

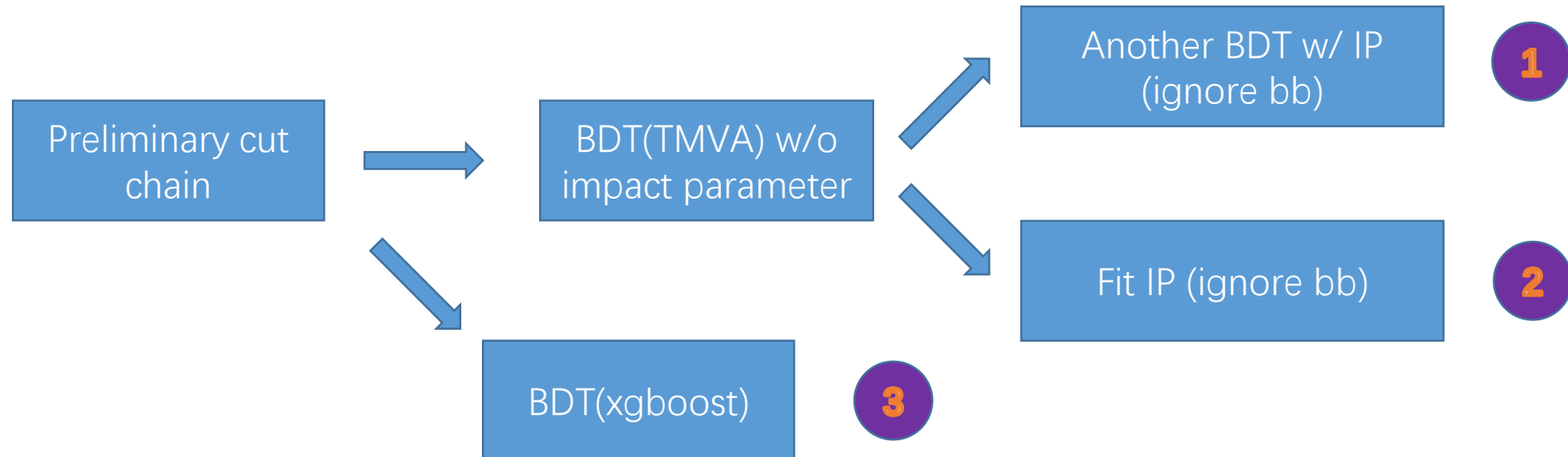
$B_C^+ \rightarrow \tau^+ \nu_\tau$  Analysis

Taifan

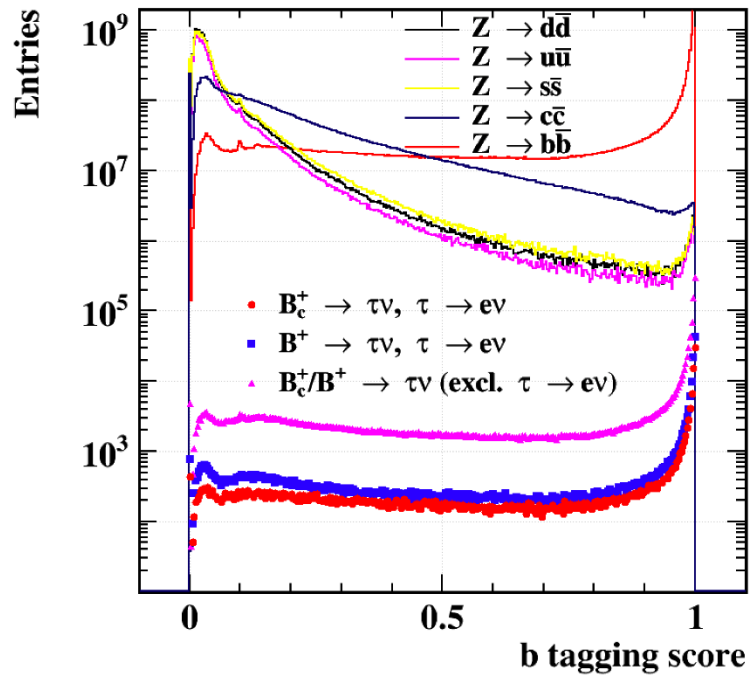
# Basic statistics

The following studies are done assuming  $1 \times 10^{11}$  Z bosons are produced.  $\rightarrow 7.5 \times 10^5 B_c^+ \rightarrow \tau^+ \nu_\tau$  &  $1 \times 10^6 B^+ \rightarrow \tau^+ \nu_\tau$  (according to the Soeren's slides. Not considering uncertainties)

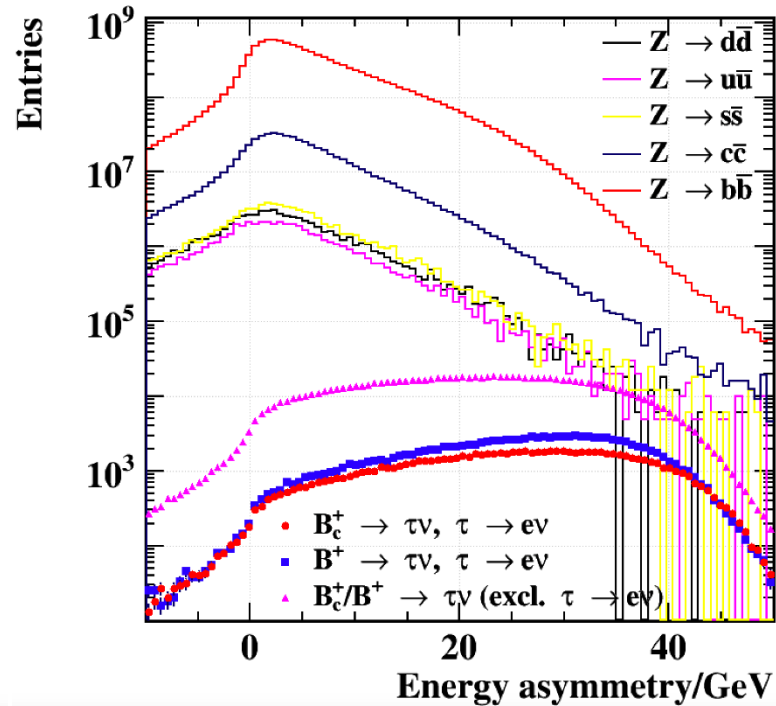
# Strategy



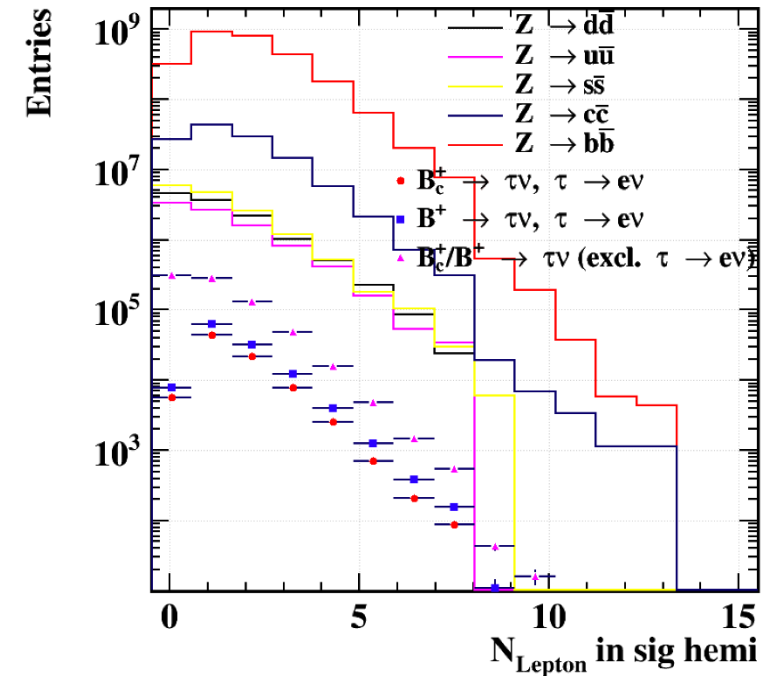
# Parameter distribution (simple scaling, $\tau \rightarrow e\nu\nu$ )



$b_{tag} > 0.6$

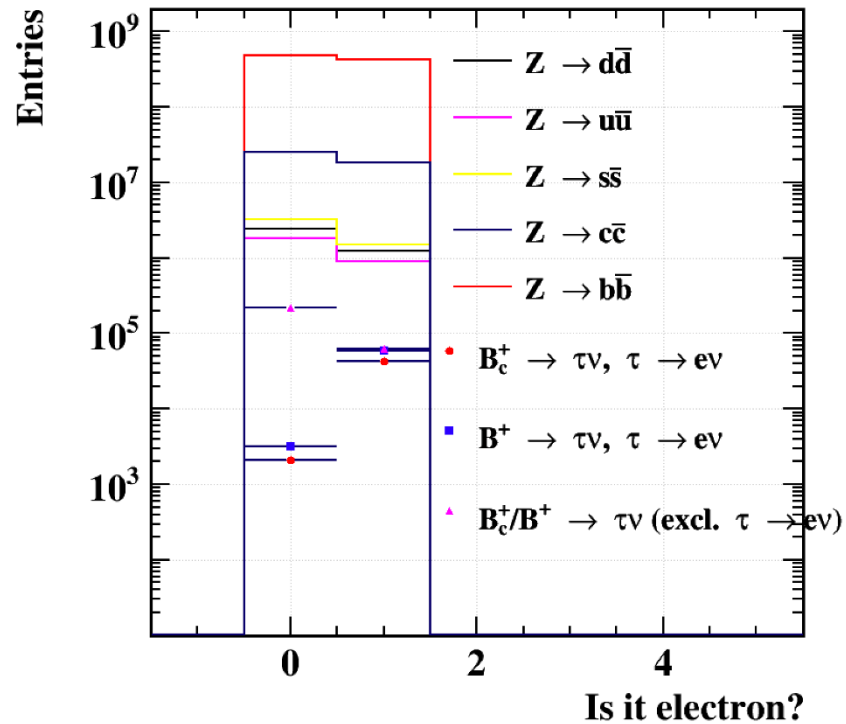


Energy asymmetry = Recoil side  $e_n$  – signal side  $e_n > 10$  GeV

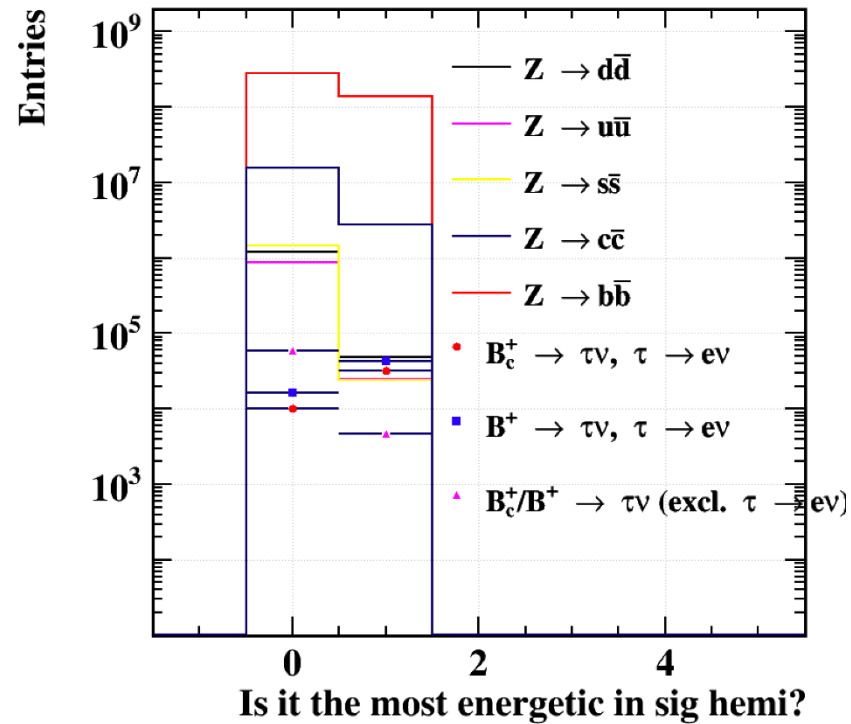


Only one lepton in the signal hemisphere

# Parameter distribution (simple scaling, $\tau \rightarrow e\nu\nu$ )



That lepton is  
electron

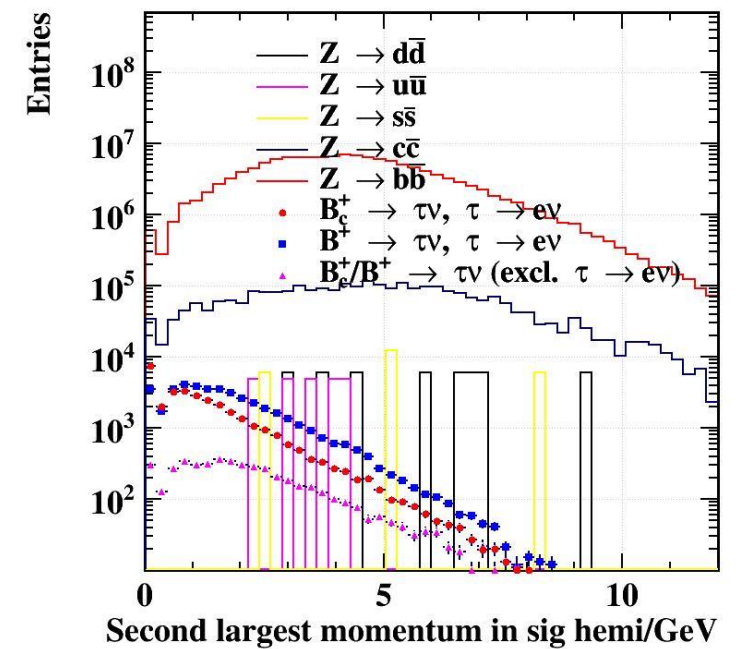
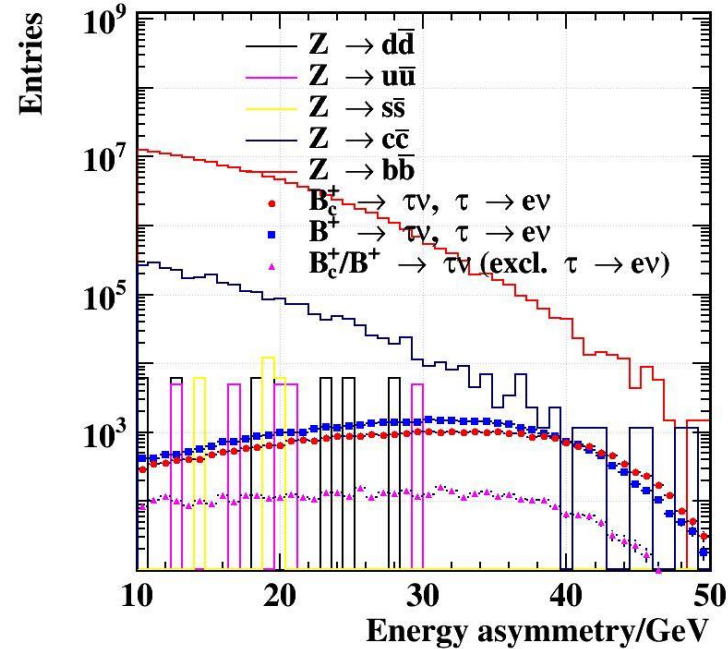
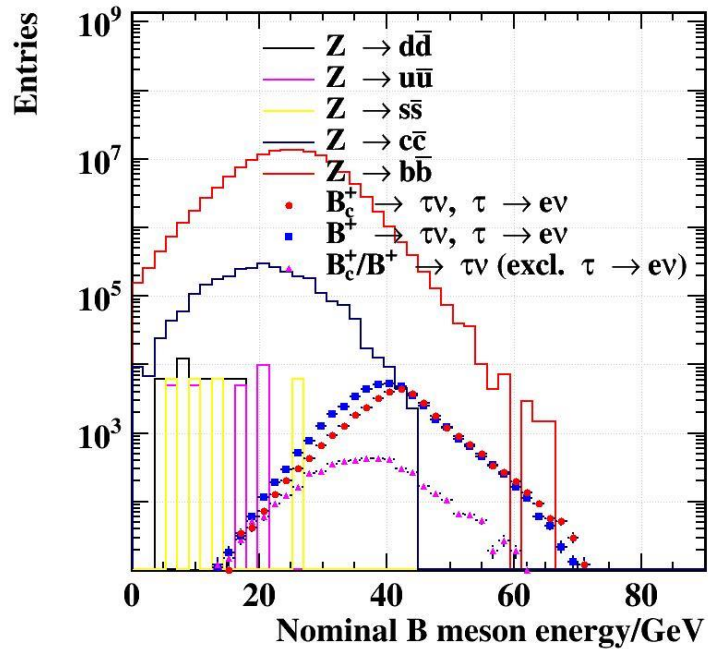


And it's the most energetic  
particle in the signal hemisphere

# Cut chain ( $\tau \rightarrow e\nu\nu$ )

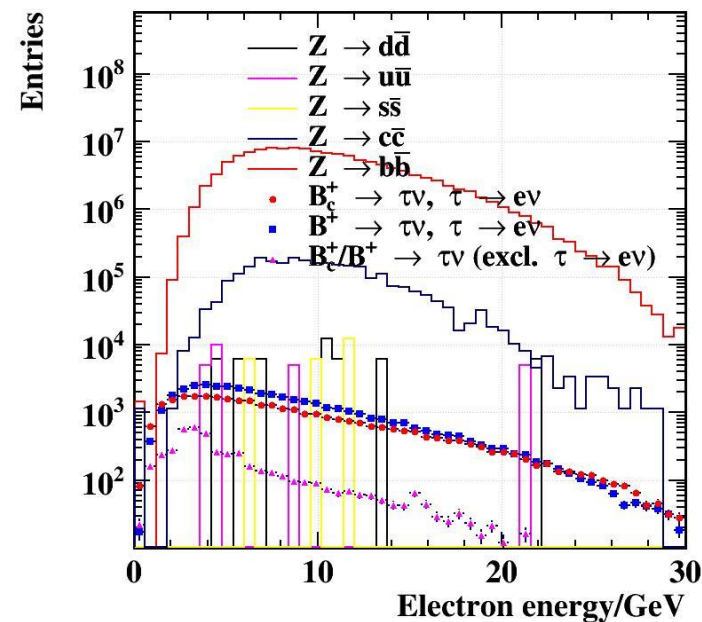
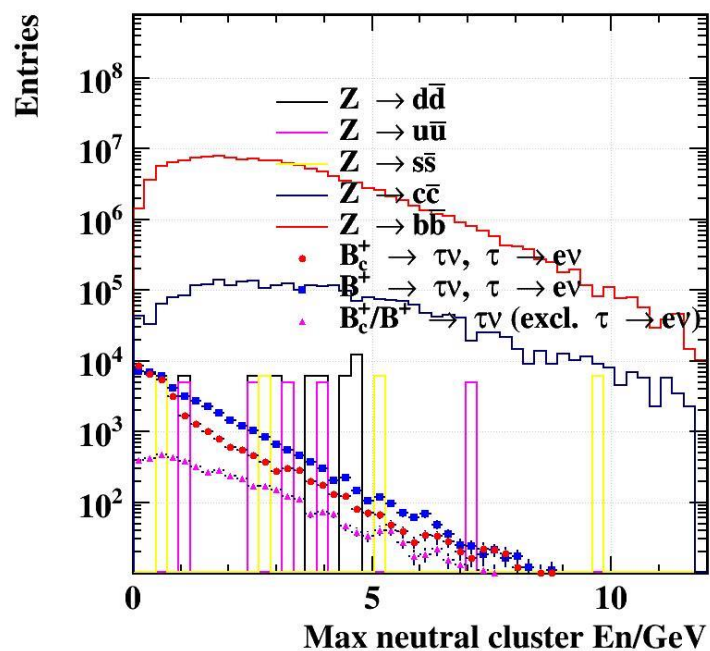
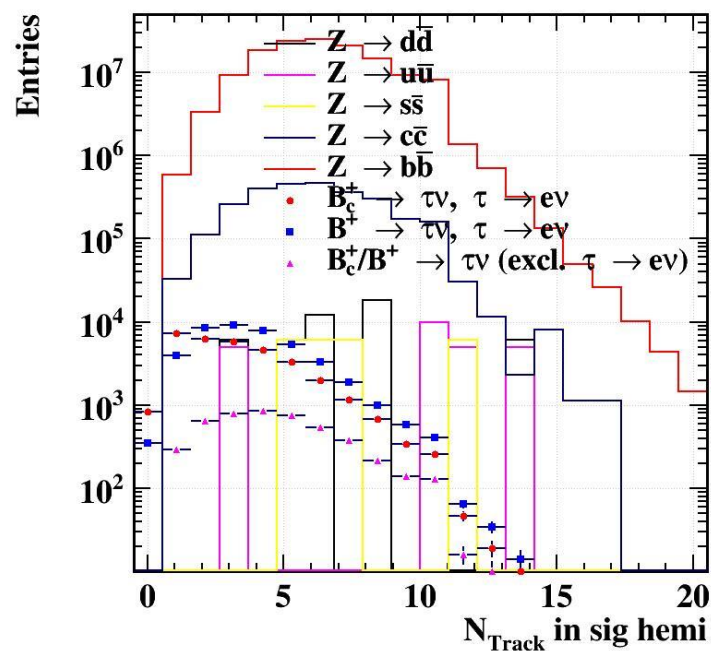
	$B_c^+ \rightarrow \tau^+ \nu_\tau$ excl. $\tau \rightarrow e/\tau \rightarrow e$	$B^+ \rightarrow \tau^+ \nu_\tau$ excl. $\tau \rightarrow e/\tau \rightarrow e$	$\frac{1}{6100}$ ↓ dd	$\frac{1}{4900}$ ↓ uu	$\frac{1}{6100}$ ↓ ss	$\frac{1}{1100}$ ↓ cc	$\frac{1}{1500}$ ↓ bb
All	625177/134681	797230/195570	2530406	2415827	2531430	10414223	10532756
b-tag > 0.6	437048/94370	536144/133336	12495	11559	14920	590417	7885422
Energy asymmetry > 10 GeV	361063/83338	433750/119520	2048	1857	2525	108464	1892666
One lepton in sig hemi	127468/44500	153697/61805	610	549	784	38263	623432
Which is electron	32044/42386	30916/58652	206	181	245	16107	287334
And it's the most energetic one	2569/32458	2173/42475	8	5	4	2449	93945

# BDT variables (simple scaling, $\tau \rightarrow e\nu\nu$ )



Nominal B meson energy = 91.2 – All visible energy (except the signal electron)

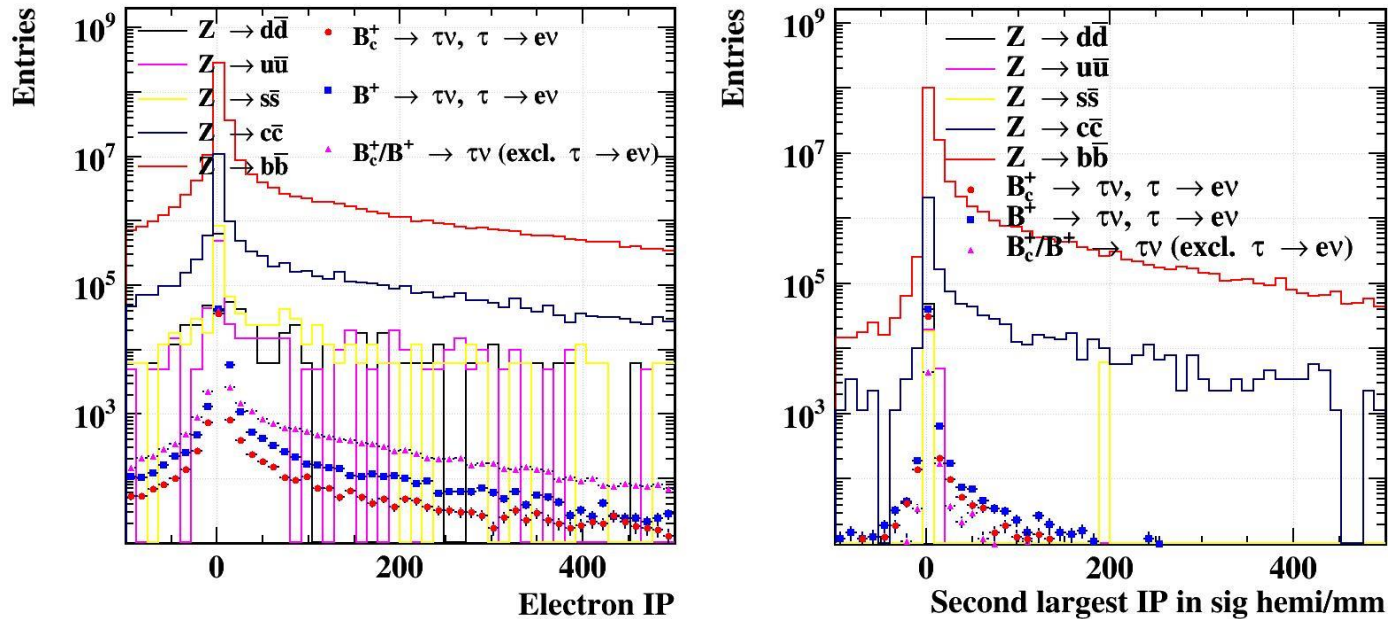
# BDT variables (simple scaling, $\tau \rightarrow e\nu\nu$ )



Max neutral cluster energy  
inside 30 deg cone around  
the thrust axis



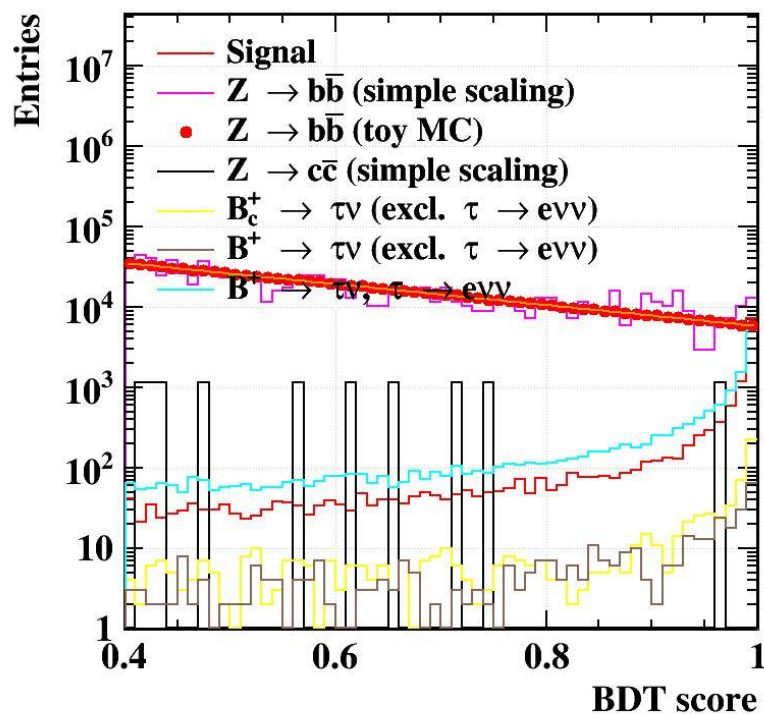
# BDT variables (simple scaling, $\tau \rightarrow e\nu\nu$ )



IP (impact parameter): Find the point on the thrust axis closest to the track. It's the signed distance from the point to the interaction point. (Another words, it's  $z_0$  in respect to the thrust axis)

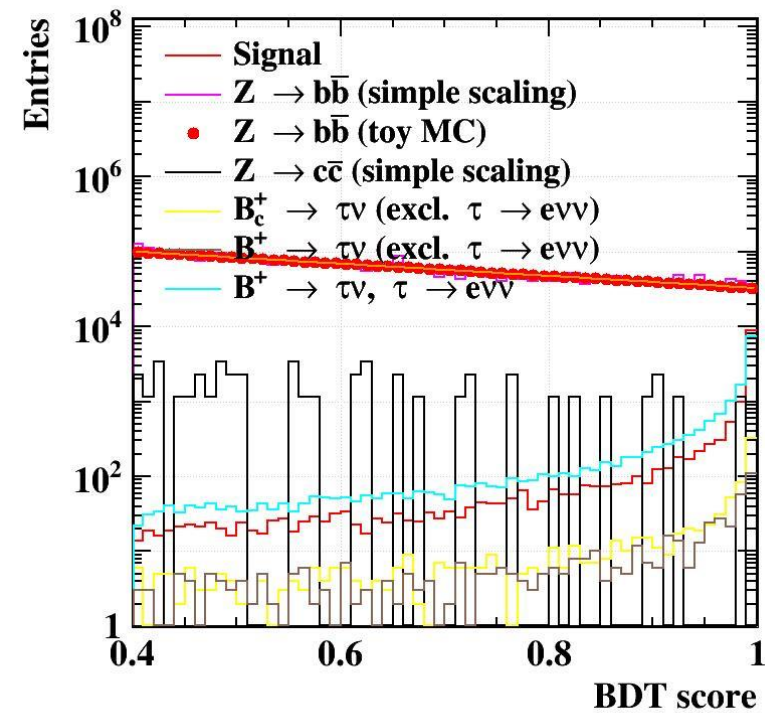
# BDT( $\tau \rightarrow e\nu\nu$ )

Variable	Importance
Nominal Bc energy	0.201
The second largest momentum in sig hemi	0.151
Maximum neutral cluster energy inside 30 deg cone	0.151
Energy asymmetry	0.148
Electron energy	0.123
Second largest IP in sig hemi	0.120
Number of tracks in sig hemi	0.106



root 5.34.07

I chose this &  
cut at 0.99



root 5.34.18

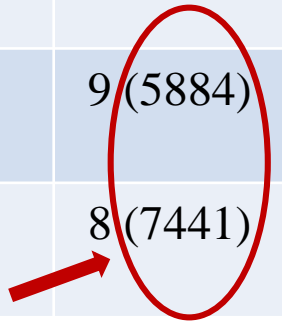
Set the weight to corresponding  
luminosity

# Cut chain ( $\tau \rightarrow e\nu\nu$ )

	$B_c^+ \rightarrow \tau^+ \nu_\tau$ excl. $\tau \rightarrow e/\tau \rightarrow e$	$B^+ \rightarrow \tau^+ \nu_\tau$ excl. $\tau \rightarrow e/\tau \rightarrow e$	1/6100 ↓ dd	1/4900 ↓ uu	1/6100 ↓ ss	1/1100 ↓ cc	1/1500 ↓ bb
All	625177/134681	797230/195570	2530406	2415827	2531430	10414223	10532756
b-tag > 0.6	437048/94370	536144/133336	12495	11559	14920	590417	7885422
Energy asymmetry > 10 GeV	361063/83338	433750/119520	2048	1857	2525	108464	1892666
One lepton in sig hemi	127468/44500	153697/61805	610	549	784	38263	623432
Which is electron	32044/42386	30916/58652	206	181	245	16107	287334
And it's the most energetic one	2569/32458	2173/42475	8	5	4	2449	93945
BDT > 0.99 (training data)	226/7226	65/5150	0	0	0	0	9 (5884)
BDT > 0.99 (test data)	223/7142	87/5178	0	0	0	1	8 (7441)

50/50 split between test and train samples

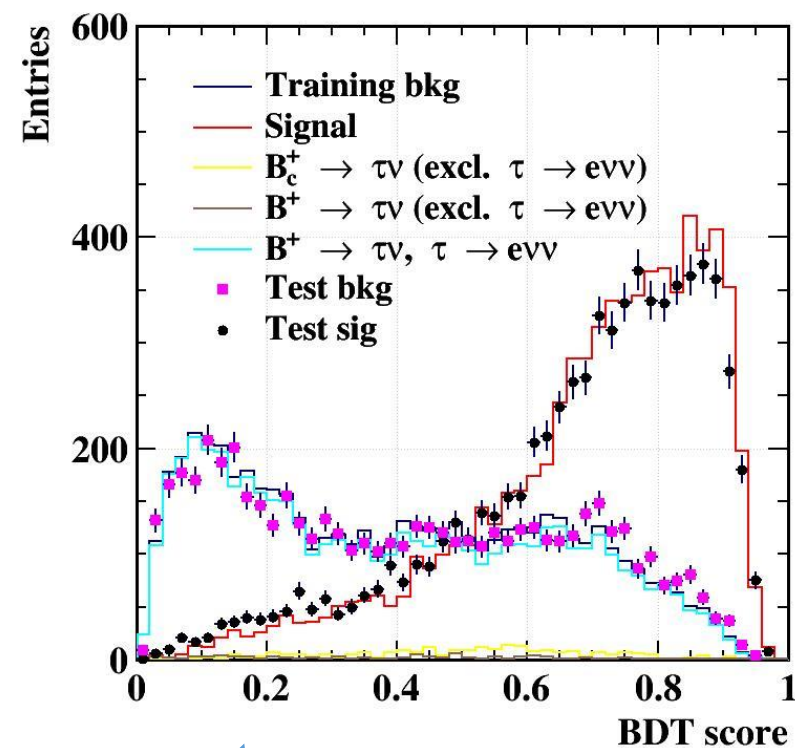
Predicted by toy MC



# Second BDT( $\tau \rightarrow e\nu\nu$ )

Using all of the previous variables + electron IP to do BDT again (ignore bb)

Variable	Importance
Electron IP	0.164
Electron energy	0.138
Nominal Bc energy	0.137
Energy asymmetry	0.134
Maximum neutral cluster energy inside 30 deg cone	0.133
The second largest momentum in sig hemi	0.127
Second largest IP in sig hemi	0.086
Number of tracks in sig hemi	0.082

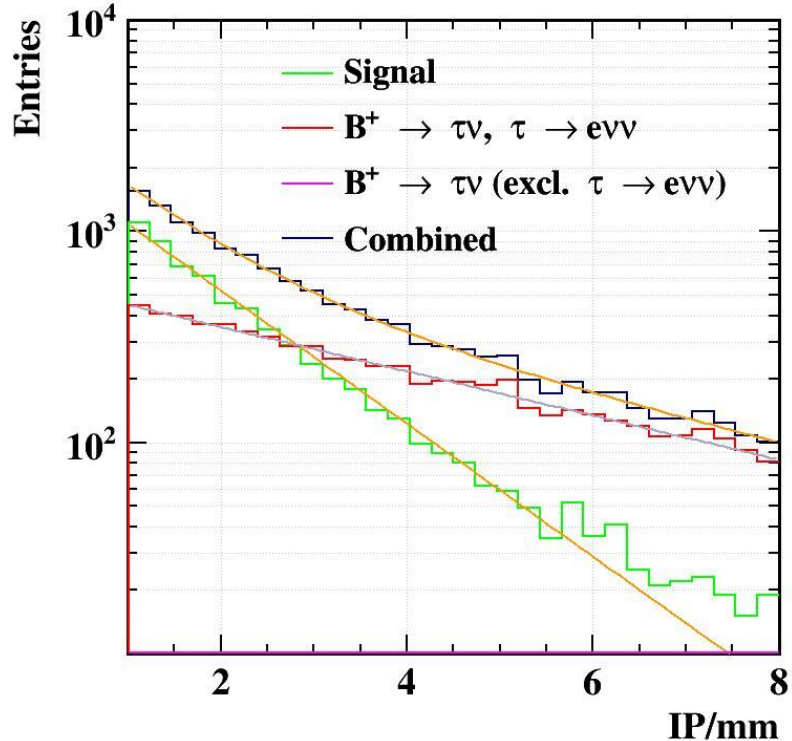


Cut at 0.6

## Second BDT( $\tau \rightarrow e\nu\nu$ )

	$B_c^+ \rightarrow \tau^+ \nu_\tau$ excl. $\tau \rightarrow e/\tau \rightarrow e$	$B^+ \rightarrow \tau^+ \nu_\tau$ excl. $\tau \rightarrow e/\tau \rightarrow e$
BDT > 0.6 (training data)	76/5444	17/1300
BDT > 0.6 (test data)	107/5201	13/1434

# Fit IP with exponential( $\tau \rightarrow e\nu\nu$ )



Alternatively, we can fit the IP with exponential  $C_1 \cdot e^{-E_1 x} + C_2 \cdot e^{-E_2 x}$  (again, ignoring bb).

EXT NO.	PARAMETER NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	C1	5.72575e+02	1.52615e+01	1.44289e-02	-7.51254e-06
2	E1	2.41352e-01	6.62978e-03	6.26832e-06	1.43783e-02
FCN=67.8532 FROM MIGRAD STATUS=CONVERGED 80 CALLS 81 TOTAL EDM=5.09469e-08 STRATEGY= 1 ERROR MATRIX ACCURATE					
EXT NO.	PARAMETER NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	C2	2.24564e+03	6.53438e+01	1.14074e-01	1.07633e-05
2	E2	7.25760e-01	1.12363e-02	1.96105e-05	-6.54741e-02
FCN=21.3704 FROM MIGRAD STATUS=CONVERGED 327 CALLS 328 TOTAL EDM=7.43106e-08 STRATEGY= 1 ERROR MATRIX ACCURATE					
EXT NO.	PARAMETER NAME	VALUE	ERROR	STEP SIZE	FIRST DERIVATIVE
1	C1	7.27399e+02	2.01951e+02	2.26757e-02	-5.88938e-06
2	E1	2.49481e-01	3.81610e-02	6.94000e-06	-2.18549e-03
3	C2	2.83089e+03	1.83058e+02	1.31003e-01	-4.50623e-06
4	E2	9.38499e-01	1.24337e-01	2.44118e-05	1.31922e-02

Number of events predicted by fit results (combined data of train and test)

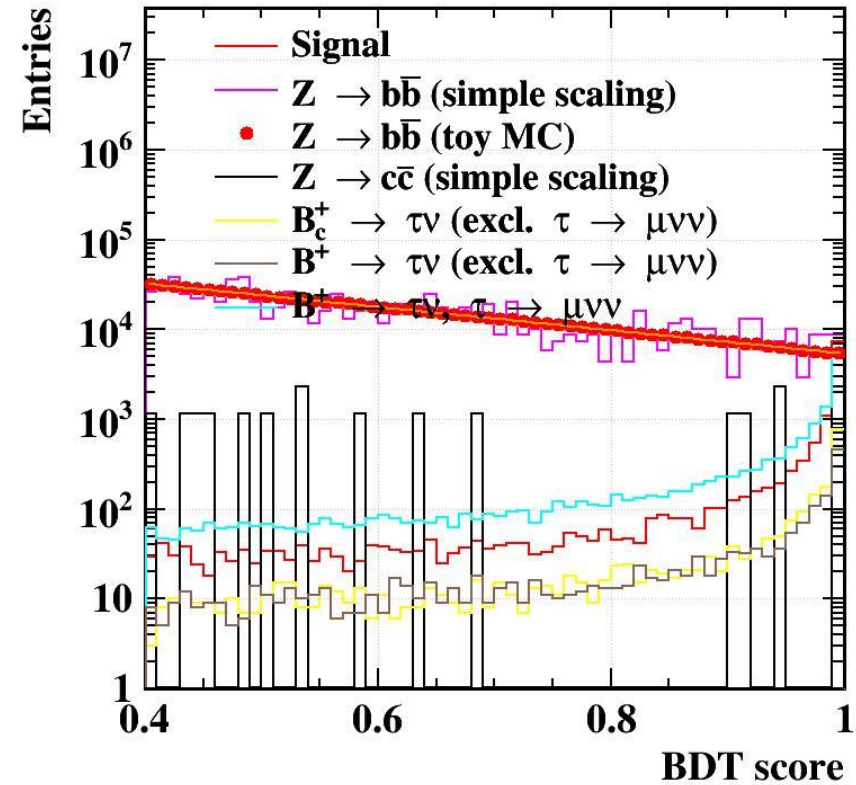
	Truth	Individual fit	Combined fit
$B_c^+ \rightarrow \tau^+ \nu_\tau, \tau^+ \rightarrow e\nu\nu$	6438	6525	5055
$B^+ \rightarrow \tau^+ \nu_\tau / \tau^+ \rightarrow e\nu\nu$	6528	6375	8047

# Cut chain ( $\tau \rightarrow \mu\nu\nu$ )

	$B_c^+ \rightarrow \tau^+ \nu_\tau$ excl. $\tau \rightarrow \mu/\tau \rightarrow \mu$	$B^+ \rightarrow \tau^+ \nu_\tau$ excl. $\tau \rightarrow \mu/\tau \rightarrow \mu$	$\frac{1}{6100}$ ↓ dd	$\frac{1}{4900}$ ↓ uu	$\frac{1}{6600}$ ↓ ss	$\frac{1}{1100}$ ↓ cc	$\frac{1}{1500}$ ↓ bb
All	628199/131659	802123/190677	2530406	2415827	2331430	10014223	10332758
b-tag > 0.6	439038/92380	539792/129688	12495	11559	13808	567891	7736169
Energy asymmetry > 10 GeV	363241/81160	437202/116068	2048	1857	2342	104333	1856916
One lepton in sig hemi	130225/41743	158052/57450	610	549	729	36843	611737
Which is muon	57721/39817	70506/55428	404	368	498	21313	329706
And it's the most energetic one	5820/31200	5173/40799	12	11	13	2779	98136

# BDT ( $\tau \rightarrow \mu\nu\nu$ )

Variable	Importance
Nominal Bc energy	0.210
Maximum neutral cluster energy inside 30 deg cone	0.157
Energy asymmetry	0.151
The second largest momentum in sig hemi	0.141
Second largest IP in sig hemi	0.128
Electron energy	0.123
Number of tracks in sig hemi	0.089



root 5.34.07

cut at 0.99

Set the weight to corresponding luminosity

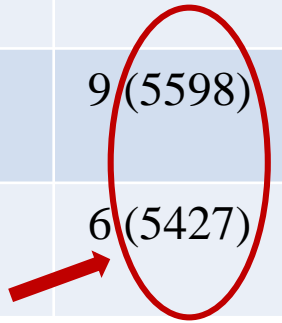


# Cut chain ( $\tau \rightarrow \mu\nu\nu$ )

	$B_c^+ \rightarrow \tau^+ \nu_\tau$ excl. $\tau \rightarrow \mu/\tau \rightarrow \mu$	$B^+ \rightarrow \tau^+ \nu_\tau$ excl. $\tau \rightarrow \mu/\tau \rightarrow \mu$	1/6100 ↓ dd	1/4900 ↓ uu	1/6600 ↓ ss	1/1100 ↓ cc	1/1500 ↓ bb
All	628199/131659	802123/190677	2530406	2415827	2331430	10014223	10332758
b-tag > 0.6	439038/92380	539792/129688	12495	11559	13808	567891	7736169
Energy asymmetry > 10 GeV	363241/81160	437202/116068	2048	1857	2342	104333	1856916
One lepton in sig hemi	130225/41743	158052/57450	610	549	729	36843	611737
Which is muon	57721/39817	70506/55428	404	368	498	21313	329706
And it's the most energetic one	5820/31200	5173/40799	12	11	13	2779	98136
BDT > 0.99 (training data)	756/7394	486/5170	0	0	0	2	9 (5598)
BDT > 0.99 (test data)	763/7313	455/5266	0	0	0	0	6 (5427)

50/50 split between test and train samples

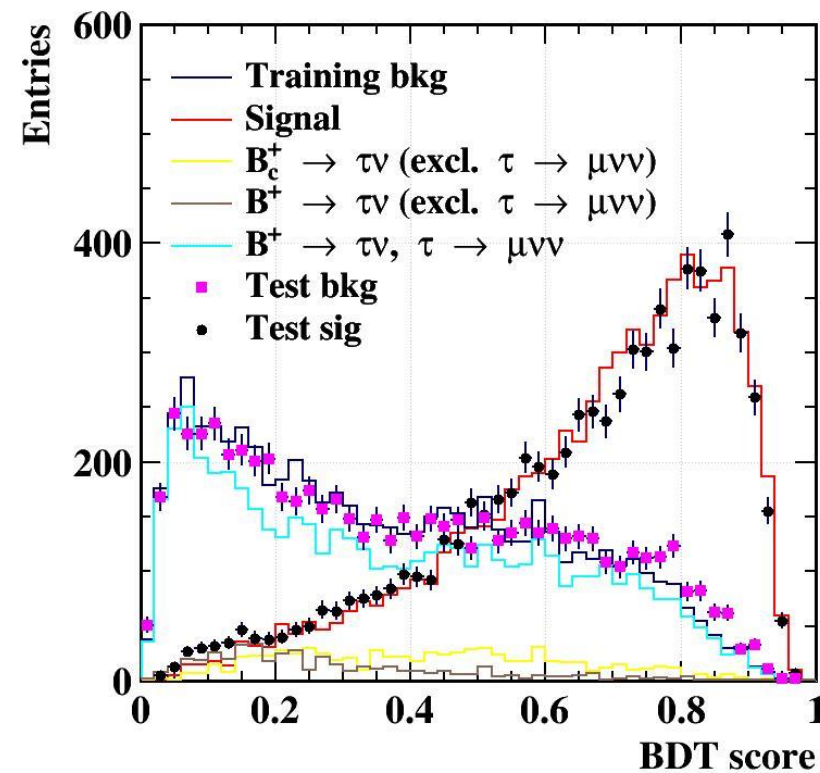
Predicted by toy MC



# Second BDT ( $\tau \rightarrow \mu\nu\nu$ )

Using all of the previous variables + electron IP to do BDT again (ignore bb)

Variable	Importance
Electron IP	0.159
Electron energy	0.143
Energy asymmetry	0.132
Maximum neutral cluster energy inside 30 deg cone	0.132
Nominal B meson energy	0.129
The second largest momentum in sig hemi	0.129
Number of tracks in sig hemi	0.091
Second largest IP in sig hemi	0.085

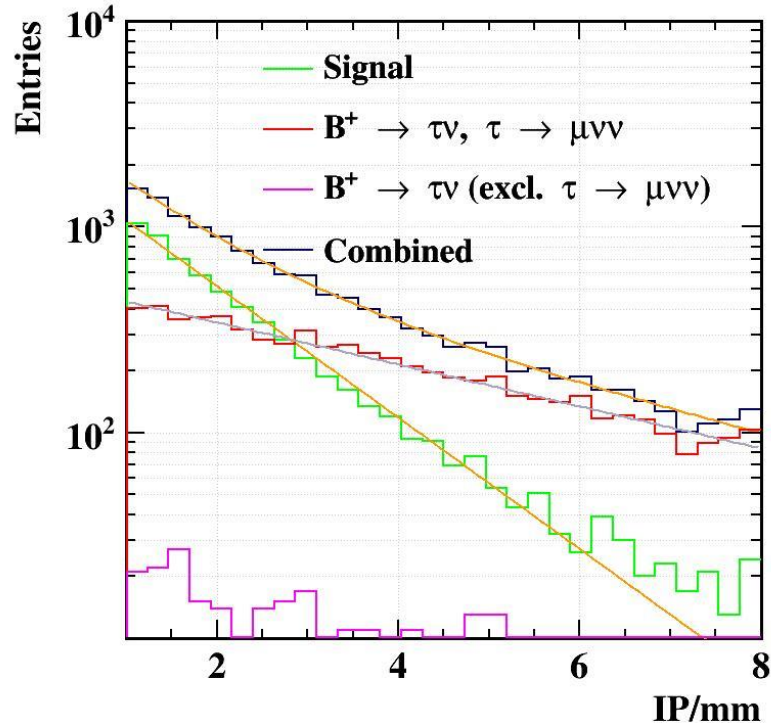


Cut at 0.6

## Second BDT ( $\tau \rightarrow \mu\nu\nu$ )

	$B_c^+ \rightarrow \tau^+ \nu_\tau$ excl. $\tau \rightarrow \mu/\tau \rightarrow \mu$	$B^+ \rightarrow \tau^+ \nu_\tau$ excl. $\tau \rightarrow \mu/\tau \rightarrow \mu$
BDT > 0.6 (training data)	159/5161	38/1130
BDT > 0.6 (test data)	240/4920	33/1298

# Fit IP with exponential ( $\tau \rightarrow \mu\nu\nu$ )



Alternatively, we can fit the IP with exponential  $C_1 \cdot e^{-E_1 x} + C_2 \cdot e^{-E_2 x}$  (again, ignoring bb).

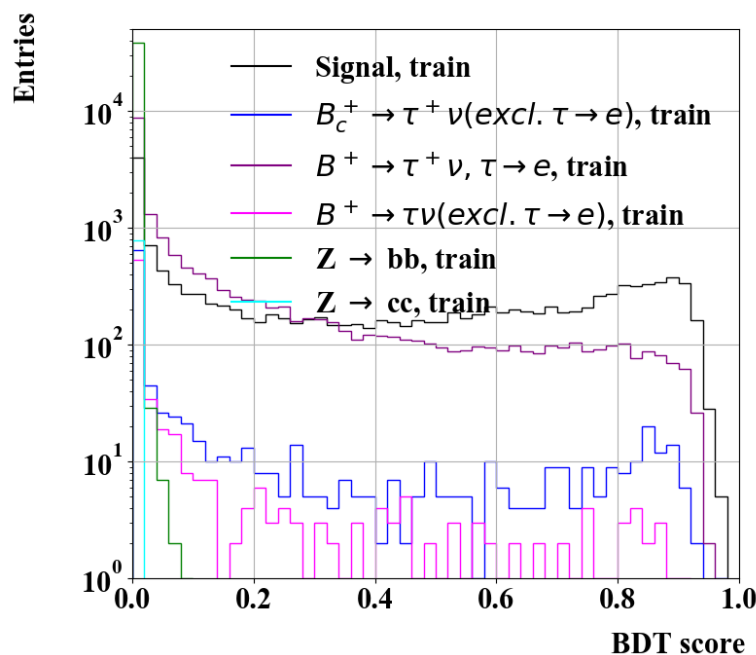
NO.	NAME	VALUE	ERROR	SIZE	DERIVATIVE
1	C1	5.51094e+02	1.45324e+01	1.95868e-02	-1.28790e-05
2	E1	2.35308e-01	6.48465e-03	8.73984e-06	1.71527e-02
FCN=64.654 FROM MIGRAD STATUS=CONVERGED 78 CALLS 79 TOTAL					
EDM=1.80213e-09 STRATEGY= 1 ERROR MATRIX ACCURATE					
EXT PARAMETER					
NO.	NAME	VALUE	ERROR	SIZE	DERIVATIVE
1	C2	2.24316e+03	6.59072e+01	1.12545e-01	1.57326e-06
2	E2	7.35570e-01	1.14151e-02	1.94939e-05	-4.68803e-03
FCN=29.2032 FROM MIGRAD STATUS=CONVERGED 336 CALLS 337 TOTAL					
EDM=2.65854e-07 STRATEGY= 1 ERROR MATRIX ACCURATE					
EXT PARAMETER					
NO.	NAME	VALUE	ERROR	SIZE	DERIVATIVE
1	C1	7.79201e+02	2.46309e+02	2.78175e-02	-1.86941e-05
2	E1	2.59603e-01	4.23892e-02	8.04291e-06	1.27713e-02
3	C2	2.66687e+03	1.67475e+02	1.44562e-01	-2.55748e-06
4	E2	9.03294e-01	1.34425e-01	2.80029e-05	2.87191e-02

Number of events predicted by fit results (combined data of train and test)

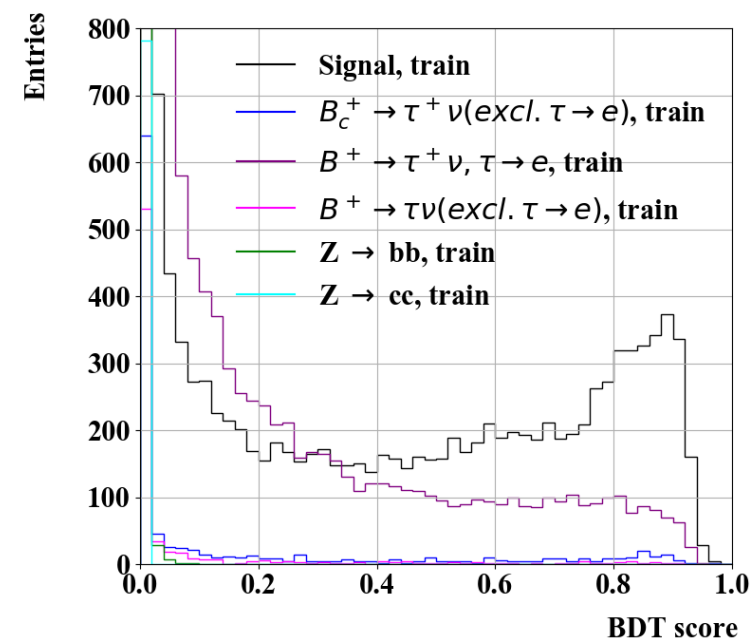
	Truth	Individual fit	Combined fit
$B_c^+ \rightarrow \tau^+ \nu_\tau, \tau^+ \rightarrow \mu\nu\nu$	6284	6220	5121
$B^+ \rightarrow \tau^+ \nu_\tau / \tau^+ \rightarrow \mu\nu\nu$	6437	6410	8715

# Training with xgboost ( $\tau \rightarrow e\nu\nu$ )

Variable	Importance
Nominal Bc energy	270
Maximum neutral cluster energy inside 30 deg cone	139
Second largest IP in sig hemi	124
Energy asymmetry	121
The second largest momentum in sig hemi	98
Impact parameter	81



Logarithmic y axis



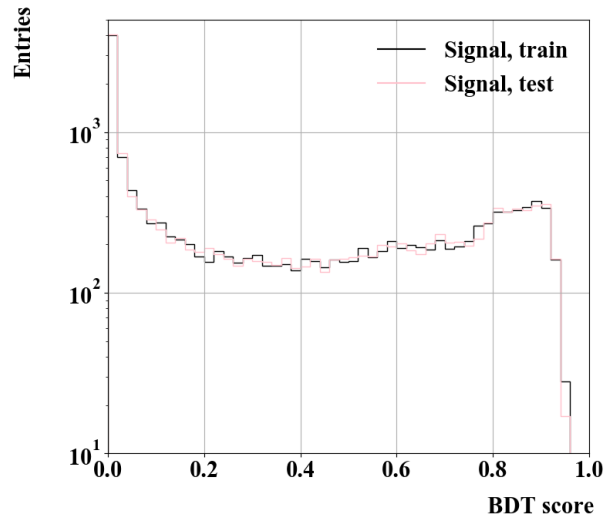
Linear y axis

**BDT response (training data)**

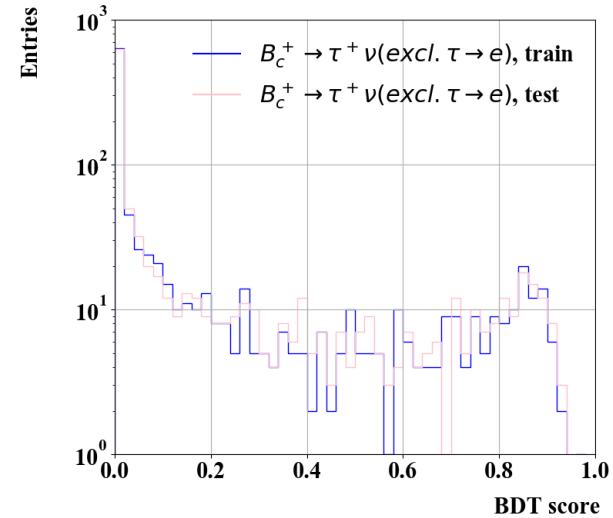
Set the weight to the corresponding luminosity

Electron energy and #track in sig hemi are dropped due to low importance

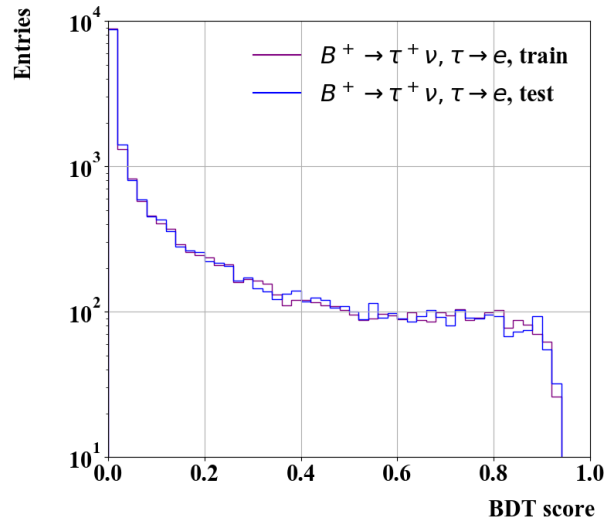
# Training with xgboost (train & test data overlay, $\tau \rightarrow e\nu\nu$ )



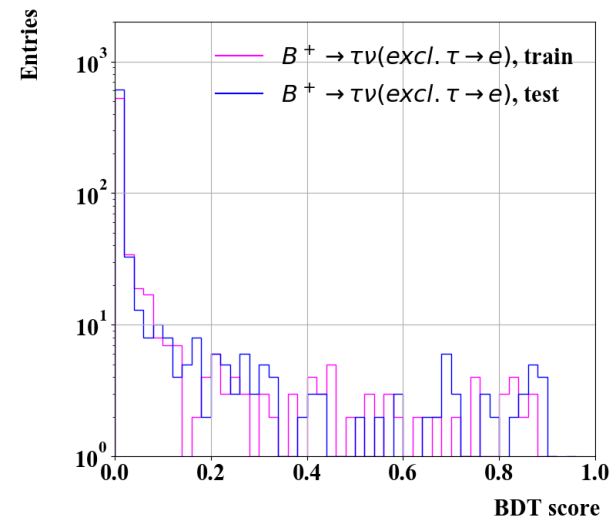
Signal



$B_c^+ \rightarrow \tau\nu$   
(excl.  $\tau \rightarrow e$ )

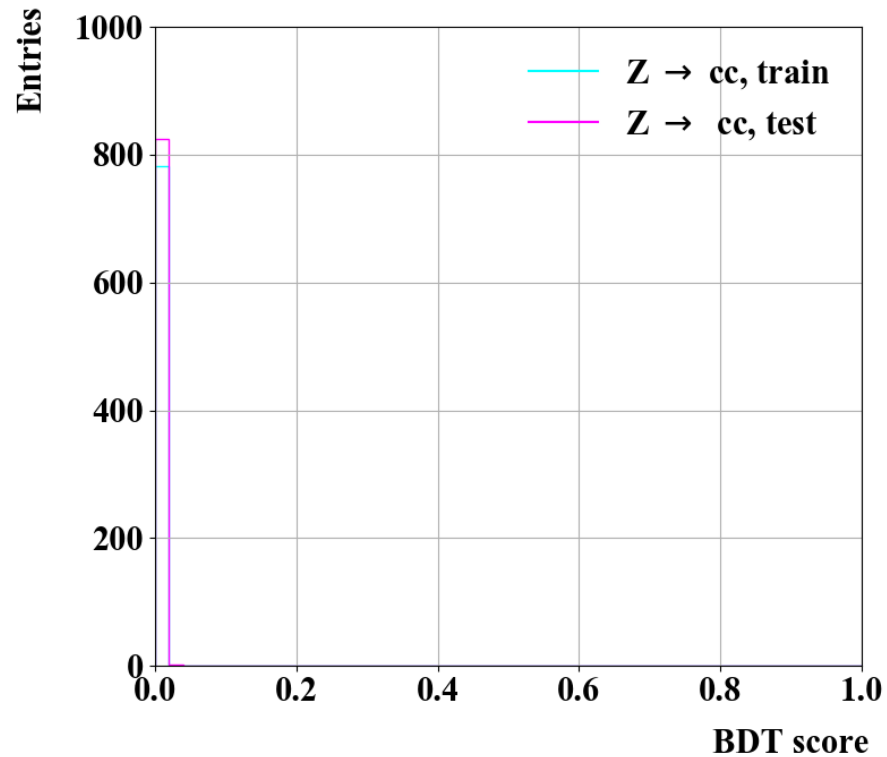


$B^+ \rightarrow \tau\nu, \tau \rightarrow e$

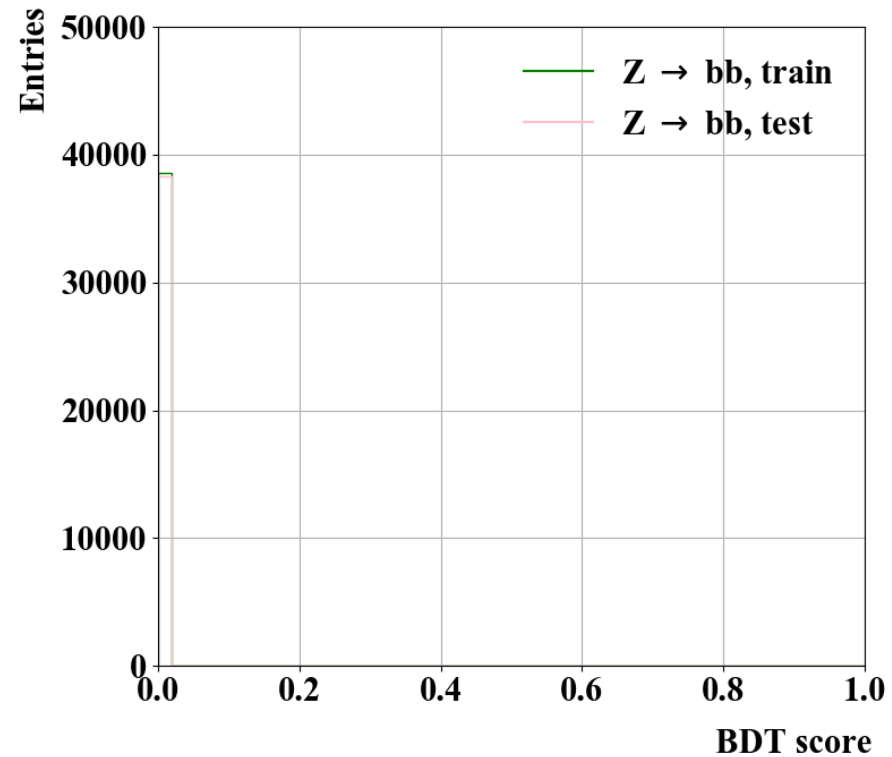


$B^+ \rightarrow \tau\nu$   
(excl.  $\tau \rightarrow e$ )

# Training with xgboost (train & test data overlay, $\tau \rightarrow evv$ )



cc



bb

# Cut chain(xgboost, $\tau \rightarrow e\nu\nu$ )

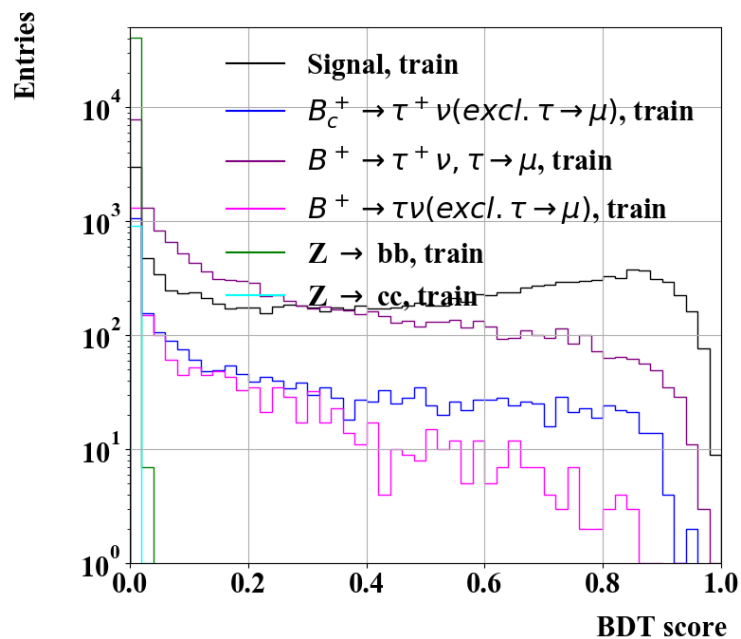
	$B_c^+ \rightarrow \tau^+ \nu_\tau$ excl. $\tau \rightarrow e/\tau \rightarrow e$	$B^+ \rightarrow \tau^+ \nu_\tau$ excl. $\tau \rightarrow e/\tau \rightarrow e$	$\frac{1}{6100}$ ↓ dd	$\frac{1}{4900}$ ↓ uu	$\frac{1}{6100}$ ↓ ss	$\frac{1}{1100}$ ↓ cc	$\frac{1}{1500}$ ↓ bb
All	625177/134681	797230/195570	2530406	2415827	2531430	10414223	10532756
b-tag > 0.6	437048/94370	536144/133336	12495	11559	14920	590417	7885422
Energy asymmetry > 10 GeV	361063/83338	433750/119520	2048	1857	2525	108464	1892666
One lepton in sig hemi	127468/44500	153697/61805	610	549	784	38263	623432
Which is electron	32044/42386	30916/58652	206	181	245	16107	287334
And it's the most energetic one	2569/32458	2173/42475	8	5	4	2449	93945
BDT > 0.4 (training data)	242/7638	60/3024	0	0	0	0	0
BDT > 0.4 (test data)	264/7369	72/3183	0	0	0	0	0

50/50 split between test and train samples

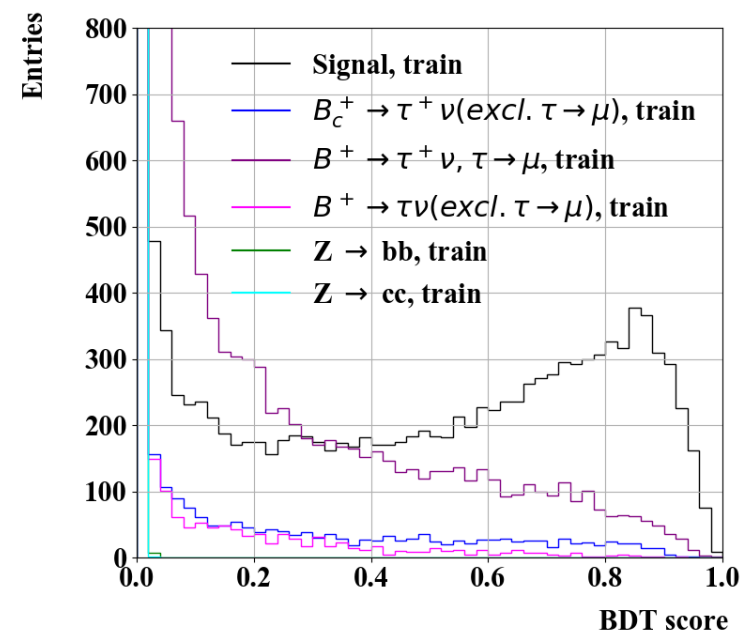


# Training with xgboost ( $\tau \rightarrow \mu\nu\nu$ )

Variable	Importance
Nominal Bc energy	275
Maximum neutral cluster energy inside 30 deg cone	160
Second largest IP in sig hemi	124
Energy asymmetry	116
The second largest momentum in sig hemi	95
Impact parameter	66



Logarithmic y axis



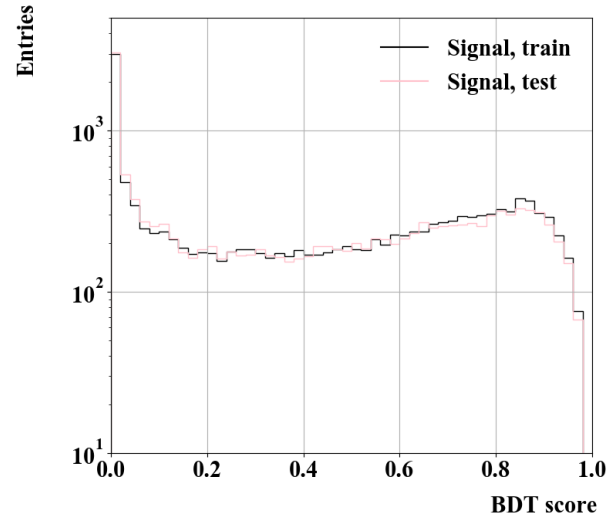
Linear y axis

**BDT response (training data)**

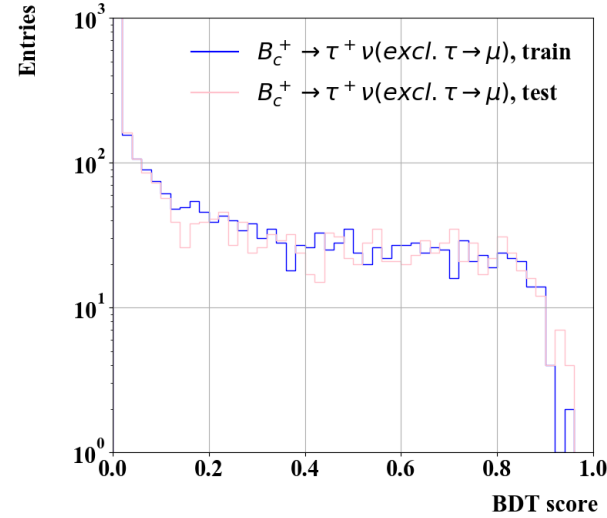
Set the weight to the corresponding luminosity

Muon energy and #track in sig hemi are dropped due to low importance

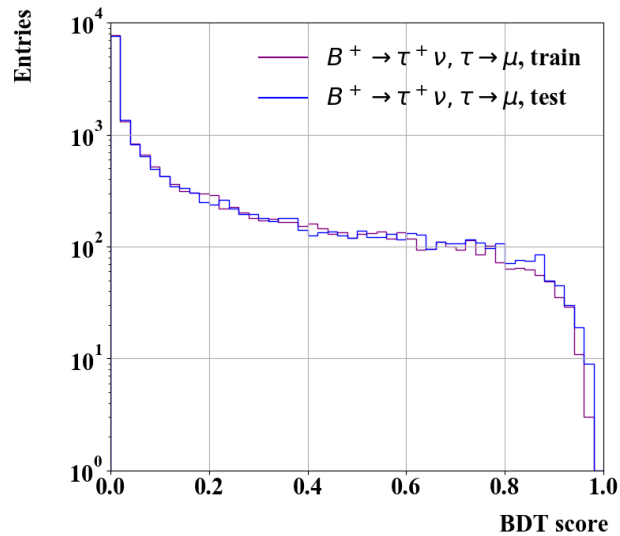
# Training with xgboost (train & test data overlay, $\tau \rightarrow \mu\nu\nu$ )



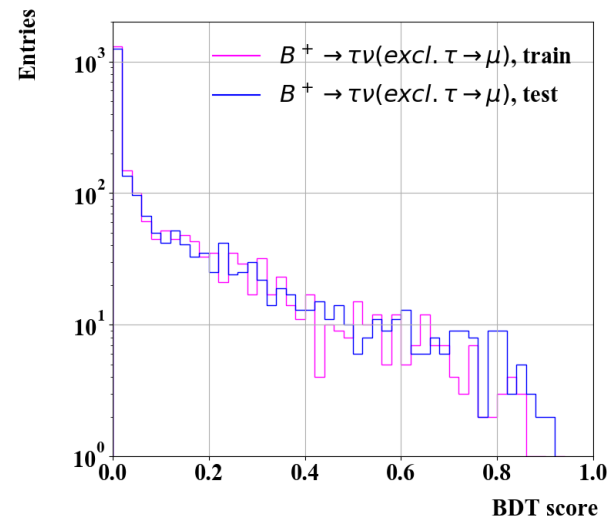
Signal



$B_c^+ \rightarrow \tau \nu$   
(excl.  $\tau \rightarrow \mu$ )

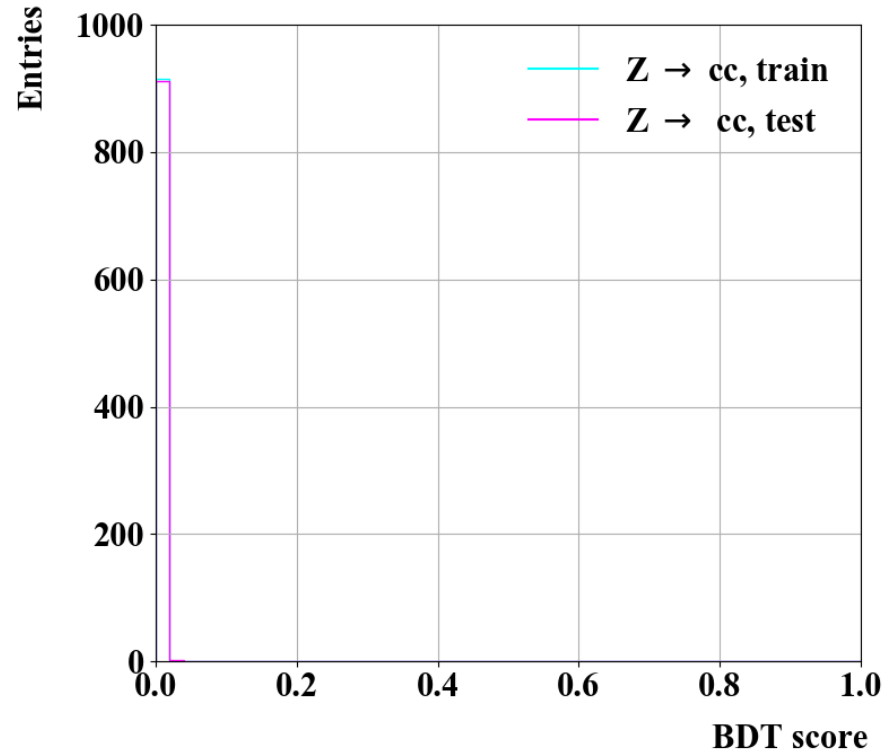


$B^+ \rightarrow \tau \nu, \tau \rightarrow \mu$

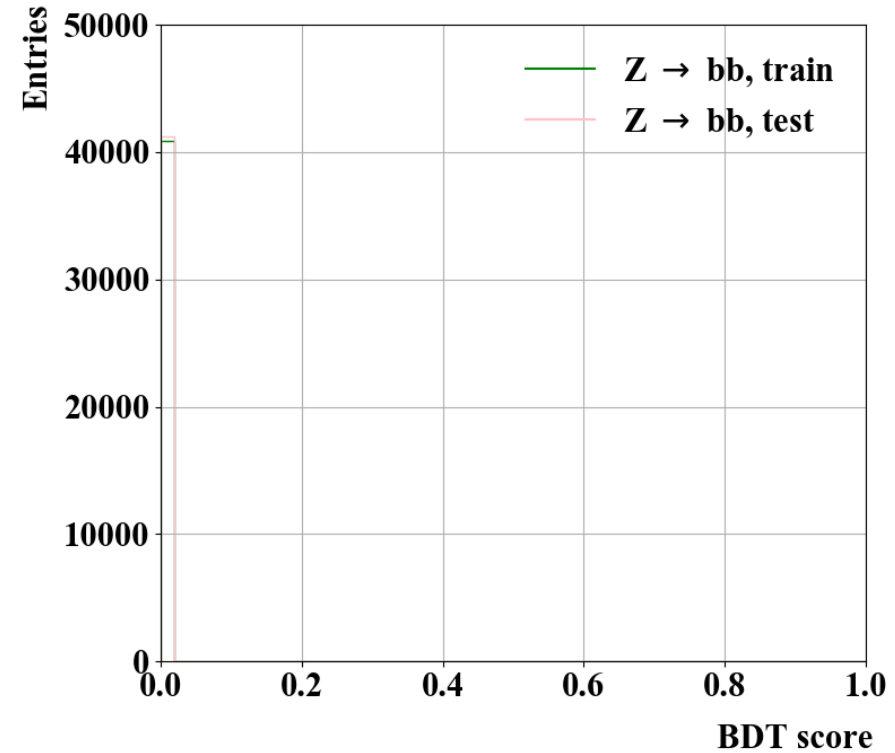


$B^+ \rightarrow \tau \nu$   
(excl.  $\tau \rightarrow \mu$ )

# Training with xgboost (train & test data overlay, $\tau \rightarrow \mu\nu\nu$ )



cc



bb

# Cut chain(xgboost, $\tau \rightarrow \mu\nu\nu$ )

	$B_c^+ \rightarrow \tau^+ \nu_\tau$ excl. $\tau \rightarrow \mu/\tau \rightarrow \mu$	$B^+ \rightarrow \tau^+ \nu_\tau$ excl. $\tau \rightarrow \mu/\tau \rightarrow \mu$	1/6100 ↓ dd	1/4900 ↓ uu	1/6600 ↓ ss	1/1100 ↓ cc	1/1500 ↓ bb
All	628199/131659	802123/190677	2530406	2415827	2331430	10014223	10332758
b-tag > 0.6	439038/92380	539792/129688	12495	11559	13808	567891	7736169
Energy asymmetry > 10 GeV	363241/81160	437202/116068	2048	1857	2342	104333	1856916
One lepton in sig hemi	130225/41743	158052/57450	610	549	729	36843	611737
Which is muon	57721/39817	70506/55428	404	368	498	21313	329706
And it's the most energetic one	5820/31200	5173/40799	12	11	13	2779	98136
BDT > 0.4 (training data)	606/7049	171/2692	0	0	0	0	0
BDT > 0.4 (test data)	606/6742	208/2839	0	0	0	0	0

50/50 split between test and train samples

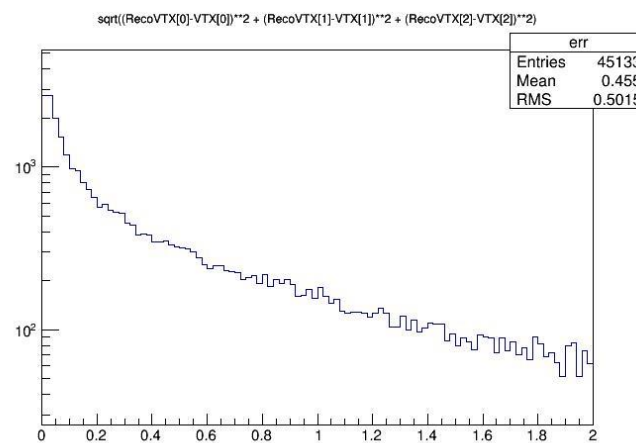
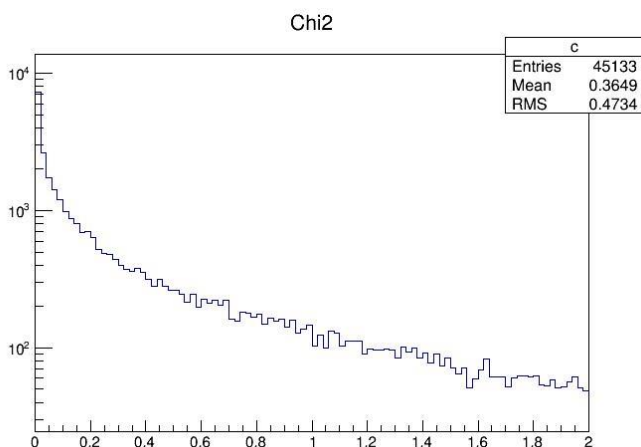
# Result evaluation

- Evaluate the signal uncertainty for strategy 1 (2 TMVAs) and 3 (xgboost).
- Combine the electron and muon data
- Combine the training and test data
- Assume no bias

	Strategy 1	Strategy 3
$N_{total}$	26591	42766
$N_{signal}$	20726	28799
$N_{bkg}$	5845	13967
$\sqrt{N_{bkg} + N_{signal}}/N_{signal}$	0.786%	0.718%
Efficiency	3.3%	4.6%

\*In strategy 1 we ignored qq backgrounds at second BDT

# Kinematic fit with pseudo track ( $\tau \rightarrow e\nu\nu$ )



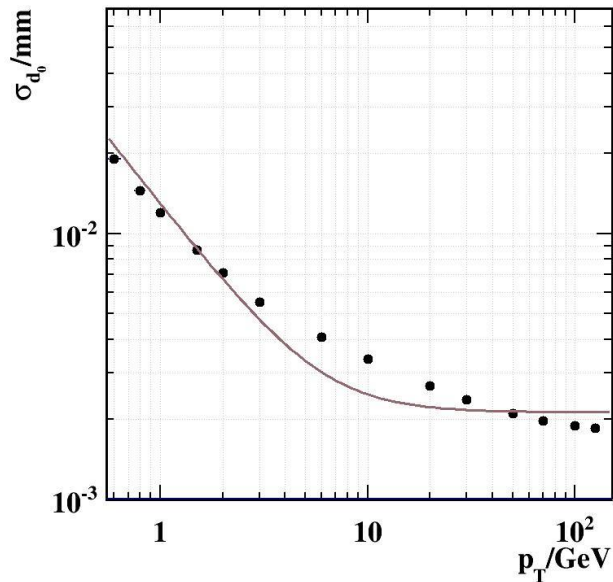
$\chi^2$

Distance (reco vtx - decay point)

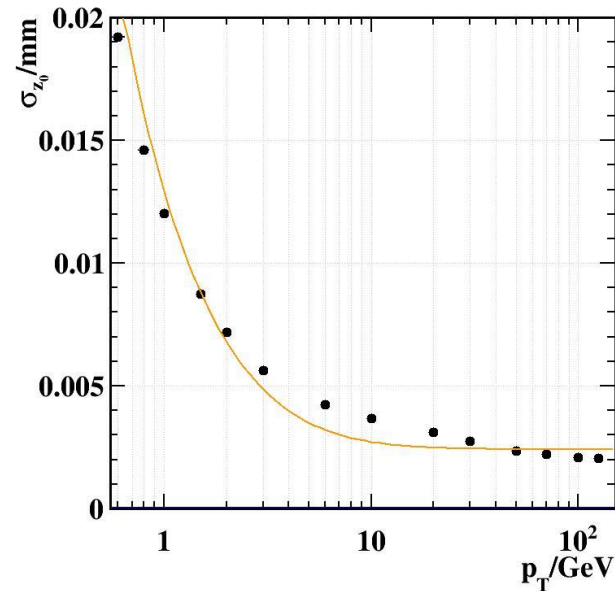
Kinematic fit of  $K_S^0 \rightarrow \pi^+ \pi^-$  decay point  
(just to check if it works)

# Kinematic fit with pseudo track ( $\tau \rightarrow e\nu\nu$ )

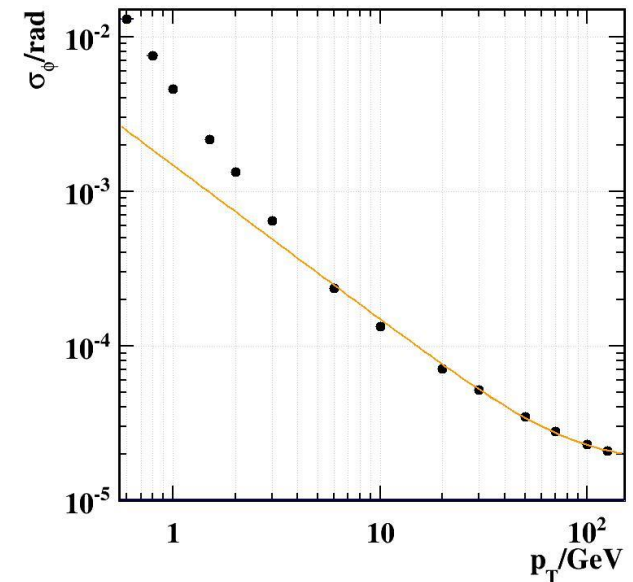
Fit the track resolution distribution with  $\sigma_{1/p_T} = a \oplus \frac{b}{p \sin^{3/2} \theta}$  [GeV<sup>-1</sup>]  
to guess the covariant matrix of the pseudo track



$d_0$



$z_0$

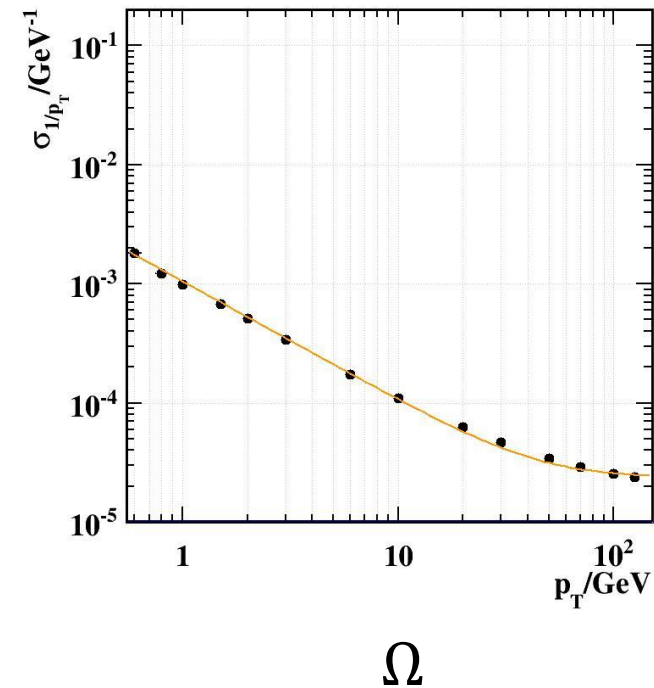
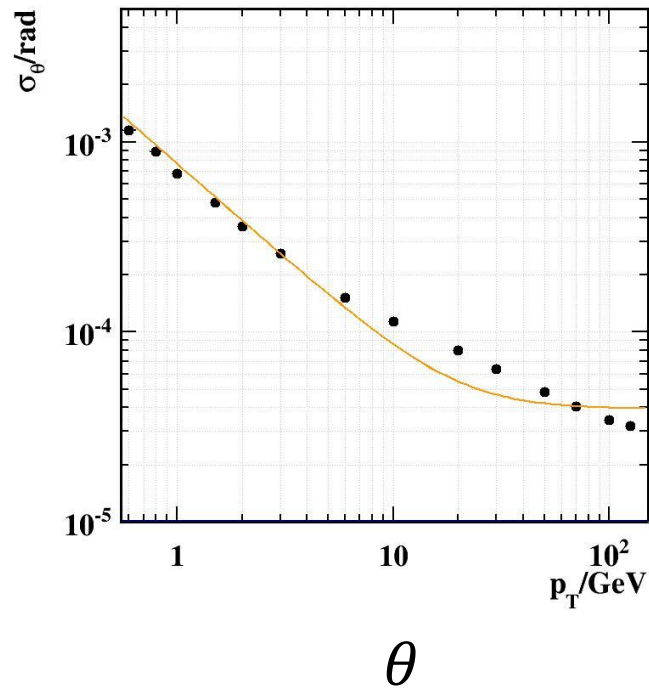


$\phi$

Track parameter resolutions from muons shot at  $\theta = 85^\circ$

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Fit the track resolution distribution with  $\sigma_{1/p_T} = a \oplus \frac{b}{p \sin^{3/2} \theta}$  [GeV<sup>-1</sup>]  
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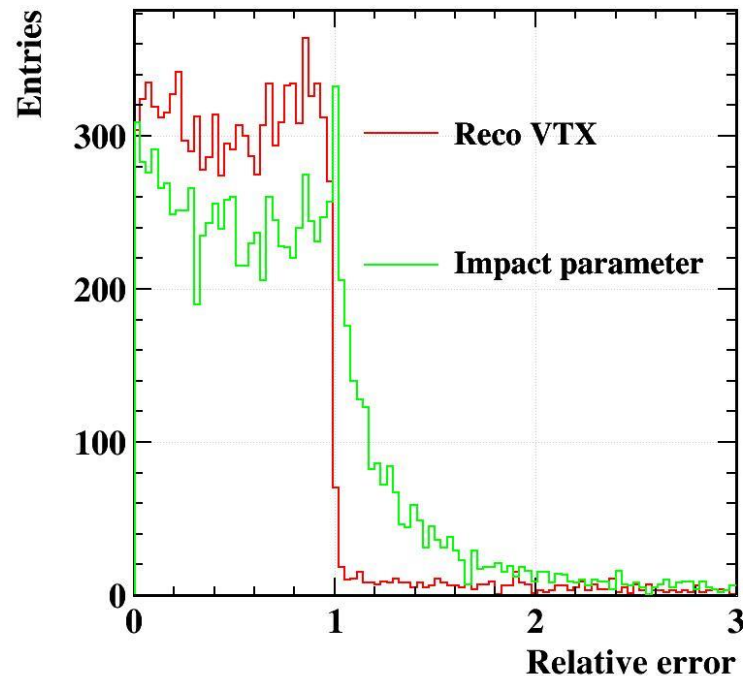


Track parameter resolutions from muons shot at  $\theta = 85^\circ$



# Kinematic fit with pseudo track ( $\tau \rightarrow e\nu\nu$ )

Use the all of the particles on the recoil side to build a pseudo track that passes through the interaction point. And fit the vertex with the electron. Set  $\text{cov}(\text{pseudo track}) = \text{cov}(\text{electron track})$ .



$$\text{Relative error(IP)} = \text{abs}\left(\frac{IP.Mag() - (\tau \text{ end}).Mag()}{(\tau \text{ end}).Mag()}\right)$$

# Pre-cut on the additional bkg samples ( $\tau \rightarrow e\nu\nu$ )

Reject obvious backgrounds at generator level.

bb:

1. Only one electron in the signal hemisphere
2. The electron is the most energetic particle in the signal hemisphere
3. Nominal B meson energy  $> 10$  GeV

Results:

1.  $4.6 \times 10^8$  events  $\rightarrow 3.7 \times 10^7$  events (92% reduction)
2. bb survive rate after cut chain 0.9%  $\rightarrow$  0.7%