$B_c^+ \to \tau^+ \nu_\tau$ Analysis

Taifan

Motivation

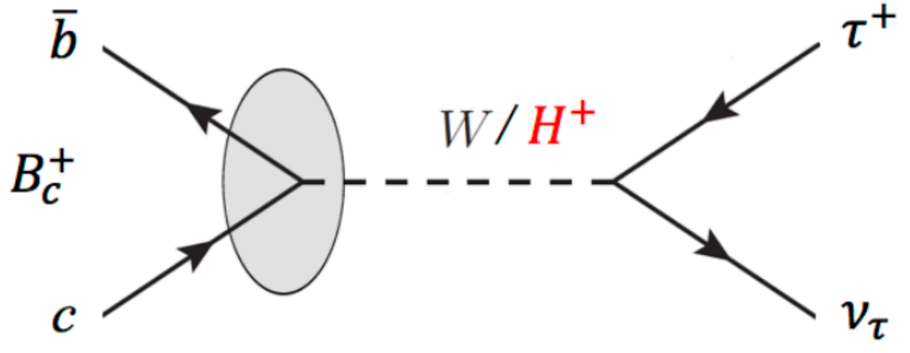
- Measure V_{cb}. Right now only semileptonic decays of B_c^+ are used to measure it.

- Put new constraints on theories on production mechanisms and BR. The current theories of its BR ranges from $o(1) \sim o(10)\%$.

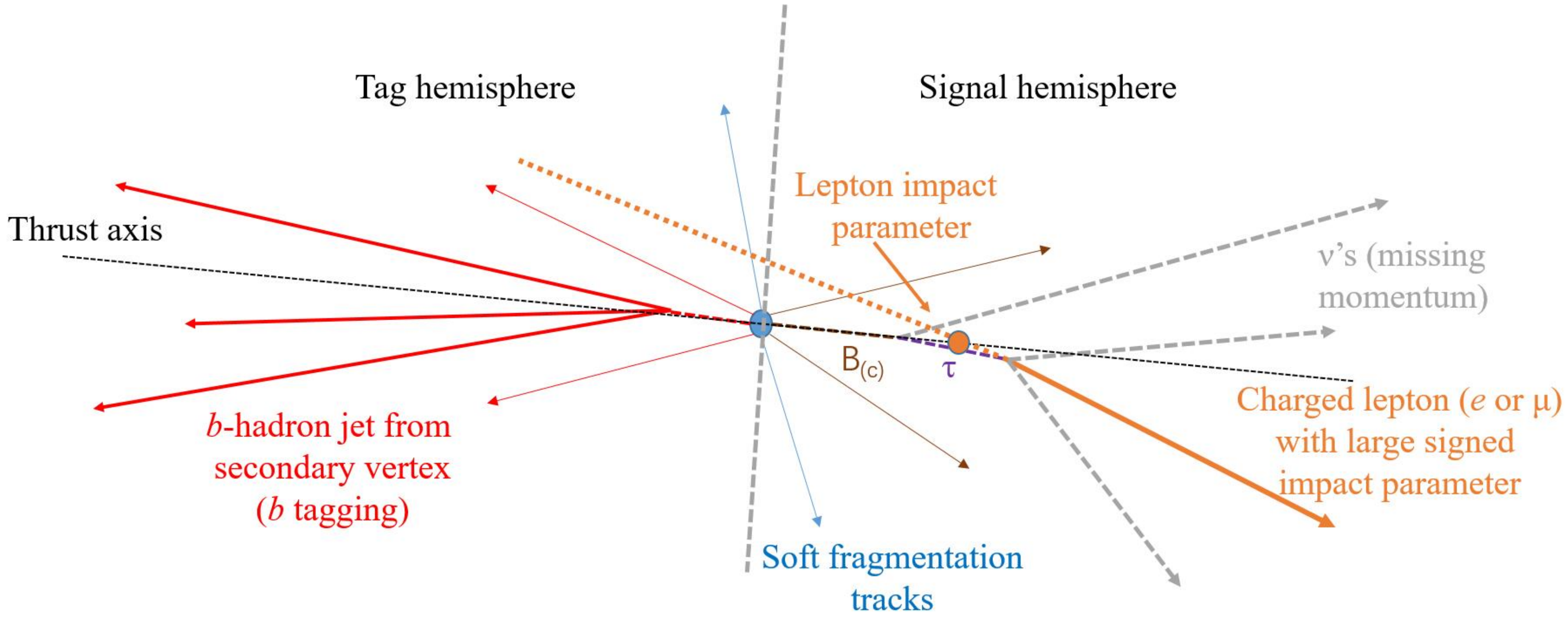
- 2HDM. A charged Higgs replaces W boson propagator and change the BR by

$$BR'(B_c^+ \to \tau\nu) = BR(B_c^+ \to \tau\nu)_{SM} \times r_H$$

$$r_H = \left(1 - \tan^2\beta \cdot \frac{m_{B_c}^2}{m_{H^+}^2}\right)^2$$



Event topology

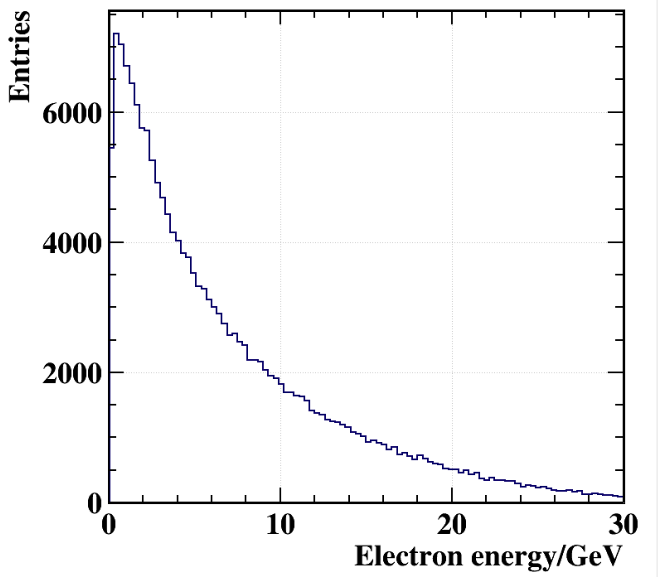


Both $B_c^+ \to \tau\nu$ and $B^+ \to \tau\nu$ share similar event topology and each one is predicted to be the other's most important background. The biggest difference is the lifetime.

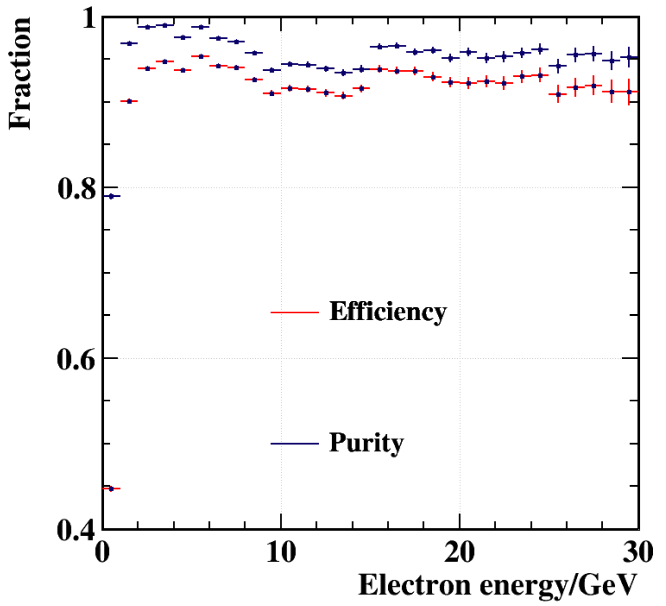
Electron reconstruction performance for signal electron

Efficiency: fraction of correctly identified electrons in respect to all of the signal electrons

Purity: fraction of correctly identified electrons among all of the reconstructed particles associated with the signal electron.



Signal electron En



Efficiency and purity

Basic statistics

The following studies are done assuming 1×10^9 Z bosons are produced. The number of $B^+ \to \tau\nu$ events is:

$$N(B^+ \to \tau\nu) = N_Z \times BR(Z \to bb) \times 2 \times f(b \to B^+X) \times BR(B^+ \to \tau\nu)$$

- N_Z: number of Z bosons, 10^9
- $BR(Z \to bb) = 0.1512 \pm 0.0005$
- 2 accounts for quark-anti quark pair
- $f(b \to B^+X) = 0.407 \pm 0.007$
- $BR(B^+ \to \tau\nu) = (1.09 \pm 0.24) \times 10^{-4}$

→ $N(B^+ \to \tau\nu) = (1.3 \pm 0.3) \times 10^4$

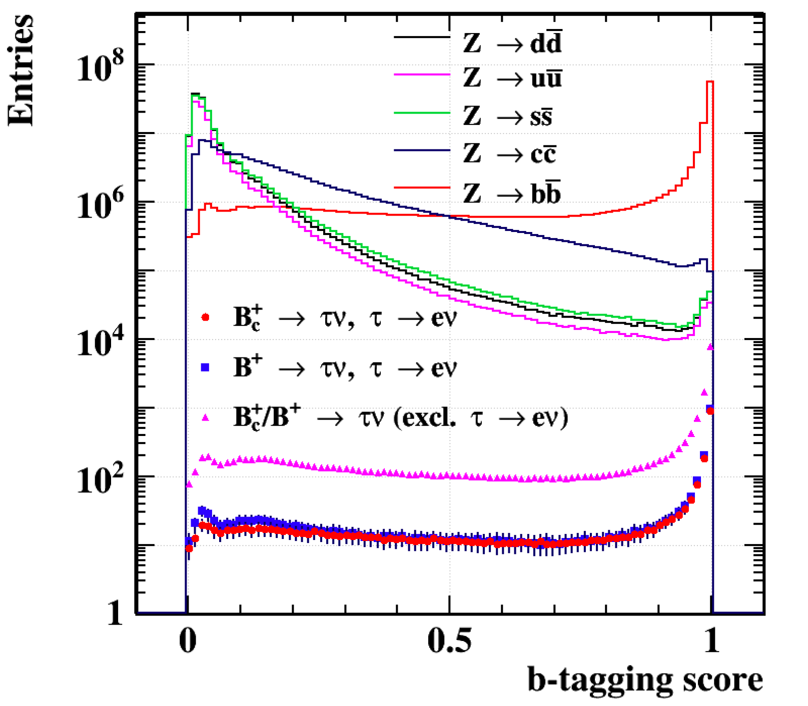
$N(B_c^+ \to \tau\nu)$ has huge uncertainties, but likely of similar order as $N(B^+ \to \tau\nu)$.
∴We assume $N(B^+ \to \tau\nu) = N(B_c^+ \to \tau\nu) = 1.3 \times 10^4$

The events under consideration: $Z \to qq, B_c^+/B^+ \to \tau\nu$

Strategy

1. A preliminary cut chain to cut off most of the light flavor backgrounds
2. Use BDT training to separate $B_c^+/B^+ \to \tau\nu, \tau \to e/\mu\bar{\nu}\nu$ from heavy flavor jets.
3. Use BDT training again to separate between Bc and B events.

Preliminary cut chain (simple scaling, $\tau \to e\nu\nu$)



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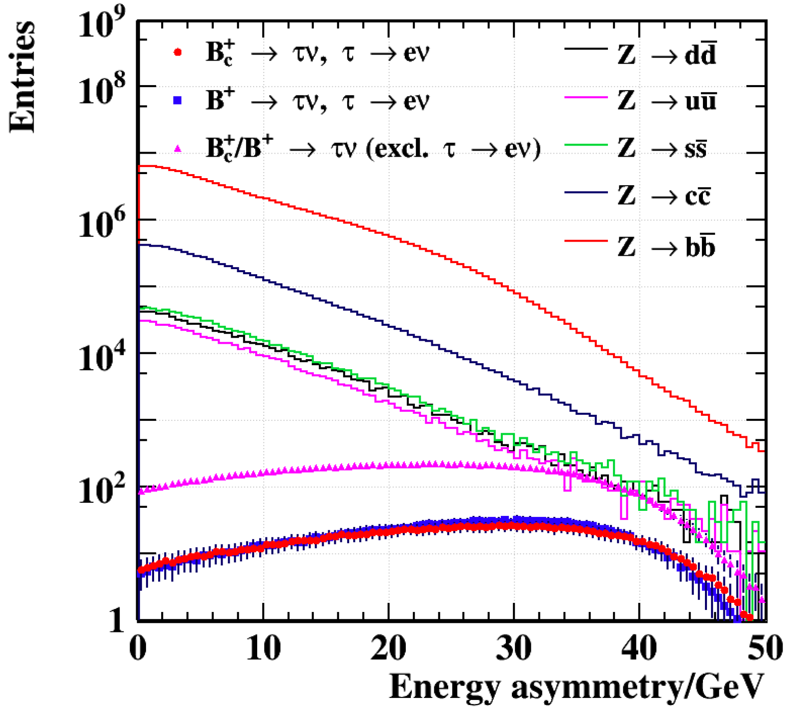
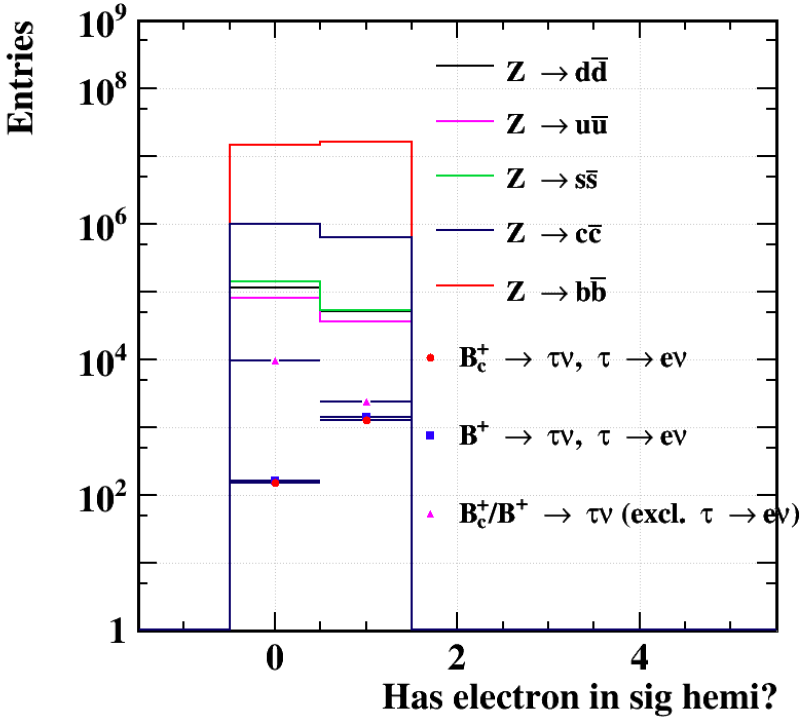
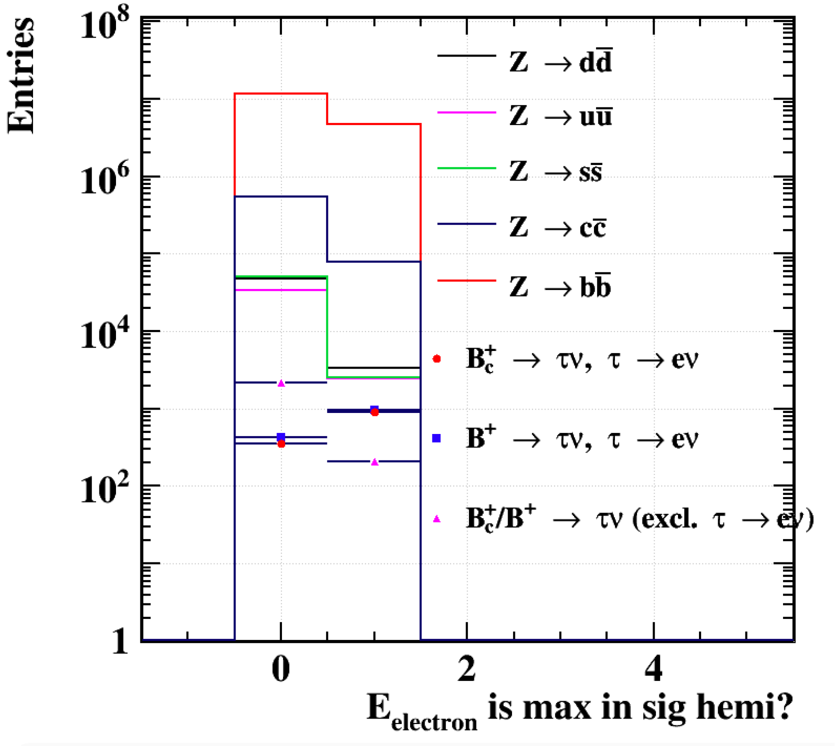


Energy asymmetry = Recoil side en – signal side en > 10 GeV

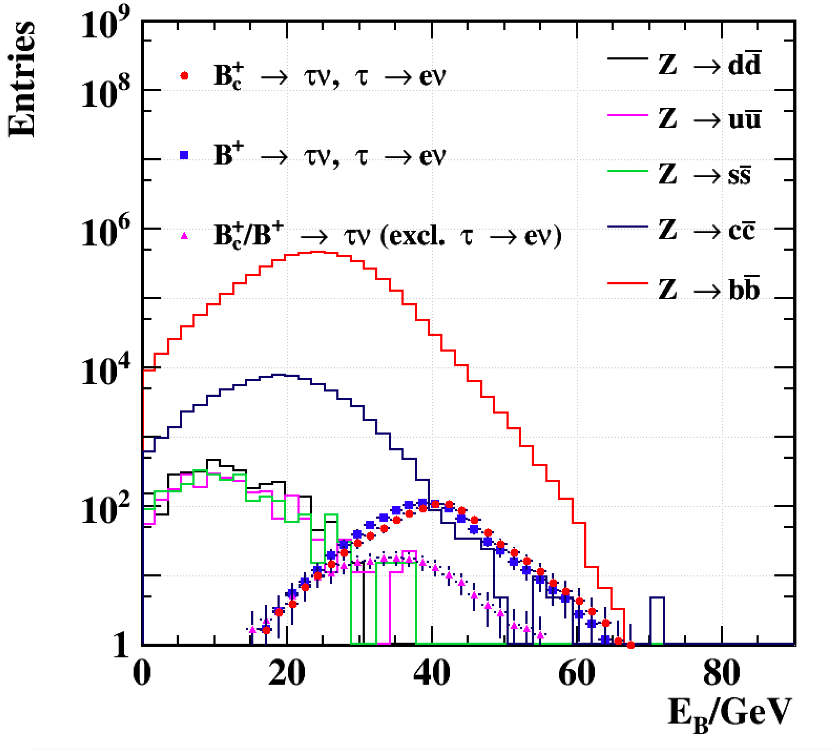


At least one electron in the signal hemisphere (if many, select the most energetic one)

Preliminary cut chain (simple scaling, $\tau \to e\nu\nu$)



The electron is the most energetic particle in the signal hemisphere



Nominal B meson energy = 91.2 – All visible energy (except the signal electron) > 20GeV

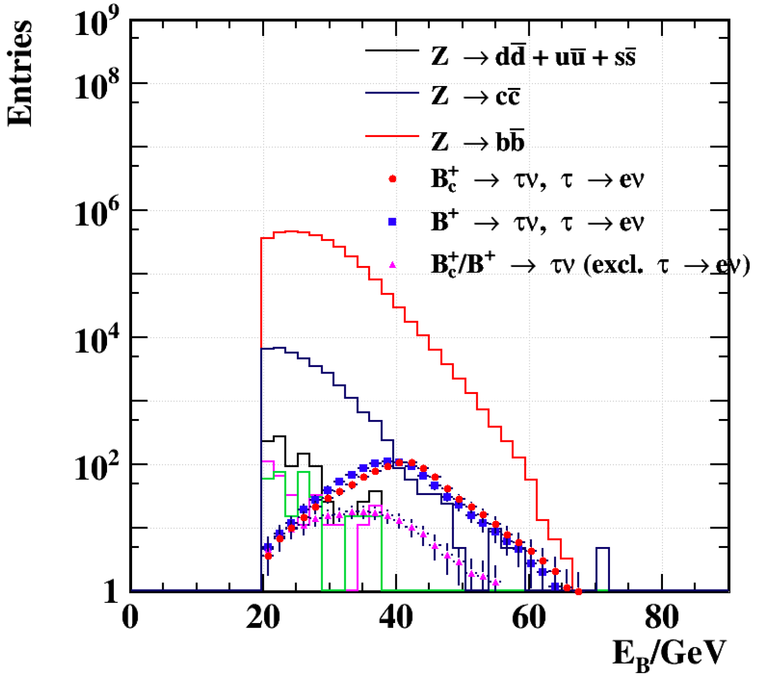
Cut chain ($\tau \rightarrow e\nu\nu$)

By now 98% of selected electrons are true electrons

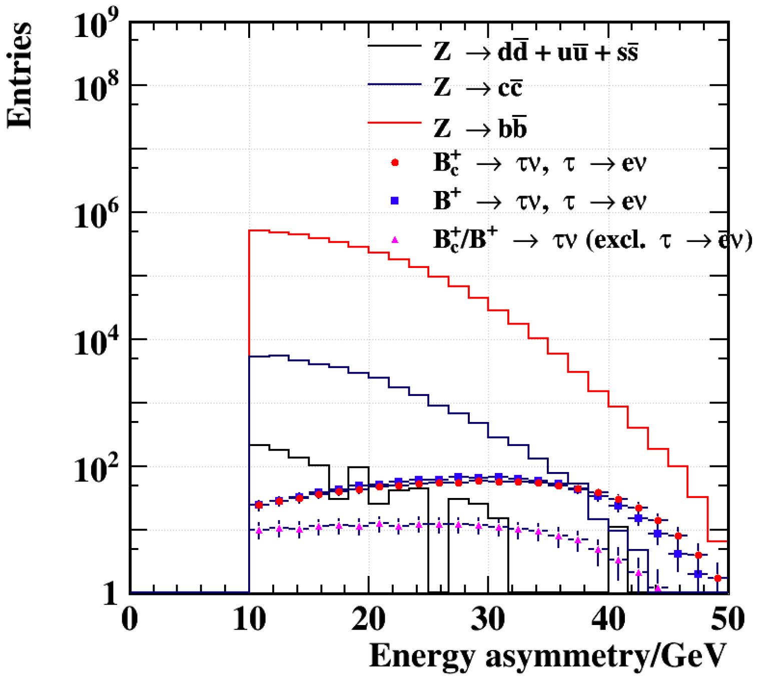
Table 1: The cut chain for electron final state. The fraction of number of each $q\bar{q}$ flavor events actually simulated is indicated in the parenthesis in the first line.

	$B_c^+ \to \tau^+\nu_\tau$		$B^+ \to \tau^+\nu_\tau$		$d\bar{d}(\frac{1}{15})$	$u\bar{u}(\frac{1}{11})$	$s\bar{s}(\frac{1}{15})$	$c\bar{c}(\frac{1}{4.8})$	$b\bar{b}(\frac{1}{3.3})$
	$\tau \to e\nu\bar{\nu}$	excl. $\tau \to e\nu\bar{\nu}$	$\tau \to e\nu\bar{\nu}$	excl. $\tau \to e\nu\bar{\nu}$					
All generated	2352	10584	2289	10647	149960130	109990276	149978820	119954033	150563659
b-tag > 0.6	1711	7615	1517	7207	720360	515636	851745	7344014	116165715
Energy asymmetry > 10 GeV	1520	6249	1381	5883	165225	116996	193905	1609771	29919812
Has electron in signal hemisphere	1352	1334	1231	1161	50685	36245	53370	625670	15828883
Electron is the most energetic particle	996	126	876	108	3315	2420	2535	79190	4565454
$E_B > 20$ GeV	987	120	873	105	345	308	300	34147	3187635
1^{st} BDT score > 0 (training data)	164	1	83	0	—	—	—	7	50
1^{st} BDT score > 0 (test data)	138	4	69	3	—	—	—	13	46
2^{nd} BDT score > 0 (training data)	110	—	27	—	—	—	—	—	—
2^{nd} BDT score > 0 (test data)	107	—	33	—	—	—	—	—	—

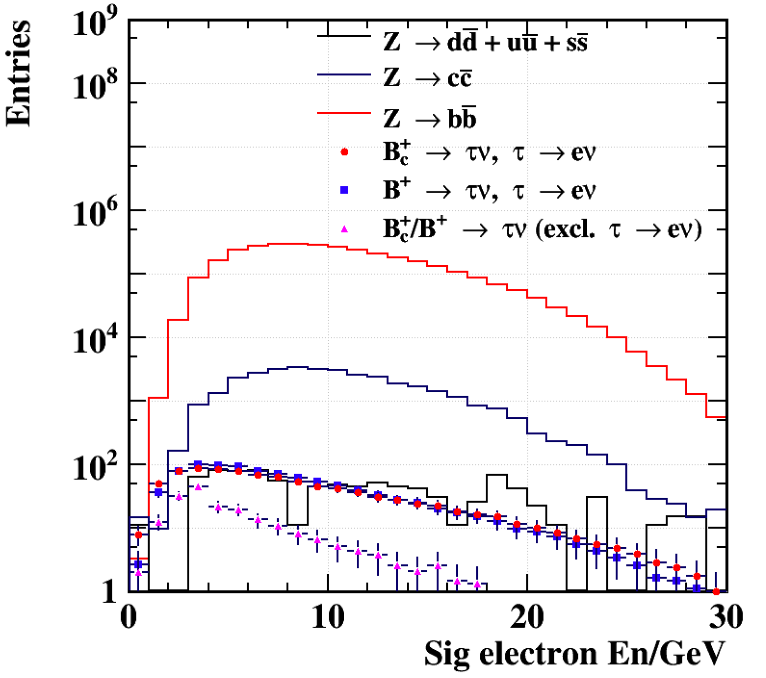
BDT variables (simple scaling, $\tau \to e\nu\nu$)



Nominal B meson En

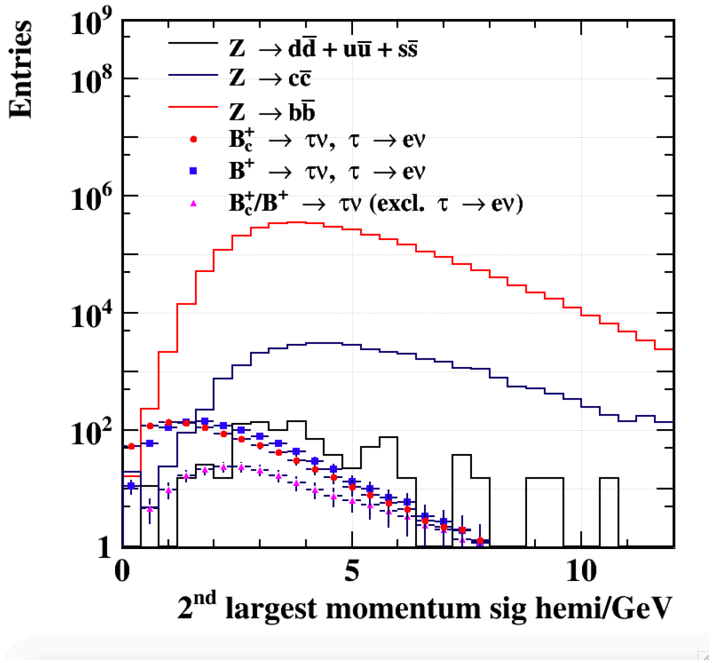


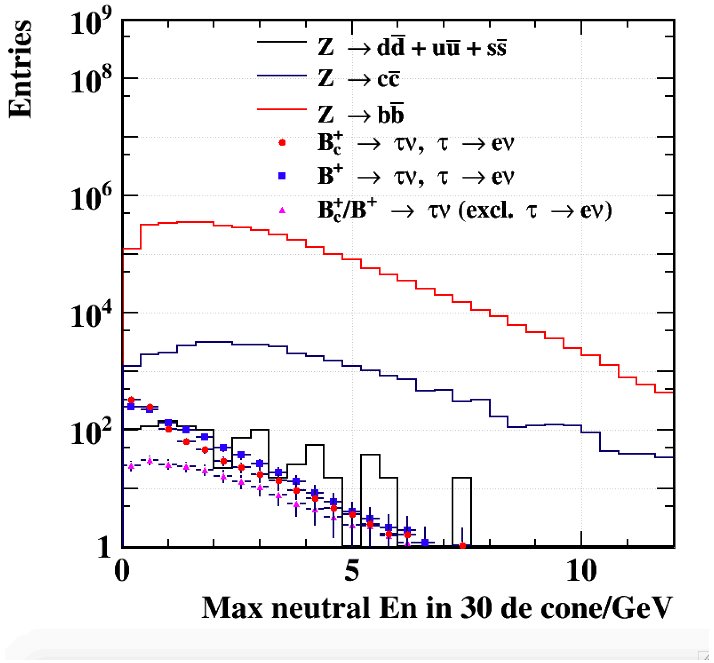
Energy asymmetry



Electron En

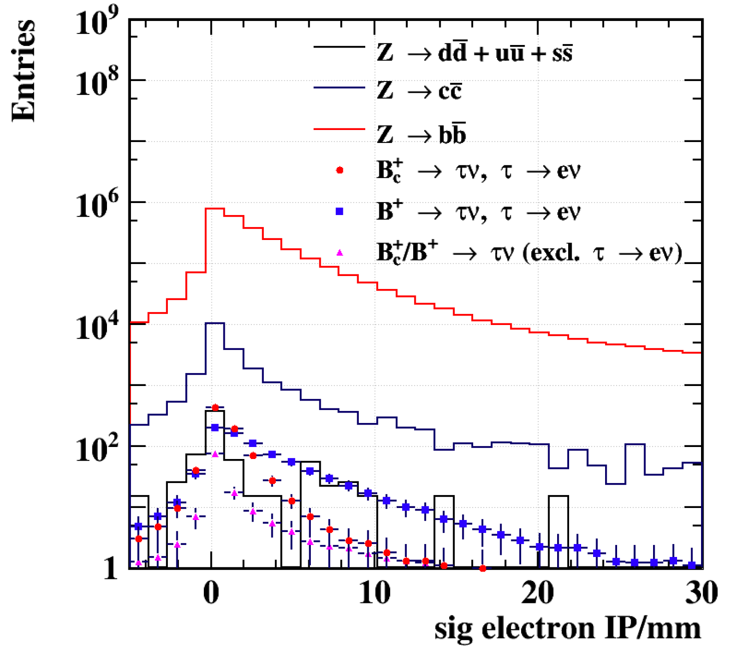
BDT variables (simple scaling, $\tau \rightarrow e\nu\nu$)



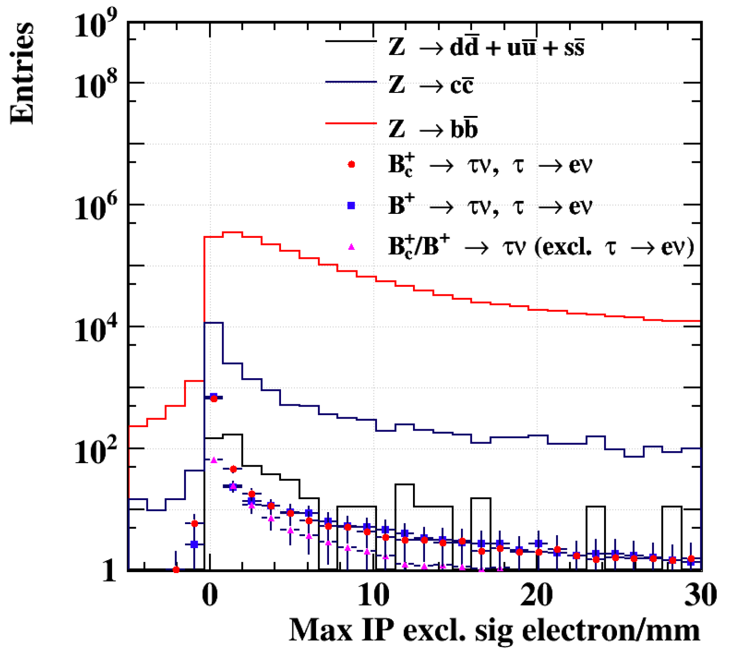


Max neutral cluster energy inside 30 deg cone around the thrust axis

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



Electron's impact parameter on the thrust axis

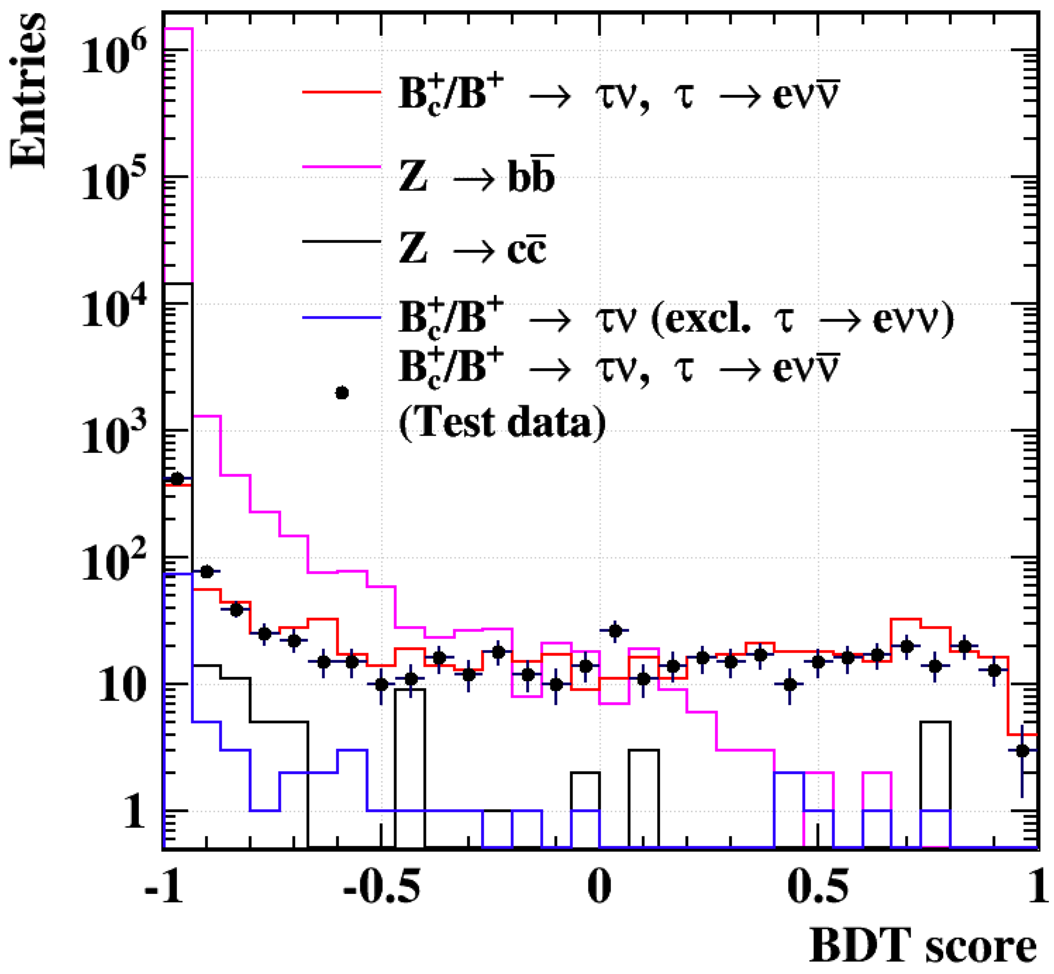


Maximum IP excluding the electron

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 z0 in respect to the thrust axis)

1^{st} BDT($\tau \to e\nu\nu$)

- Use all but electron's IP as variables
- Split the data into equal amounts for training and testing
- Both $B_c^+/B^+ \to \tau\nu, \tau \to e\bar{\nu}\nu$ are considered as signal
- The figure shows the results for training data and signal test data
- Cut at 0



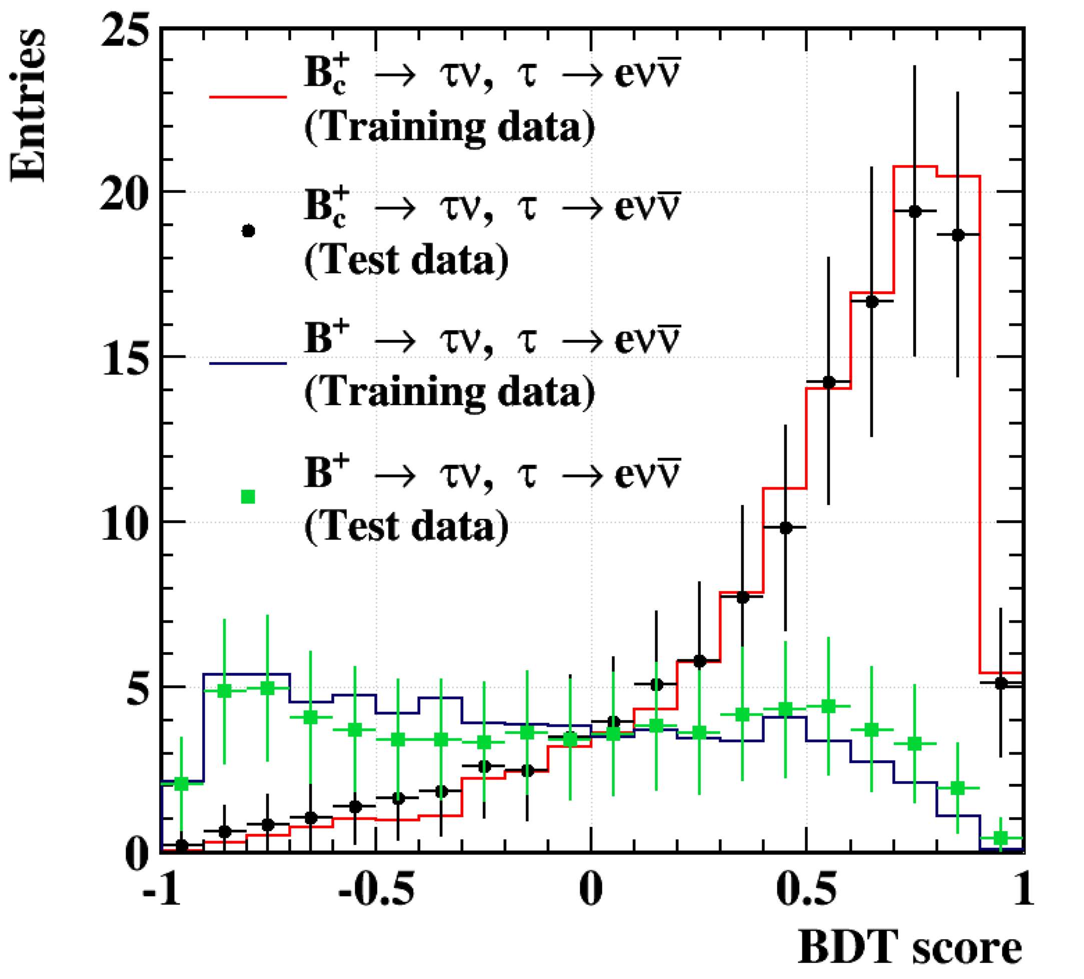
2nd BDT($\tau \rightarrow e\nu\nu$)

After 1st BDT cut, we do not have sufficient data for 2nd BDT training. Here's the solution:

1. Use weight file generated from 1st training to evaluate $1.76\times10^5 B_c^+/B^+ \rightarrow \tau\nu, \tau \rightarrow e\bar{\nu}\nu$ each. Other tau decay channels and qq backgrounds are ignored.
2. Cut at the BDT score at 0, same as in 1st BDT.
3. Perform 2nd BDT training using electron's IP as additional variable.
4. Scale down the result numbers to match original statistics

2nd BDT($\tau \to e\nu\nu$)

- Split the data into equal amounts for training and testing
- The results in the figure are already scaled down
- Cut at 0



Cut chain ($\tau \to \mu\nu\nu$)

Table 2: The cut chain for muon final state. The fraction of number of each $q\bar{q}$ flavor events actually simulated is indicated in the parenthesis in the first line.

	$B_c^+ \to \tau^+\nu_\tau$		$B^+ \to \tau^+\nu_\tau$		$d\bar{d}(\frac{1}{15})$	$u\bar{u}(\frac{1}{11})$	$s\bar{s}(\frac{1}{15})$	$c\bar{c}(\frac{1}{4.8})$	$b\bar{b}(\frac{1}{3.3})$
	$\tau \to \mu\nu\bar{\nu}$	excl. $\tau \to \mu\nu\bar{\nu}$	$\tau \to \mu\nu\bar{\nu}$	excl. $\tau \to \mu\nu\bar{\nu}$					
All generated	2256	10680	2279	10657	149960130	109990276	149978820	119954033	150563659
b-tag > 0.6	1646	7680	1586	7129	720360	515636	851745	7344014	116165715
Energy asymmetry > 10 GeV	1428	6341	1428	5832	165225	116996	193905	1609771	29919812
Has Muon in signal hemisphere	1224	2304	1232	2282	82935	59356	97065	813083	19476244
Muon is the most energetic particle	936	231	903	180	3225	2596	3720	89290	4920088
$E_B > 20$ GeV	932	223	892	174	570	429	675	39583	3499993
1^{st} BDT score > 0 (training data)	128	3	67	2	—	—	—	8	48
1^{st} BDT score > 0 (test data)	98	6	70	7	—	—	—	7	85
2^{nd} BDT score > 0 (training data)	95	—	24	—	—	—	—	—	—
2^{nd} BDT score > 0 (test data)	91	—	29	—	—	—	—	—	—

Relative signal strength accuracy $\Delta\lambda/\lambda$

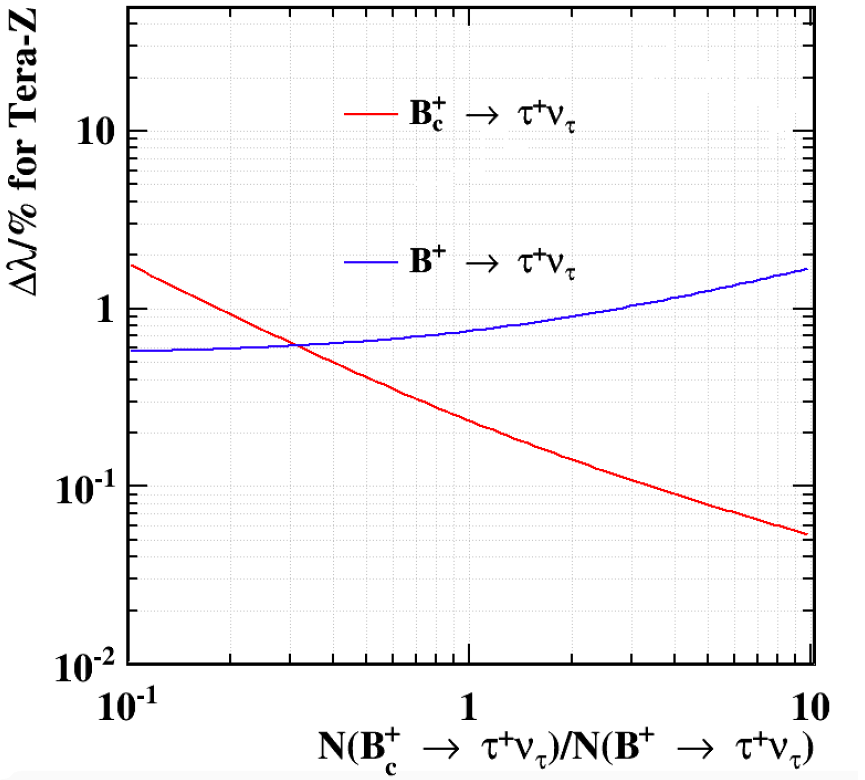
$$\Delta\lambda/\lambda = \sqrt{N_S + N_B}/N_S$$

- N_S: Total number of signals
- N_B: Total number of backgrounds
- Both N_S and N_B are obtained by multiplying the test data by 2. Which means we assume training and test data are equal and combine the two. Also, we assume all the test data from the 1st BDT survives 2nd BDT cut. So for electron final state N_B=(4+33+3+13+46)x2=198

	Signal	Others	$\Delta\lambda/\lambda$
$\tau \rightarrow e\nu\bar{\nu}$	214	198	9.5%
$\tau \rightarrow \mu\nu\bar{\nu}$	182	268	11.7%
Total	396	466	7.4%

$\Delta\lambda/\lambda$ at Tera-Z

It is now straightforward to calculate $\Delta\lambda/\lambda$ for both $B_c^+/B^+ \to \tau\nu$ at Tera-Z for various Bc statistics. The number of $B^+ \to \tau\nu$ events is fixed at $1.3\text{x}10^4$ per 1 billion Z bosons. For our assumption $\Delta\lambda/\lambda$ at Tera Z are 0.23% and 0.75% for Bc and B, respectively.



Conclusion

- If $N(B^+ \to \tau\nu) = N(B_c^+ \to \tau\nu) = 1.3\times10^4$ for 10^9 Z, the projected relative signal strength accuracies at Tera-Z are 0.23/0.75% for Bc/B→tau nu, respectively.
- We need around 1.4×10^8 Z decays to discover Bc→tau nu.
- Predictions for other Bc statistics.