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

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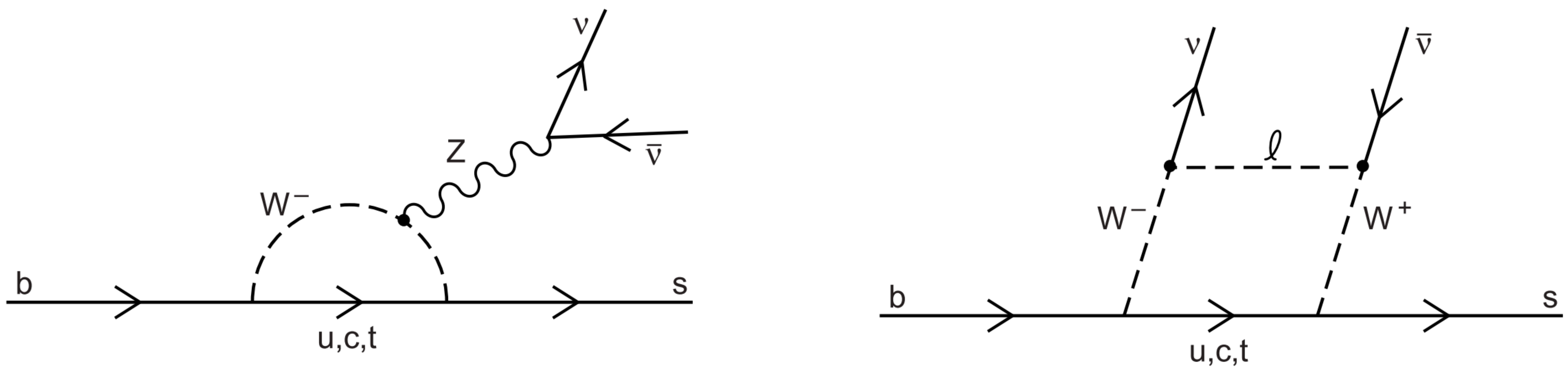
Motivation

- Investigation of flavor-changing neutral current (FCNC) decays is of fundamental interest.
- SM prediction for the FCNC decay $b \to s\nu\bar{\nu}$ is nearly free from strong interaction effects and has very small theoretical uncertainty.
- An observation of this decay at a level significantly above the SM prediction would provide unambiguous evidence for new physics.

$B_s \to \phi\nu\bar{\nu}$

$b \to s\nu\bar{\nu}$:

Flavor-change-neutral-current(FCNC) process. Be suppressed by the loop factor and heavy weak boson mass .



One-loop level in the Standard Model (SM) via “penguin” and “box” diagrams.

$B_s \to \phi\nu\bar{\nu}$

The measure of the inclusive decay rate probably can not be achieved due to the missing neutrinos.

The exclusive channels(such as $B_S \to \phi\nu\nu$) are more promising as far as the branching ratios with related observables and main background are concerned.

	Experimental [1]	SM Prediction [2]
$\mathrm{BR}(B^0 \to K^0\nu\bar{\nu})$	$< 2.6 \times 10^{-5}$	$(2.17 \pm 0.30) \times 10^{-6}$
$\mathrm{BR}(B^0 \to K^{*0}\nu\bar{\nu})$	$< 1.8 \times 10^{-5}$	$(9.48 \pm 1.10) \times 10^{-6}$
$\mathrm{BR}(B^\pm \to K^\pm\nu\bar{\nu})$	$< 1.6 \times 10^{-5}$	$(4.68 \pm 0.64) \times 10^{-6}$
$\mathrm{BR}(B^\pm \to K^{*\pm}\nu\bar{\nu})$	$< 4.0 \times 10^{-5}$	$(10.22 \pm 1.19) \times 10^{-6}$
$\mathrm{BR}(B_s \to \phi\nu\bar{\nu})$	$< 5.4 \times 10^{-3}$	$\sim 10^{-5}$

Table 1: Constraints and predictions for various $b \to s\nu\bar{\nu}$ decays.

[1] M. Tanabashi *et al.*, "Review of Particle Physics," *Phys. Rev.*, vol. D98, no. 3, p. 030001, 2018.

[2] D. M. Straub, "$b \to k^{(*)}\nu\bar{\nu}$ sm predictions," Dec 2015.

The Bs at CEPC

At Z pole at CEPC ($N_Z = 10^{12}$),

$$N(B_s) = 2 \times N_Z \cdot Br(Z \to b\bar{b}) \cdot Br(\bar{b} \to B_s)$$

$$= 3 \times 10^{10}$$

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

B-hadron fractions in Z decays

b–hadron species	fraction in *Z* decays	correlation with *f*(B_s)	correlation with *f*(*b*–baryon)
B_s	$f(B_s) = 0.101 \pm 0.008$		
b baryons	$f(b\text{–baryon}) = 0.085 \pm 0.011$	+0.065	
B^0 or B^+	$f(B_d) = f(B_u) = 0.407 \pm 0.007$	−0.628	−0.817
B_s / (B^0 or B^+) ratio	$f(B_s)/f(B_d) = 0.249 \pm 0.023$		

The signal up limit:

SM prediction :

$$Br(Bs \to \phi\nu\bar{\nu}) \sim 10^{-5}$$

$$N(B_s \to \phi\nu\bar{\nu}) \sim 1.5 \times 10^5$$

The Events samples

Truth level MC performance:

Background: whizard + pythia6

$b\bar{b} : 5 \times 10^8,$

$c\bar{c} : 3.6 \times 10^8,$

$\tau^+\tau^- : 1 \times 10^8$

Signal: Pythia8 + EvtGen1.30

$B_s \to \phi\nu\bar{\nu} : 10^6$

The Events Analysis

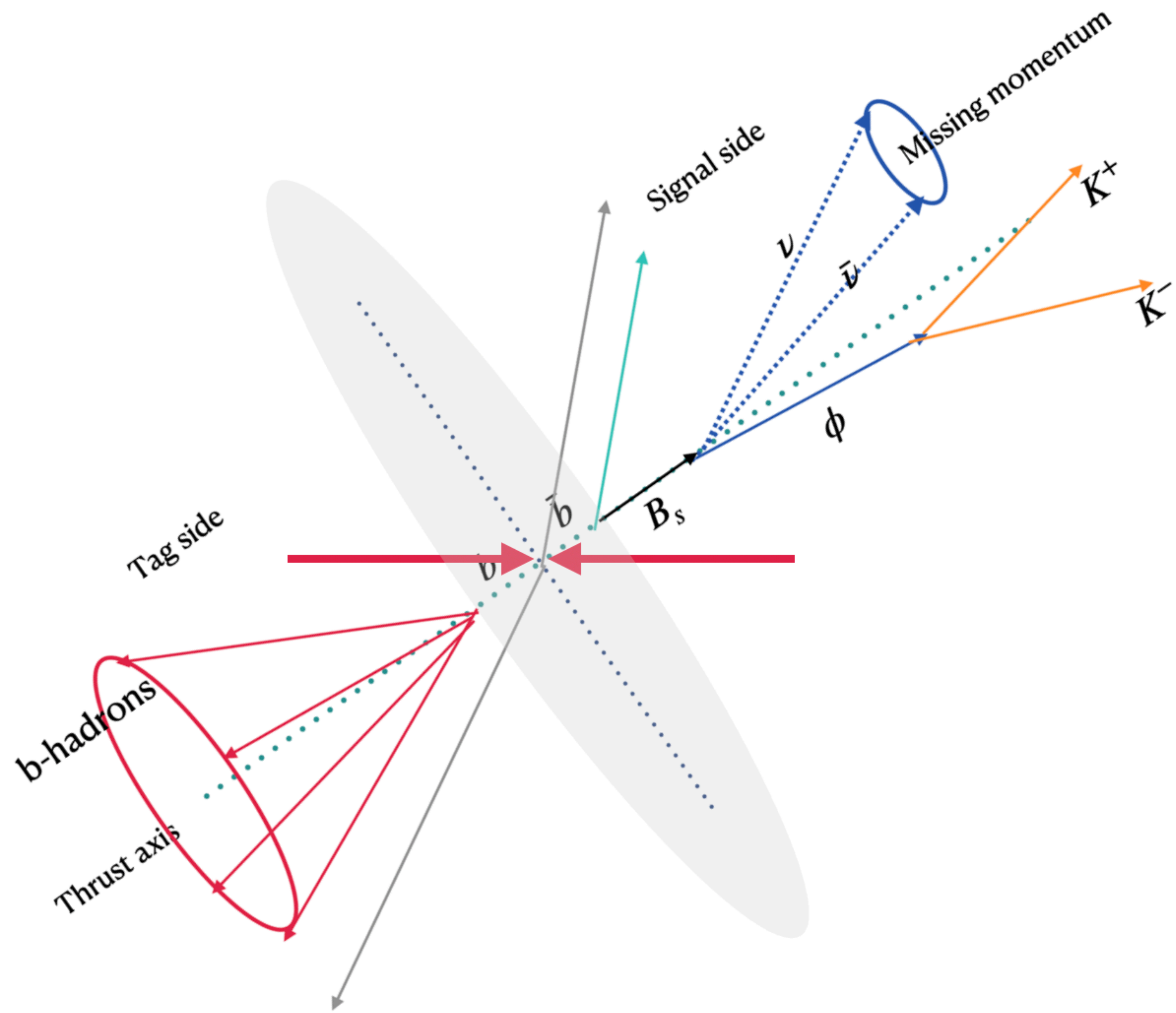
The whole space is divided into two hemisphere by the plane perpendicular to the thrust

$$T = \frac{\sum_i |\overrightarrow{p}_i \cdot \hat{n}_i|}{\sum_i |\overrightarrow{p}_i|}$$

Signal and tag hemisphere definition:

The visible energy at the signal-semi is smaller than other side.

$$E_{vis}^{sig} < E_{vis}^{tag}$$



The preliminary cut chosen:

$N_\phi(K^+K^-)$: Number of ϕ reconstructed by K^+K^- pair.

α : The ratio defined by $\alpha = \dfrac{E_{vis}}{E_{hemi}} / \dfrac{E_\phi}{E_{vis}}$.

D_ϕ : Position of ϕ production.

E_{lepton} : Energy of lepton(e, μ) at signal hemisphere.

m_{vis} : Invariant mass of visible particles at signal sphere.

m_{inv} : Invariant mass of all invisible particles.

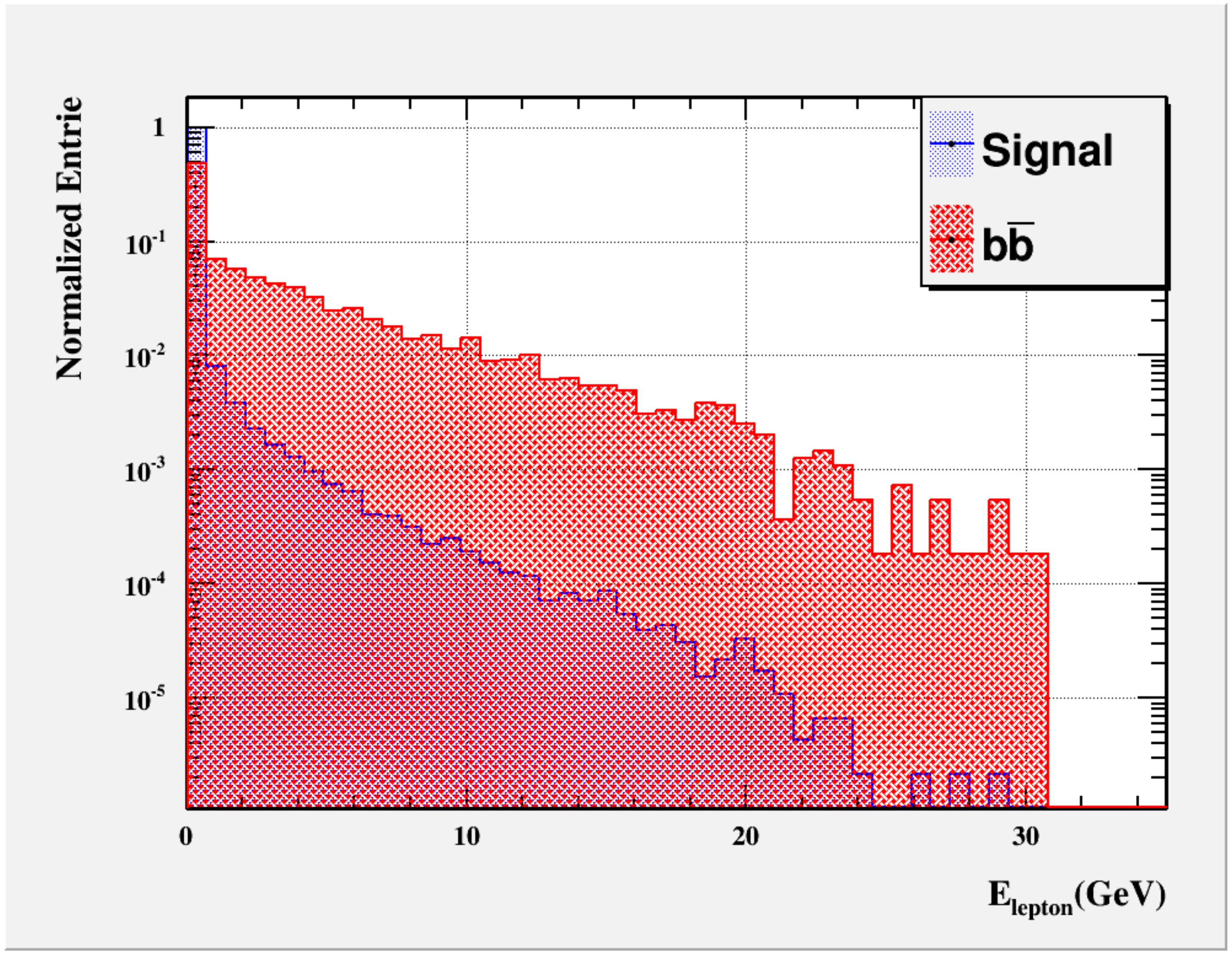
$E_{isolated}$: The energy of particles with direction close to ϕ.

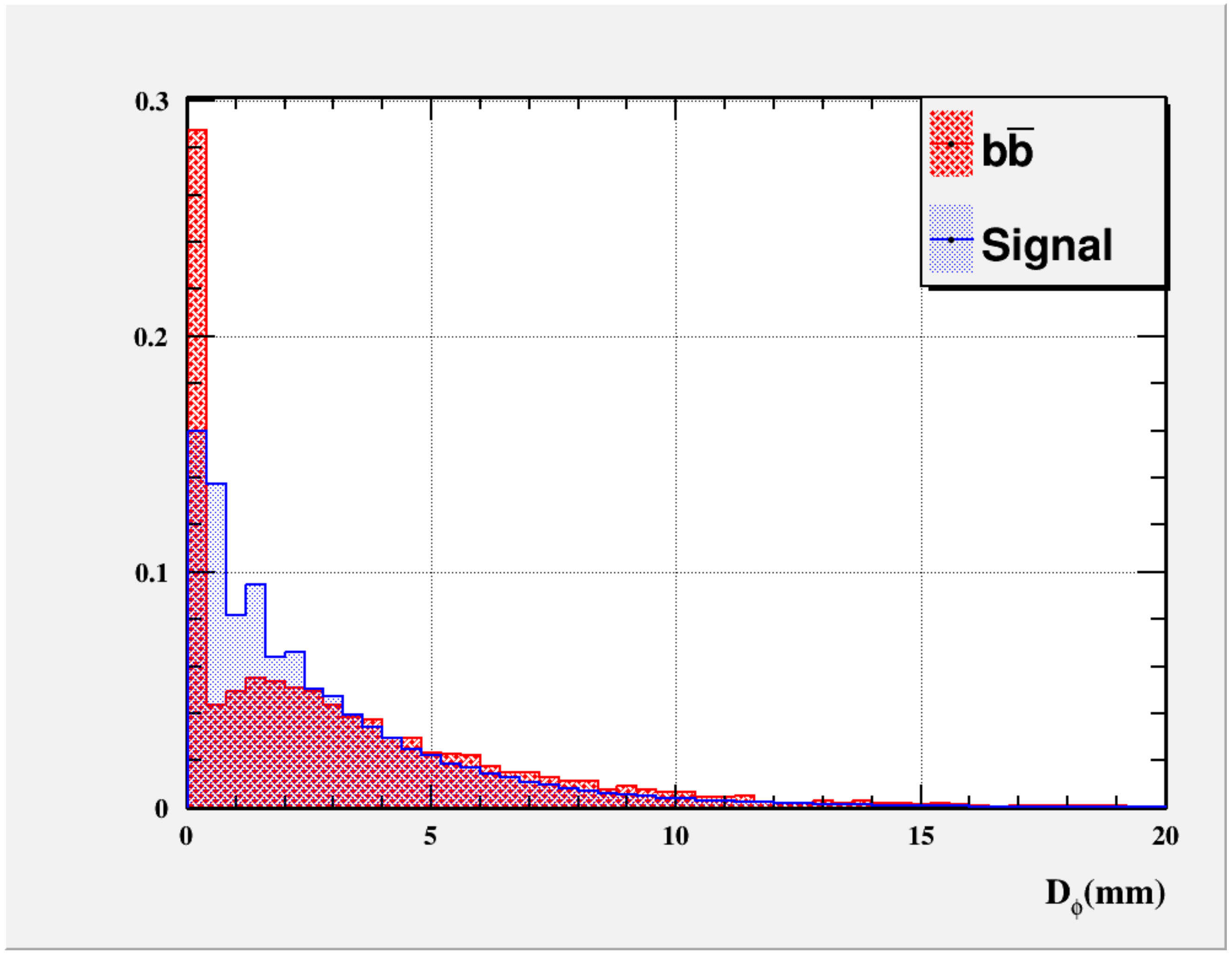
The lepton(μ, e) cut

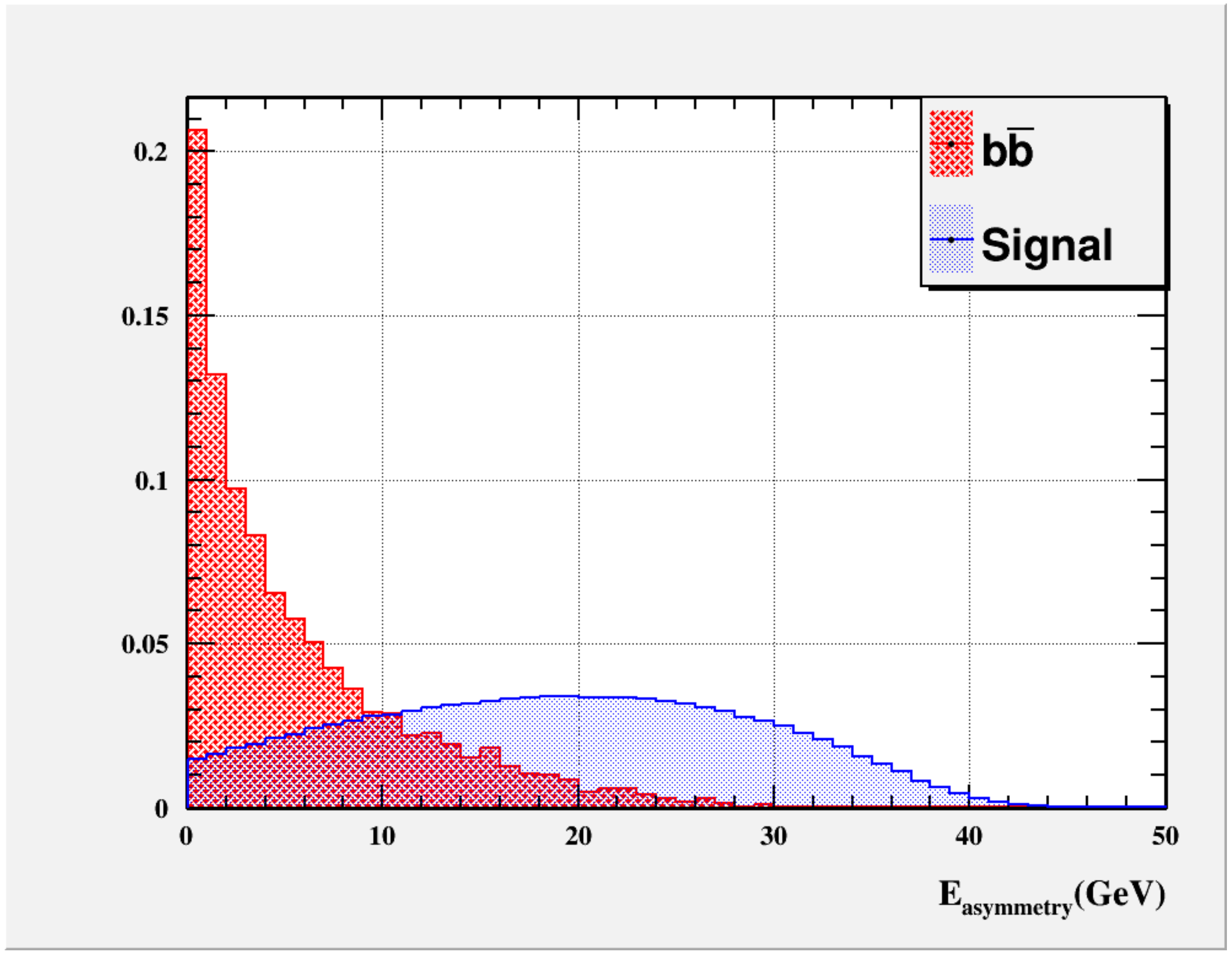
$b \to Bs + X$:
X is mainly light meson such as π.

$Bs \to \phi\nu\bar{\nu}$:
No lepton.

$E_{lepton} = 0$ GeV.





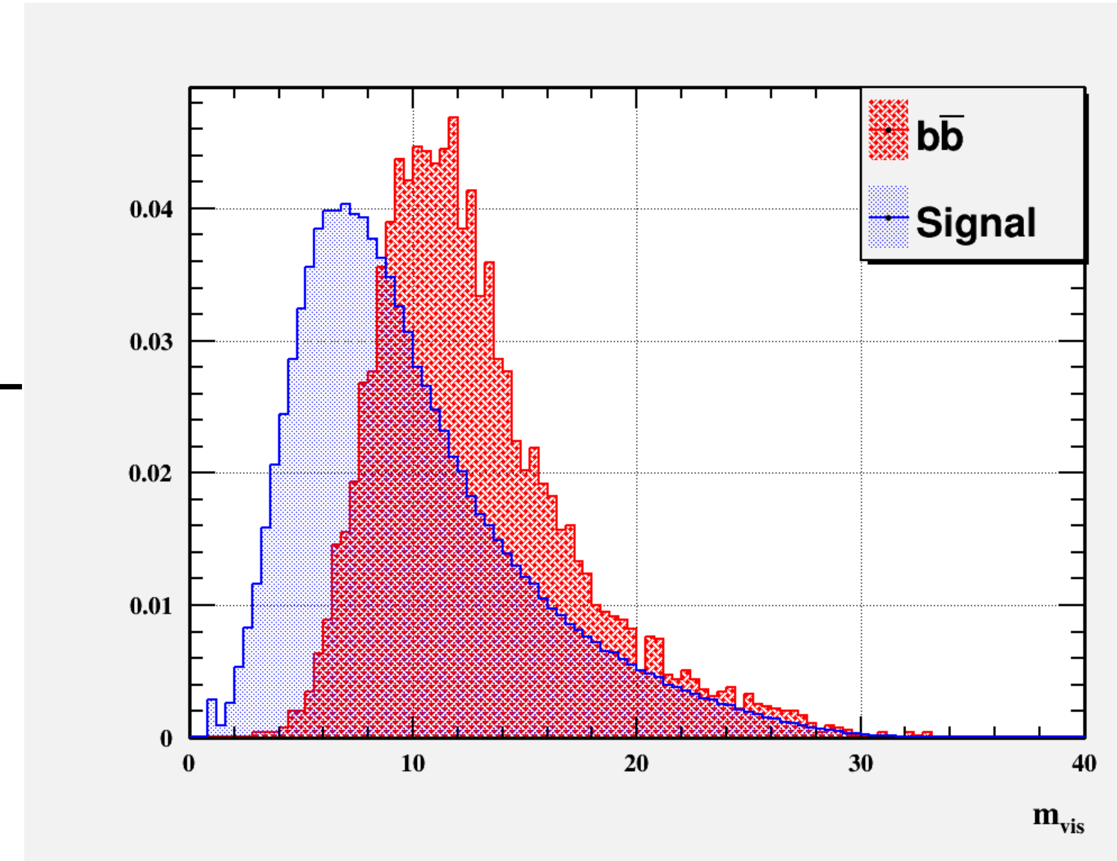


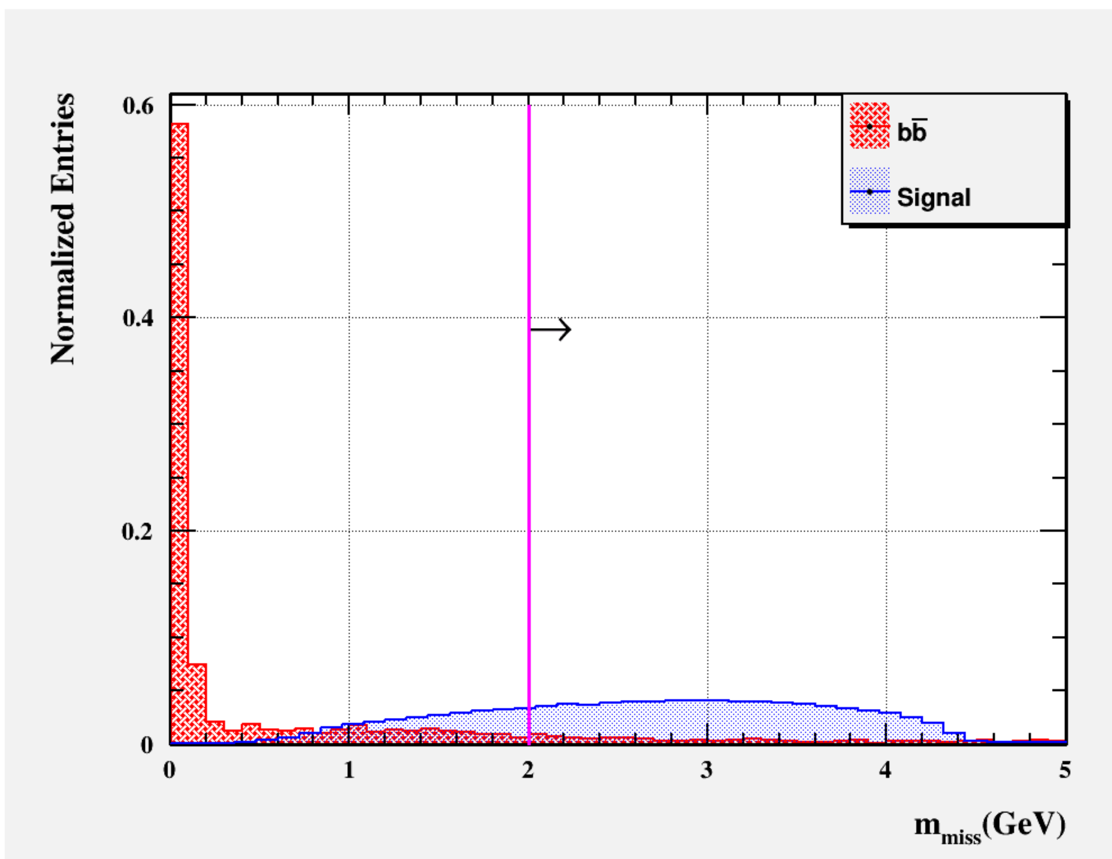
$D_\phi > 0.5$ mm

$E_{asymmetry} > 10$ GeV

$$m_{vis}^{sig} = \left(\sum_i p_i^{sig} \right)^2$$

where p_i^{sig} is the momentum of visible particles.





$$m_{miss} = \sqrt{\left(p_0 - \sum_i p_i \right)^2}$$

p_i is the momentum of visible particles of both tag and signal-side.

For single neutrino in bkg:

$$m_{miss} \sim m_\nu^2 = 0.$$

Constrains for E_ϕ and E_{vis}^{sig}

$$\alpha = \frac{E_{vis}^{sig}}{E_{beam}} / \frac{E_\phi}{E_{vis}^{sig}}$$

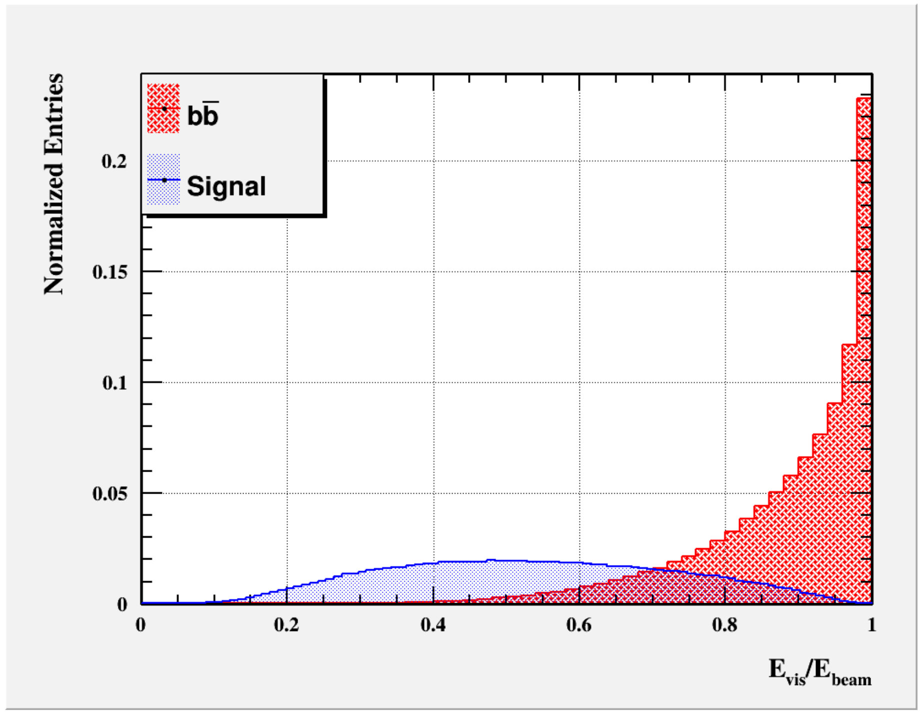
Where E_{vis}^{sig} is total energy of visible particles at signal-hemisphere.

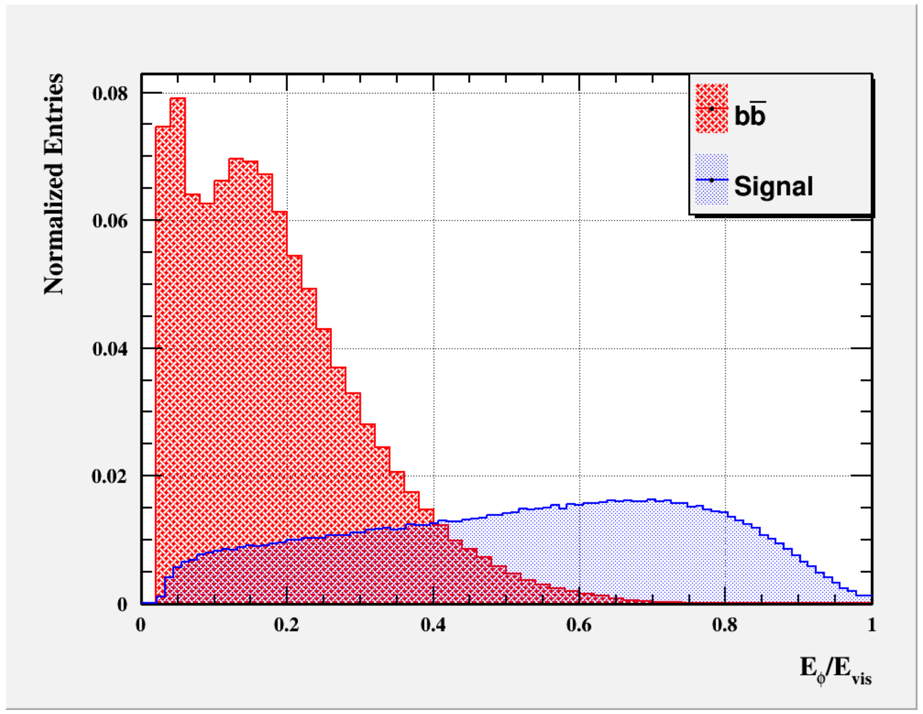
As the large miss energy for $\nu\bar{\nu}$ pair in signal,

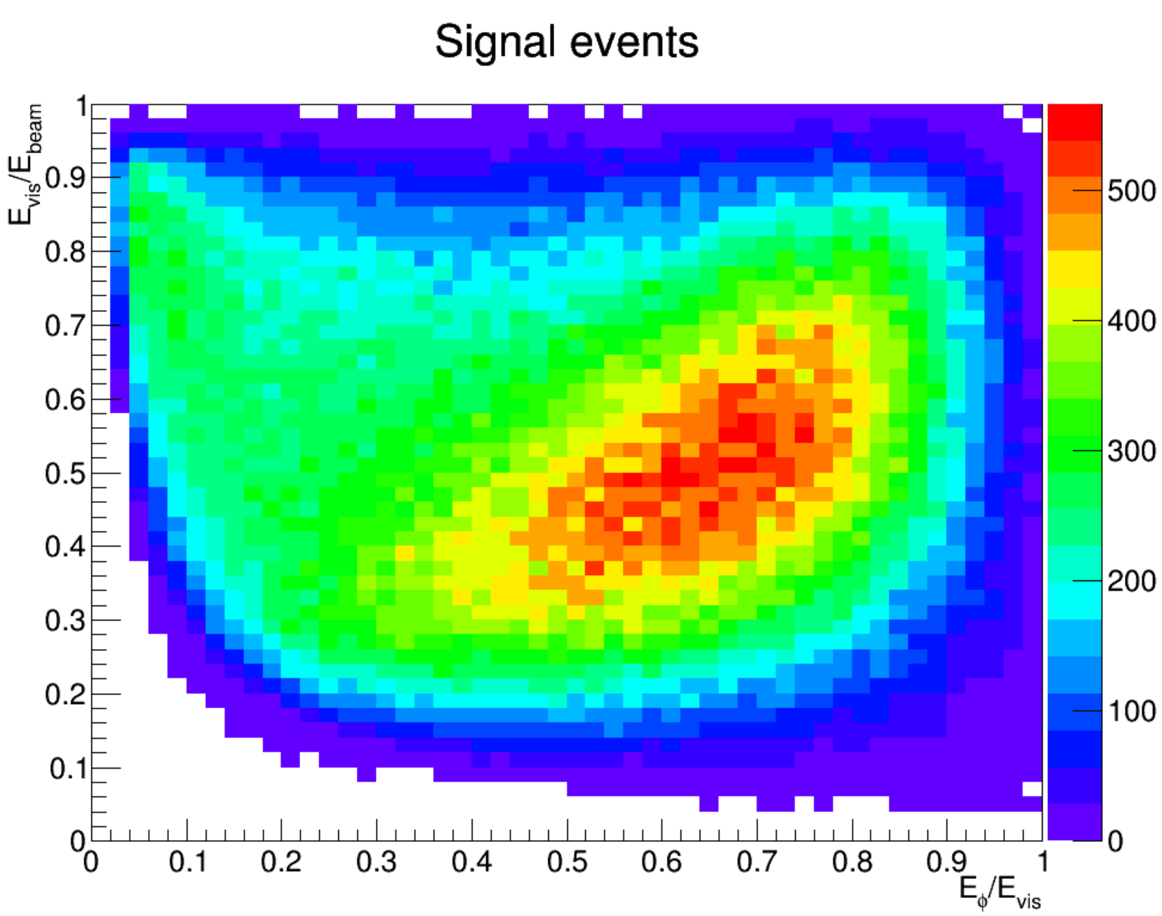
$E_{vis}^{sig}/E_{beam} \rightarrow$ low ratio

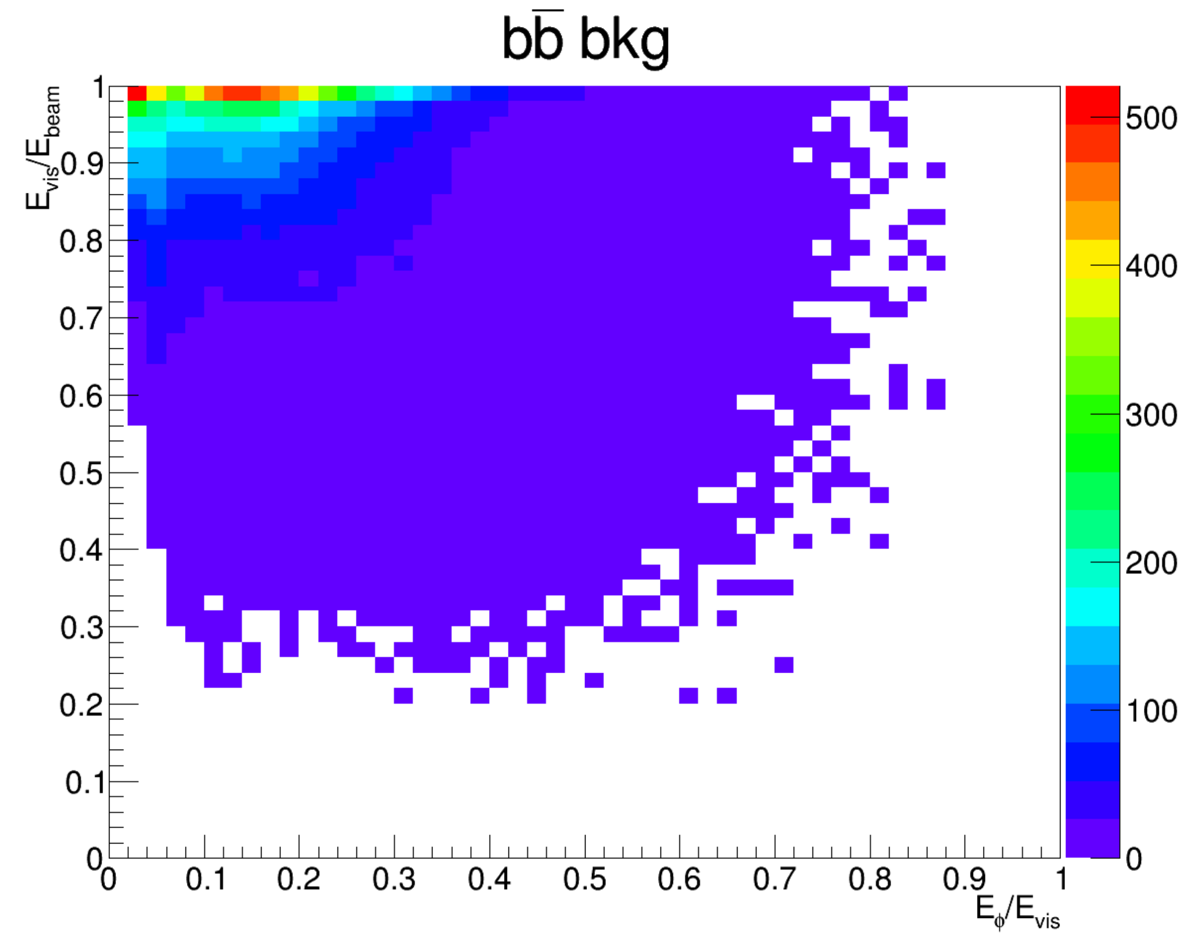
$E_\phi/E_{vis}^{sig} \rightarrow 1$

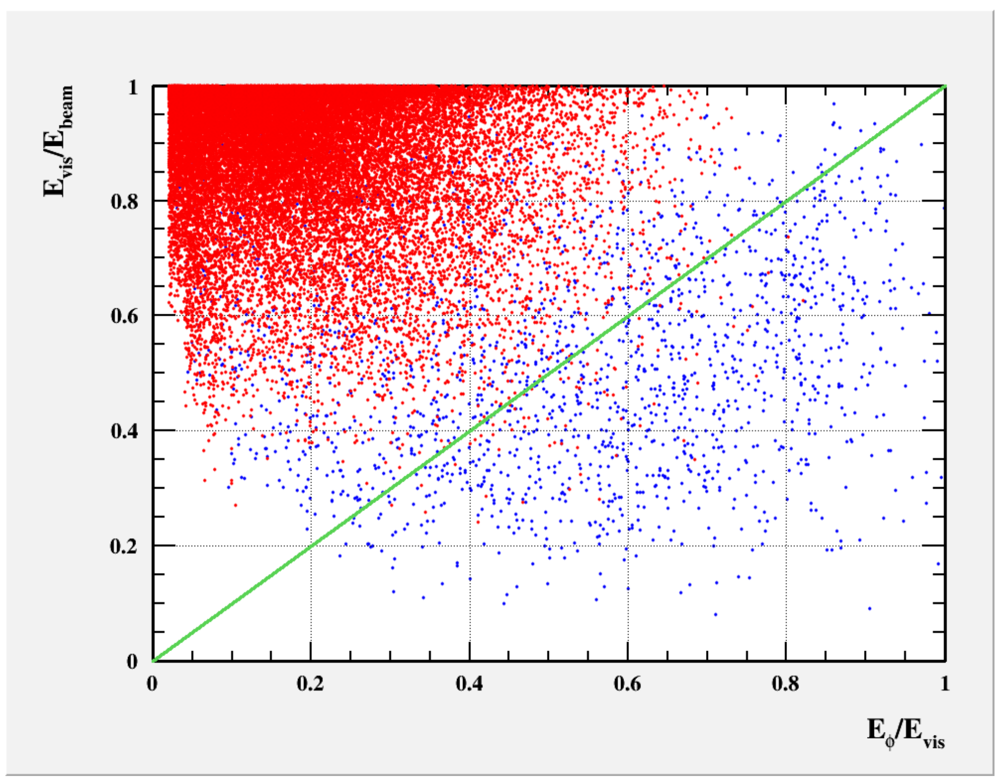
And should exits correction between the two variables.

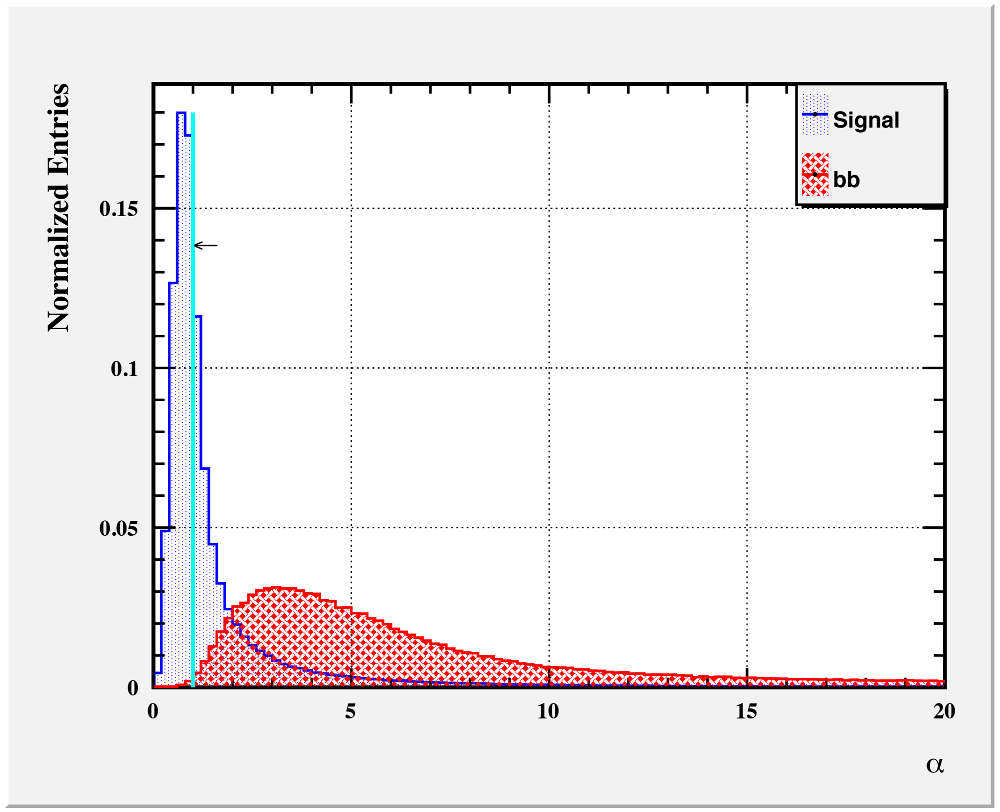





Signal events
E_{vis}/E_{beam}
E_{ϕ}/E_{vis}
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
0 100 200 300 400 500


$b\bar{b}$ bkg
E_{vis}/E_{beam}
E_{ϕ}/E_{vis}
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
0 100 200 300 400 500


E_{vis}/E_{beam}
E_{ϕ}/E_{vis}
0 0.2 0.4 0.6 0.8 1


Normalized Entries
Signal
bb
0 0.05 0.1 0.15
0 5 10 15 20
α

Main background from $q\bar{q}$

The ϕ production in each $b\bar{b}$ event.

Parents	B	D	Jets	Others
Num/Events	0.055	0.159	0.086	0.004

The ϕ with missing particles.

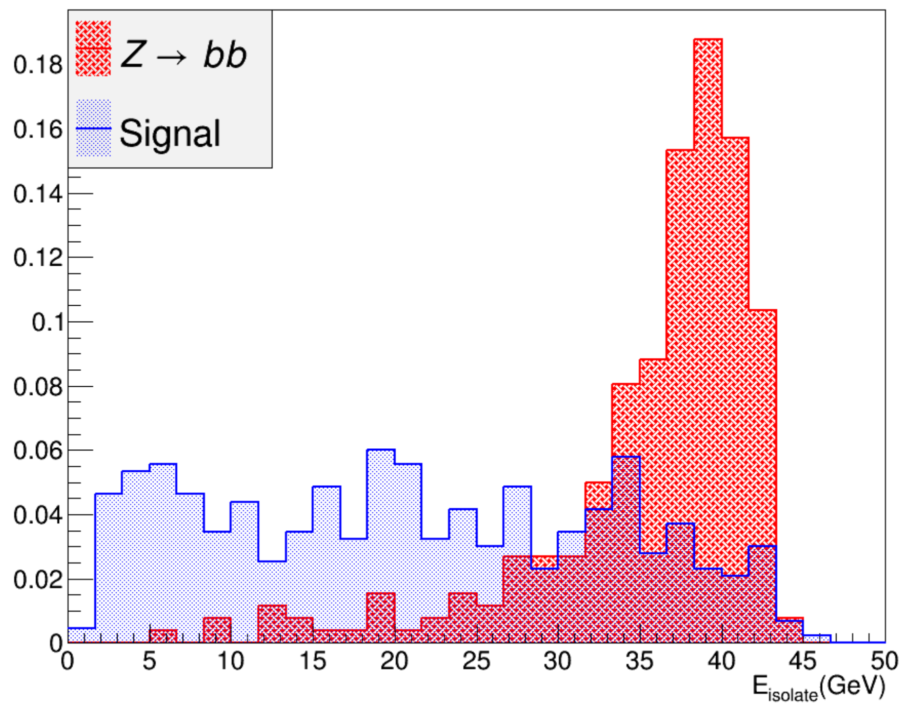
$$b\bar{b} : b \to B \to Dl\nu_l \text{ with } D \to \phi X$$

$$\boxed{\text{Especially: } B_s \to D_s l\nu_l \text{ with } D_s \to \phi l\nu_l \text{ (two neutrinos)}}$$

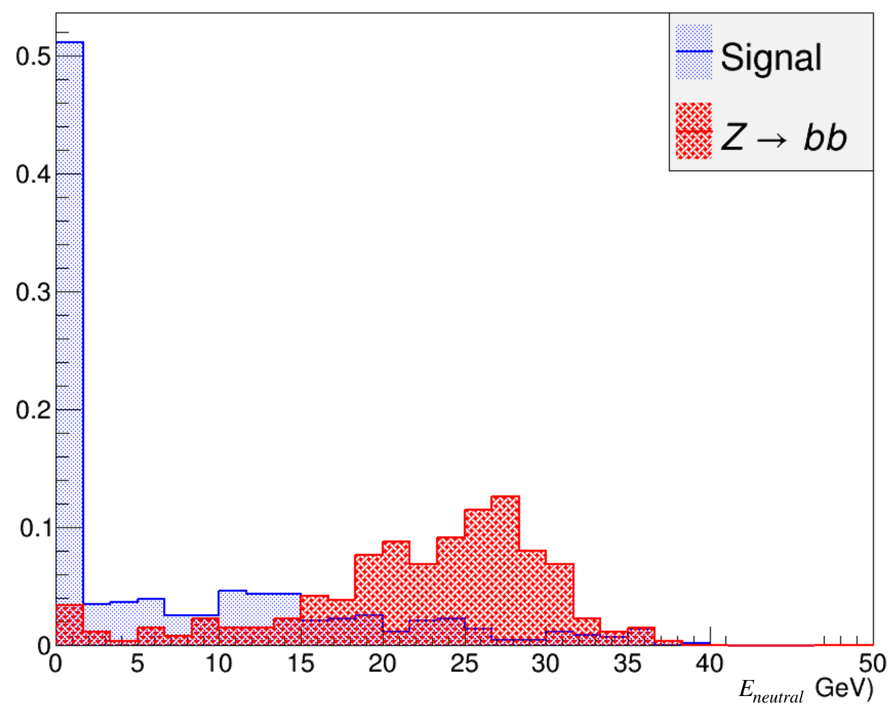
The optimized cut chain

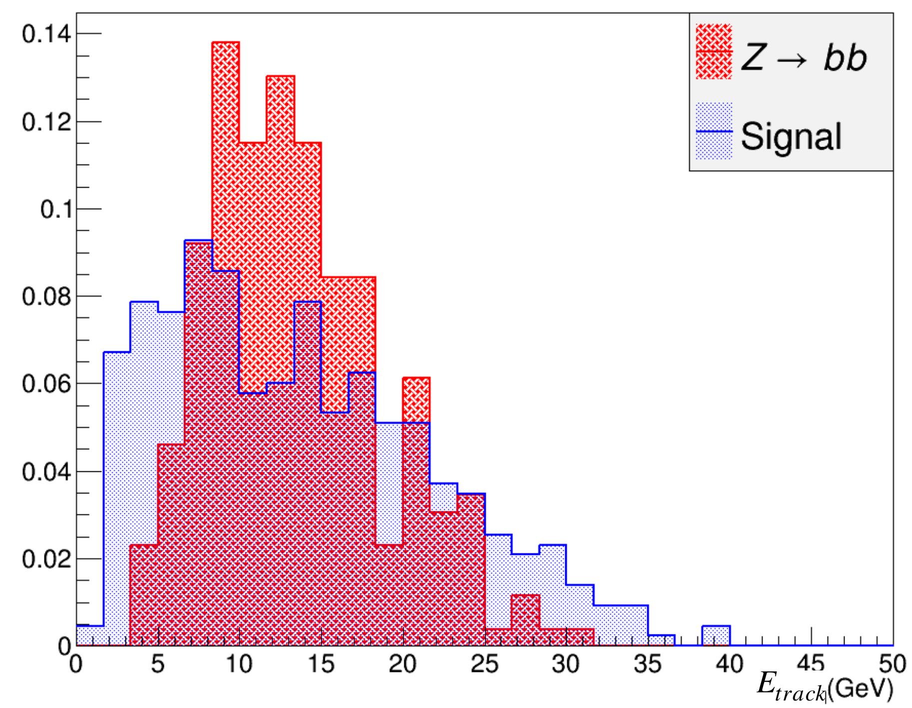
Conditions	**Signal**	$b\bar{b}$	$c\bar{c}$	**Total**	$\sqrt{S+B}/S$
Total	150000	3e+11	2.4e+11	5.4e+11	3.651
$N_\phi > 0$	68798	8.15e+09	5.37e+09	13.52e+10	1.312
$E_{lepton} = 0$ GeV	64851	3.41e+09	3.60e+09	7.01e+9	0.901
m_{inv}>2.2 GeV	51421	9.07e+07	3.25e+06	9.39e+7	0.185
$\alpha < 0.8$	20294	127827	5333	133150	0.019
Efficiency	0.14	4.26e-07	2.22e-08		

bb background : selected after above cut conditions.



$E_{isolate}$ is defined as the sum of both tracks and neutral which the direction with ϕ less than 0.2 rad. And E_{track} and $E_{neutral}$ corresponding to above two kinds of particles.





Next scheme

The simulation and reconstruction performance.

- Reconstruction efficiency of ϕ
- Particle identification(between $\mu^{\pm}$, $\pi^{\pm}$ and $K^{\pm}$)performance.
- The energy resolution of the calorimeter system.
- Dependence on the missing energy/momentum reconstruction.
- Impact parameter resolution of charged particles.
- … …

End

Thanks

The reconstruction of ϕ

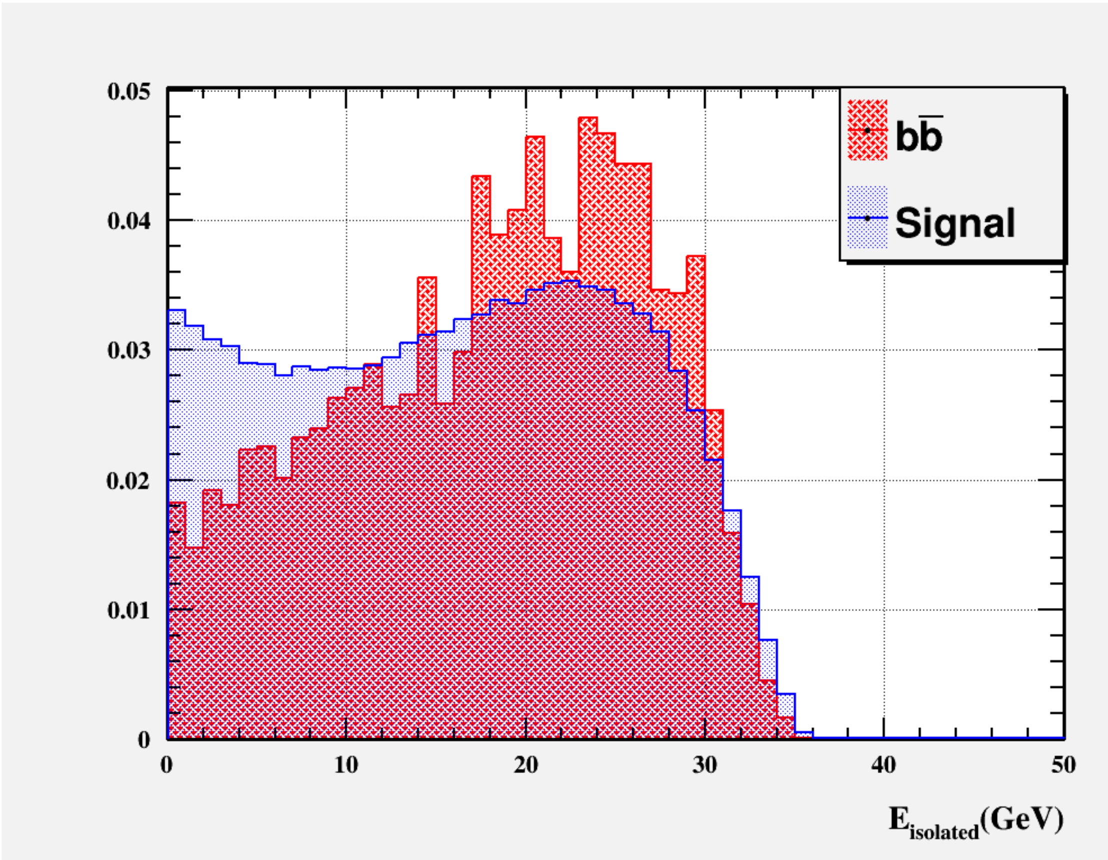
The main background: $b\bar{b}$

By the definition of signal-hemisphere, at least one ϕ reconstructed via K^+K^- pair.

$$B_s \to \phi\nu\bar{\nu}, \quad \phi \to K^+K^-$$

The truth K^+K^- pairs are selected. The efficiency of reconstruction Would be considered in the following reconstruction step.

Bakup



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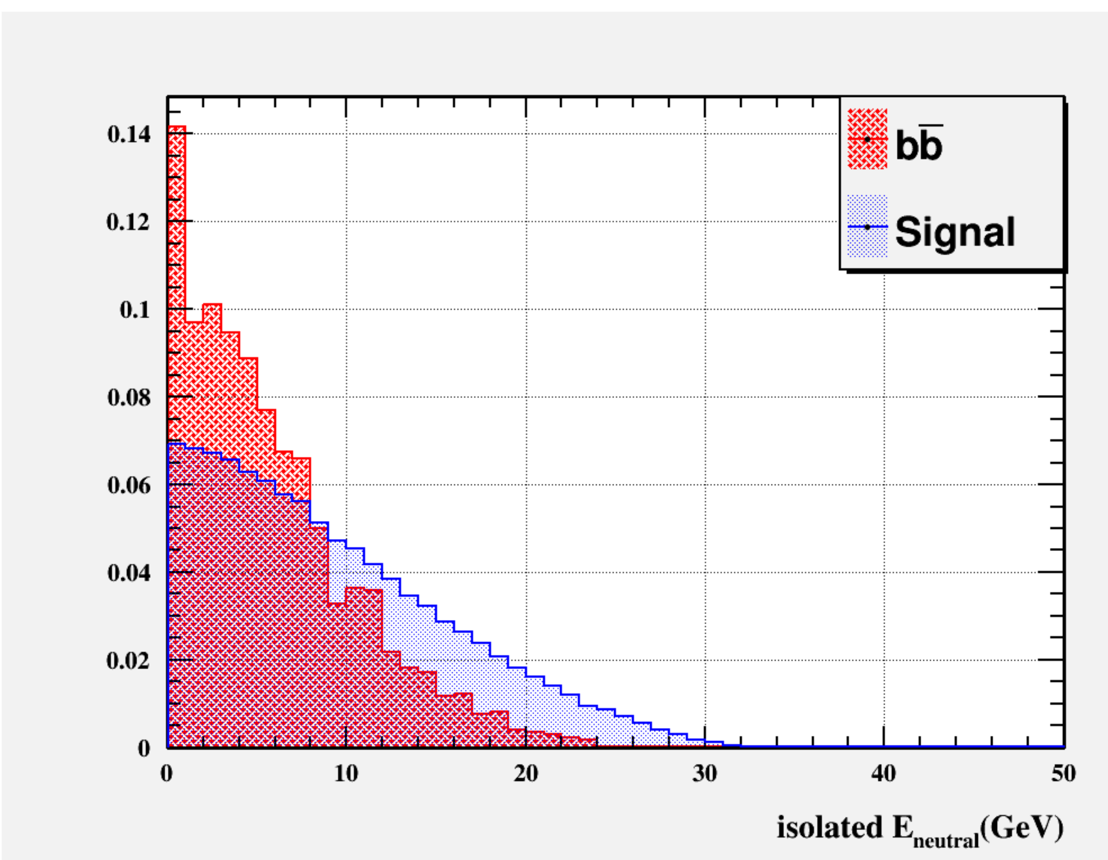
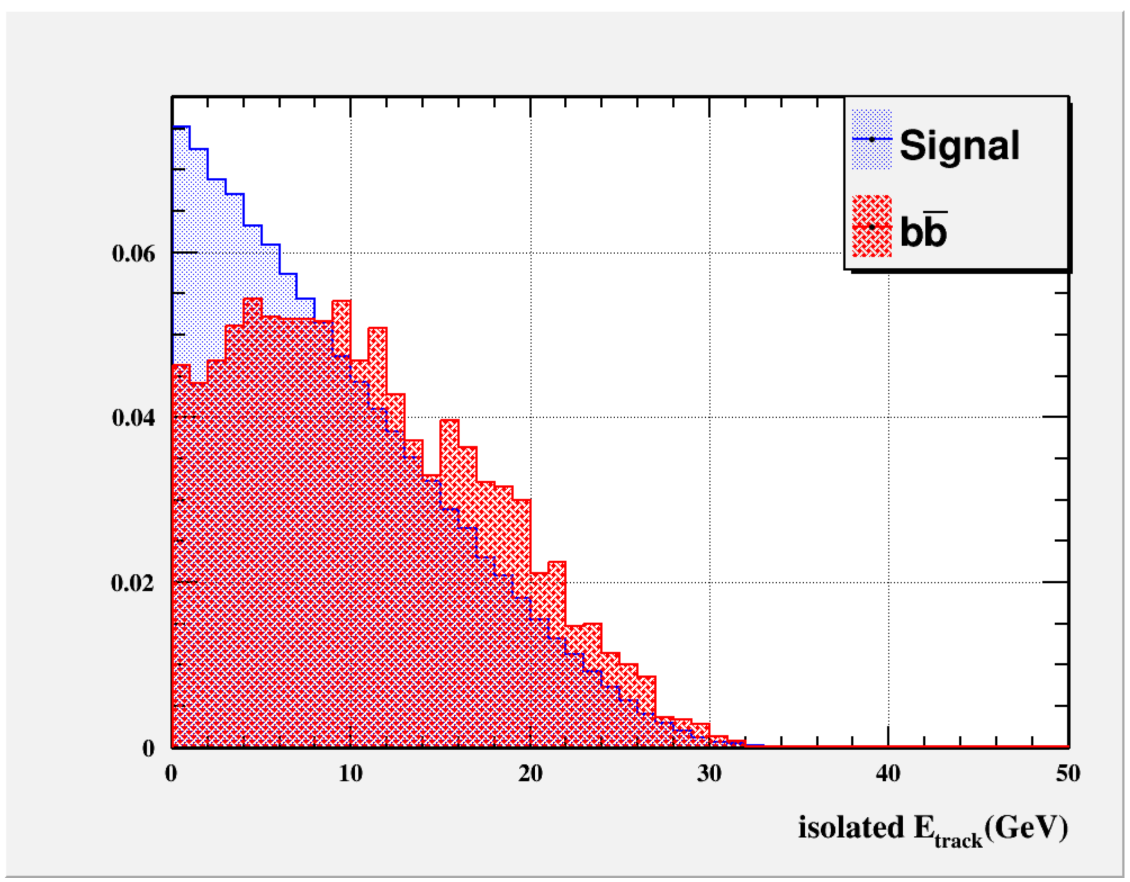




Particle properties

ϕ:

$m_\phi = 1019.46\,\mathrm{MeV}$

$\mathrm{Br}(K^+K^-) = 49.2\,\%$

$\mathrm{Br}(K_L K_S) = 34\,\%$

B_s

$m_{B_s} = 5366.89\,\mathrm{MeV}$

$\mathrm{Br}(D_s^- X) = 93 \pm 25\,\%$

$\mathrm{Br}(D_s^- l^+ \nu_l X) = 8.1\,\%$

$\mathrm{Br}(D_s^{-*} l^+ \nu_l X) = 5.4\,\%$

$m_{D_s} = 1968.34\,\mathrm{MeV}$

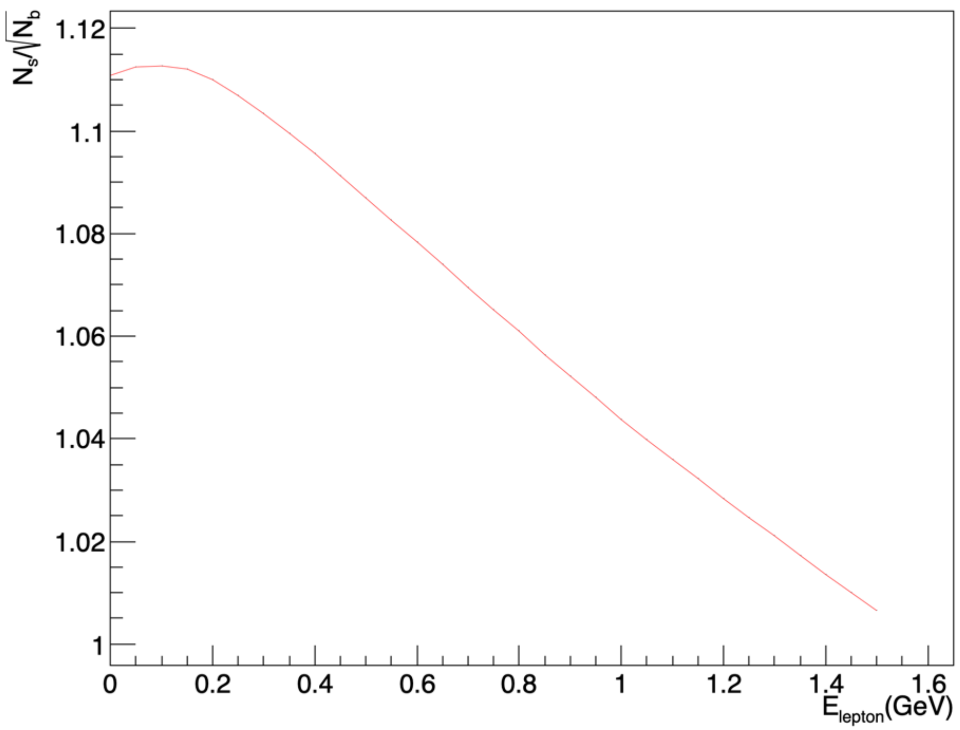
$\mathrm{Br}(\phi X) = 15.7\,\%$

$\tau^\pm$

$\mathrm{Br}(\phi \pi^- \nu_\tau) = 3.4 \times 10^{-5}$

$\mathrm{Br}(\phi K^- \nu_\tau) = 4.4 \times 10^{-5}$

The optimization of cut boundary



The up limit for energy of lepton chosen. The best point is about 0.1 GeV, but considering that the main bkg come from $B \to Dl\nu \to \phi Xl\nu$, the cut "No lepton" is better.