Search for $B_c^+ \to \tau^+ \nu$

- an example of flavor physics at the Z pole

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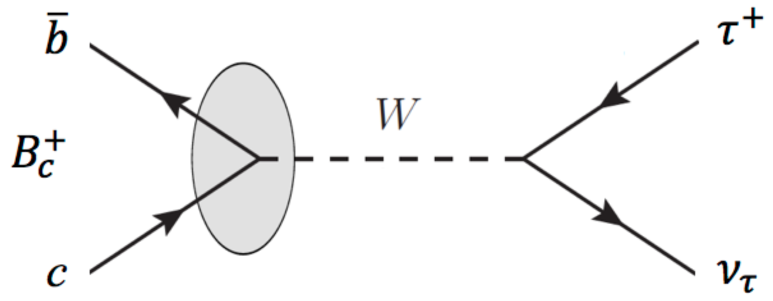
Outline

- Introduction
- Analysis strategy
- Event selection
- Similar analysis
- Summary and outlook

Theory behind

Meas. of decay constant $f_{B_c^+}$ is interesting

	f_{B_c} [MeV]
lattice NRQCD	420 ± 13
QCD sum rules	360 ± 60
various quark models	[430, 570]

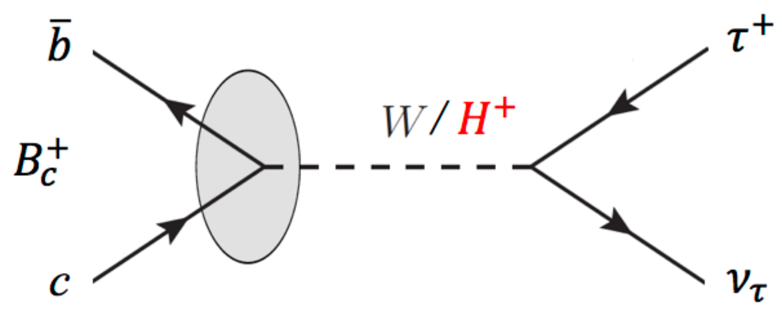


$$\Gamma(B_c^+ \to \tau^+ \nu)_{SM} = \frac{G_F^2 |V_{cb}|^2 f_{B_c}^2}{8\pi} \left(1 - \frac{m_\tau^2}{m_{B_c}^2}\right)^2 m_{B_c}\, m_\tau^2$$

τ −channel, the only experimentally accessible leptonic decay due to helicity supppression

NP search (charged Higgs)

E.g.: type II Two-Higgs doublet model (2HDM), replaces the W^+ propogator [Phys. Rev. D 48, 2342 (1993)]

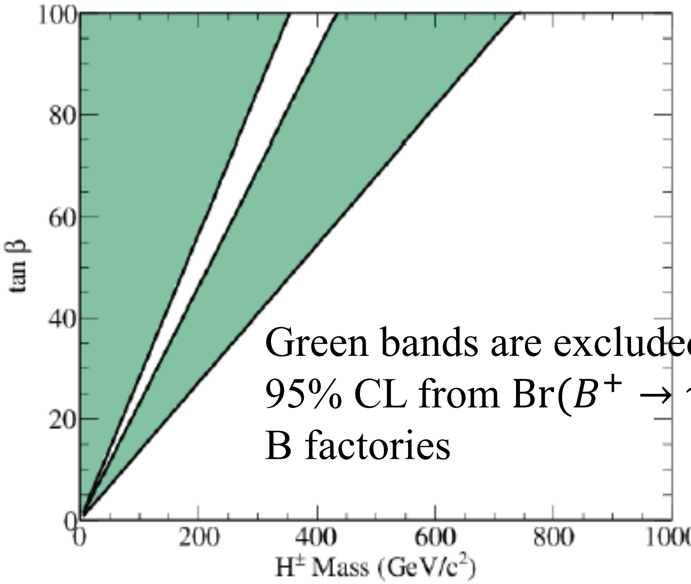


H^+ interferes with the SM process and contributes constructively or destructively

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

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

Constraint on tanβ and m_{H^+} in the type-II 2HDM model



Current status

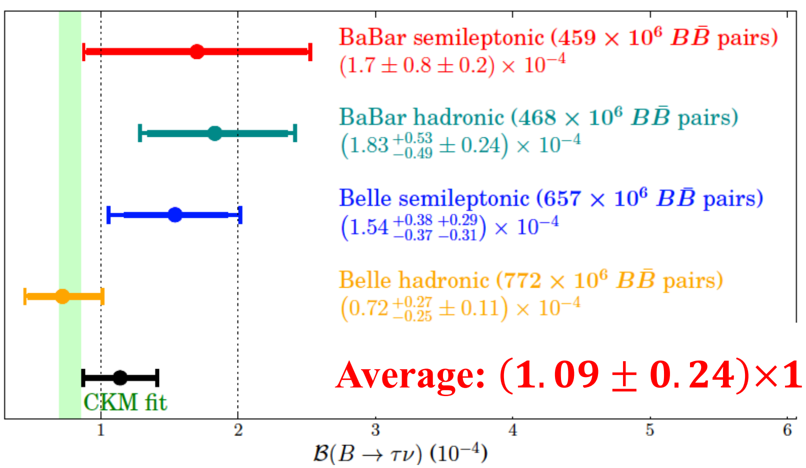
No measurements for $B_c^+ \to \tau^+\nu$ so far

$B^+ \to \tau^+\nu$ results can cast light on B_c^+ study: similar feynman diagram, similar event topology, comparable production …

$$\frac{N_{B_c^+\to\tau^+\nu}}{N_{B^+\to\tau^+\nu}} \sim O(1)$$

- ✓ $N_{B_{(c)}^+\to\tau^+\nu}$: # of $B_{(c)}^+ \to \tau^+\nu$ decays generated at the Z pole
- ✓ Small $f(b \to B_c^+)$ cancels out mostly with $|V_{cb}/V_{ub}|^2$

Measurements of $B^+ \to \tau^+\nu$ at B factories
Consistent with SM within 2σ: $(0.75 \pm 0.10)\times10^{-4}$



Average: $(1.09 \pm 0.24)\times10^{-4}$

$B^+ \to \tau^+\nu$ search at Z pole by L3 with 1.475M hadronic Z decays
5.7×10^{-4} @90% UL

L3 Collaboration, PLB 396 (1997) 327

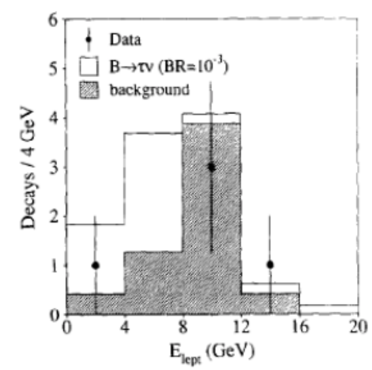


Fig. 6. Lepton energy spectrum for the selected $B^- \to \tau^-\bar{\nu}_\tau$, $\tau^- \to l^-\bar{\nu}_l\nu_\tau$ candidates. The hatched histogram represents the background, the open histogram shows the signal contribution assuming $\mathcal{B}(B^- \to \tau^-\bar{\nu}_\tau) = 10^{-3}$.

Prospect at CEPC

CEPC is (almost exclusively) the ideal factory for $B_c^+ \to \tau^+\nu$

- ✓ Belle II: clean, but no heavy b-hadrons (B_s, B_c or b-baryon)
- ✓ LHCb: energetic and rich in all heavy b-hadrons, but hard for final states with missing energy or photons

Prospect at CEPC (10^{11} Z bosons):

- ✓ ~1M $B_{(c)}^+ \to \tau^+\nu$ will be generated
- ✓ With $\varepsilon_{B_c^+\to\tau^+\nu} = 0.01$, a statistic error at 1% level is expected

Data sample

- ✓ Signal MC (Pythia 8)

  16k $Z \to b\bar{b}$, $B_c^+ \to \tau\nu$, $\tau \to e + 2\nu$

  1/10 of the expected sample in 10^{11} Z bosons

We start with one-prong of e in the τ decay, but later will extend to $\tau \to \mu/\pi/3\pi + n\nu$

- ✓ Background MC (whizard):

  10M $Z \to b\bar{b}\ /c\bar{c}\ /u\bar{u}\ /d\bar{d}\ /s\bar{s}$, respectively

  1/1000 of the expected sample in 10^{11} Z bosons

Thanks Gang

Analysis strategy

1. Define thrust axis $\boldsymbol{n}$ using all the charged and neutral particles, when T is maximized:

$$T = \max_{|\boldsymbol{n}|=1} \frac{\Sigma_i |p_i \cdot n|}{\Sigma_i |p_i|}$$

T=0: two back-to-back pencil jets;
T=1/2: spherically symmetric

2. Divide the final state into signal and recoiling hemispheres along the thrust axis:

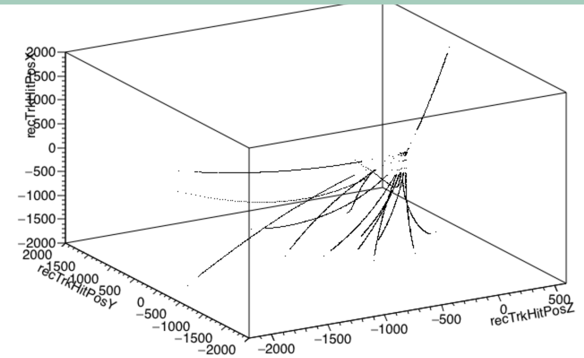
In the signal side:

- Much smaller total energy due to the missing $\nu' s$
- Low multiplicity

In the recoiling side

- Tagged as b-jet

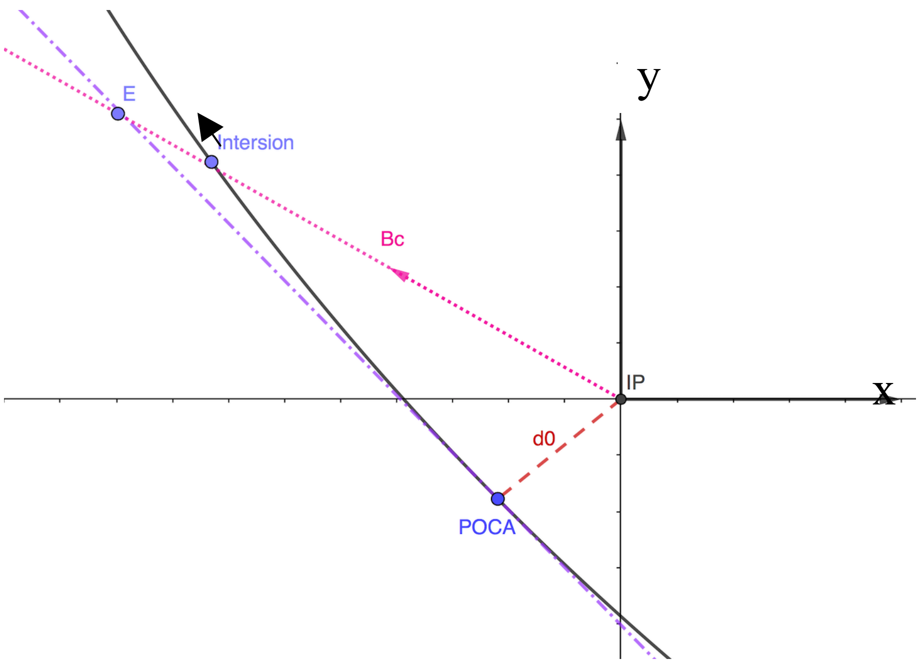
characteristic event topology: 1 b-jet in one hemisphere + 1 prong (e) in the other



Analysis strategy

3. In the cone ($\Delta\theta < 0.5$ rad) around the thrust axis:

- One energetic charged track with displaced vertex (characteristic IP)
- Other tracks are soft and come from PV
- Little neutral energy



Impact Parameter (IP) is d0 (clsoest distance to IP)

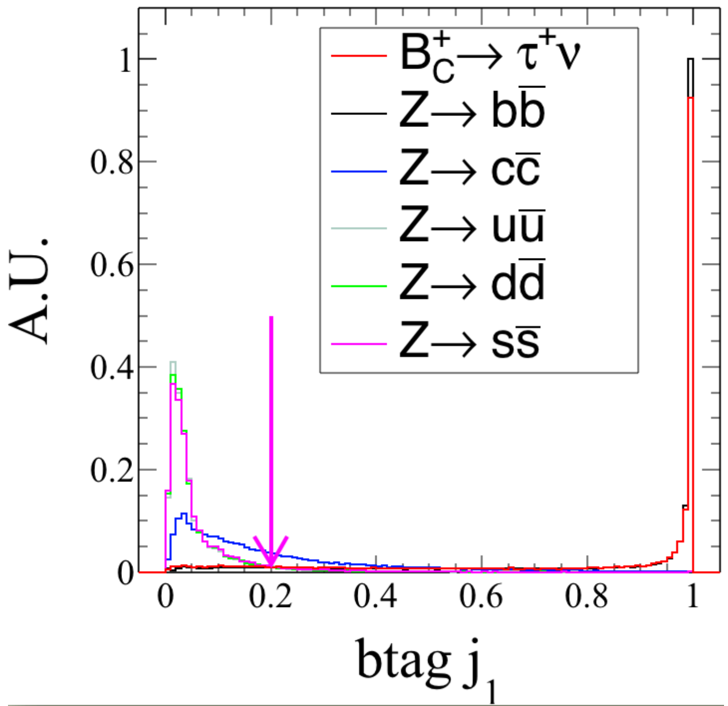
Its sign is determined by the intercept of the track with the B_c^+ flight path

b-jet tagging

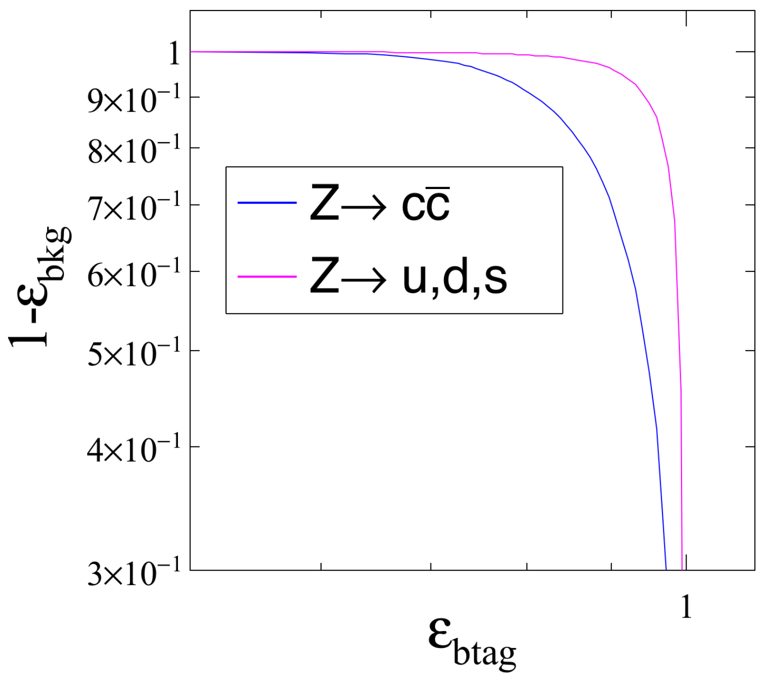
Cluster the events into two jets

The leading jet is well identified as b-jet:

$btag > 0.2$



b-tag efficiency vs bkg rejection

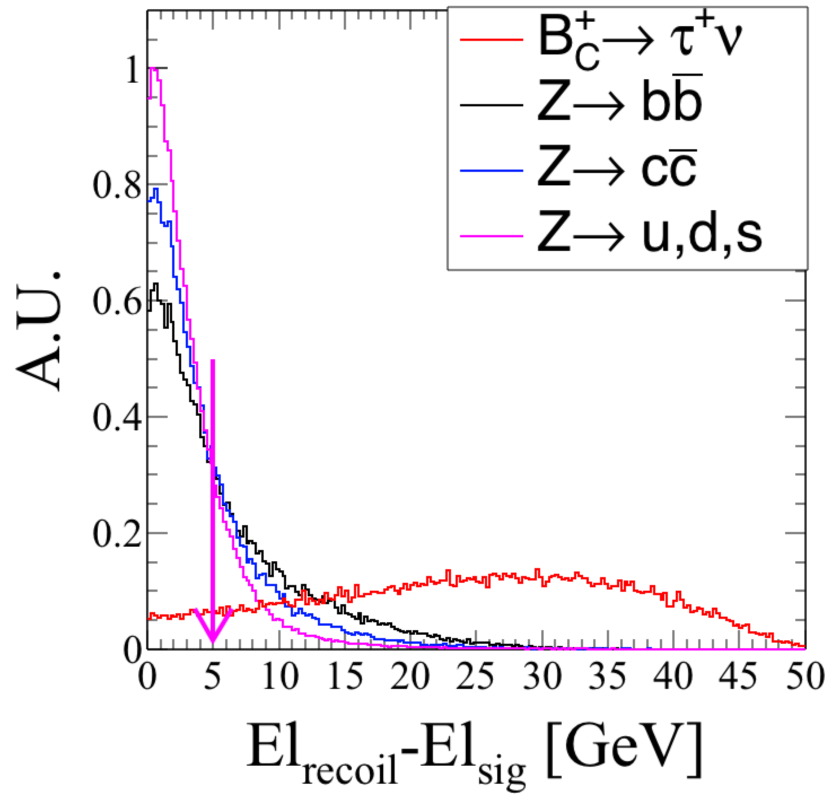


Energy imbalance btw two hemispheres

$E_{recoil\ (sig)}$: the total energy projected along the thrust in the recoiling (signal) side

Large energy imbalance is expected in signal MC due to the missing $\nu's$

$E_{recoil} - E_{sig} > 5$ GeV



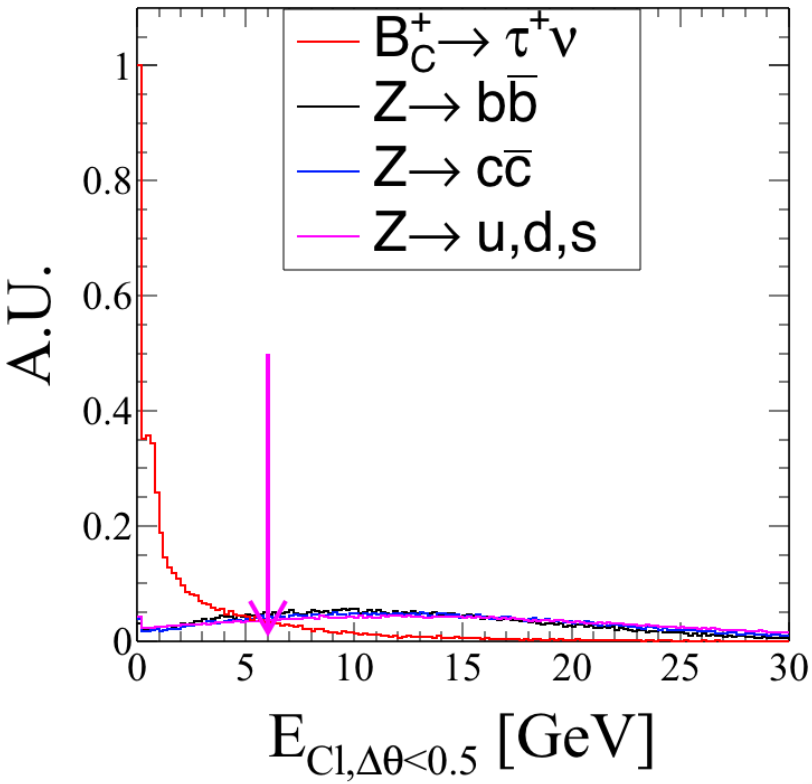
Neutral clusters in the B_c^+ cone

B_c^+ cone definition: $\Delta\theta < 0.5$ around the thrust

$E_{Cl,\Delta\theta<0.5}$: total energy of neutral particles in the B_c^+ cone

Little neutral energy deposit is expected in the B_c^+ cone

$E_{Cl,\Delta\theta<0.5} < 6$ GeV

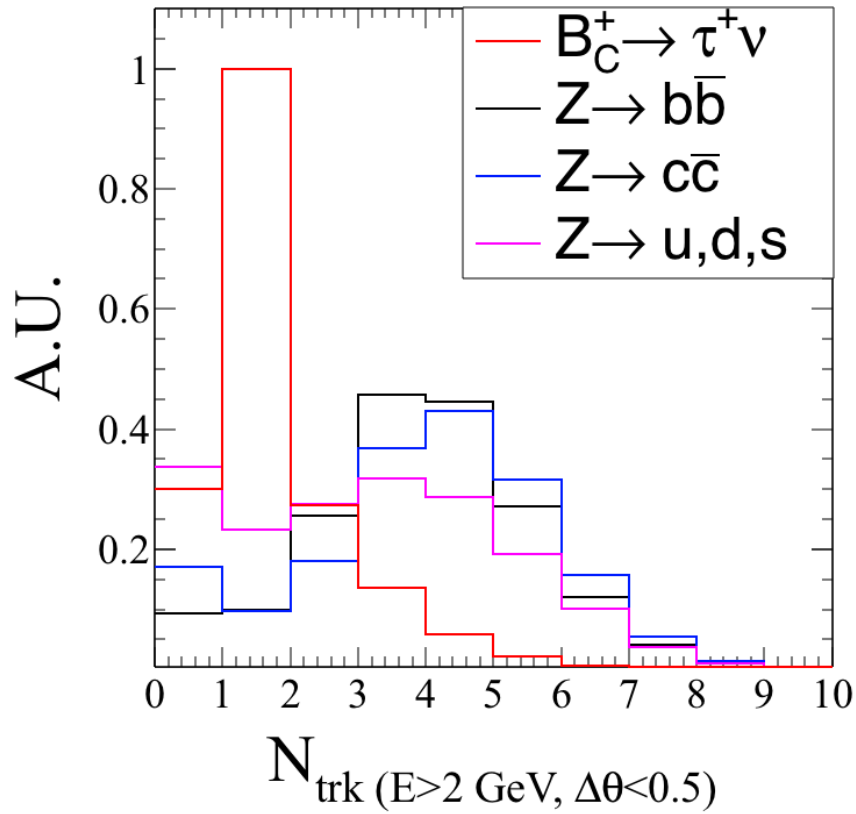


Charged tracks in the B_c^+ cone

N_{trk}: number of charged tracks (E>2 GeV) within the cone

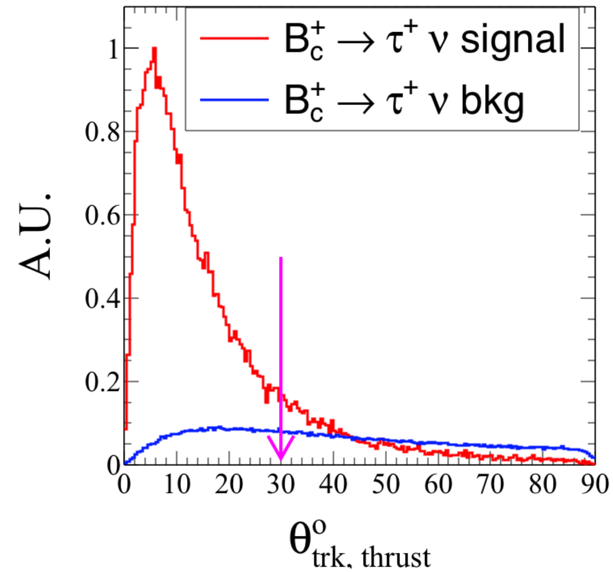
Tracks from the other c-quark may also fall in the cone

Pre-cuts applied!

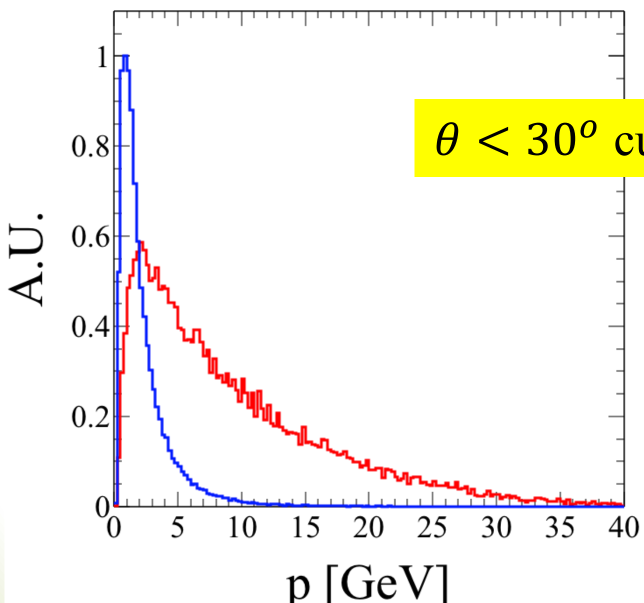


Signal and fragmentation tracks in the B_c^+ cone

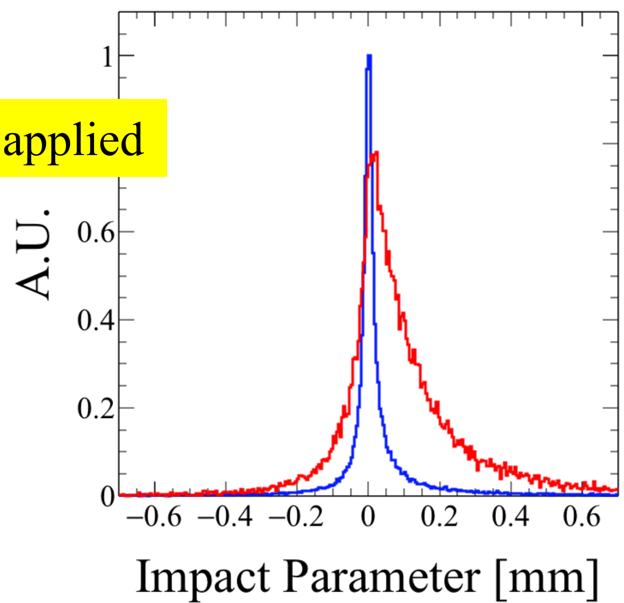
Most signal tracks (from τ) stay within 30^o of the thrust



Signal tracks are harder, and assymetric IP



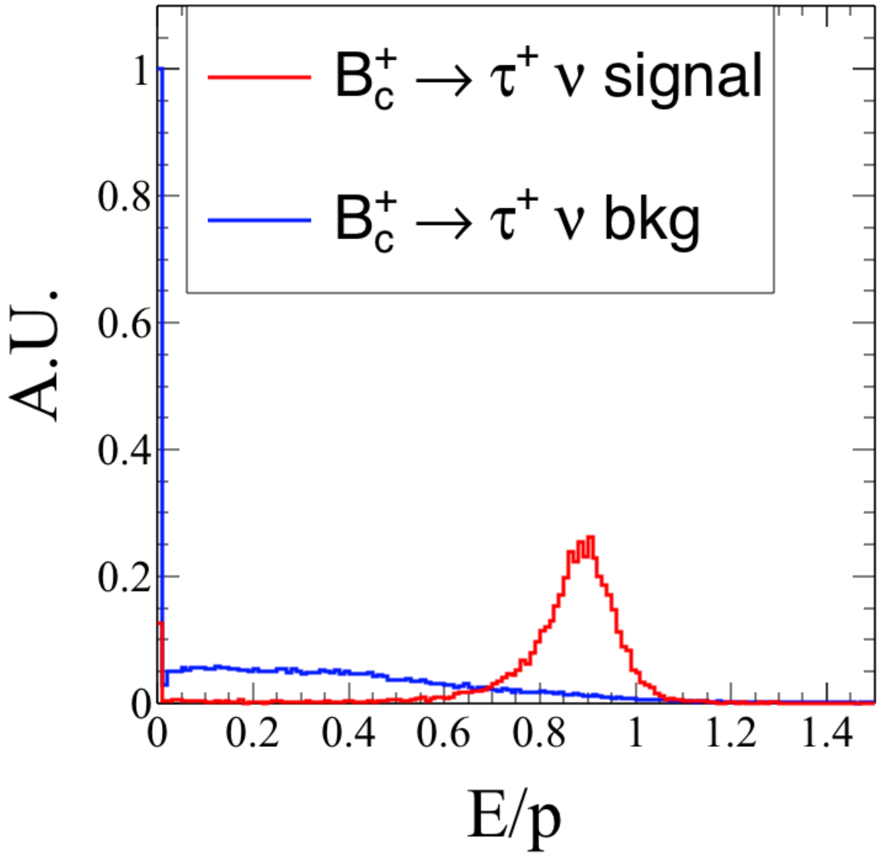
$\theta < 30^o$ cut applied



Electron identification

E/p gives good discriminant power between the signal electron and fragmentation tracks

Tentative signal electron identification: E/p>0.8, p>2GeV



Similar analysis

EW box decays with 2 neutrinos have a similar signiture as $B_c^+ \rightarrow \tau\nu$: clean charged track(s) plus large missing energy, e.g.:

$B_s \rightarrow \phi\nu\nu$, $\Lambda_b \rightarrow \Lambda\nu\nu$ (unique at Z pole)
$B^0 \rightarrow K_S\nu\nu, B^+ \rightarrow K^+\nu\nu$ (even better precision than BelleII)

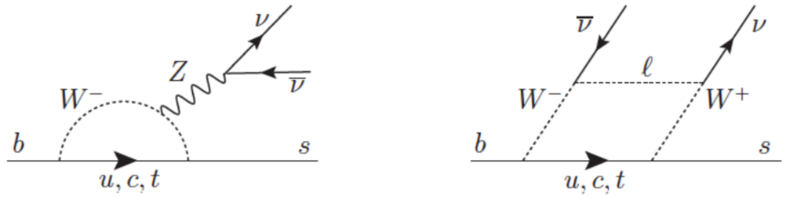


FIG. 1: Lowest-order SM Feynman diagrams for $b \rightarrow s\nu\overline{\nu}$ transitions. The virtual top quark provides the dominant contribution in each case.

Wide variety of NP scenarios can modify the expected branching fractions and q2 (lepton pair mass) distribution:

- ✓ Particles contributing to additional loop diagrams (non-standard Z couplings with SUSY particles, 4th generation quarks, anomalous top-charm transitions, or a massive U(1) gauge boson Z)
- ✓ New particles forming the missing four momentum, such as low-mass dark-matter candidates, unparticles, right-handed neutrinos, or SUSY particles
- ✓ Models with universal extra dimension also predict higher BR

Summary:

- ✓ $B_c \to \tau\nu$ search is of great interest and can even be exclusively studied best at CEPC
- ✓ Based on MC simulation, analysis methodology is investigated for electron channel
- ✓ b-hadron with similar final-state topology could also be promising

Outlook:

- ✓ Explore more selection to suppress the backgrounds
- ✓ To discriminate signal from fragmentation tracks on the signal side
- ✓ Disentange $B_c^+ \to \tau\nu$ and $B^+ \to \tau\nu$ and measure the BFs simultaneously.
  BF($B^+ \to \tau\nu$) can be used to measure V_{ub} with f_{B^+} taken from LQCD calculation

  How? Tag cham-hadron, Impact parameter distribution, energy of the signal track …

- ✓ $f(b \to B_c^+)$ will be the largest uncertainty in $\mathrm{Br}(B_c^+ \to \tau\nu)$ measurement

  One probable solution: drop out $f(b \to B_C)$ by measuring $\frac{\mathrm{Br}(B_c \to \tau\nu)}{\mathrm{Br}(B_c \to J/\psi l\nu)}$

Backup

#$B_c \to \tau\nu$ vs #$B_u \to \tau\nu$ at the Z pole

$$\frac{N_{B_c}}{N_{B_u}} = \frac{f(b\to B_c)}{f(b\to B_u)} \left|\frac{V_{cb}}{V_{ub}}\right|^2 \left(\frac{f_{B_c}}{f_{B_u}}\right)^2 \frac{m_{B_c}}{m_{B_u}} \frac{\tau_{B_c}}{\tau_{B_u}} \frac{(1-\frac{m_\tau^2}{m_{B_c}^2})^2}{(1-\frac{m_\tau^2}{m_{B_u}^2})^2}$$ ~ O(1)

- $\frac{\tau_{B_c}}{\tau_{B_u}}$ ~ 0.31 (±2%)
- $\frac{m_{B_c}}{m_{B_u}} \frac{(1-\frac{m_\tau^2}{m_{B_c}^2})^2}{(1-\frac{m_\tau^2}{m_{B_u}^2})^2}$ ~ 1.3 (<< ±0.1%)
- $\left(\frac{f_{B_c}}{f_{B_u}}\right)^2$ ~ 6.2 (±10%; ±3.5% each f_{Bc} and f_{Bu} each, correlated?
- $\left|\frac{V_{cb}}{V_{ub}}\right|^2$ ~ 120 (±20%; ±9% V_{ub}, ±2% V_{cb}, BELLEII expects to measure V_{ub} with 1% precision)
- $\frac{f(b\to B_c)}{f(b\to B_u)}$ ~ O(1/400) (0.02% - 0.1% $f(b\to B_c)$, ±5.8% $f(b\to B_u)$)

Signal and fragmentation tracks in the B_c^+ cone

$\theta < 30^o$ cut applied