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

2020-10-2

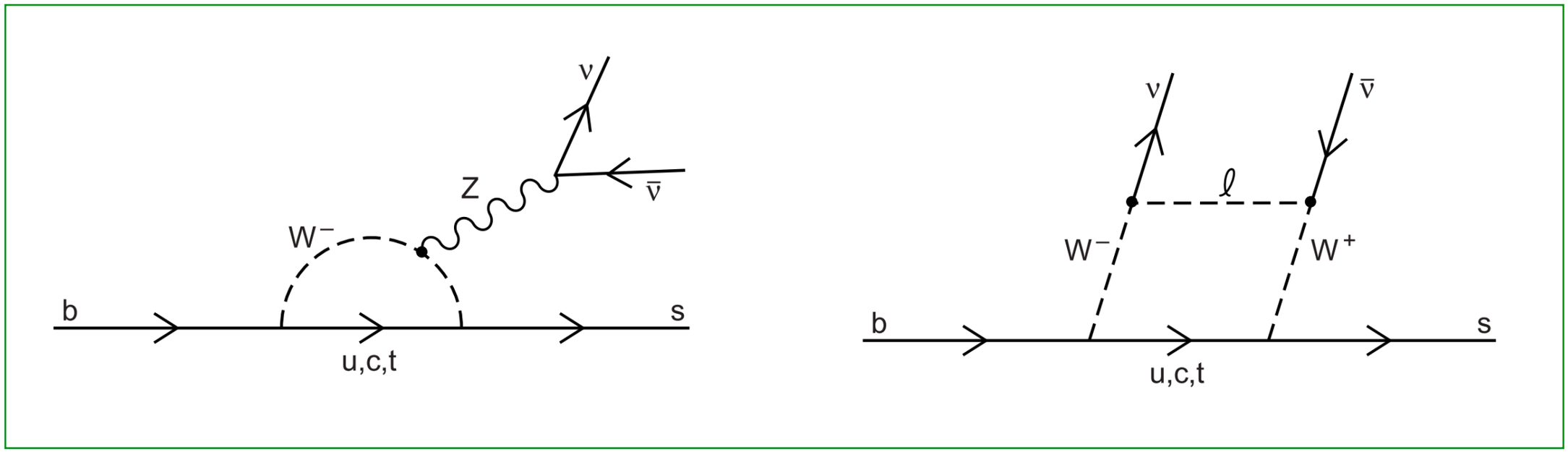
Yudong Wang, Lingfeng Li, Manqi Ruan, Yanyun Duan
Tao Liu, Taifan Zheng

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.

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

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.

	Experimental [1]	SM Prediction [2]
$\mathrm{BR}(B^0 \to K^0 \nu\bar{\nu})$	$< 2.6 \times 10^{-5}$	$(2.17 \pm 0.30) \times 10^{-6}$
$\mathrm{BR}(B^0 \to K^{*0} \nu\bar{\nu})$	$< 1.8 \times 10^{-5}$	$(9.48 \pm 1.10) \times 10^{-6}$
$\mathrm{BR}(B^\pm \to K^\pm \nu\bar{\nu})$	$< 1.6 \times 10^{-5}$	$(4.68 \pm 0.64) \times 10^{-6}$
$\mathrm{BR}(B^\pm \to K^{*\pm} \nu\bar{\nu})$	$< 4.0 \times 10^{-5}$	$(10.22 \pm 1.19) \times 10^{-6}$
$\mathrm{BR}(B_s \to \phi \nu\bar{\nu})$	$< 5.4 \times 10^{-3}$	$(11.84 \pm 0.19) \times 10^{-6}$

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.

B_s at CEPC

At Z pole at CEPC ($N_Z = 10^{12}$ with $L = 5.6\ \text{ab}^{-1}$),

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

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

B-hadron fragmentation fractions $f(b \to B)$ 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–baryon)* = 0.085 ± 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	$f(B_s)/f(B_d) = 0.249 \pm 0.023$		

SM prediction :

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

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

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

Truth level MC samples:

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

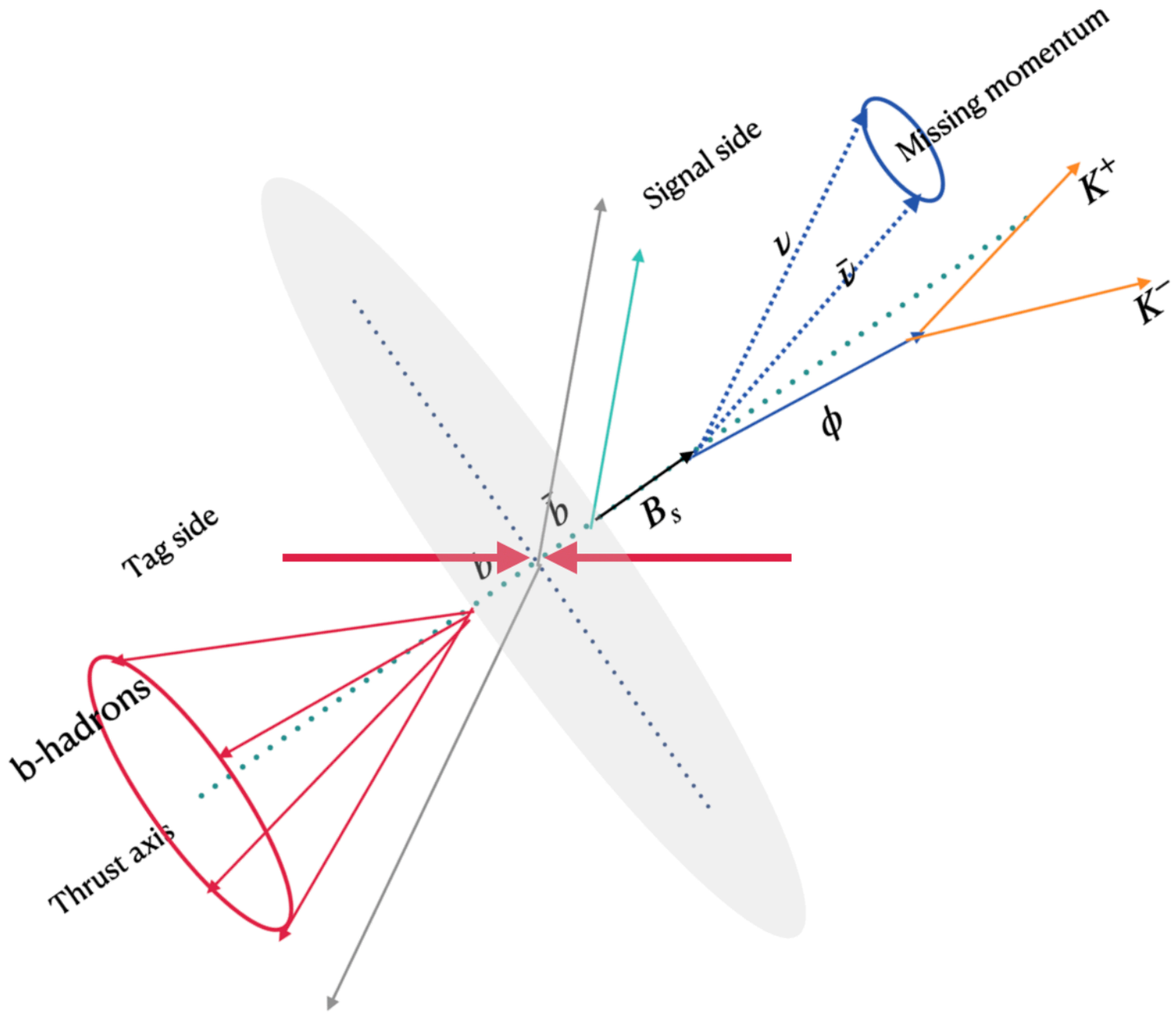
The whole space is divided into two hemisphere by the plane perpendicular to the thrust

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

Signal and tag hemisphere definition:

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

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

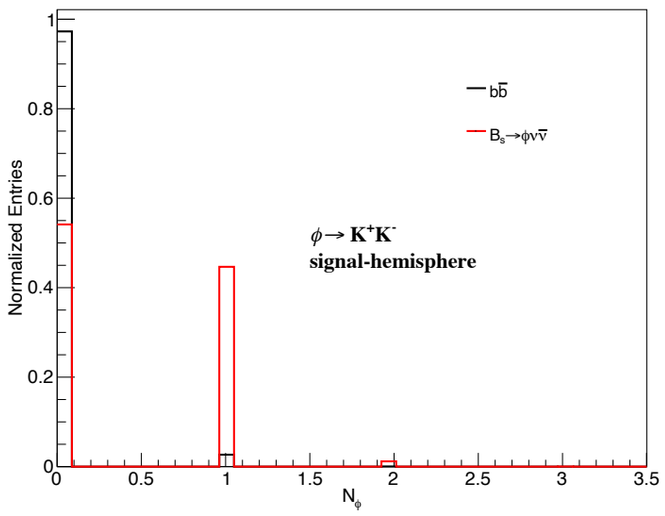


ϕ productions

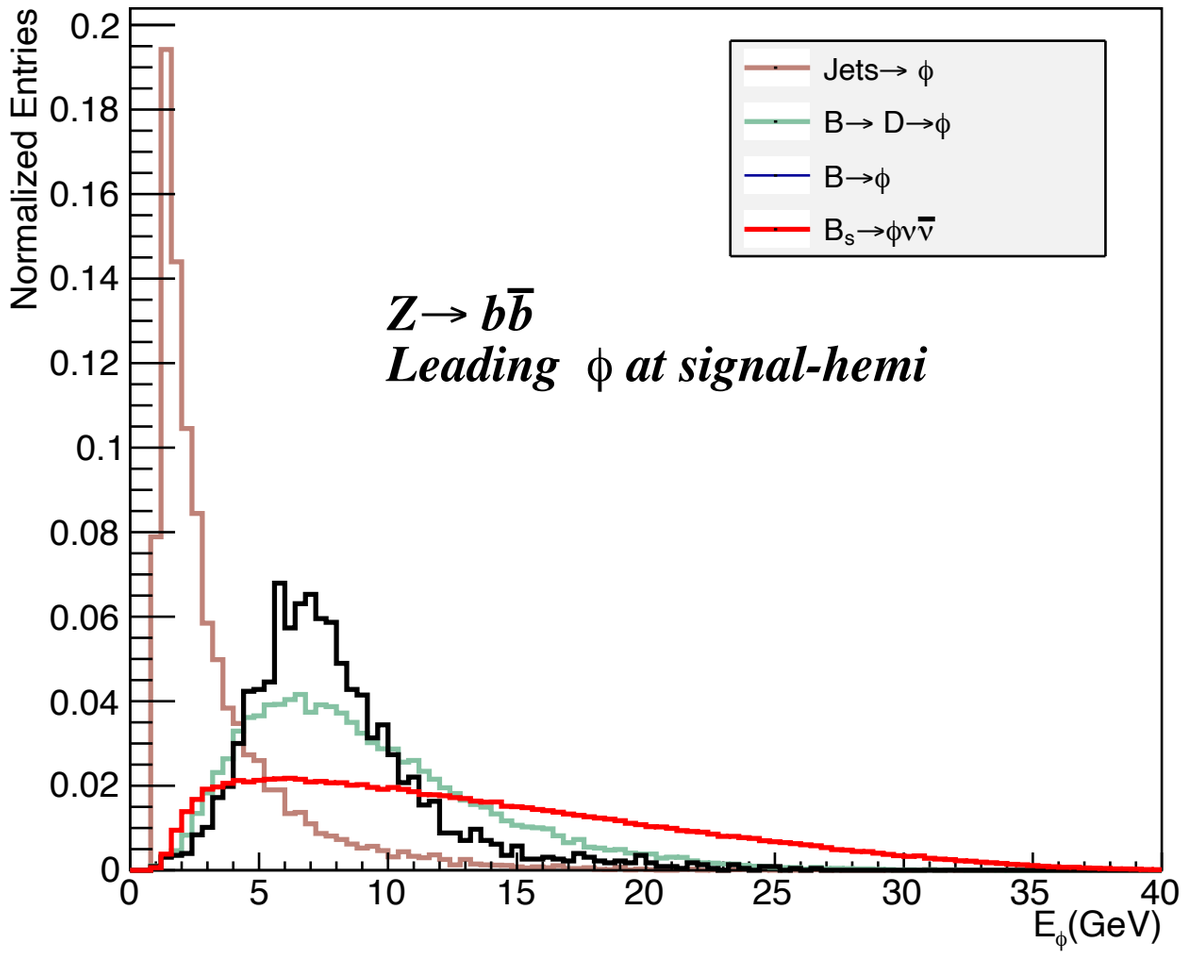
The ϕ production in $Z \to b\bar{b}$ events.

Parent	Num/Events
B	0.055
D	0.159
Jets	0.086
Others	0.004
Total	**0.304**

Number of $\phi(K^+K^-)$ distributions.

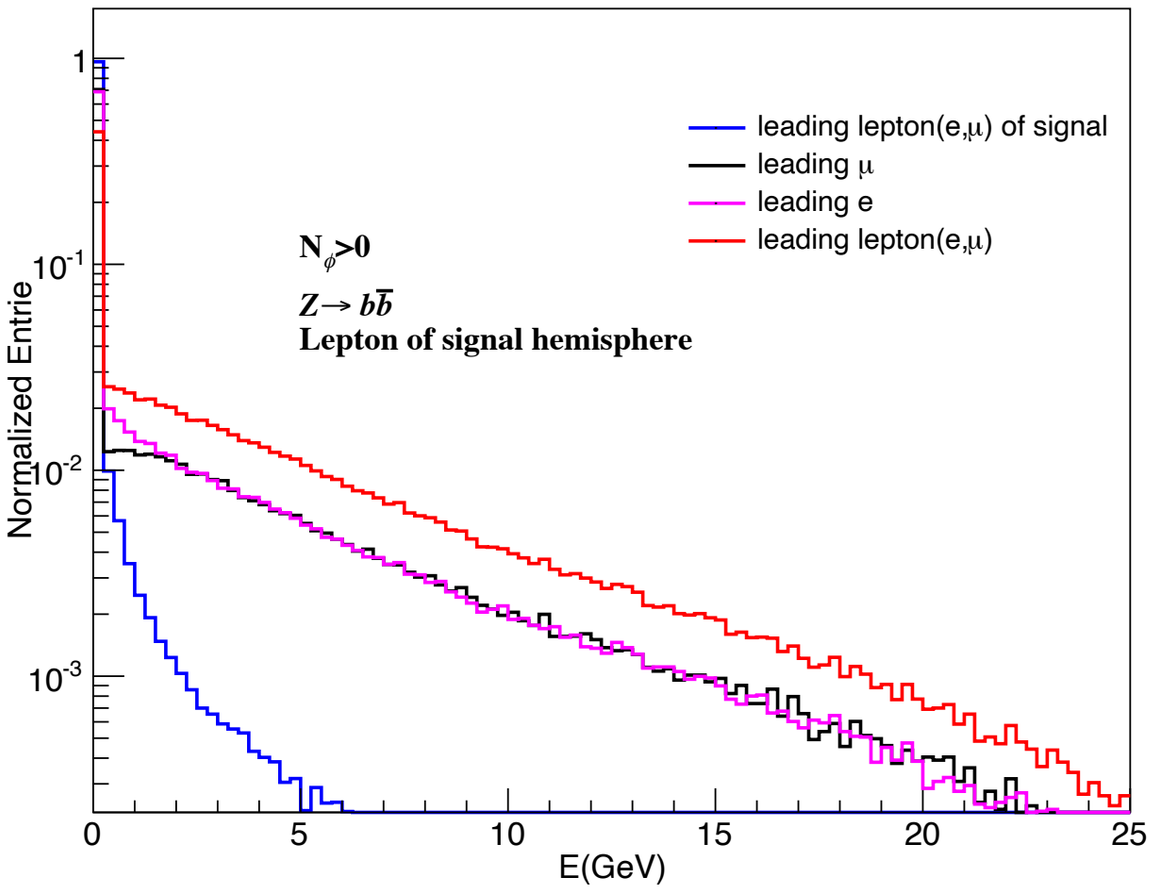


The energy distribution of ϕ from different decay process



The lepton(μ, e)

The energy spectrum of lepton.



$b \rightarrow Bs + X$: X are mainly light meson such as π, $K^{\pm}$.

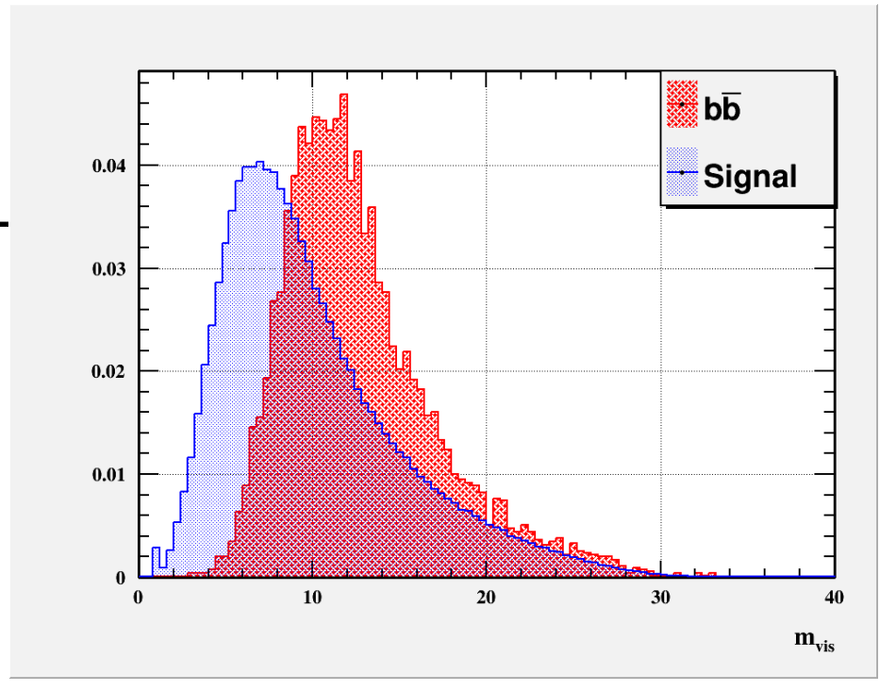
$Bs \rightarrow \phi\nu\bar{\nu}$: No lepton.

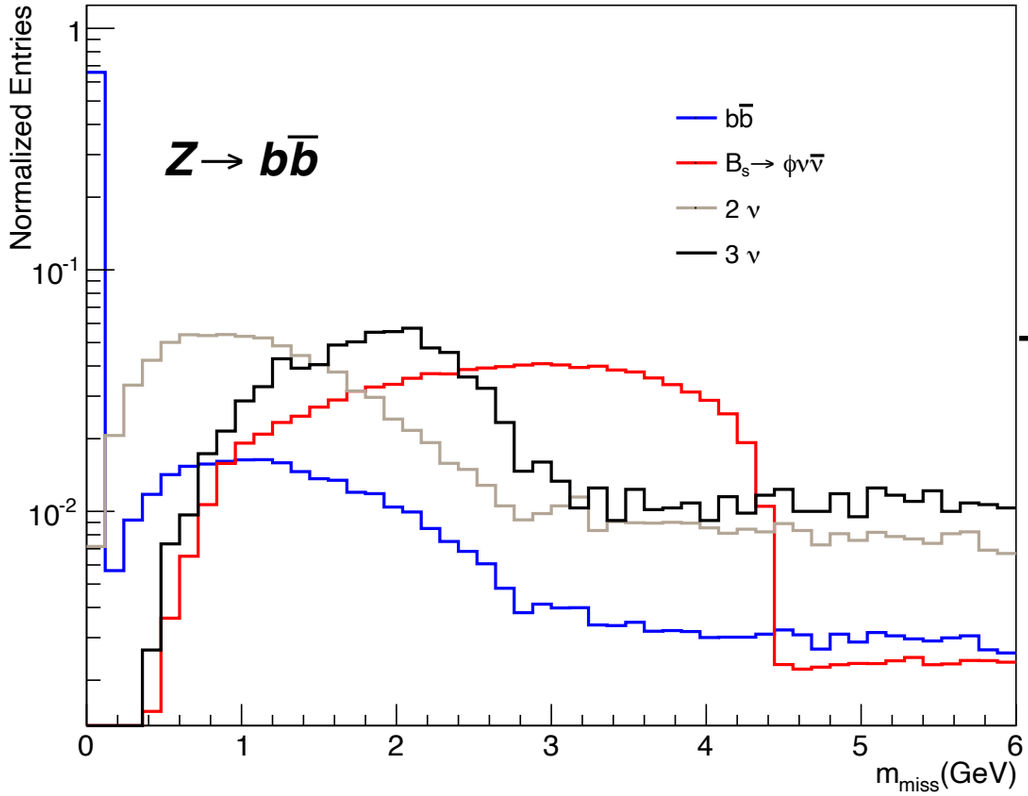
$E_{lepton} \sim 0$ (GeV).

Missing mass

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

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





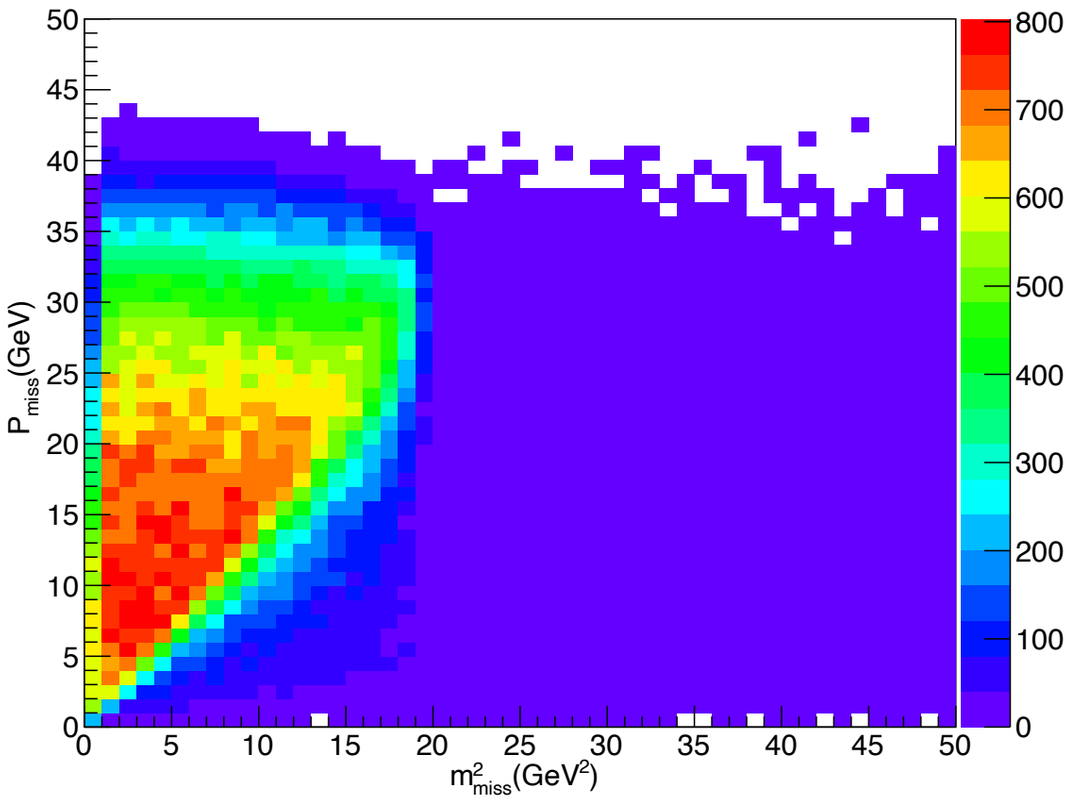
$$m_{miss} = \sqrt{\left(p_0 - \sum_i p_i \right)^2}$$

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

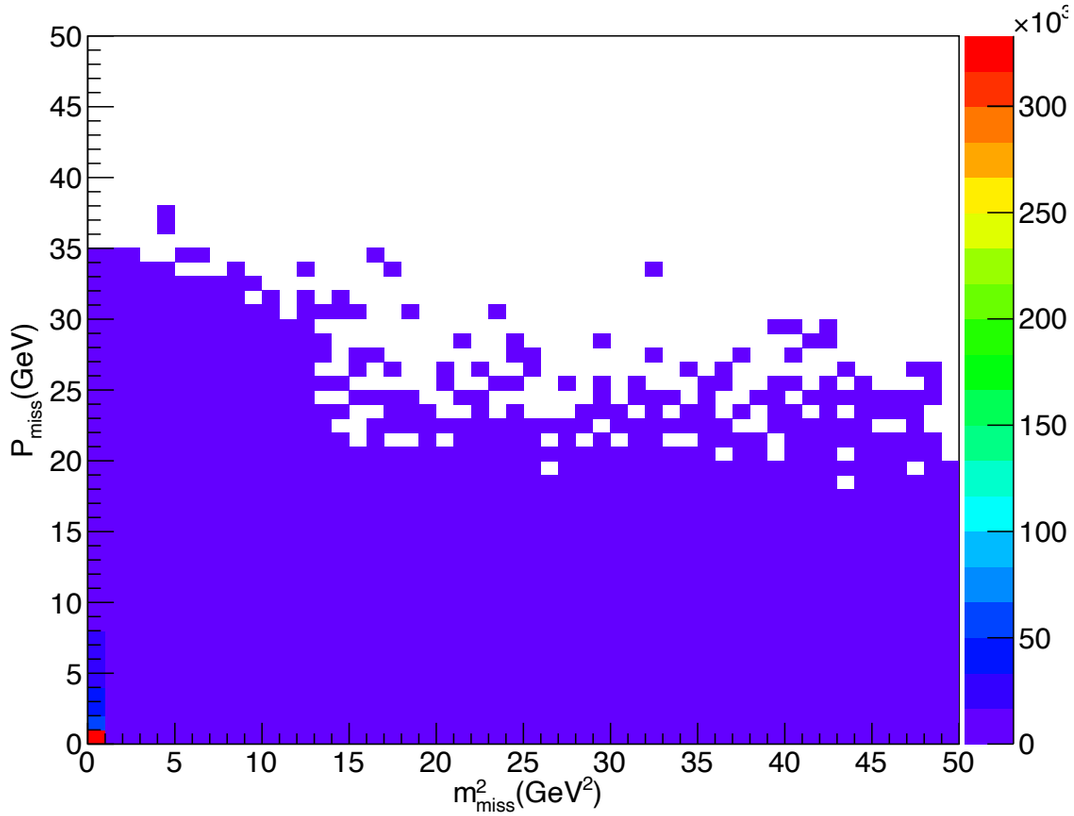
For single neutrino in mostly bkg:

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

The $P_{miss} - m^2_{miss}$ distribution of signal $B_s \to \phi\nu\bar{\nu}$.



The $P_{miss} - m^2_{miss}$ distribution of $Z \to b\bar{b}$ events.



Constrains for E_ϕ and E_{vis}^{sig}

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

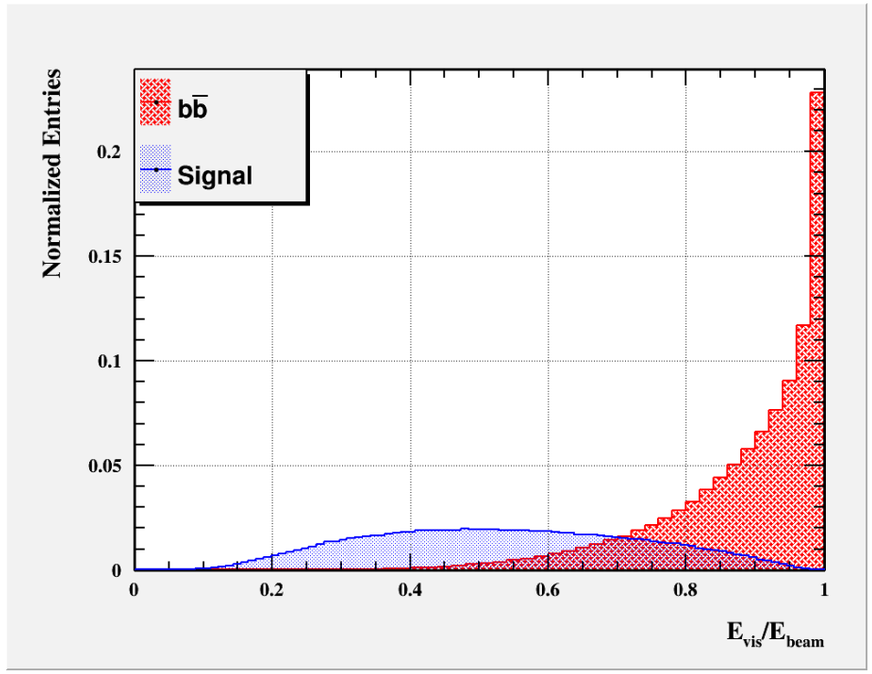
Where E_{vis}^{sig} is total energy of visible particles at signal-hemisphere.

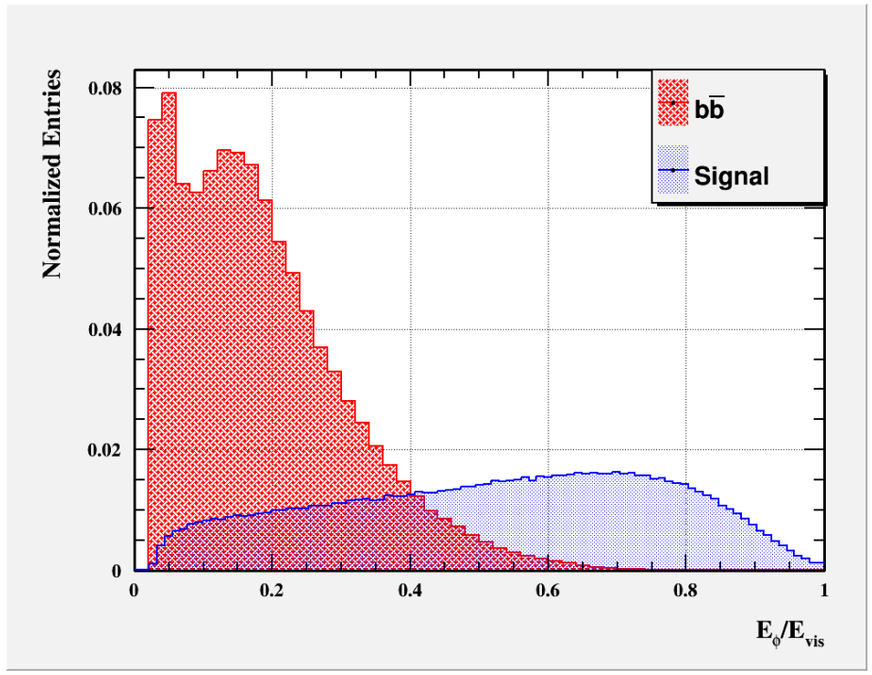
As the large miss energy for $\nu\bar{\nu}$ pair in signal,

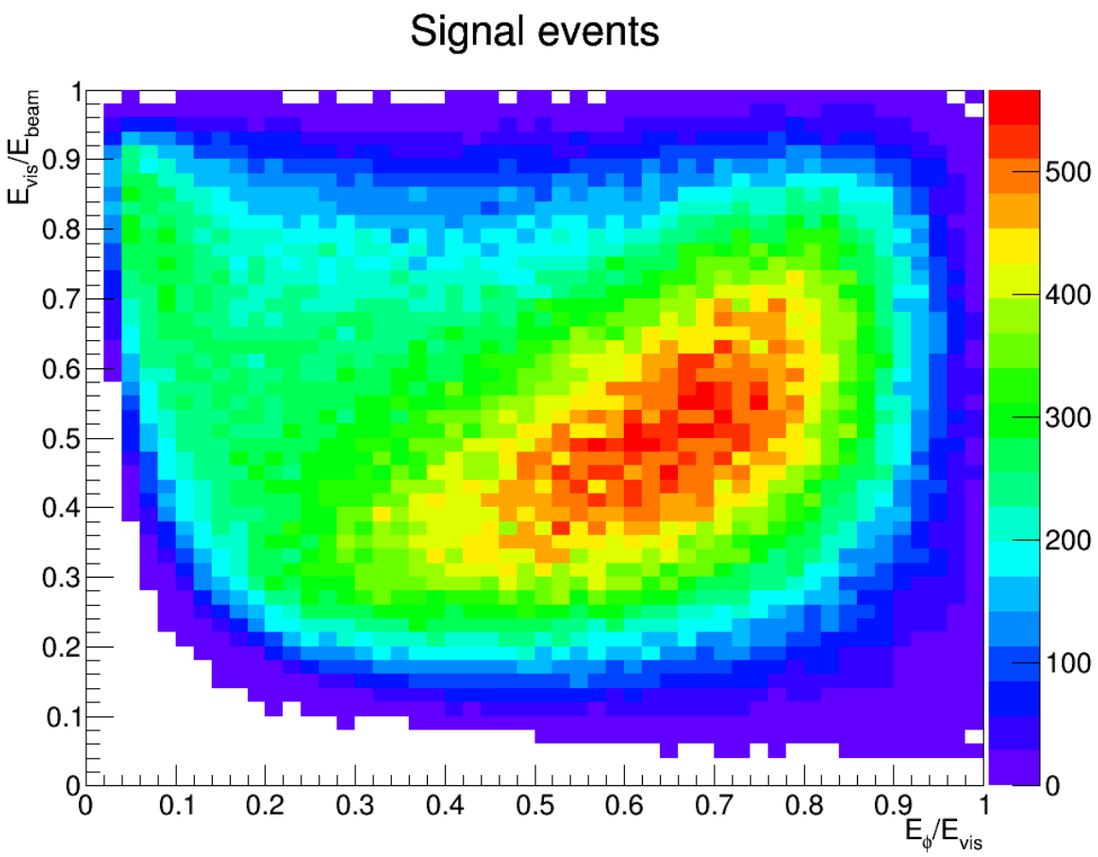
$E_{vis}^{sig}/E_{beam} \rightarrow$ low ratio

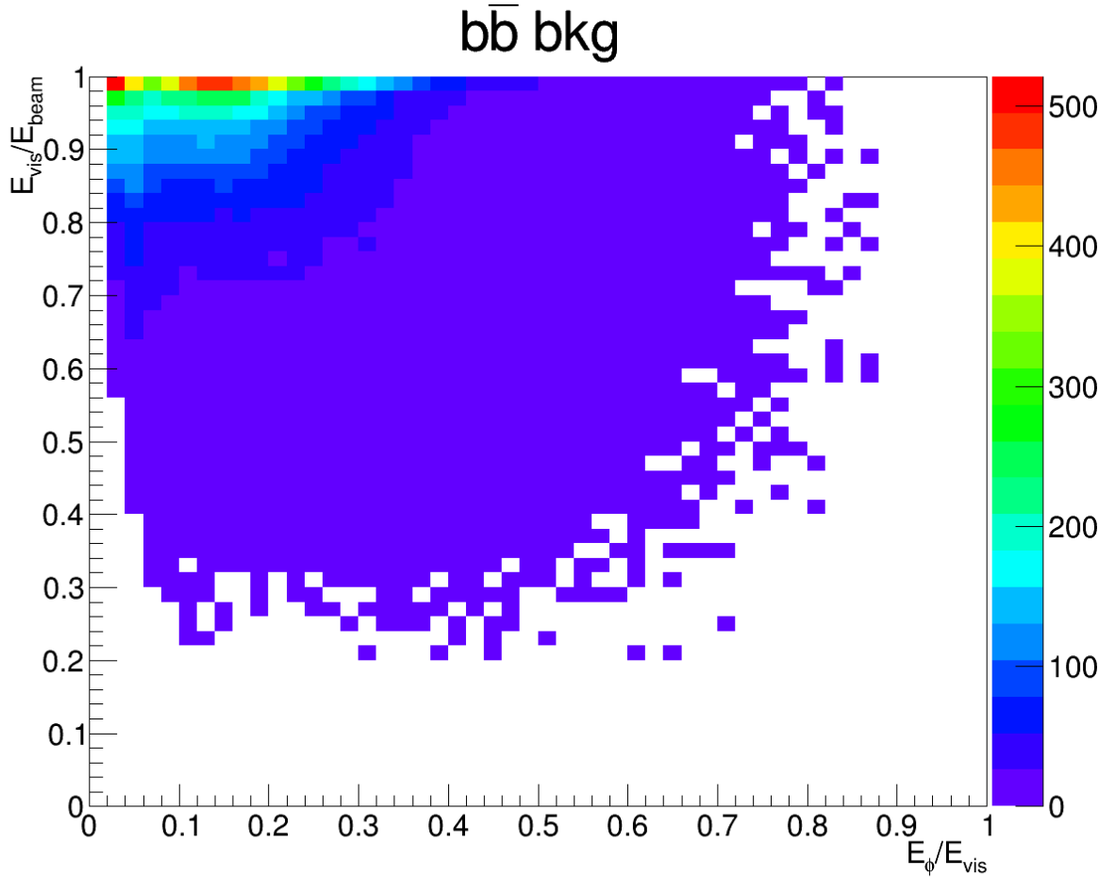
$E_\phi/E_{vis}^{sig} \rightarrow 1$

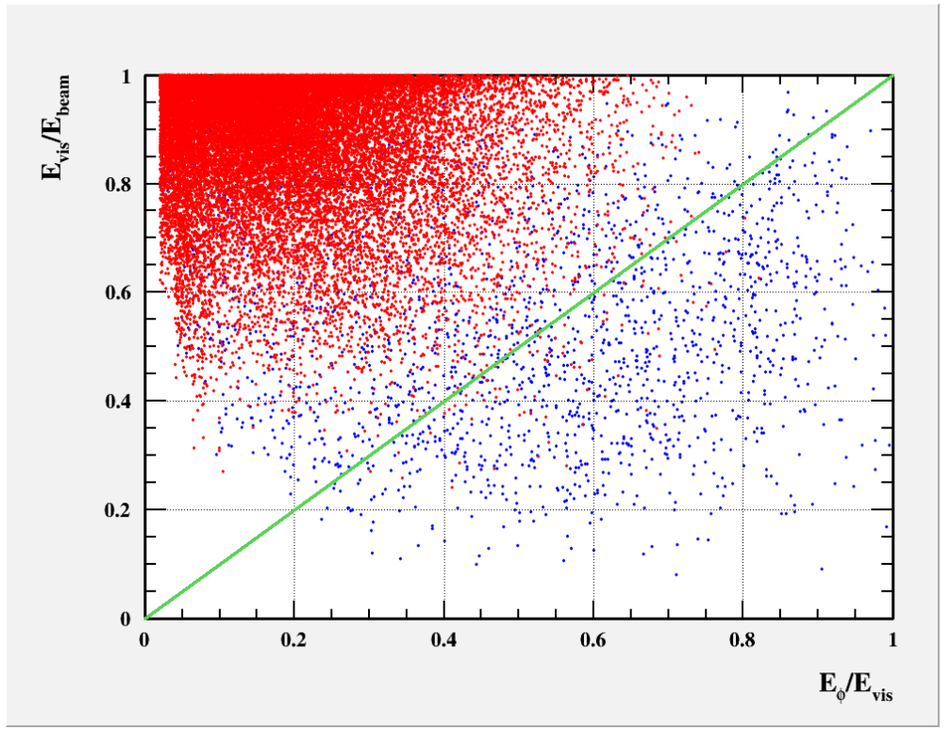
And should exits correction between the two variables.

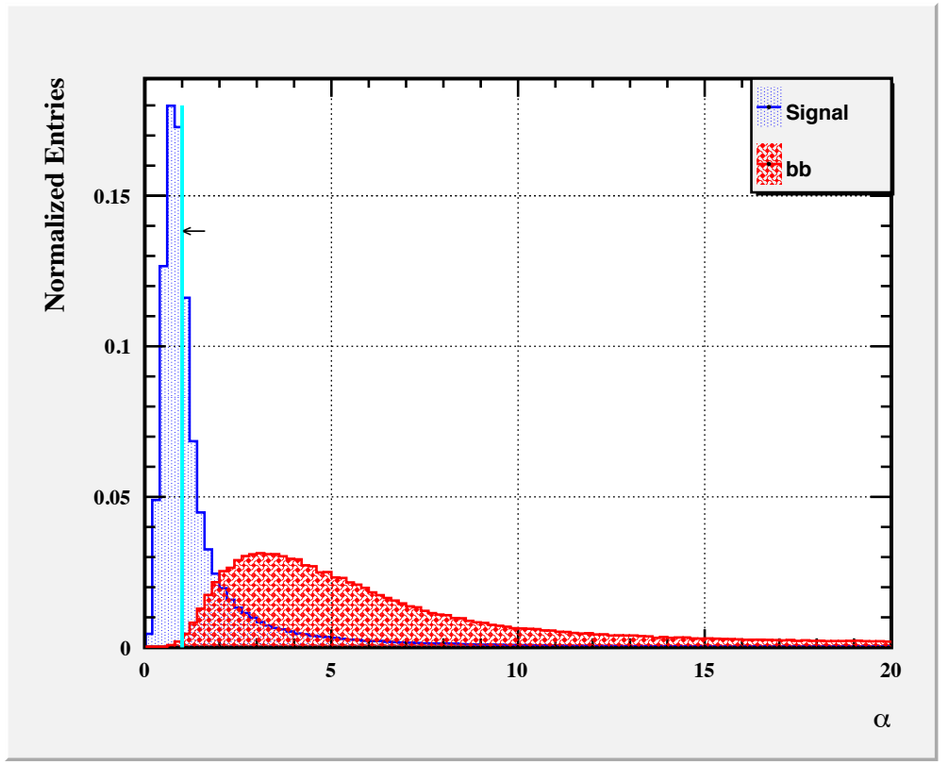





Signal events
E_{vis}/E_{beam}
E_ϕ/E_{vis}


$b\bar{b}$ bkg
E_{vis}/E_{beam}
E_ϕ/E_{vis}


E_{vis}/E_{beam}
E_ϕ/E_{vis}


Normalized Entries
Signal
bb
α

Main background from $q\bar{q}$

The ϕ with missing neutrinos.

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

Especially: $B_s \to D_s l\nu_l$ with $D_s \to \phi l\nu_l$ (two neutrinos)

$$c\bar{c} : c \to D(D^*) \to X\ell\nu_\ell$$

Mostly removed by flavor tagging.

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
$E_{lepton} > 0.2$ GeV	66039	3.55e+09	3.60e+09	7.01e+9	0.902
m_{inv}>2.2 GeV	52385	1.06e+08	3.25e+06	9.39e+7	0.197
$\alpha < 0.8$	20578	204783	5333	133150	0.023
Efficiency	0.14	6.83e-07	2.22e-08		

End

Thanks