	ρ_{dxy}	0.446	n_20d30	0.461
η	0.514	ρ_{dxy}	0.471	n_20d30	0.462	n_{Pix}	0.467
n_{TEndC}	0.521	η	0.511	ρ_{dd}	0.480	n_{Pix}	0.467
chi2	0.524	n_30d40	0.515	n_30d40	0.509	η	0.506
n_{TID}	0.525	ρ_{dd}	0.516	η	0.512	n_30d40	0.508
ρ_{dz}	0.553	chi2	0.525	chi2	0.524	r1	0.527
ρ_{dxy}	0.575	n_{TID}	0.544	n_{TID}	0.539	chi2	0.527
n_{TECH}	0.582	n_{TEndC}	0.551	r1	0.550	n_{TID}	0.532
ρ_{dd}	0.598	r1	0.588	n_{TEndC}	0.552	$z1_{\eta>1.5}$	0.548
n_40d	0.673	n_{TECH}	0.600	$r1_{\eta<1.5}$	0.573	$r1_{\eta<1.5}$	0.550
r1	0.687	$z1_{\eta>1.5}$	0.607	$z1_{\eta>1.5}$	0.579	n_{TEndC}	0.554
$r1_{\eta<1.5}$	0.694	$r1_{\eta<1.5}$	0.612	n_{TECH}	0.593	n_{TECH}	0.585
z1	0.705	n_40d	0.648	n_40d	0.624	z1	0.612
$z1_{\eta>1.5}$	0.719	z1	0.666	z1	0.638	n_40d	0.614

TABLE 6.1 – Classement des observables selon leur intégrale ROC pour les 4 lots de simulation. (à noter : $r1 = \sqrt{x1^2 + y1^2}$ distance entre deux premiers hits dans le plan transverse et TID : Inner Disk.

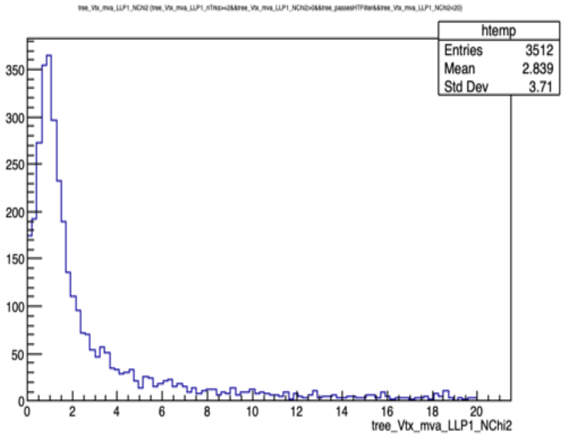
Correlation Matrix between the 27 initial variables for the signal



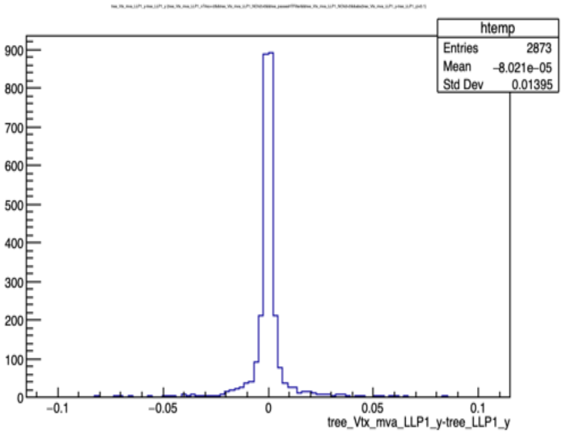
Correlation Matrix between the 27 initial variables for the background



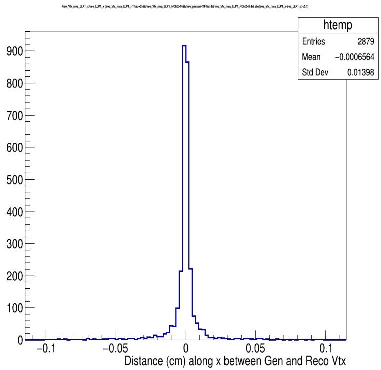
Reconstruction of displaced Vertices

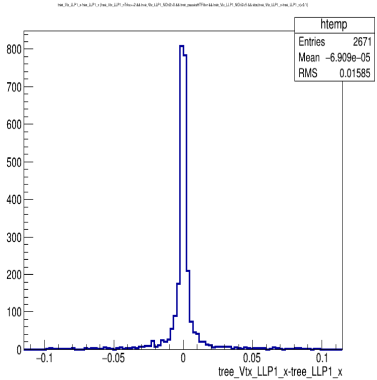


Reconstruction of displaced Vertices in the y axis

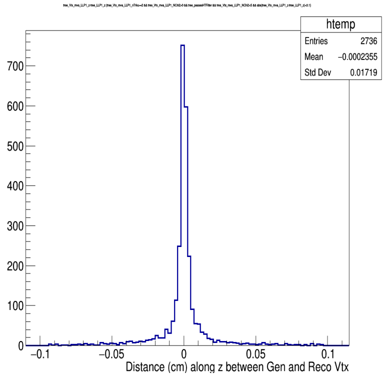


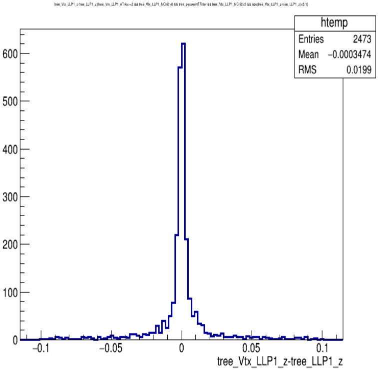
Reconstruction of displaced Vertices with and without BDT along x



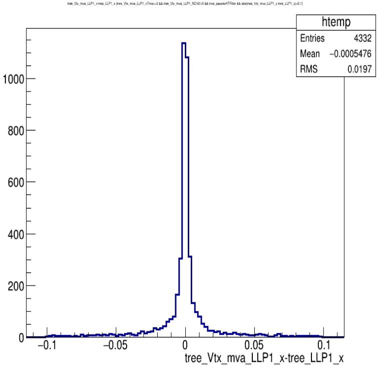


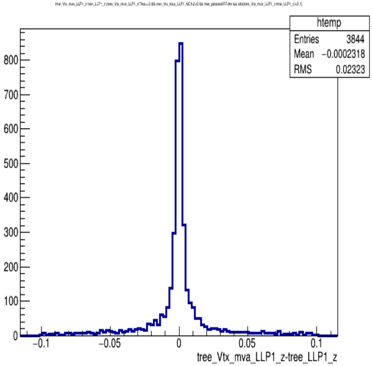
Reconstruction of displaced Vertices with and without BDT along z



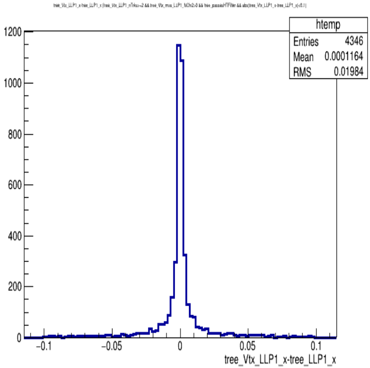


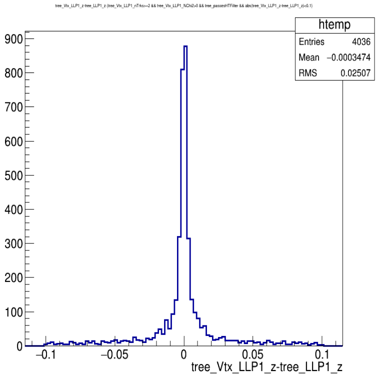
Reconstruction of displaced Vertices without chi2 along x and z with BDT





Reconstruction of displaced Vertices without chi2 along x and z without BDT





RPV couplings in the superpotential

$$W = W_{MSSM} + W_{RPV}$$

with $W_{RPV} = \epsilon_i (H_u.L_i) + \frac{1}{2}\lambda_{ijk}(L_i.L_j)E^c_k + \lambda^{'}_{ijk}(L_i.Q_j)D^c_k + \frac{1}{2}\lambda^{''}_{ijk}U^c_i D^c_j D^c_k$

- i, j, k going from 1 to 3 indicating the generation family
- ^{c} : Charge Conjugate
- L_i, Q_j et H_u are respectively the lepton, the quark and the up-Higgs SU(2) doublets superfields
- E_i et D_i are respectively the lepton and the quark SU(2) singlets.
- $\epsilon_i, \lambda_{ijk}, \lambda^{'}_{ijk}$ and $\lambda^{''}_{ijk}$ are dimensionless RPV couplings
- Only the trilinear coupling $\lambda^{''}_{312}$ is considered to be different from 0
- Only this coupling allows a top in the final state as well as the decay of a stop into quarks.

RPV couplings in the superpotential

The boosting procedure is now employed to adjust the parameters P such that the deviation between the model response F(x) and the true value y obtained from the training sample is minimised. The deviation is measured by the so-called loss-function L(F, y), a popular choice being squared error loss L(F, y) = $(F(x)y)^2$. It can be shown that the loss function fully determines the boosting procedure.The GradientBoost algorithm attempts to cure this weakness by allowing for other, potentially more robust, loss functions without giving up on the good out-of-the-box performance of AdaBoost. The current TMVA implementation of GradientBoost uses the binomial log-likelihood loss L(F, y) = ln $(1 + e^{2F(x)y})$, for classification. As the boosting algorithm corresponding to this loss function cannot be obtained in a straightforward manner, one has to resort to a steepest-descent approach to do the minimisation. This is done by calculating the current gradient of the loss function and then growing a regression tree whose leaf values are adjusted to match the mean value of the gradient in each region defined by the tree structure. Iterating this procedure yields the desired set of decision trees which minimises the loss function. Note that GradientBoost can be adapted to any loss function as long as the calculation of the gradient is feasible.

Resampling includes the possibility of replacement, which means that the same event is allowed to be (randomly) picked several times from the parent sample. This is equivalent to regarding the training sample as being a representation of the probability density distribution of the parent sample: indeed, if one draws an event out of the parent sample, it is more likely to draw an event from a region of phase-space that has a high probability density, as the original data sample will have more events in that region. If a selected event is kept in the original sample (that is when the same event can be selected several times), the parent sample remains unchanged so that the randomly extracted samples will have the same parent distribution, albeit statistically fluctuated. Training several classifiers with different resampled training data, and combining them into a collection, results in an averaged classifier that, just as for boosting, is more stable with respect to statistical fluctuations in the training sample.

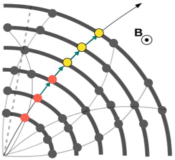
stop mass and coupling dependence

Tracking in CMS

1.EXPERIMENT & SOFTWARE

1. Local reconstruction — Clusters into hits

2. Global reconstruction — Hits into tracks



Seed reconstruction	Created from 2, 3 or 4 hard coded successive hits
Track building	Pattern recognition using an Iterative Kalman Filter Building track candidates and compare them Taking into consideration multiple scattering effects
Track fitting	Parameter definition of the final track collection by fitting and smoothing
Track selection	Collections and quality flags

for each step :

10 iterations

Track production position

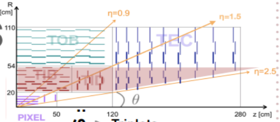
- Initial
- HighPtTriplet
- LowPtQuad
- LowPtTriplet
- PixelPair
- DetachedQuad
- DetachedTriplet
- DuplicateMerged
- MixedTriplet
- PixelLess
- TobTec
- JetCore

stop mass and coupling dependence

Tracking in CMS

1.EXPERIMENT & SOFTWARE

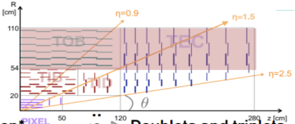
PixelLess



Tracking Region* :
- OriginHalfLength = 12 cm
- OriginRadius = 1 cm

Seeds :
- Triplets
- Outer Tracker
- TIB + TID + TEC ring 1-4

TobTec

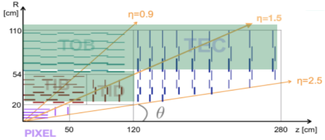


Tracking Region* :
- OriginHalfLength = 20 cm
- OriginRadius = 3.5 cm

Seeds :
- Doublets and triplets
- Outer Tracker
- TOB + TEC ring 5-7

* Tracking Region : Cylindre in which we expect to have the point of closest approach of the seed

New Tracking Iteration : DisplacedGeneralStep



Seeds :
- Triplets
- Outer Tracker
- TIB + TID + TOB + TEC ring 5-7

Track Building :
- Max fraction shared = 0.25
- Allow shared first hits

Tracking Region:
- OriginHalfLength = 55 cm
- OriginRadius = 10 cm
- ptMin = 1 GeV

Quality Cuts :
- Max lost hits = 1
- Min number of hits = 8
- Max Chi2 = 10

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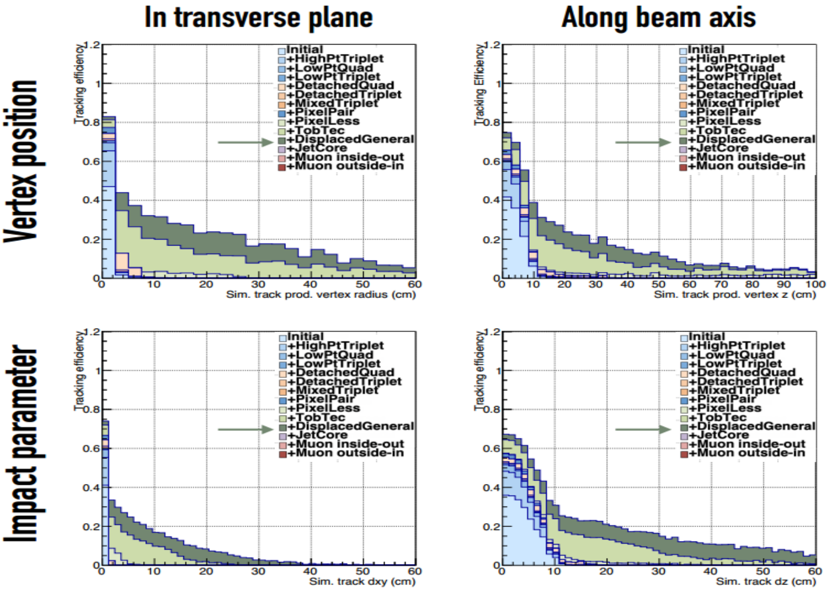
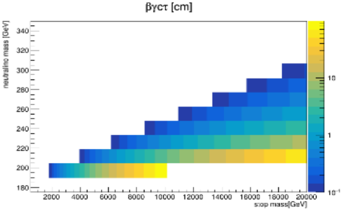
Mid-term thesis defence – 10/06/2021

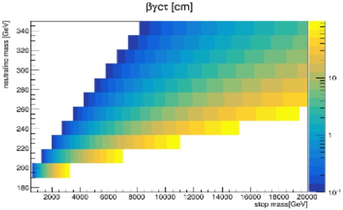
stop mass and coupling dependence



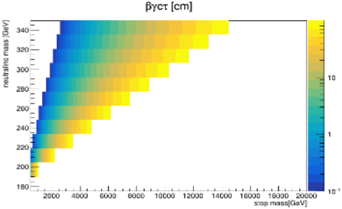
stop mass and coupling dependence



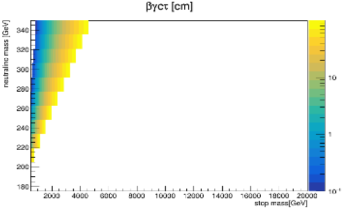
(a) $\lambda'' = 10^{-1}$



(b) $\lambda'' = 10^{-2}$



(c) $\lambda'' = 10^{-3}$



(d) $\lambda'' = 10^{-4}$

Figure 7: Mean flight distance of the neutralino in the laboratory frame as a function of neutralino and squark mass, and according to different values of λ'' coupling.

stop mass and coupling dependence

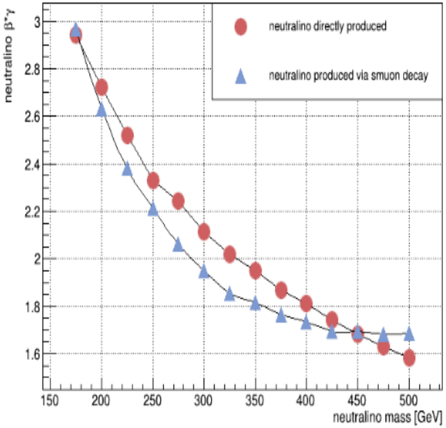


Figure 6: Mean value of the Lorentz factor $\beta \cdot \gamma$ for the flying neutralinos in the both production cases.