Simulation of LHeC experiment

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   - Higgs production at the LHeC
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2. Event selection and kinematics
3. Results
4. Summary/Future plan

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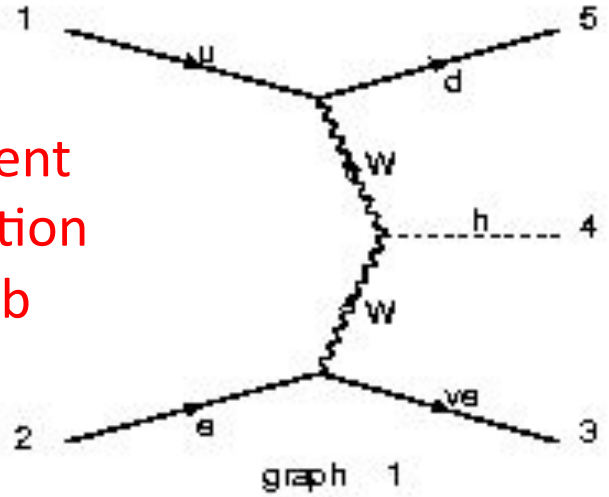
Higgs production at the LHeC

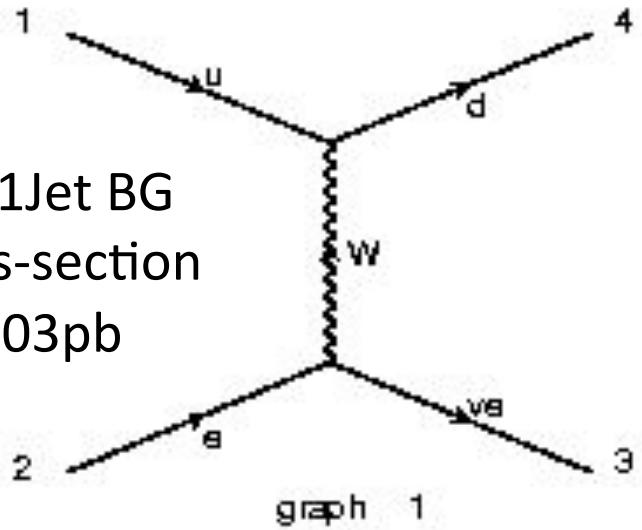
- Studying the measurement of $H \rightarrow b\bar{b}$ mode in LHeC experiment.

In this study,
Signal : CC Higgs event
BG : CC 1 and 3 Jets BG

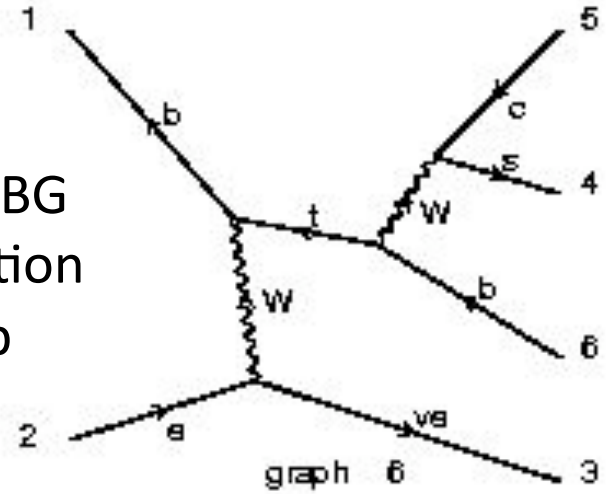
Higgs event
cross-section
0.235pb



CC 1Jet BG
cross-section
503pb



CC 3Jets BG
cross-section
58.8pb



Parameters and Procedure

- Generated Higgs and CC background events with following framework.
  MadGraph : generate possible Feynman diagrams and calculate cross sections
  PYTHIA : fragment the quarks and gluons to generate hadronic final states
  PGS : detector simulation, based on parameterized resolution smearing etc, including B-tag: based on CDF-II performance.
  (Whole setup for ep collision prepared by U. Klein, Liverpool)

- Set the parameters
  - Beam energy → E_p : 7 TeV + E_e : 150 GeV ($\sqrt{s}$: 2050 GeV)
  - Higgs mass →120 GeV : Higgs to $b\bar{b}$: 71.8%, $c\bar{c}$: 8.3%
  - Luminosity → 10 fb^{-1}
  - Energy Resolution (cal) → 80% default (60%, 40% for comparison)
  - Kinematic cut → $E_{jet} > 5GeV$, $\theta_{jet} > 0.5^o$, $\theta_{lepton} > 10^o$, $M_{jj} > 30GeV$

Event selection including B-tag

Cut (1) : $Q^2>400GeV^2$, $y<0.9$, $missE_T>20GeV$,
N_{Jet} ($P_{T,Jet}>20GeV$) ≥2, $E_{T,total}$ > 100GeV,

Cut (2) : $N_{b\text{-}Jet}$ ($P_{T,Jet}>20GeV$) ≥2
b-Jet meant jet with B-tag requirement

Cut (3) : N_{Jet} ≥ 3, M_{top}< 200 GeV, M_W > 130 GeV

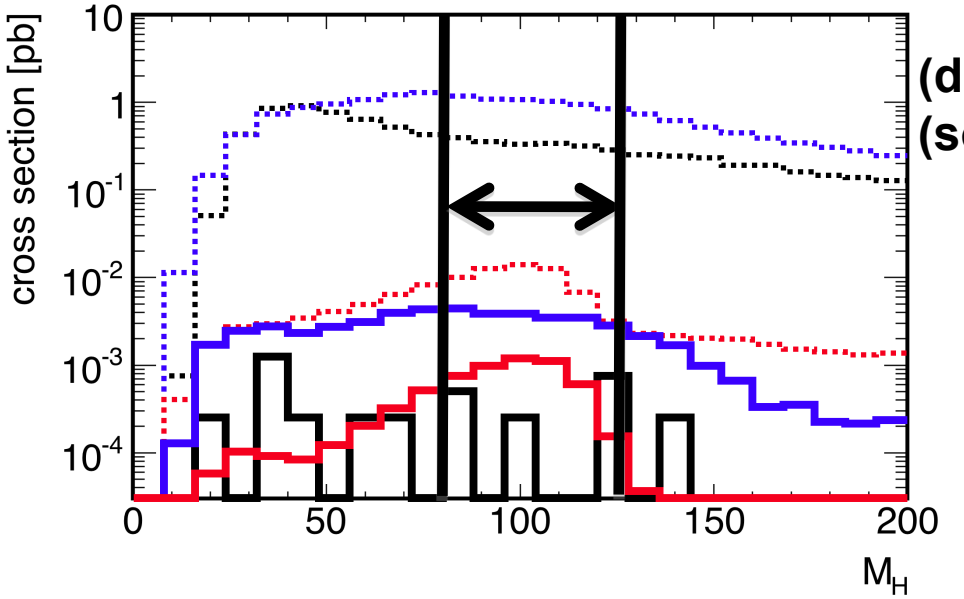
• We selected lowest η jets for making M_{jj} or M_{jjj} (referring to Uta)

Jet kinematics

We required B-tag for at least 2 jets to reconstruct M_H (solid line)

After Cuts (1) & (2) and 80GeV < M_H < 125GeV

— **Higgs event**
— **CC 3Jets BG**
— **CC 1Jets BG**



(dashed line) Cuts(1)
(solid line) Cuts (1) & (2)

Higgs event / CC 1+3Jets BG S/N = 401/80500 = 5.0×10^{-3} (w/o B-tag)

=> S/N = 47.7/251 = 0.2 (w/ B-tag)

Components of remaining backgrounds

CC 3Jets BG / CC 1+3Jets BG 235/251 = 94%

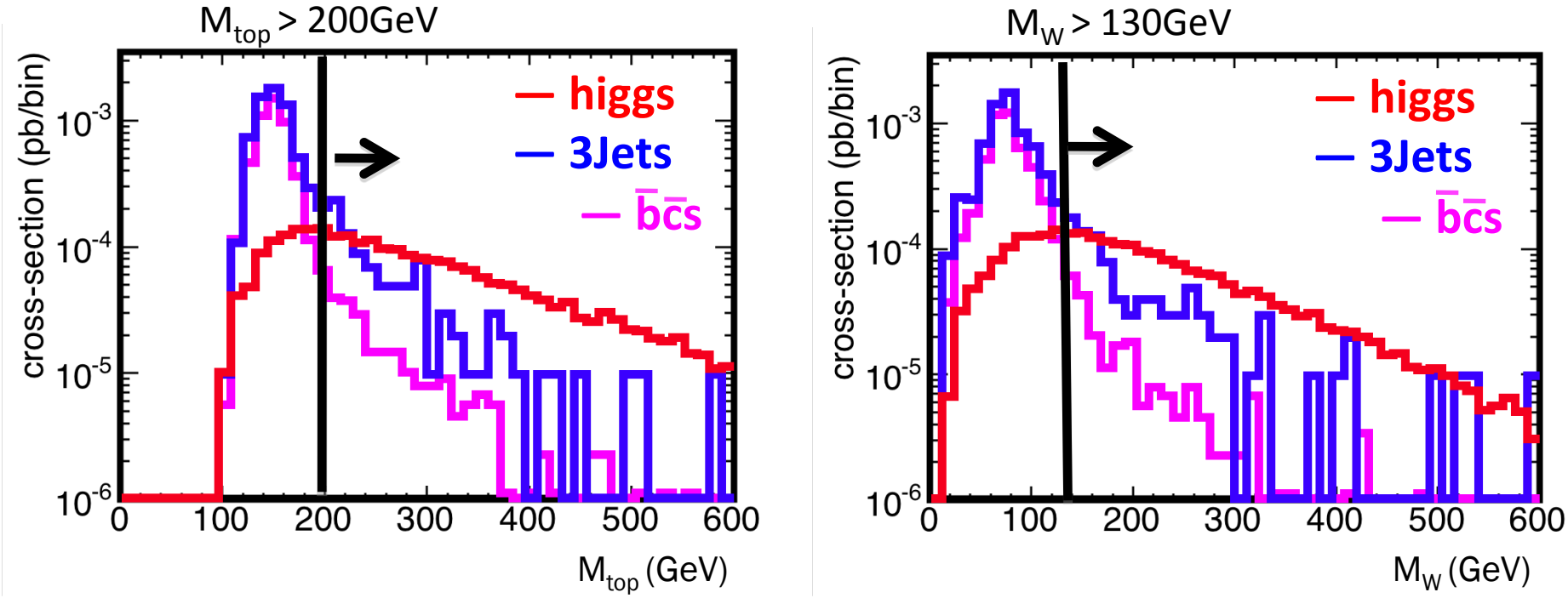
CC $\bar{t}\rightarrow\bar{b}\bar{c}s$ BG / CC 1+3 Jets BG 138/251 = 55%

sub-process

Main components of remaining background was single-top production decay to $\bar{t}\rightarrow W\bar{b} \rightarrow \bar{b}+\bar{c}+s$.

Reduction in single top production.

After Cuts (1) & (2) and 90GeV < M_H < 120GeV



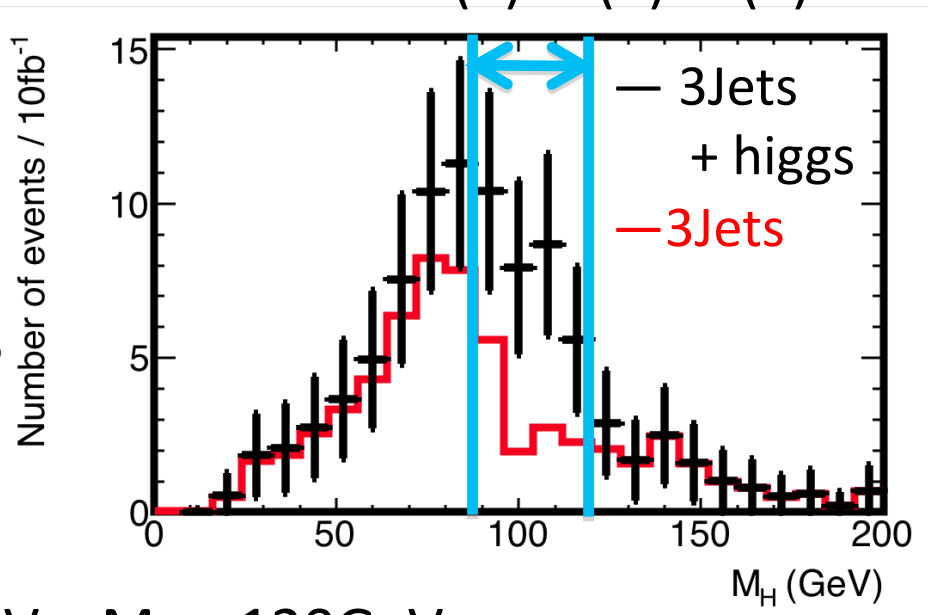
M_{top} was reconstructed from two lowest η B-tagged jets + lowest η jet (regardless of B-tag).

M_W was reconstructed from lowest η B-tagged jet + lowest η jet (regardless of B-tag but excluding 2nd lowest η B-jet).

Number of events, S/N and S/√N for 10 fb^{-1}

- Remaining BG process : $Z \rightarrow b\bar{b}$
  (~130 fb for $bb\bar{d}$ process)
- After Cuts (1) & (2) & (3) & M_H,
  Higgs event efficiency : 8.51×10^{-3}

After Cuts (1) & (2) & (3)



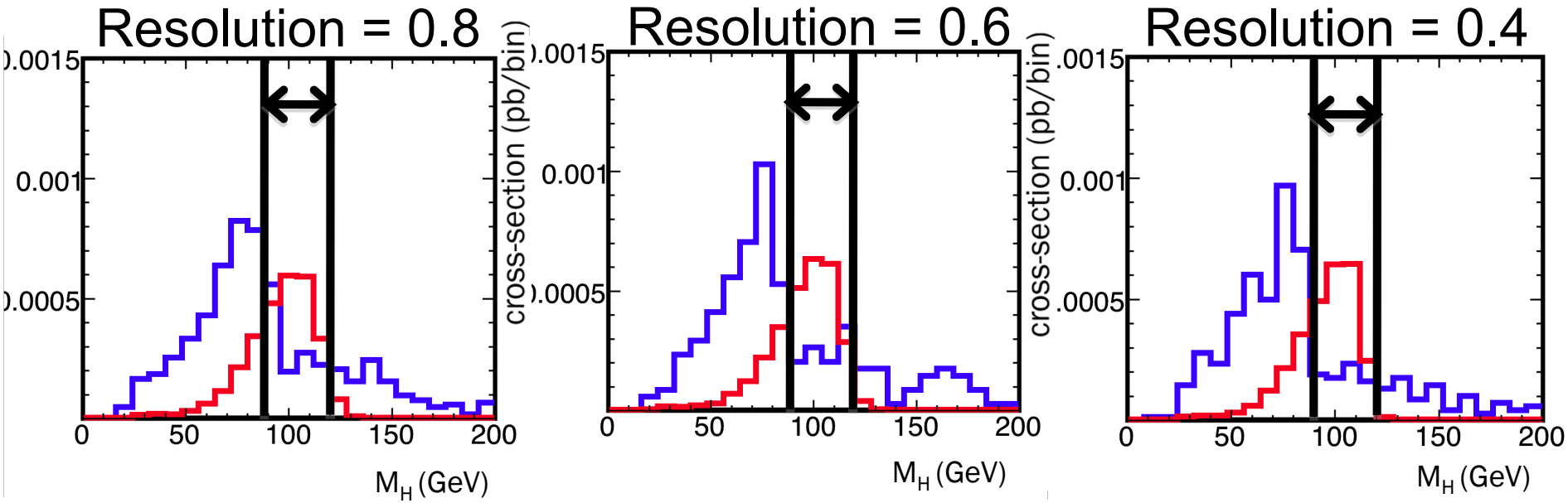
Cut M_H : 90GeV < M_H < 120GeV

Applied Cut	Higgs event	CC 3Jet BG	S/N	S/√N
No Cut	2350	5.88×10^5	4.0×10^{-3}	3.0
Cuts (1) & (2) & M_H	47.7	235	0.20	3.11
Cuts (1) & (2) & (3) & M_H	20.0	12.6	1.59	5.65

Dependence on hadronic energy resolution

After Cuts (1) & (2) & (3) & M_H

— Higgs event — CC 3Jet BG



Resolution	Higgs event	CC 3Jet BG	S/N	S/√N
80 %	20.0	12.6	1.59	5.65
60 %	20.5	10.3	1.99	6.39
40 %	20.3	7.2	2.81	7.55

Summary

- Remaining $\bar{t}\rightarrow\bar{b}W\rightarrow\bar{b}\bar{c}s$ background was reduced by top and W mass cut.
- After Cuts (1)−(3) & M_H for 10 fb^{-1}
  - S/N = 20.0/12.6 = 1.59 (S/√N = 5.65)
  - Efficiency of Higgs event was 20.0 / 2350 = 8.51×10^{-3}.
- After top and W Mass cut, a remaining BG process was $Z\rightarrow b\bar{b}$.
- Good hadronic resolution is desirable for Higgs peak separation.

Future

- For more serious study of $H\rightarrow b\bar{b}$ decay mode we should have a realistic detector simulation.

Back up

Generated processes infomation

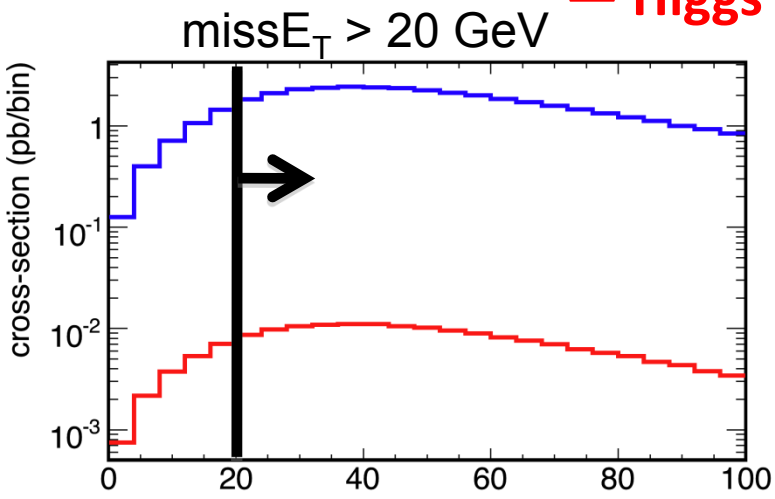
Cross-section and number of diagrams of each process

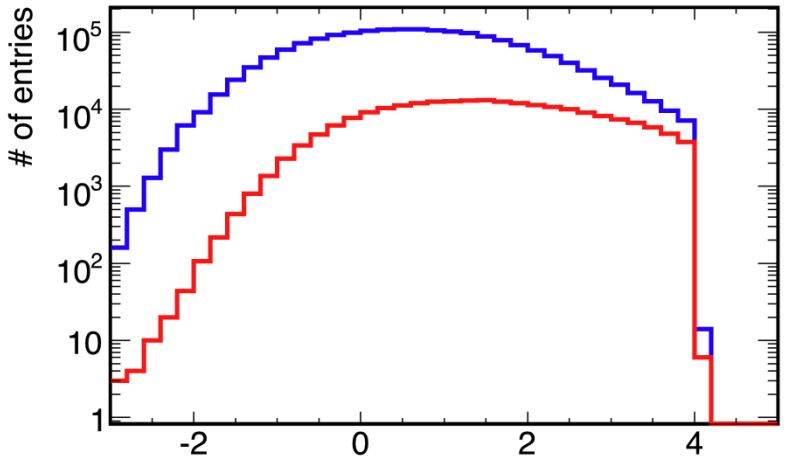
process	Cross-section (pb)	Number of diagrams
Higgs event	0.235 pb	2
CC 1Jets BG	503 pb	2
CC 3Jets BG	58.8 pb	536
CC $\bar{b}jj$ BG	5.36 pb	48
CC $\bar{b}\bar{c}s$ BG	2.25 pb	12
CC $b\bar{b}j$ BG	0.865 pb	24
CC $b\bar{b}d$ BG (only $Z \rightarrow \bar{b}b$)	0.132 pb	5

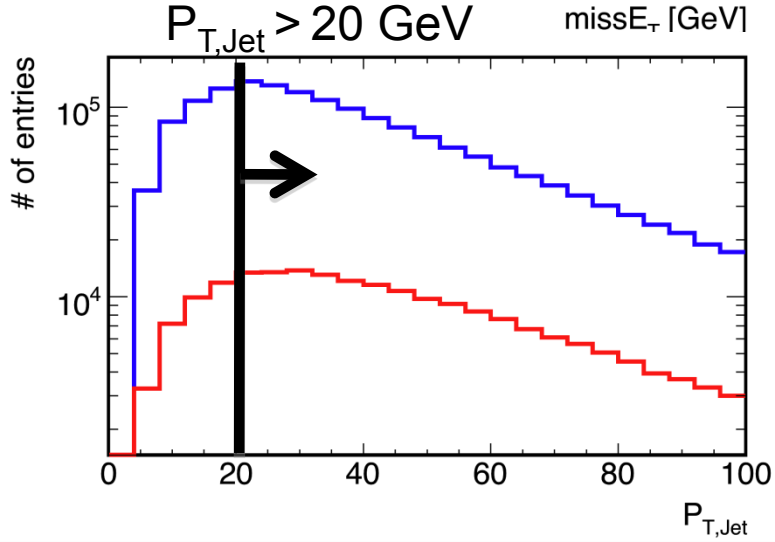
sub-process

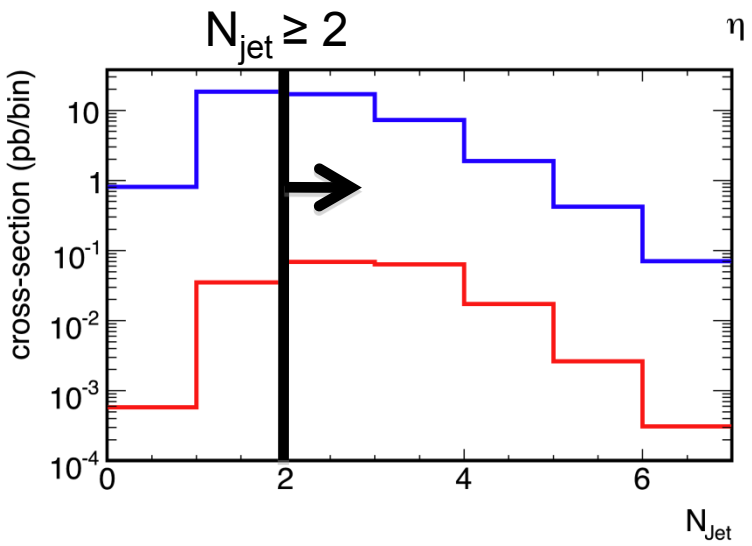
Distribution of PGS variables

— Higgs event — CC 3Jet BG









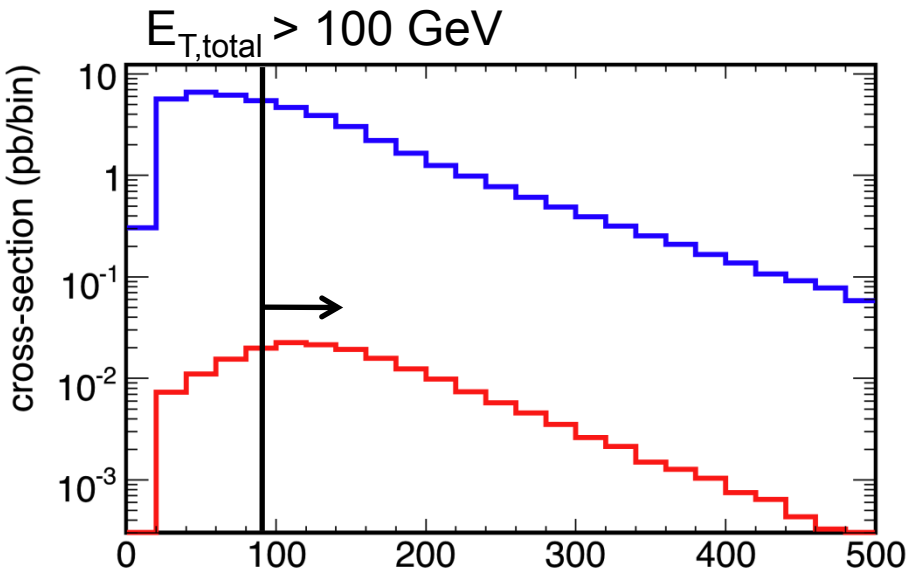
Q^2>400GeV^2 & y<0.9 & missE$_T$>20GeV & N_{Jet}≥2 ($P_{T,Jet}$>20GeV) & $E_{T,total}$ > 100GeV

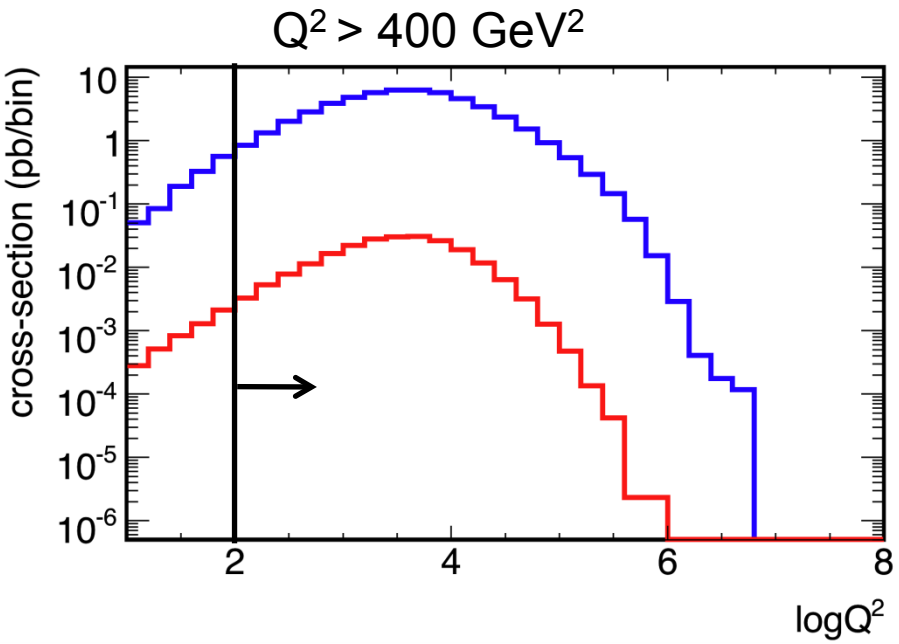
We named above cuts Cut (1).

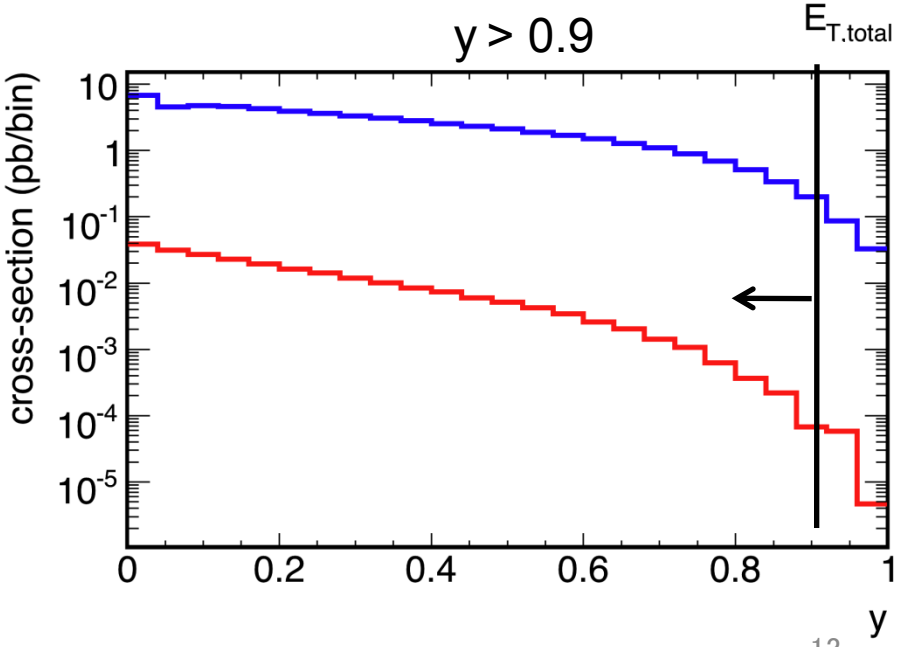
Distribution of PGS variables

$y = \{\Sigma(E-P_z)\} / 2\times E_{electron}$,
$Q^2 = P_T^2 / (1-y)$,
$P_T^2 = (\Sigma P_x)^2 + (\Sigma P_y)^2$

Cut : $Q^2 > 400 GeV^2$ & $y < 0.9$
& $E_{T,total} > 100 GeV$





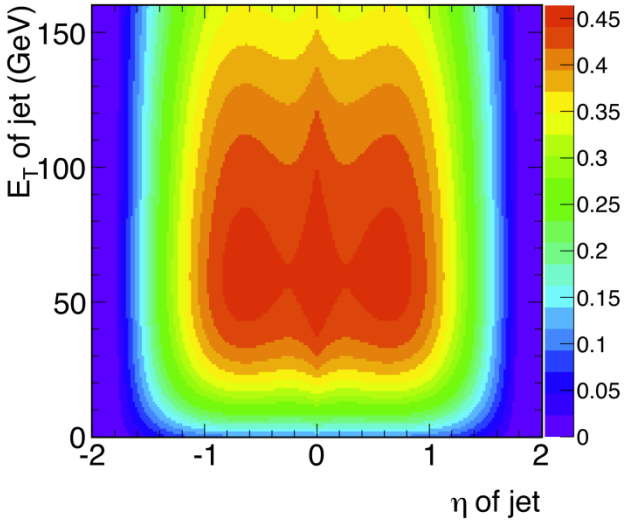


B-tag

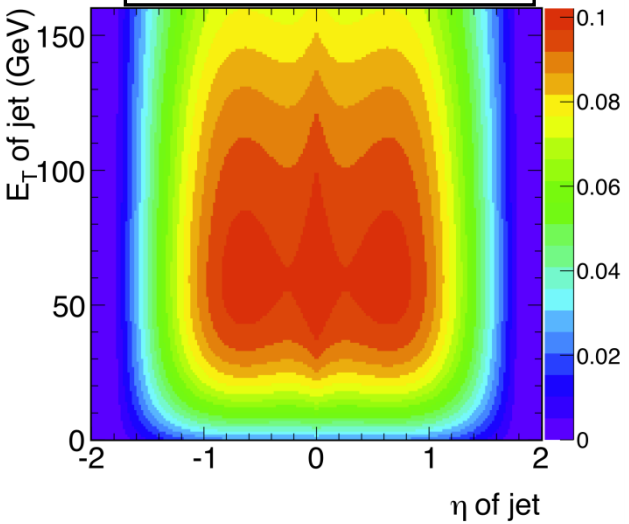
PGS identifies to each jet whether it is a jet of b or $\bar{b}$ quark origin（B-tag）.

B-tag efficiency is defined depending on whether b or $\bar{b}$, c or $\bar{c}$ or others ($u\bar{u}$, $d\bar{d}$, $s\bar{s}$ or g) exist within the cone of 20° from the jet.
It is a function of η, E_T and calculated based on CDF performance.

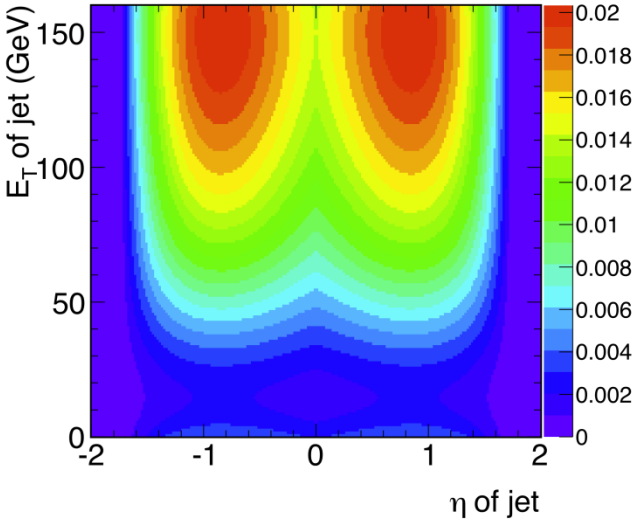
Tight B-tag



(1) B-tag efficiency for jets including *b* ($f_b(E_T, \eta)$)



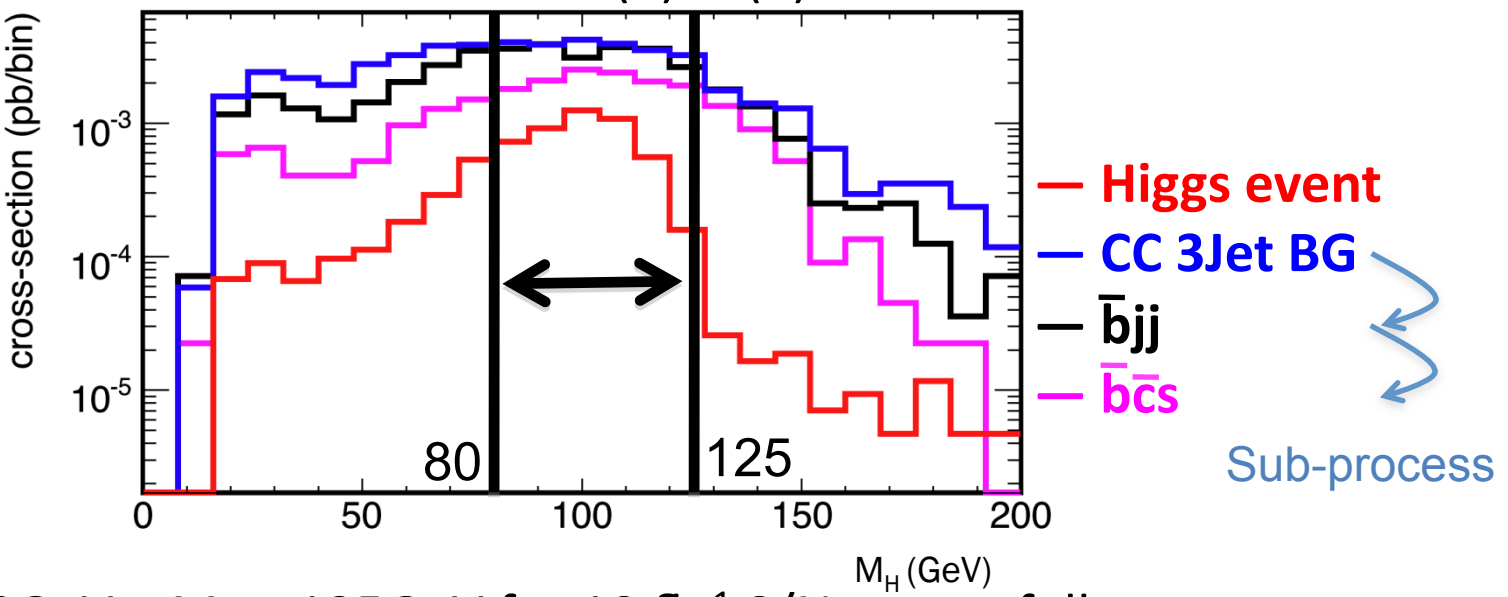
(2) B-tag efficiency for jets including *c* ($f_c(E_T, \eta)$)



(3) B-tag efficiency for jets including *uds* or *g* ($f_{udsg}(E_T, \eta)$)

Remaining BG

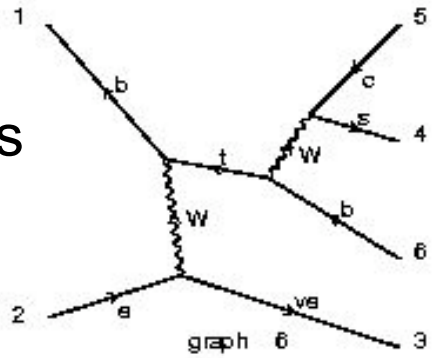
After Cuts (1) & (2)



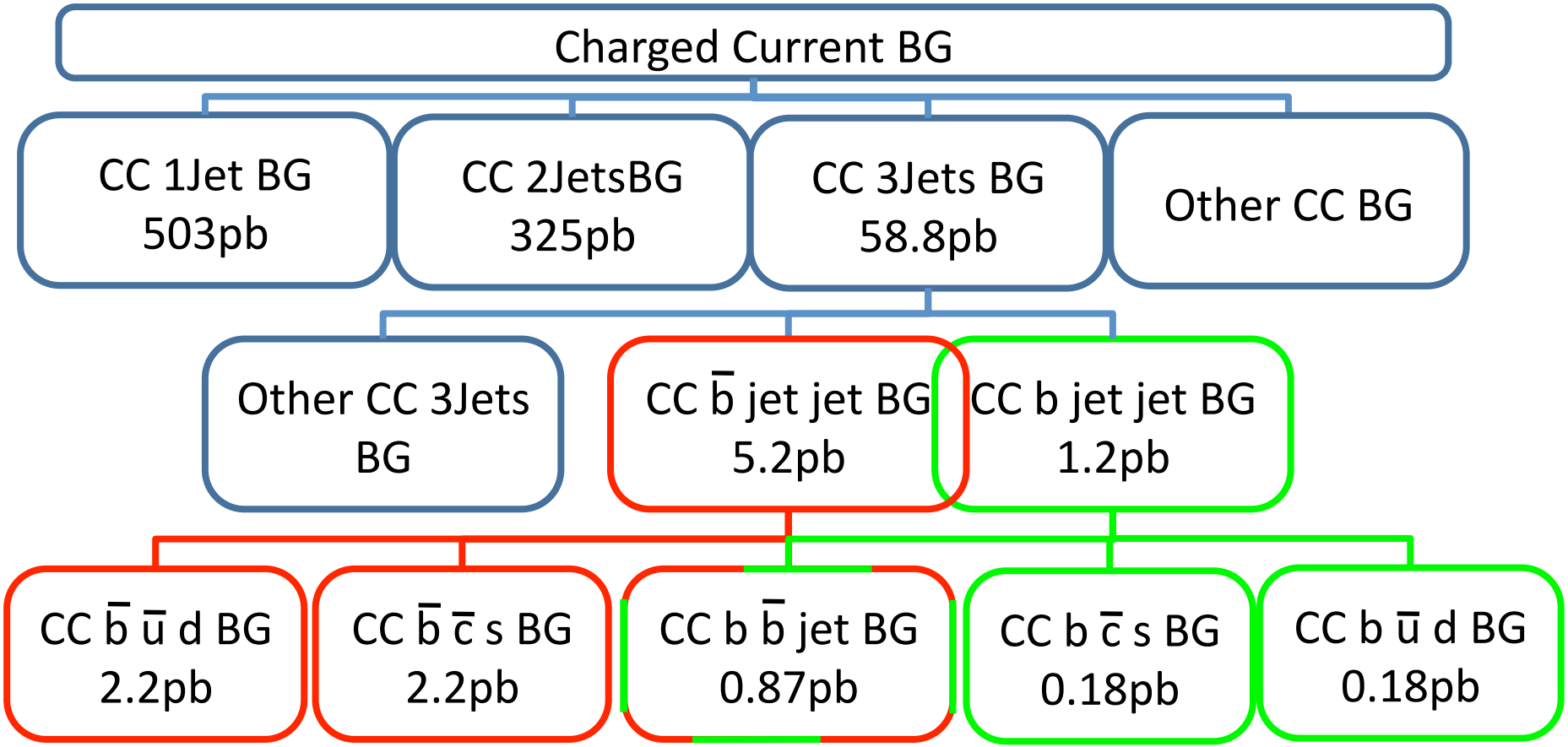
in 80GeV < M_H < 125GeV for 10 fb^{-1} S/N was as follows

Higgs / CC 3Jets BG	S/N = 46.9 / 229 = 0.20
$\bar{b}jj$ BG in 3Jets BG	205 / 229 = 91 %
$\bar{b}\bar{c}s$ BG in 3Jets BG	128 / 229 = 57 %

- Dominant process in the final CC 3Jets BG was $\bar{b}\bar{c}s$ ($\bar{c}$-jet had high B-tag efficiency.)
- 95% of $\bar{b}\bar{c}s$ process came from single-top diagram. ($\bar{t} \rightarrow W^- \bar{b} \rightarrow \bar{b}\bar{c}s$)



Subprocess cross sections by MadGraph



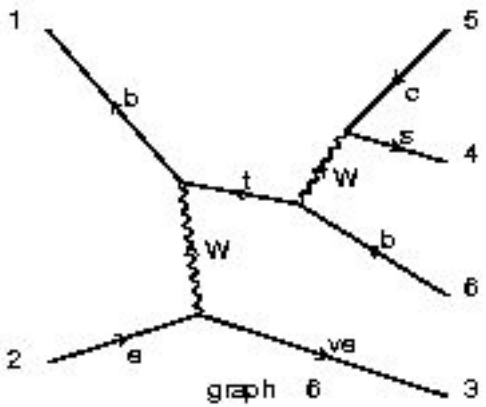
Large cross-sction of $\bar{b}\bar{c}s$ or $\bar{b}\bar{u}d$ 3 Jets events.

95% of these processes was single-top production $\bar{t} \rightarrow W\bar{b} \rightarrow (\bar{c}s$ or $\bar{u}d)\ \bar{b}$

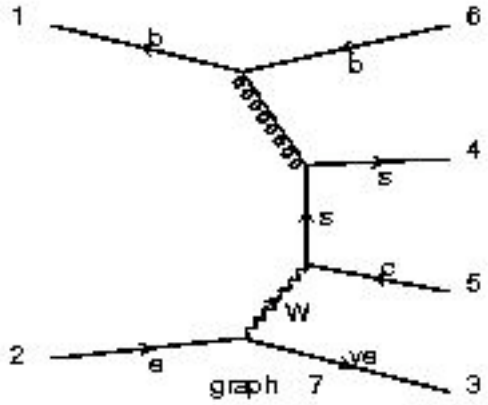
They were suspected 3Jets bg for Higgs seach.

$\bar{b}\bar{c}s$ process (12 diagrams)

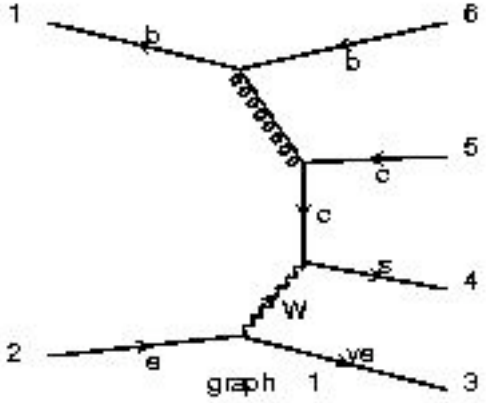
Cross-section = 2201fb



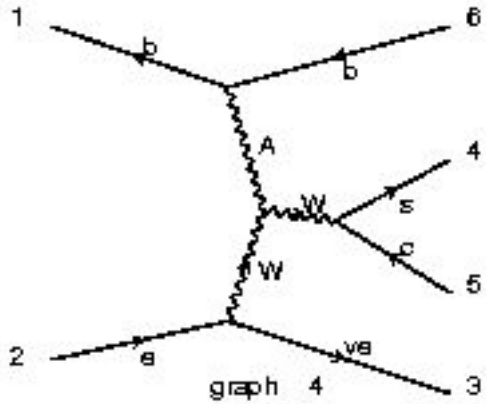
2100fb



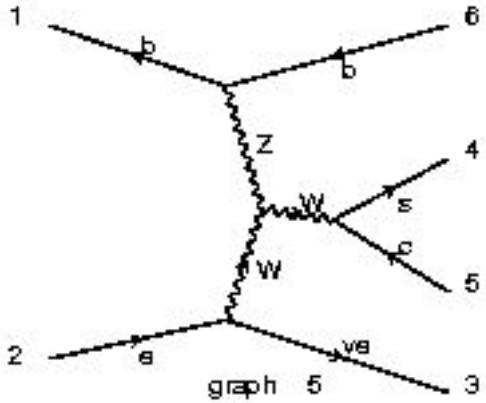
52fb



35fb



5.2fb



6.6fb

Single-top production process was dominant.

Condition of N_{Jet}

If we reduce the $\bar{t} \rightarrow \bar{b}W^{-} \rightarrow \bar{b}\bar{c}s$ process, S/N will be improved.

We calculated S/N for 10 fb^{-1} on the condition following Cut (2), (2-a) and (2-b) in $80GeV < M_H < 125GeV$.

Number of events

	Cut (2)	Cut (2-a)	Cut (2-b)
Number of jets	$N_{Jet} \geq 2$, $N_{bJet} \geq 2$	$N_{Jet} = N_{bJet} = 2$	$N_{Jet} \geq 3$, $N_{bJet} \geq 2$
Higgs event	47	10	37
CC 3Jets BG	229	82	147
S/N	0.21	0.12	0.252

S/N was improved with Cut (2) and (2-b) compared with Cut (2-a).
Exclude the event of Cut (2-a).

Jet selection

3 Jets for the reconstruction of top mass (M_{top}) were selected as following b-Jet1, b-Jet2 and Jet3.

1. We required $N_{Jet} \geq 3$ & $N_{bJet} \geq 2$
2. We selected 2jets with B-tag requirement
   lowest η b-Jet (b-Jet1) & 2^{nd} lowest η b-Jet (b-Jet2)
3. Excluding b-Jet1 and b-Jet2 we selected the jet with lowest η regardless of B-tag.
   lowest η Jet (Jet3)

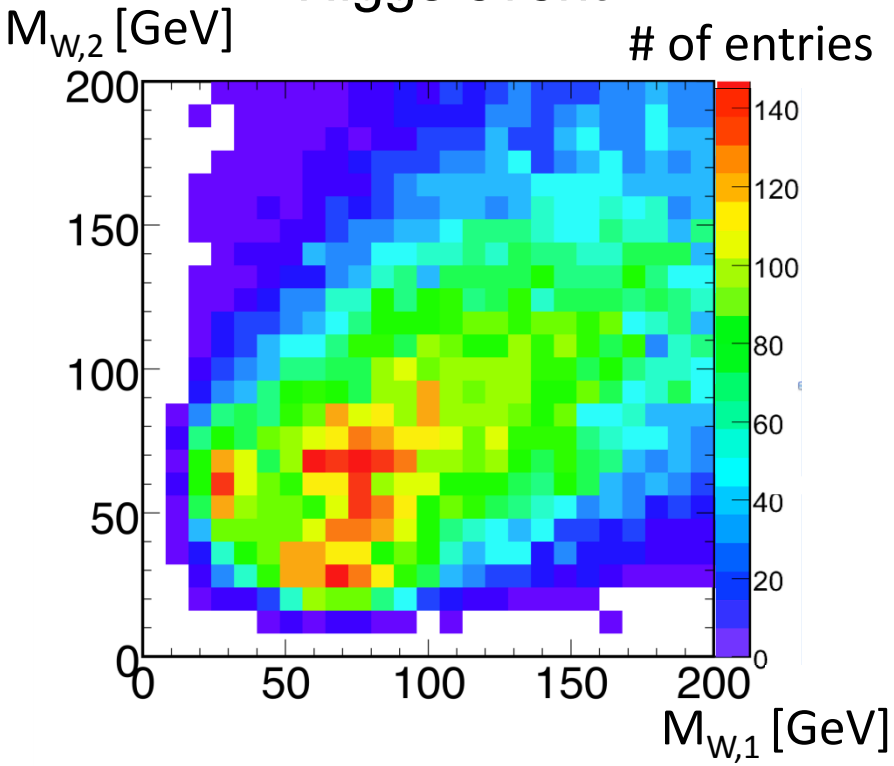
the reconstruction of M_{top} with b-Jet1, b-Jet2 and Jet3.

that of W Mass (M_W) with b-Jet1 and Jet3 ($M_{W,1}$)
or with b-Jet2 and Jet3 ($M_{W,2}$)

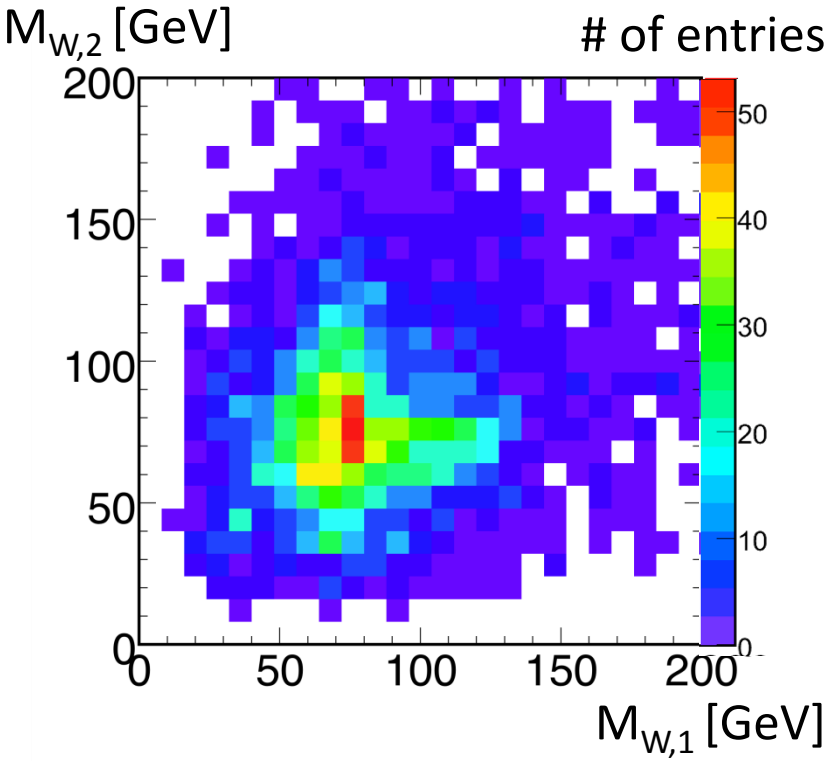
Correlation of $M_{W,1}$ and $M_{W,2}$

we didn't know which $\bar{c}$-jet was, b-Jet1 or b-Jet2.
Correlation of $M_{W,1}$ and $M_{W,2}$ is shown in two figures below.

Higgs event

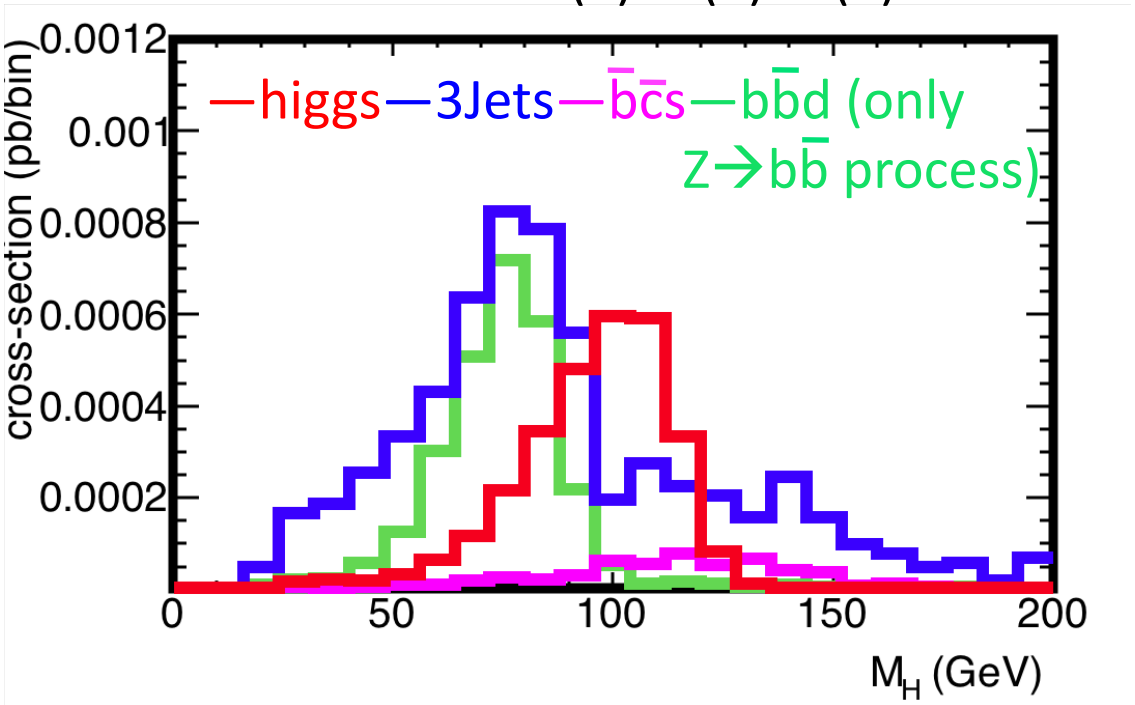


CC 3Jets BG



Higgs mass after M_{top}& M_W cuts

After Cuts (1) & (2) & (3)



- $CC\bar{b}\bar{c}s$ BG was reduced but CC $b\bar{b}d$ BG remains.
- Peak around 80GeV was due to $Z \rightarrow b\bar{b}$ (~130 fb) process.
- In order to reduce this process changed the lower limit of M_H to 90GeV.

Number of events, S/N and S/√N for 10 fb^{-1}

∗ mass cut range :
90GeV < M_H < 120GeV

(A) 200 GeV < M_{top} (b-Jet1 & b-Jet2 & Jet3).
(B) 130 GeV < $M_{W,1}$ (b-Jet1 & Jet3).
(C) 130 GeV < $M_{W,2}$ (b-Jet2 & Jet3).

Applied Cut (Cut (b) default)	Higgs event	CC dijet BG	S/N	S/√N
Cut(1)-(2)&M→Cut(b)	31.0	96.2	0.32	3.16
(A)	21.8	15.5	1.41	5.54
(A) & (B)	20.0	12.6	1.59	5.65
(A) & (C)	16.3	10.5	1.55	5.03
(A) & {(B) or (C)}	21.7	15.5	1.40	5.51
(A) & (B) & (C)	14.7	7.56	1.94	5.33

S/N was improved with only (A) and
reached the highest value with Cut (A) & (B) & (C) applied.
S/√N reached the highest value with Cut (A) & (B) applied.

Number of events, S/N and S/√N for 10 fb^{-1} <loose B-tag>

∗ mass cut range ：
90GeV < M_H < 120GeV

(A) 200 GeV < Mjjj (b-Jet1 & b-Jet2 & Jet3).
(B) 130 GeV < Mjj (b-Jet1 & Jet3).
(C) 130 GeV < Mjj (b-Jet2 & Jet3).

Applied Cut (Cut (b) default)	Higgs event	CC 3Jet BG	S/N	S/√N
Cut(1)-(2)&M→Cut(b)	40.0	159	0.25	3.15
(A)	27.7	28.2	0.983	5.22
(A) & (B)	25.4	21.8	1.16	5.44
(A) & (C)	20.8	19.4	1.07	4.71
(A) & { (B) or (C) }	27.6	28.2	0.98	5.19
(A) & (B) & (C)	18.5	12.9	1.43	5.15

S/√N reached the highest value with Cut (A) & (B) applied as well as in the case of tight B-tag requirement.

Number of events, S/N and S/√N for 10 fb^{-1}

∗ mass cut range ：
90GeV < M_H < 120GeV

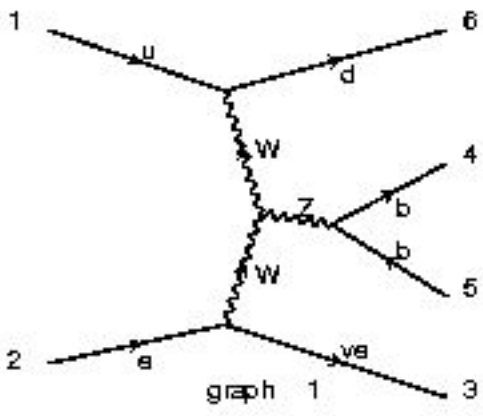
(A) 200 GeV < M_{top} (b-Jet1 & b-Jet2 & Jet3).
(B) 130 GeV < $M_{W,1}$ (b-Jet1 & Jet3).
(C) 130 GeV < $M_{W,2}$ (b-Jet2 & Jet3).

Applied Cut (Cut (b) default)	Higgs event	CC dijet BG	S/N	S/√N
Cut(1)-(2)&M→Cut(b)	31.0	96.2	0.32	3.16
(A)	21.8	15.5	1.41	5.54
(B)	21.4	15.0	1.43	5.52
(C)	16.9	12.4	1.36	4.79
(B) or (C)	14.7	7.56	1.94	5.33
(B) & (C)	23.6	19.8	1.19	5.30

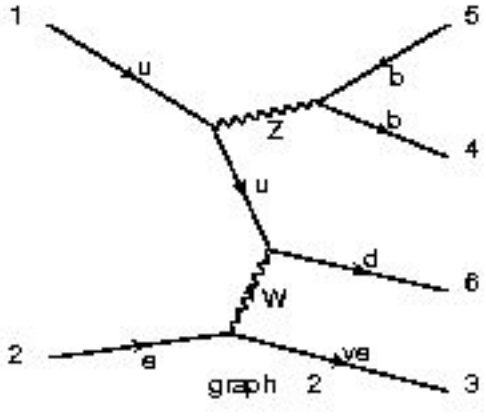
S/N is the same value in Cut (B) & (C) as in Cut (A) & { (B) & (C) }.
Cut (A) and Cut (B) gave almost the same value for S/N and S/√N .

$Z \rightarrow b\bar{b}$ process (= 132fb) for CC $b\bar{b}d$ BG

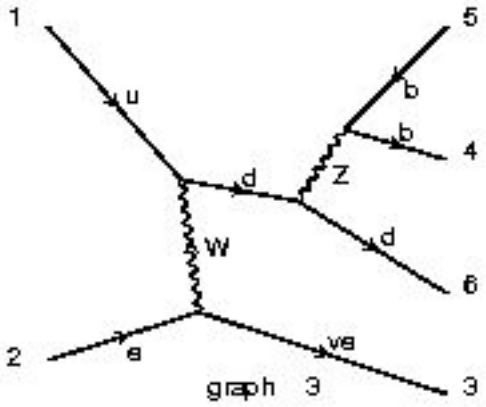
~5 diagrams~



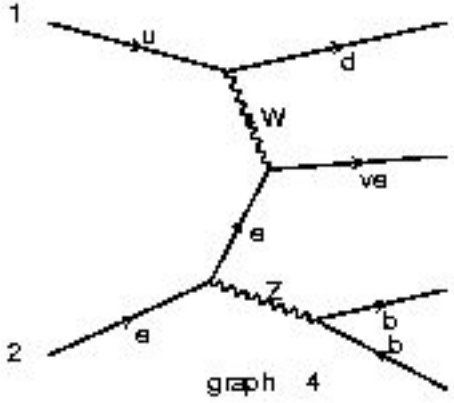
72.046 fb



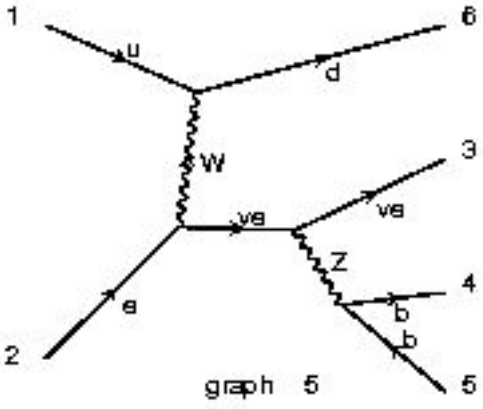
13.156 fb



17.193 fb



7.553 fb



22.413 fb

Number of events, S/N and S/√N for 10fb^{-1}

∗ mass cut :
90GeV < M_H < 115GeV

(A) 200 GeV < M_{top} (b-Jet1 & b-Jet2 & Jet3).
(B) 130 GeV < $M_{W,1}$ (b-Jet1 & Jet3).
(C) 130 GeV < $M_{W,2}$ (b-Jet2 & Jet3).

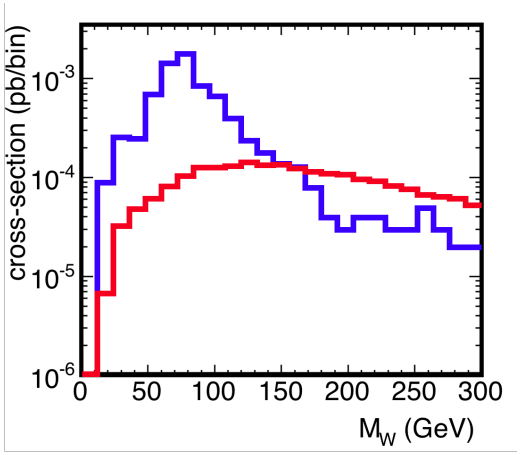
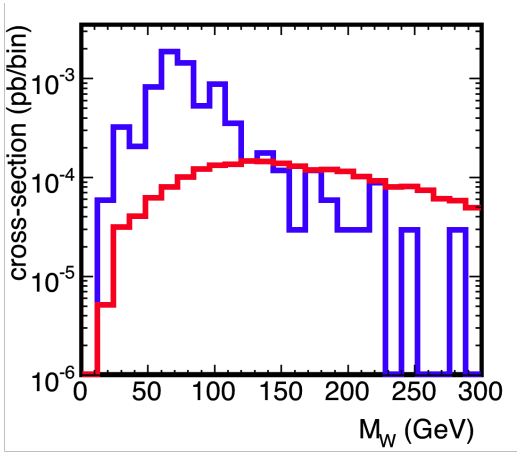
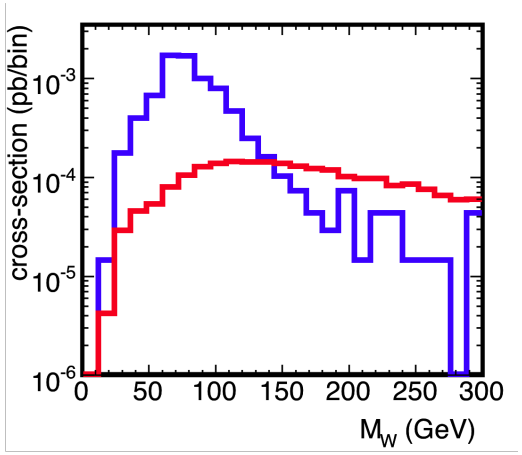
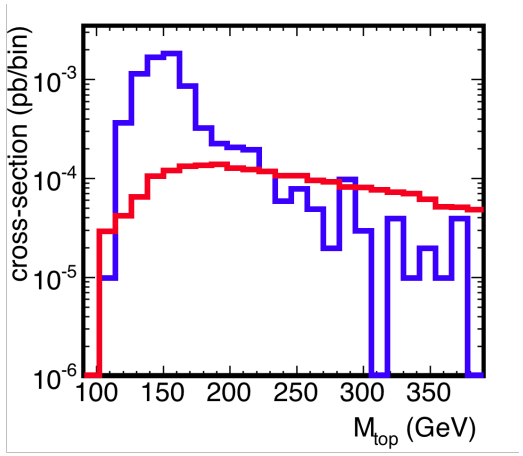
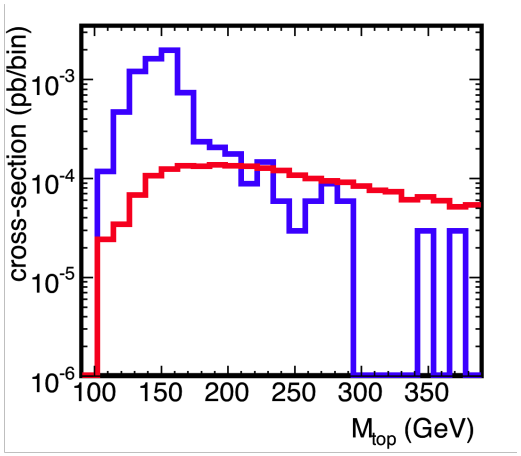
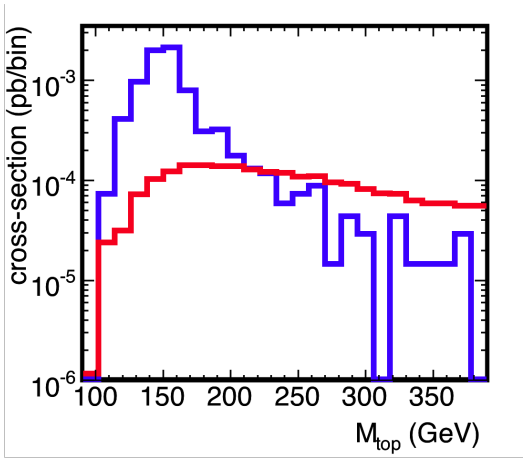
	Resolution = 0.8				Resolution = 0.4		
Applied Cut (Cut (1)-(2), M_H default)	Higgs / 3Jets BG	S/N	S/√N		Higgs / 3Jets BG	S/N	S/√N
(A)	21.8/15.5	1.41	5.54		22.2/11.9	1.86	6.42
(A) & (B)	20.0/12.6	1.59	5.65		20.3/7.2	2.81	7.55
(A)&(B)&(C)	14.7/7.56	1.94	5.33		14.9/3.23	4.61	8.29

3Jets BG was reduced by changing the value of resolution from 0.8 to 0.4.

Dependence on hadronic energy resolution

After Cuts (0) & (1) & (2)

— Higgs event — CC 3Jet BG

	Resolution = 0.8	Resolution = 0.6	Resolution = 0.4
M_W			
M_{top}			

Effect of $|\eta| < 3$ cut

After Cuts (1) – (3) & M_H

Energy resolution of hadronic calorimeter	Higgs event	CC 3Jet BG	S/N	S/√N
80 %	20.0	12.6	1.59	5.65
60 %	20.5	10.3	1.99	6.39
40 %	20.3	7.2	2.81	7.55

After $|\eta| < 3$ cut

Energy resolution of hadronic calorimeter	Higgs event	CC 3Jet BG	S/N	S/√N
80 %	13.5	10.9	1.24	4.09
60 %	13.9	9.12	1.52	4.60
40 %	13.8	6.61	2.08	5.35