The analysis of $Bs \to \phi\nu\bar{\nu}$ At CEPC

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Outline

1. Introduction and Motivation
2. Signal and background
3. Reconstruction of ϕ
4. Events analysis
5. Results and conclusion

Luminosity and Statistics

CEPC scheme

operation mode	Z factory	WW threshold scan	Higgs factory
center-of-mass energy (GeV)	91.2	160	240
running time (yeas)	2	1	7
L ($10^{34}cm^{-2}s^{-1}$)	32	10	3
intergrated luminosity (ab^{-1})	16	2.6	5.6
Higgs yield	-	-	10^6
W yield	-	10^7	10^8
Z yield	10^{12}	10^8	10^8

$Z \to b\bar{b}$: ~1.5×10^{11}

$Z \to c\bar{c}$: ~1.2×10^{11}

$Z \to \tau^+\tau^-$: ~3.37×10^{10}

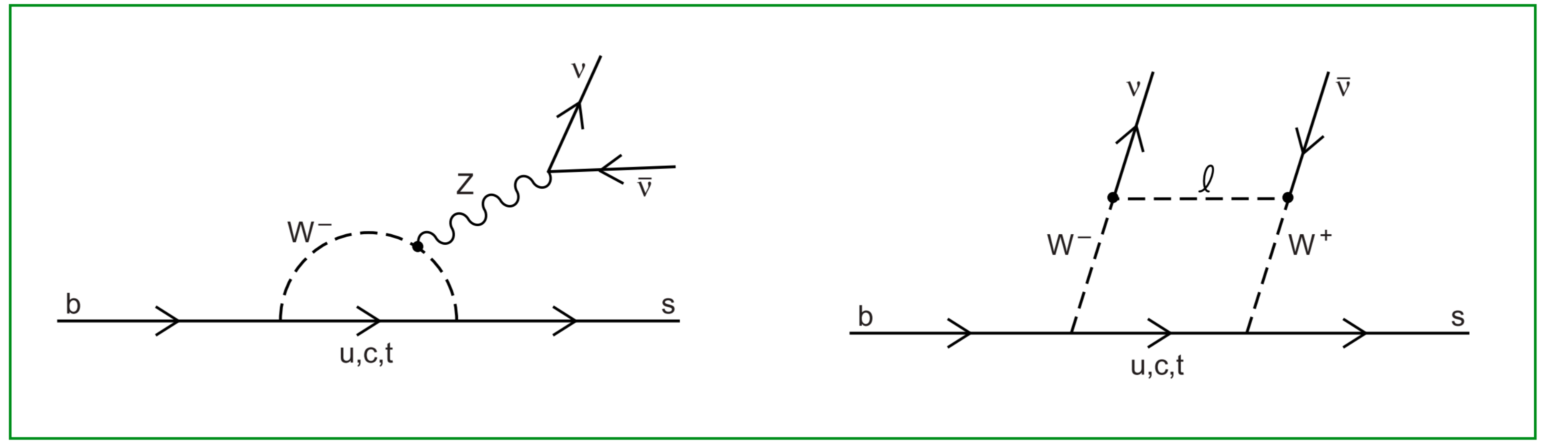
Provides unique opportunities
for various flavor measurements

Huge B flavor physics potential of Tera-Z, especially B_s , B_c and Λ_b $\cdots$

Channel	Belle II	LHCb	Giga-Z	Tera-Z	10×Tera-Z
B^0, $\bar{B}^0$	5.3×10^{10}	$\sim 6 \times 10^{13}$	1.2×10^8	1.2×10^{11}	1.2×10^{12}
$B^\pm$	5.6×10^{10}	$\sim 6 \times 10^{13}$	1.2×10^8	1.2×10^{11}	1.2×10^{12}
B_s, $\bar{B}_s$	5.7×10^8	$\sim 2 \times 10^{13}$	3.2×10^7	3.2×10^{10}	3.2×10^{11}
$B_c^\pm$	-	$\sim 2 \times 10^{11}$	2.2×10^5	2.2×10^8	2.2×10^9
Λ_b, $\bar{\Lambda}_b$	-	$\sim 2 \times 10^{13}$	1.0×10^7	1.0×10^{10}	1.0×10^{11}

Rare decay $b \to s\nu\bar{\nu}$

The decay rates of exclusive channel by SM ranges from $10^{-6} \sim 10^{-5}$.



- Difficulty on the experimental

  Direct measurement on $\nu\bar{\nu}$ system is difficult

  Need the full reconstruction technique

  Large luminosity

  PFA algorithm at CEPC

- Main experiments attempted at B factory

  None have been found

- The precise measurement are expected in the future e^+e^- collider

	Experimental [2]	SM Prediction [3, 4]
$\mathrm{BR}(B^0 \to K^0\nu\bar{\nu})$	$< 2.6 \times 10^{-5}$	$(2.17 \pm 0.30) \times 10^{-6}$
$\mathrm{BR}(B^0 \to K^{*0}\nu\bar{\nu})$	$< 1.8 \times 10^{-5}$	$(9.48 \pm 1.10) \times 10^{-6}$
$\mathrm{BR}(B^\pm \to K^\pm\nu\bar{\nu})$	$< 1.6 \times 10^{-5}$	$(4.68 \pm 0.64) \times 10^{-6}$
$\mathrm{BR}(B^\pm \to K^{*\pm}\nu\bar{\nu})$	$< 4.0 \times 10^{-5}$	$(10.22 \pm 1.19) \times 10^{-6}$
$\mathrm{BR}(B_s \to \phi\nu\bar{\nu})$	$< 5.4 \times 10^{-3}$	$(11.84 \pm 0.19) \times 10^{-6}$

DELPHI

Rare decay $b \to s\nu\bar{\nu}$

- Investigation of flavor-changing neutral current (FCNC) decays is of fundamental interest

- Large luminosity and advantage on the τ, B_s, B_c, Λ_b… measurements especially the missing final state rare decay

- Rare FCNC decay $b \to s\nu\bar{\nu}$ is free from strong interaction effects and not affected by non-factorizable corrections, theoretically cleaner compared to $b \to \phi\ell\ell$ transitions.

- Observation of this decay could test the SM prediction and provide opportunity to explore new physics.

- Performance the benchmark of simulation and reconstruction at CEPC, such as charged lepton identify, $\phi(1020) \to K^+K^-$ reconstruction, boson mass resolution (BMR) and missing energy, mass.

The Signal Topology

Number of signal decay by SM prediction at CEPC :

$$N(B_s \to \phi(K^+K^-)\nu\bar{\nu}) \sim 1.8 \times 10^5 \times 0.492$$

Branch of $B_0 \to \phi\nu\nu$ is much smaller than $B_s \to \phi\nu\nu$ and thus free of the B_0 influence.

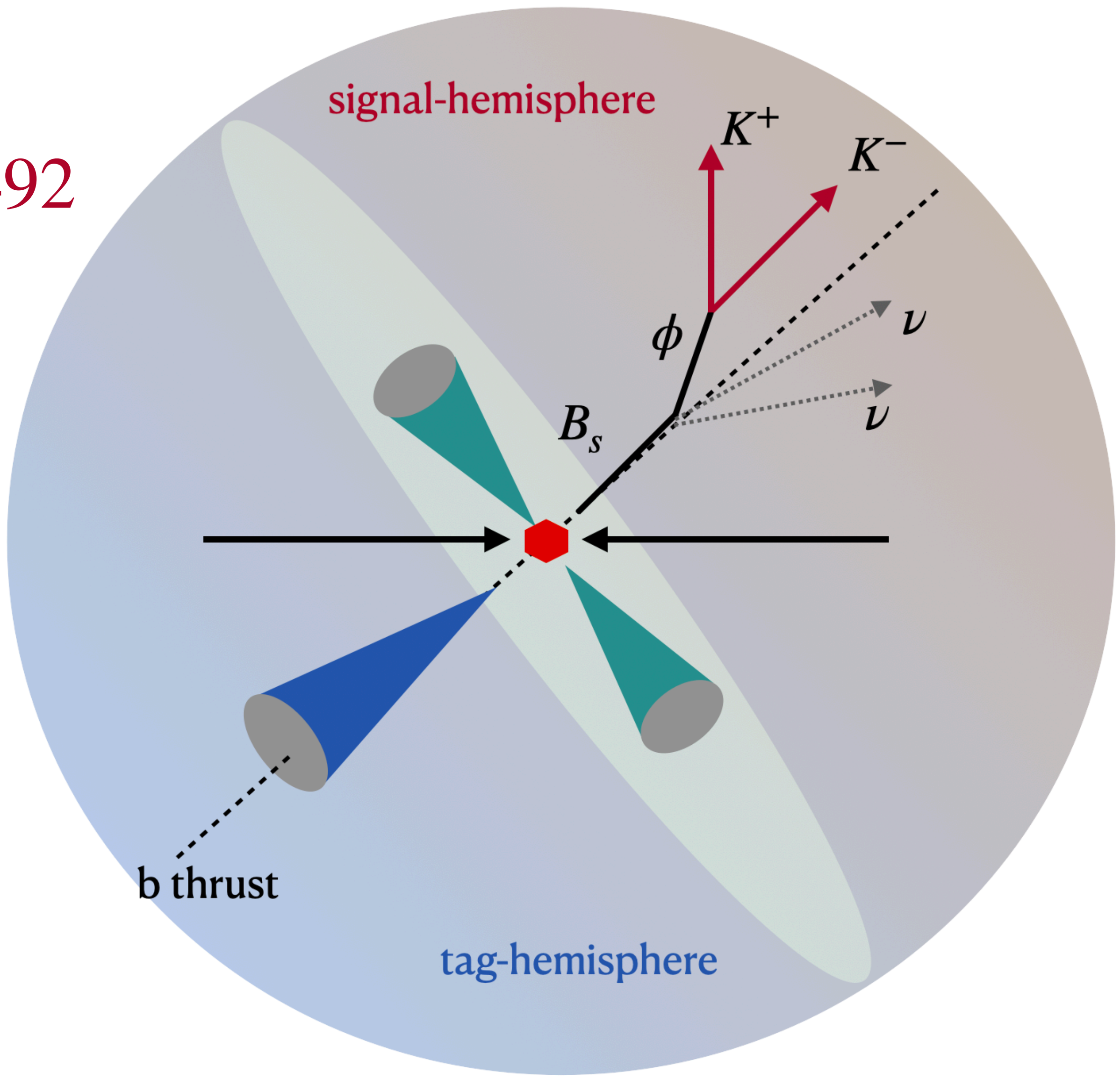
Signal ϕ reconstruction:

$\phi \to K^+K^-$ (49.2%)

Signal samples:

10^6 signal events by Pythia8 with EvtGen

$$e^+e^- \to Z \to b\bar{b},\ \bar{b} \to B_sX, B_s \to \phi\nu\bar{\nu}$$



The Background

Generator : CEPC official - whizard-1.9.5

General background

- The $q\bar{q}$ events especially the heavy-flavor $b\bar{b}$ and $c\bar{c}$
- $10^6 \sim 10^7$ full simulation samples for each channel

Main background

- The semi-leptonic decay of $B^{(*)}$ or $D^{(*)}$ decay

  $b\bar{b} : b \to B(B^*) \to D(D^*)\ell\nu_\ell$ with $D(D^*) \to \phi X$

- One or more ϕ produced and decay to K^+K^- pair
- Significant missing energy
- Full simulation samples generated corresponding to ~3×10^8 for each heavy-flavor channel

At CEPC, with 1.5×10^{11} $b\bar{b}$ events, the expected advance?

- More than 5 higher order of magnitude than current limit (2.844×10^6 $e^+e^- \to Z$)
- At least 2-3 order optimization for the branch limit
- Test the SM prediction precisely

ϕ reconstruction

Reconstruct the decay $\phi(1020) \rightarrow K^+K^-$

- Lose ~50% signal decay inevitable
- Take pairs of oppositely charged tracks in the jet chamber
- Assuming both tracks to be Kaons (No Kaon PID yet)
- Employ the kinematic fit package for ILC to reconstruct the secondary vertex

Suehara, T. & Tanabe, T. LCFIPlus: A framework for jet analysis in linear collider studies. *Nucl Instruments Methods Phys Res Sect Accel Spectrometers Detect Assoc Equip* **808**, 109–116 (2016).

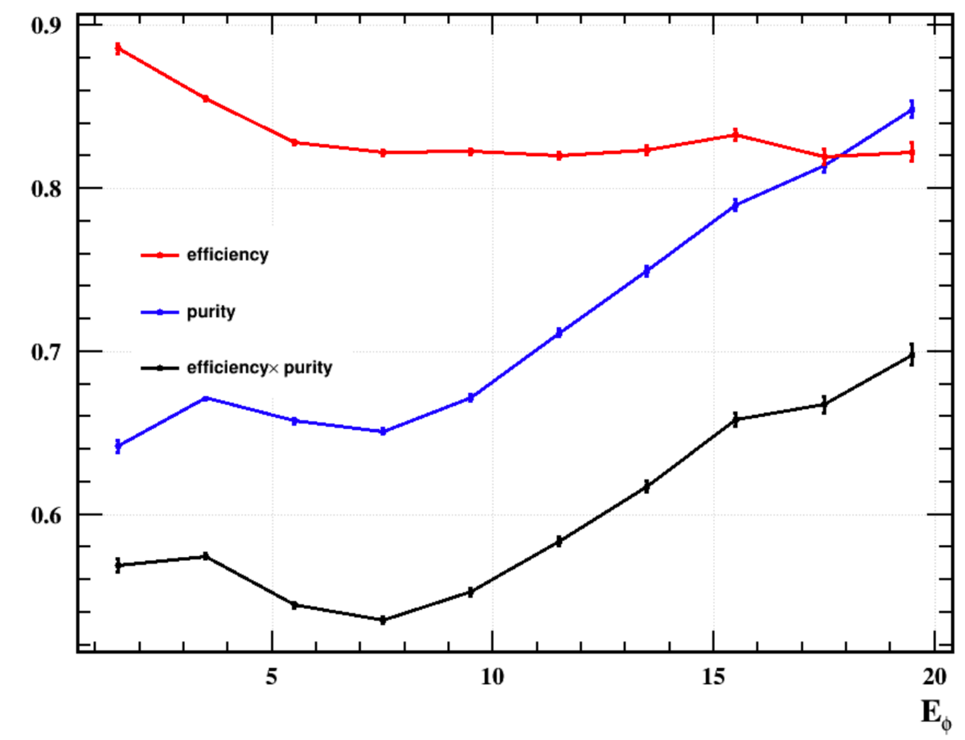
- Form their invariant mass

$$|M_{trk1,trk2} - M_{\phi}| < 0.01 \text{ GeV}$$

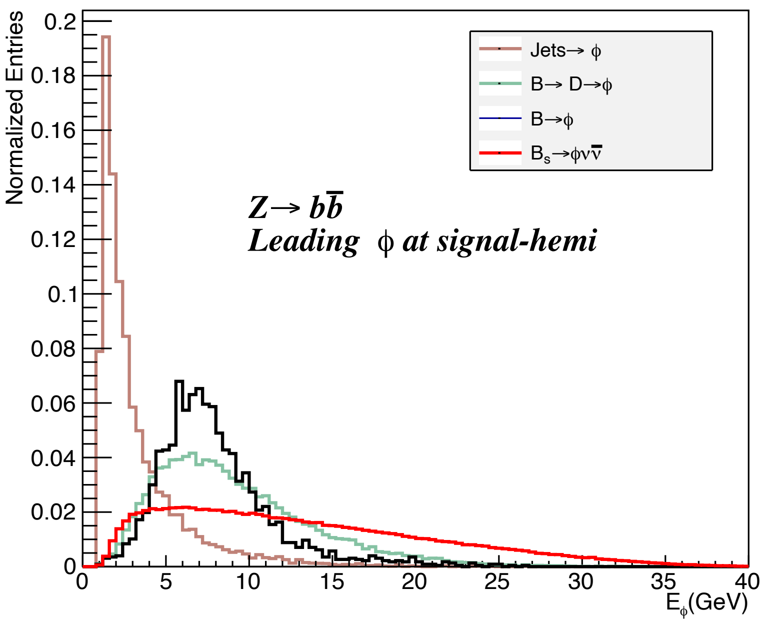
The ϕ reconstruction efficiency and purity for general background

$$\epsilon = \frac{\text{Number of correctly selected track pair candidates}}{\text{Number of } \phi \rightarrow K^+K^- \text{ events}}$$

$$p = \frac{\text{Number of correctly selected track pair candidates}}{\text{Number of selected track pair candidates}}$$

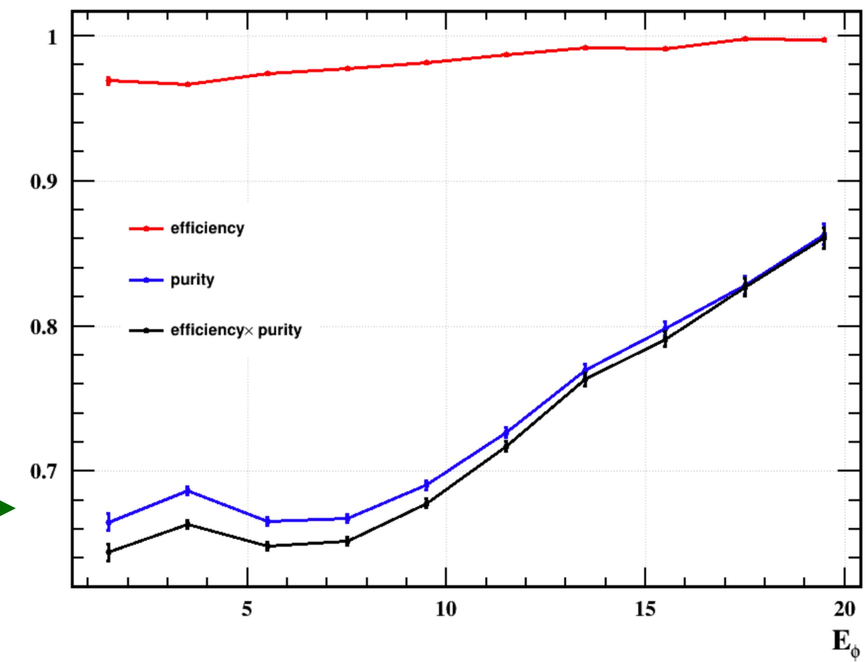


ϕ reconstruction



In the $B_s \to \phi\nu\bar{\nu}$ analysis

- ϕ in signal-hemisphere
- Leading energy one

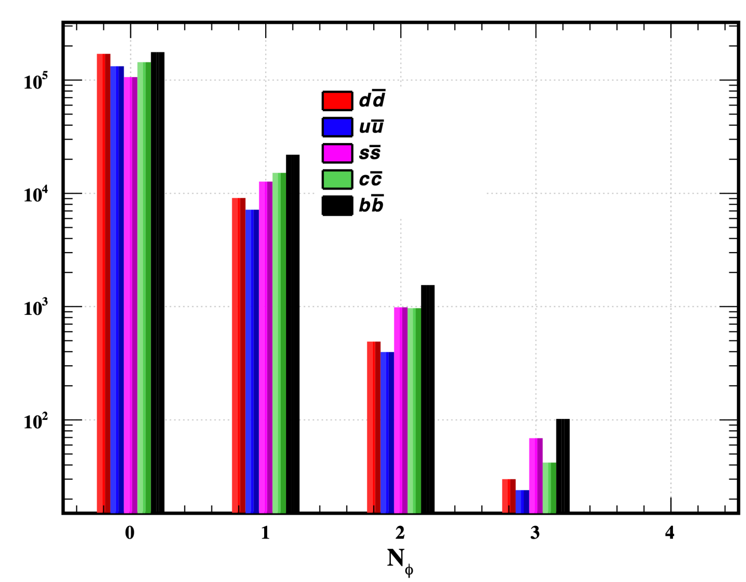


- Integrated efficiency and luminosity

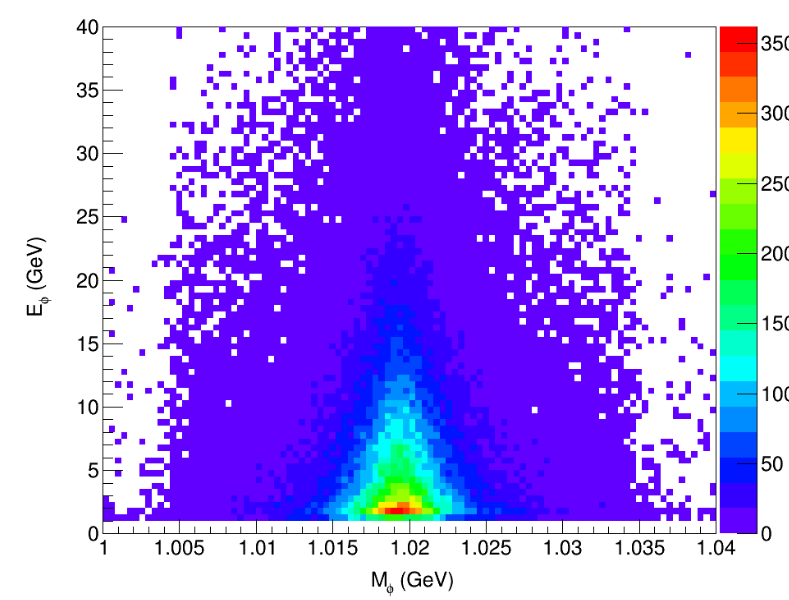
0.9790 and 0.7062

By ϕ with track pair decay in signal-sphere, background are suppressed by about 1/40

Potential optimization space for purity by Kaon PID ?



Number of ϕ distributions for each channel



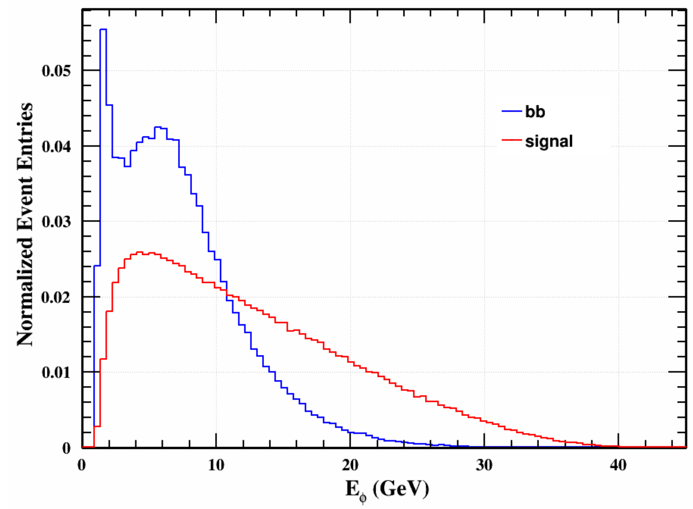
Energy-Mass distribution of reconstructed ϕ

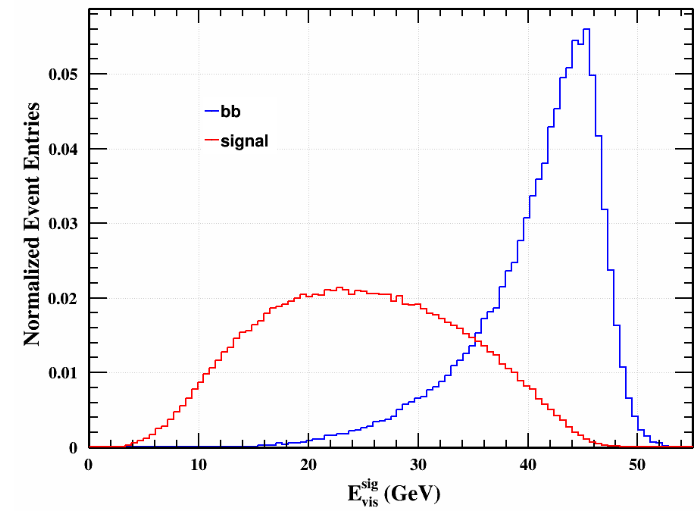
Events Analysis By ϕ

Now, we have a leading ϕ with its kinematic and vertex

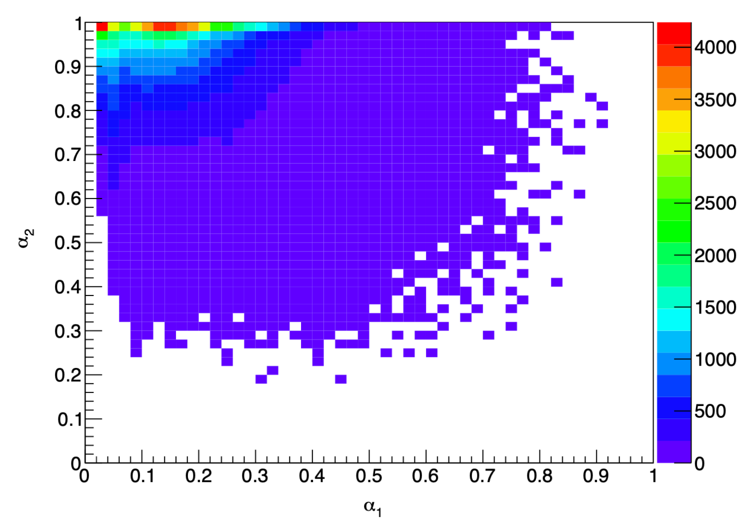
Define the scaleless variables $\alpha_1 = \frac{E_\phi}{E_{vis}^{sig}}$ and $\alpha_2 = \frac{E_{vis}^{sig}}{E_{beam}}$

E_{vis}^{sig} is the energy of signal-hemisphere and $E_{beam} = 45.6$ GeV

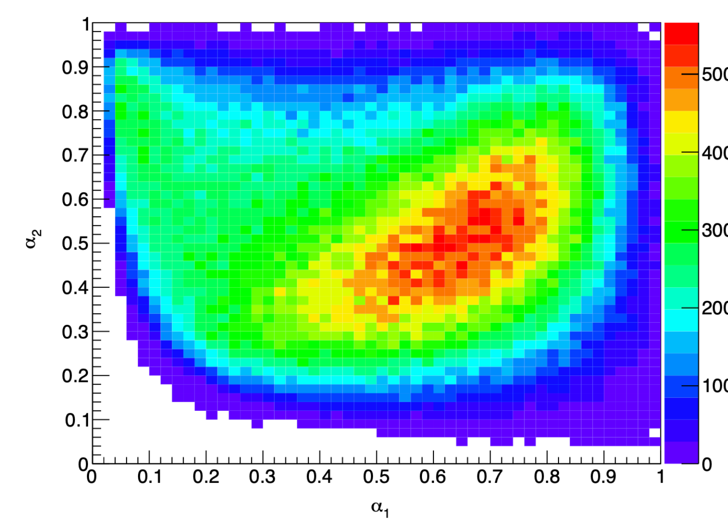




α_1 and α_2 show the strong correlation between missing energy, signal-hemi energy and ϕ energy.



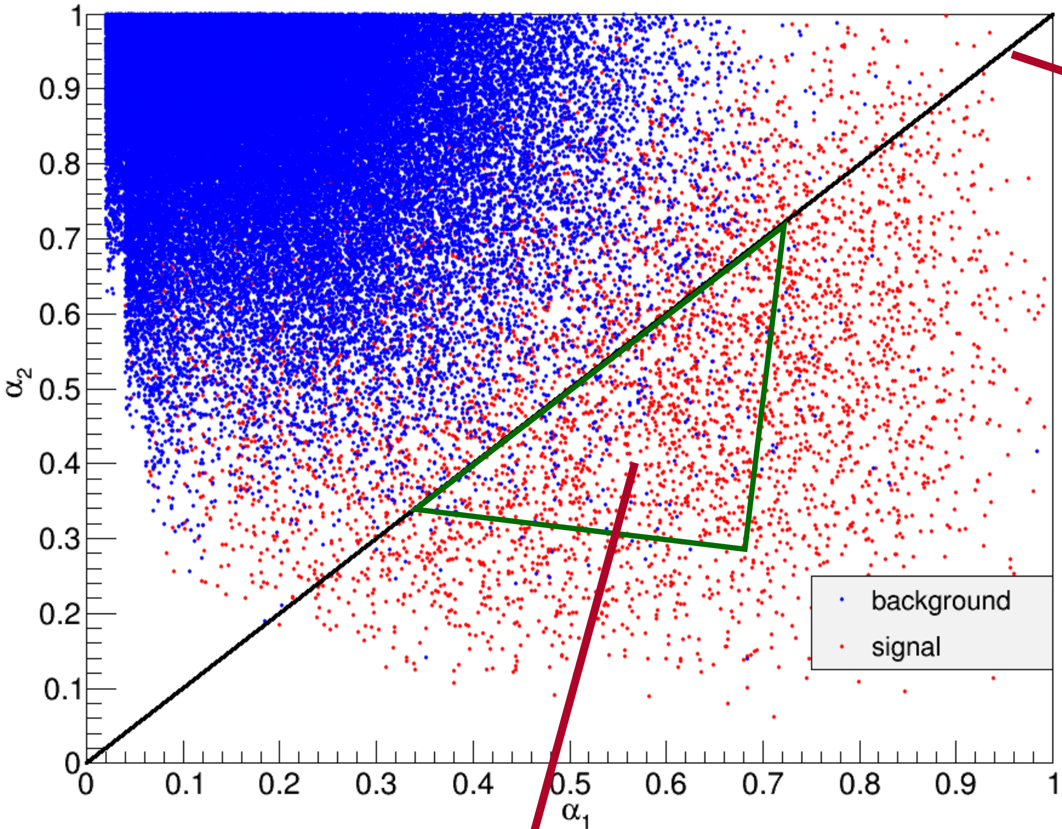
$b\bar{b}$ background



Signal events

Significant difference of $\alpha_2 - \alpha_1$ distribution for background and signal events.

Events Analysis By ϕ

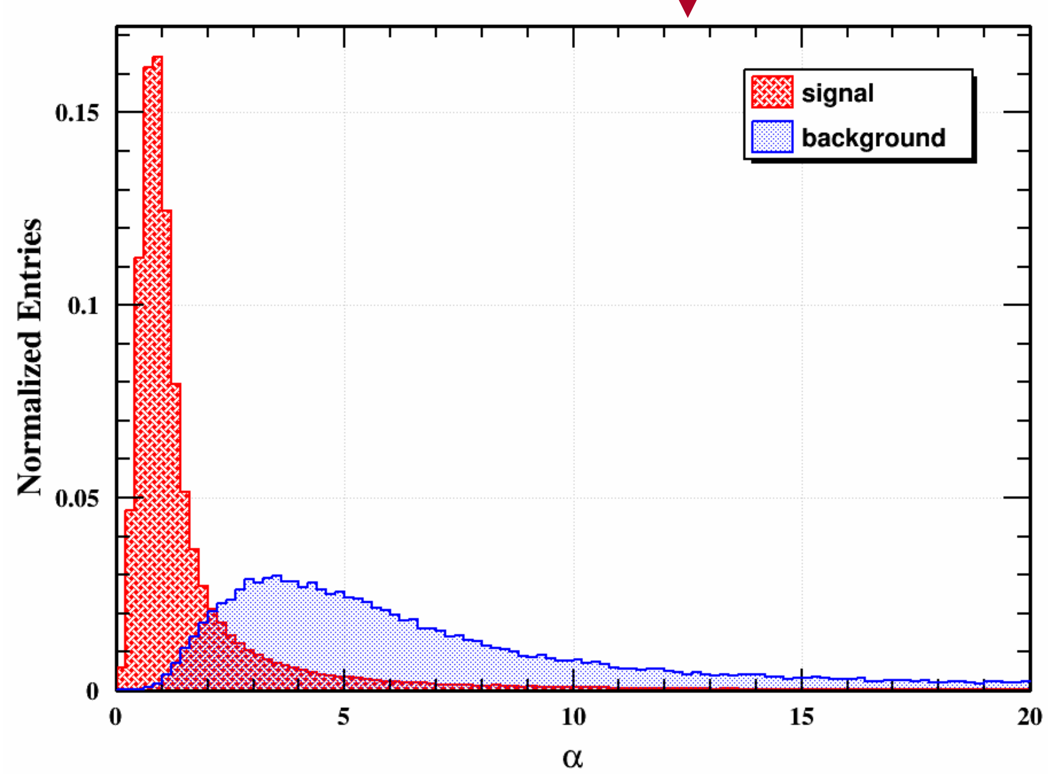


Loose boundary defined by

$$\alpha = \frac{\alpha_2}{\alpha_1} = \frac{(E_{vis}^{sig})^2}{E_\phi \cdot E_{beam}}$$

The accuracy of α depend on the BMR (is about 4 % of CEPC in simulation)

The other complex unlinear region will be analysis by BDT method of TMVA



Analysis of $\nu\bar{\nu}$ System

Indirect measurement by the full reconstruction

The general missing energy in the whole events

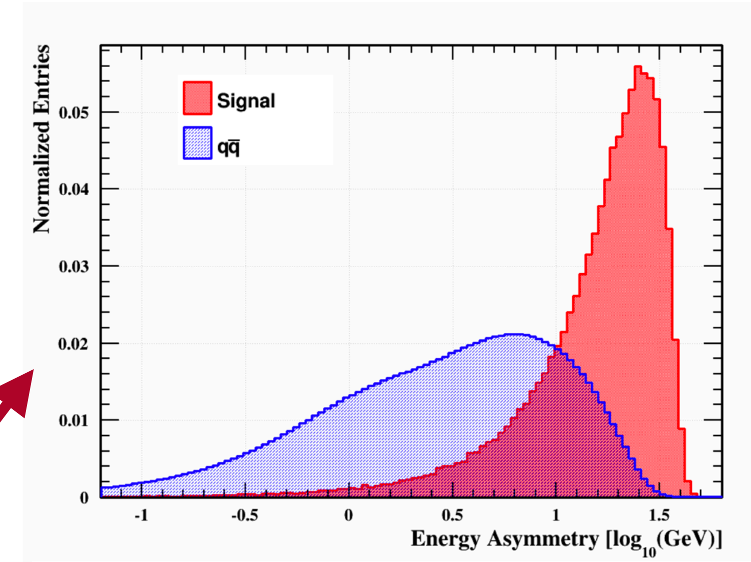
The detail of missing energy origin.

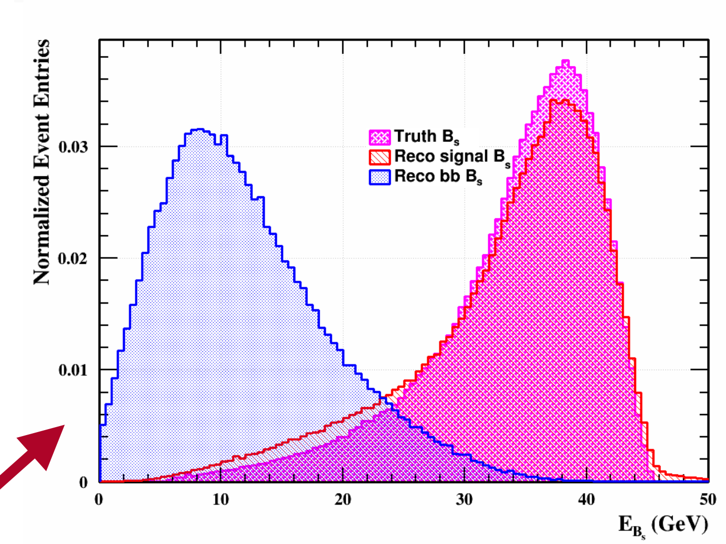
a. In the signal hemishphere, weather the missing energy count for mostly energy except ϕ. ($\alpha_1 = E_\phi / E_{sig}$)

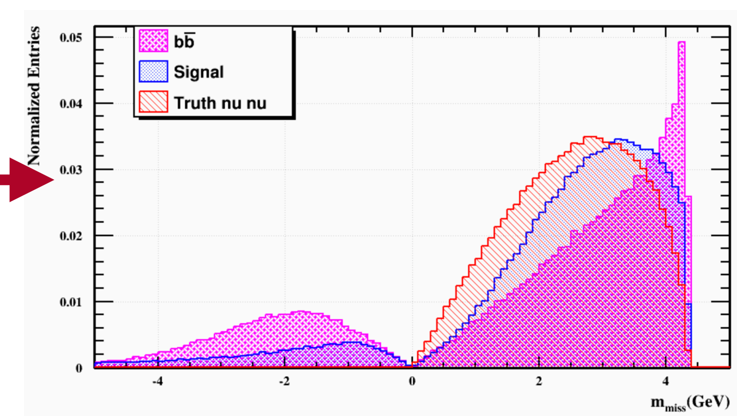
b. Weather the missing energy come from the signal-hemisphere. ($\alpha_2 = E_{sig} / E_{beam}$ and $E_{asymmetry}$)

c. The possibility that missing energy come from the same mother particle as ϕ.

d. An algorithm to get the signal energy of B_s and mass of $\nu\bar{\nu}$







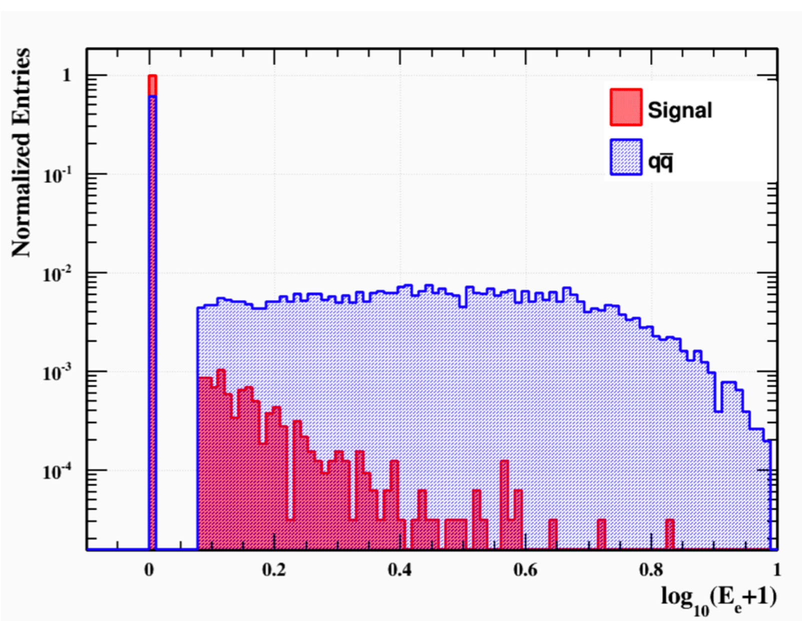
Analysis

Charged Lepton Identify

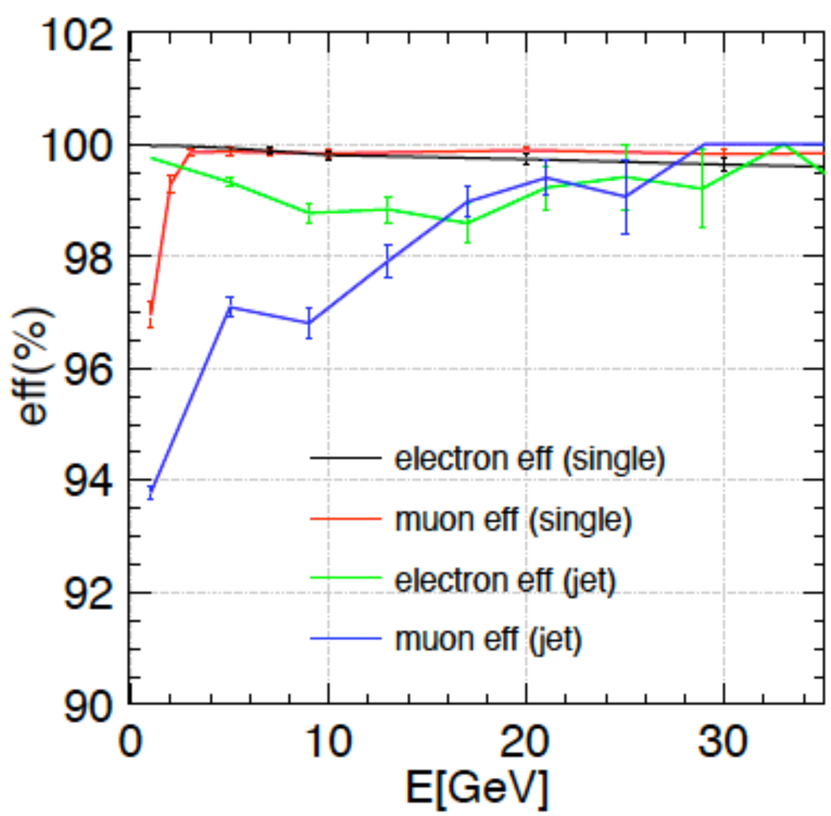
No charged lepton generated in the signal hemisphere for signal decay

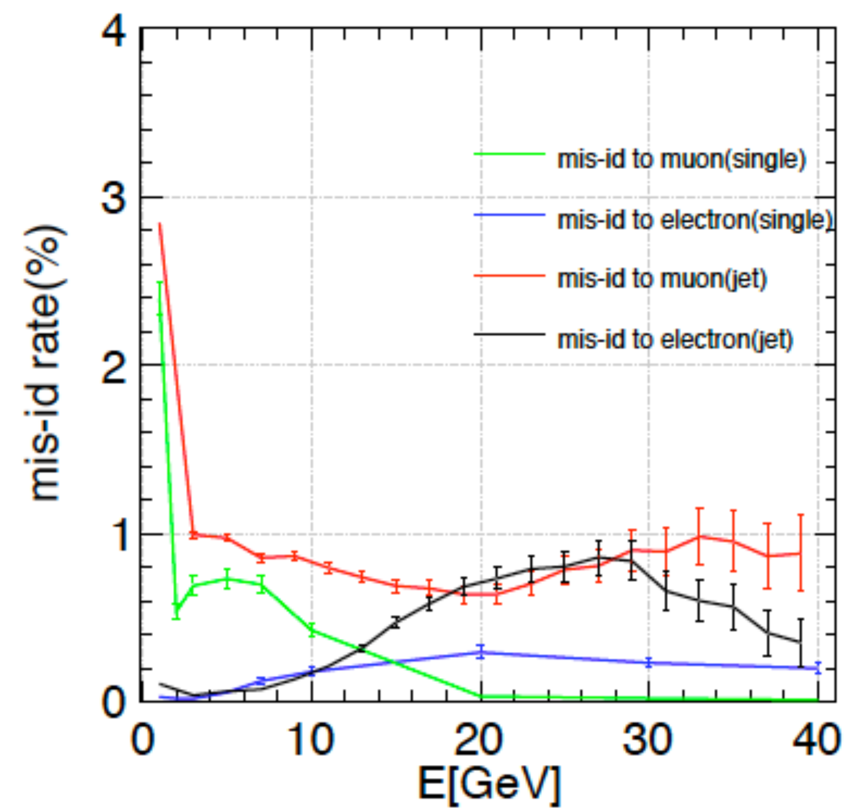
Main background usually generated accompanied with a charged lepton

Good performance for the charged lepton as the energy larger than 1 GeV



Samples satisfy $N_\phi > 0$ and $\alpha < 1.0$



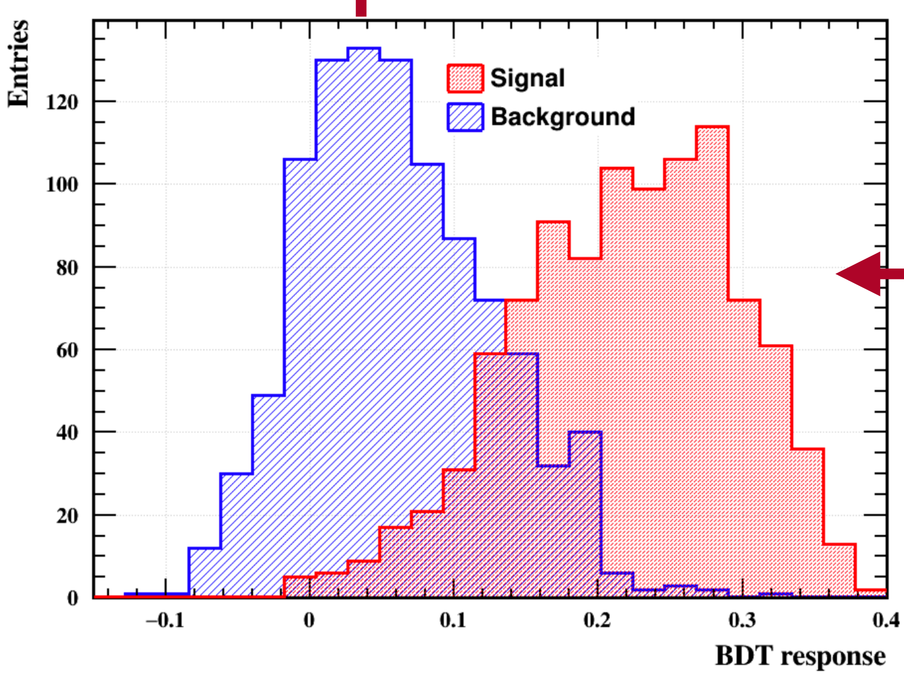


Charged lepton (muon and electron) identify by DanYu.

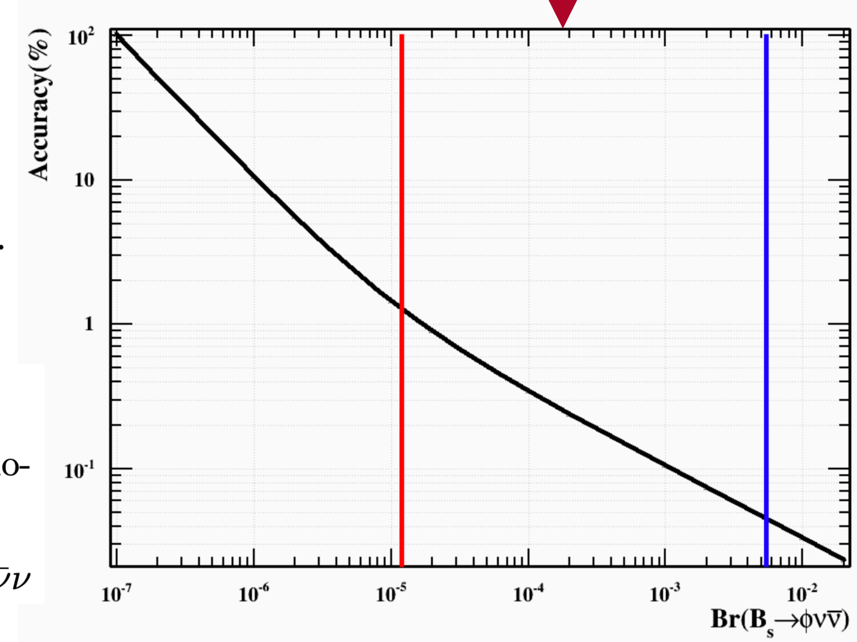
Cut chain and result

conditions	$B_s \to \phi\nu\bar{\nu}$	$u\bar{u}$	$d\bar{d}$	$s\bar{s}$	$c\bar{c}$	$b\bar{b}$	total bkg	$\sqrt{S+B}/S$ (%)
total generated	1.8e5	1.12e11	1.585e11	1.58511	1.20e11	1.51e11	7e11	464.81
b-tag > 0.6	1.359e5	8.0931e8	1.18558e9	1.1685e9	8.2392e9	1.1852e11	1.2992e+11	265.22
$N_{\phi(\to K^+K^-)} > 0$ at signal-hemisphere	51171	1.06277e7	1.30285e7	3.29526e7	2.15203e8	3.84348e9	4.11529e9	125.36
$E_\phi < 45$ GeV Kaon IP > 0.008 mm Energy asymmetry > 8 GeV	42054	3.3382e6	3.07042e6	6.26759e6	4.86347e7	1.04533e9	1.10665e9	79.10
Energy total < 85	40579	408759	746859	856441	1.28413e7	5.30604e8	5.45457e8	57.56
$E_{B_s} > 30$ GeV	32033	68126	0	38929	1.18081e6	4.93844e7	5.06723e7	22.23
$\alpha < 1.0$	22699	0	0	0	516605	7.70471e6	8.22132e6	12.65
$E_\mu < 1.1$ GeV and $E_e < 1.0$ GeV	20091	0	0	0	110922	2.18398e6	2.2949e6	7.57
$(1-\alpha_1)/\theta_{<miss,\phi>} < 2.0$	13543	0	0	0	29060	426879	455940	5.06
BDT score > 0.20	7285	0	0	0	0	5240	5240	1.45
Efficiency(%)	4.687	0	0	0	0	3.47e-6	7.49e-7	

Good separation performance



- The scaleless ratio α_1.
- The scaleless ratio α_2.
- The invariant mass of all visible final states.
- The invariant mass of tag hemisphere.
- The invariant mass of signal hemisphere.
- The angle between missing momentum and ϕ momentum.
- The energy of signal B_s and invariant mass of $\bar{\nu}\nu$



Summary

- By 10^{12} Z decay, CEPC will produce 1.5×10^{11} $b\bar{b}$ and 1.8×10^{5} rare decay $B_s \to \phi\nu\bar{\nu}$ under SM
- B_s Statistics : More than 5 higher order than the LEP (current up limit) and 2 higher order than Belle II
- Expected good accuracy to search the rare decay $B_s \to \phi\nu\bar{\nu}$.

  Be the level of 1.5 % under SM
- More optimization and detector requirement.
  - PID: Necessary if one desires to separate π/K modes (0 – 45 GeV momentum range)
  - More full simulation samples to study rare decay and calorimeter
  - Missing mass performance?
- More measurement of flavor rare decay processes of B_s, B_c and Λ_b at CEPC are expected

End

Thanks