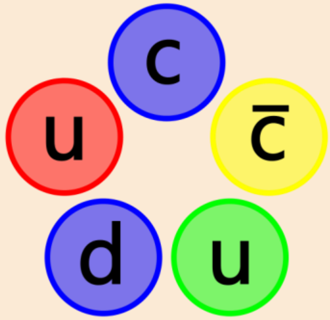
Analysis of Higgs production in the VBF-VH channel at LHC



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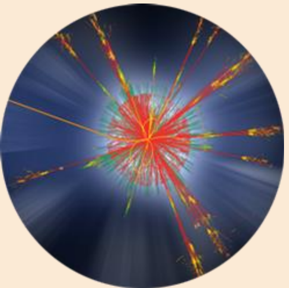
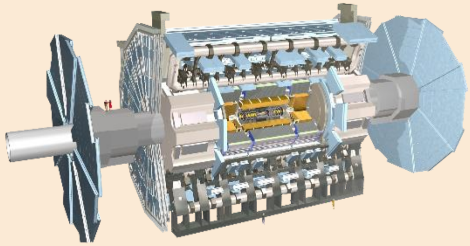
Virtual summer project

@ Carleton University

~ Chaitanya Paranjape, IIT Dhanbad, India

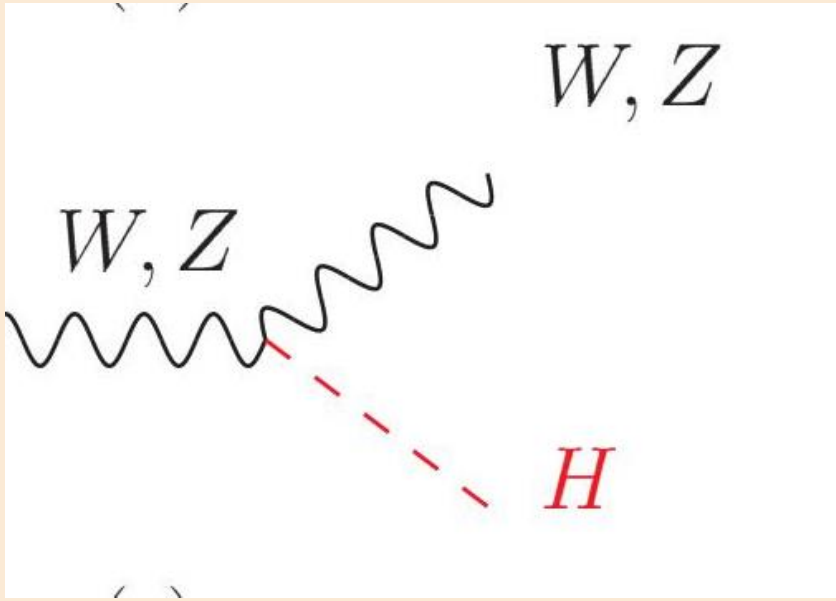




➢ The VBF-VH channel

- Production of Vector Boson + Higgs (VH) through Vector Boson Fusion (VBF)
- Rare channel, hasn't been studied well so far
- Propose to probe the Higgs(H) couplings

To W & Z bosons : kW & kZ



➢ Signal Process

- First need to fix the 'signal' process suiting the VBF-VH channel
- p p > z h j j QCD=0, z > l l~ , h > b b~
  - **Quantum Interference** between different Diagrams & thus **sensitive to both couplings kW & kZ**

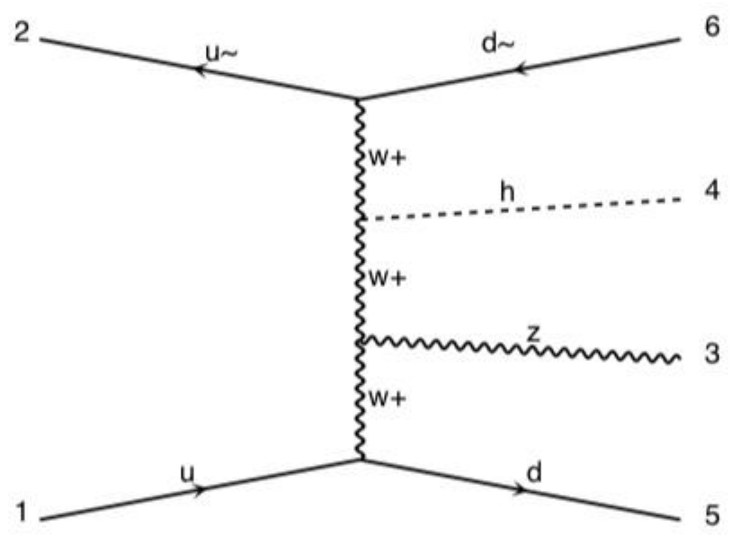


diagram 10 QCD=0, QED=4

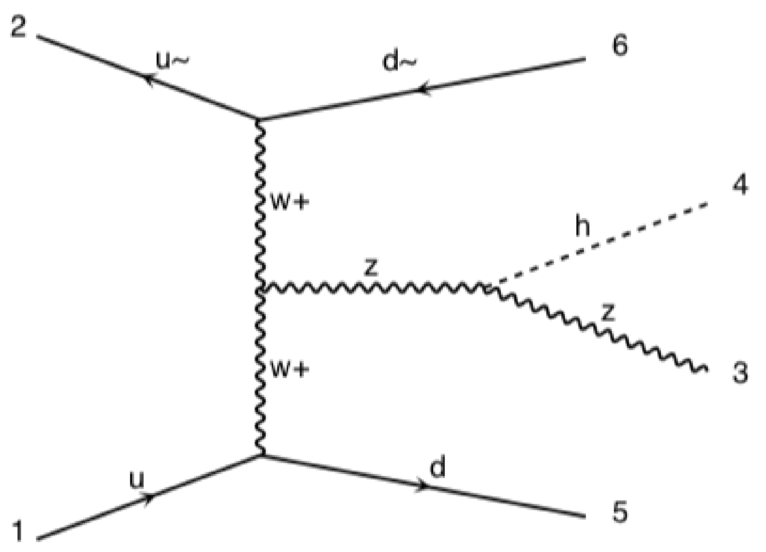
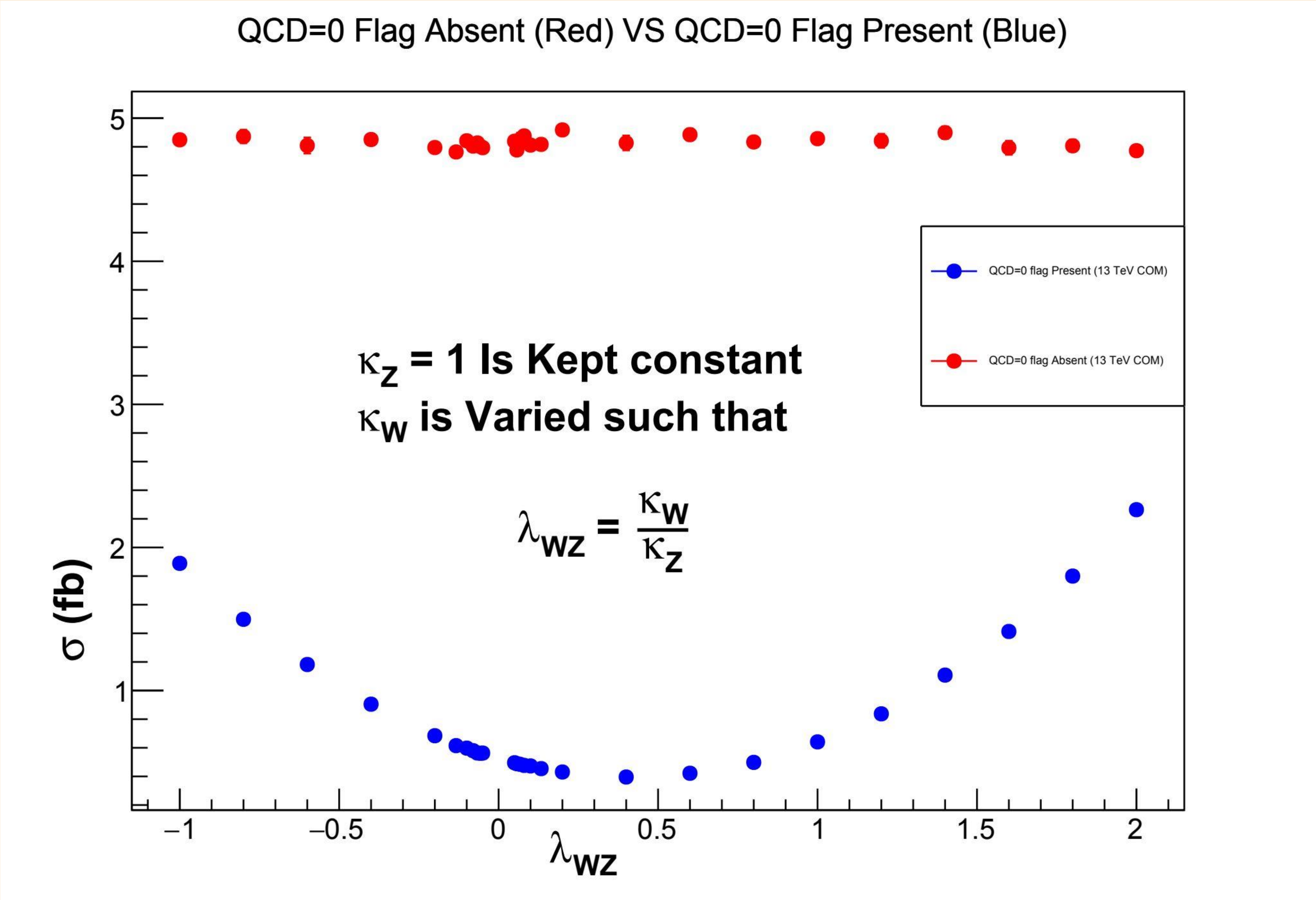


diagram 12 QCD=0, QED=4

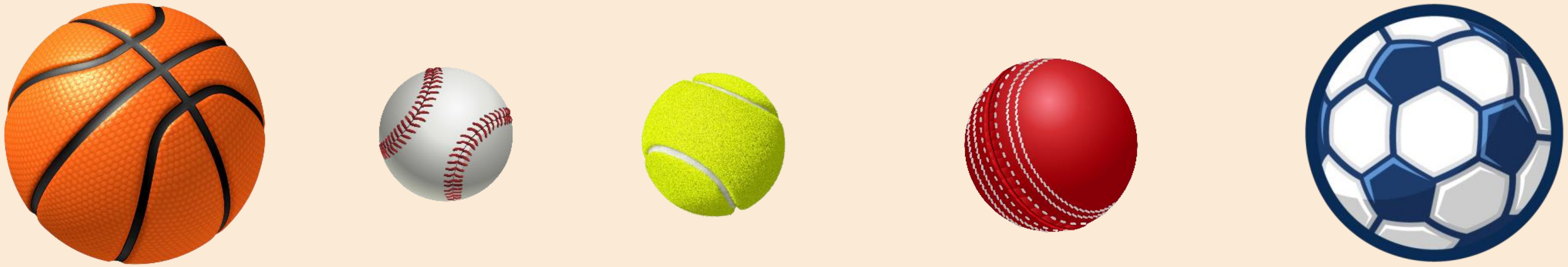

QCD=0 Flag Absent (Red) VS QCD=0 Flag Present (Blue)
QCD=0 flag Present (13 TeV COM)
QCD=0 flag Absent (13 TeV COM)
κ_Z = 1 Is Kept constant
κ_W is Varied such that
$\lambda_{WZ} = \frac{\kappa_W}{\kappa_Z}$
σ (fb)
λ_{WZ}
5
4
3
2
1
−1
−0.5
0
0.5
1
1.5
2

➢ Analysis strategy

- Central part of the project is to devise an analysis strategy to discriminate background processes from the signal.
- Signal : Process we would like to observe at the experiments
- Background : Processes that we don't want to include in our analysis, however they mimic the signal process very well and end up getting mixed in the analysis.
- Task at hand : Devise an analysis strategy to obtain maximum signal events and minimum background events

➢ Analogy : Balls ~ Processes

- Consider a ground filled with various types of balls :



- Let's say, we want a computer to look for the basketball (signal) , thus the other balls will be the (background).

➢ Distinctive features

- For our case we can just ask the computer to select the ball with

  Diameter ~ 25 cm & Colour = Orange

- This will make sure, we will only select the basketball and not other ones. However, in reality, problem is much harder because the balls have colours like dark orange, light orange & sizes ranging over 24.7 cm, 25.2 cm, etc.

- Crux of the problem : We need to find the Distinctive features that separate signal from background and apply a set of cuts to obtain maximum signal and minimum bcg.

➢ All processes

Signal : p p > z h j j QCD=0, z > l l~ , h > b b~ : 0.9104 fb

Bcg1 : p p > z h j j , z > l l~ , h > b b~ : 1.916 fb

Bcg2 : p p > t t~ , t t~ => l l~ b b~ vl vl~ : 5313.0 fb

Bcg3 : p p > z z j j QCD=0, z > l l~ , z > b b~ : 1.214 fb

Bcg4 : p p > z z j j , z > l l~ , z > b b~ : 8.737 fb

Bcg5 : p p > z b b~ j j, z > l l~ : 1113.0 fb

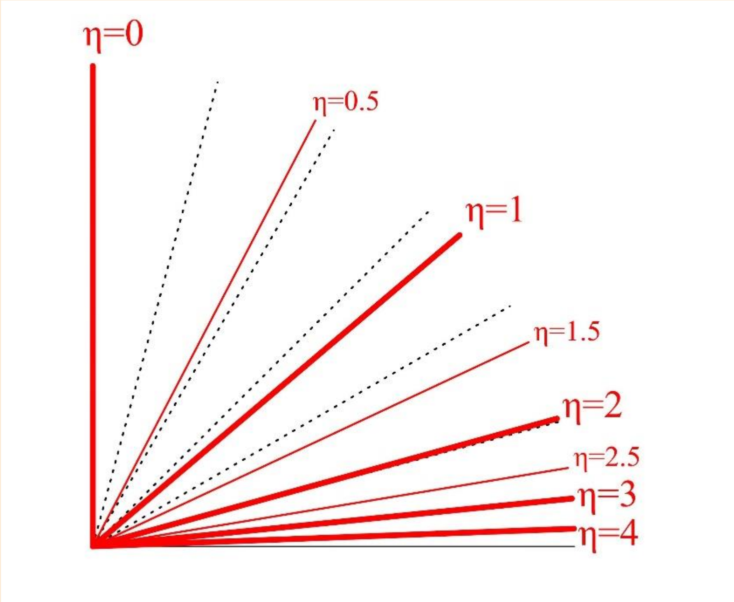
➢ DeltaEta & DiJetMass

- **The VBF-Tagging jets are oriented along the beam in forward-backward direction & thus have large pseudo-rapidity difference**

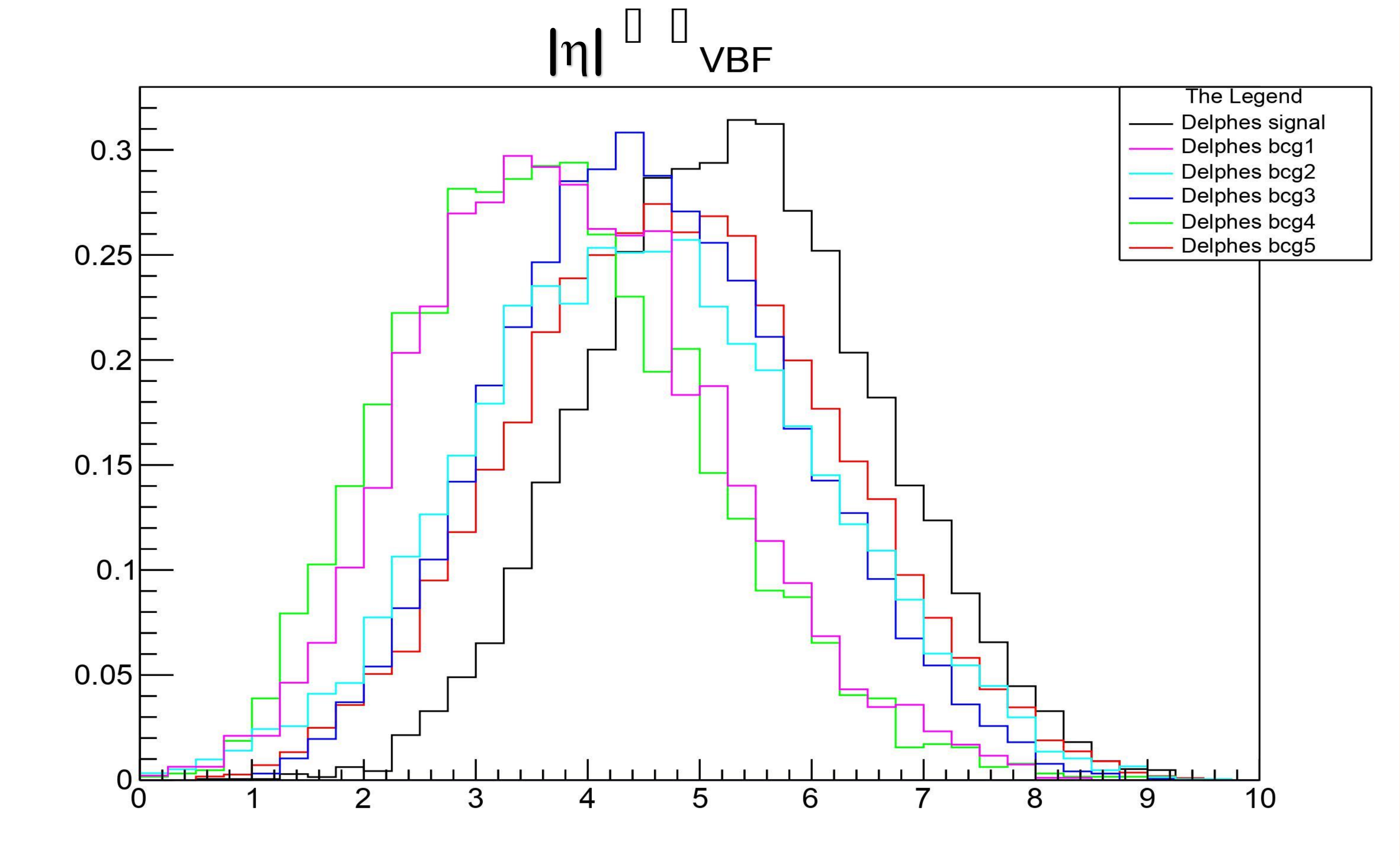
  (DeltaEta)

- **VBF Tagging jets have high invariant mass**

  (DiJetMass)

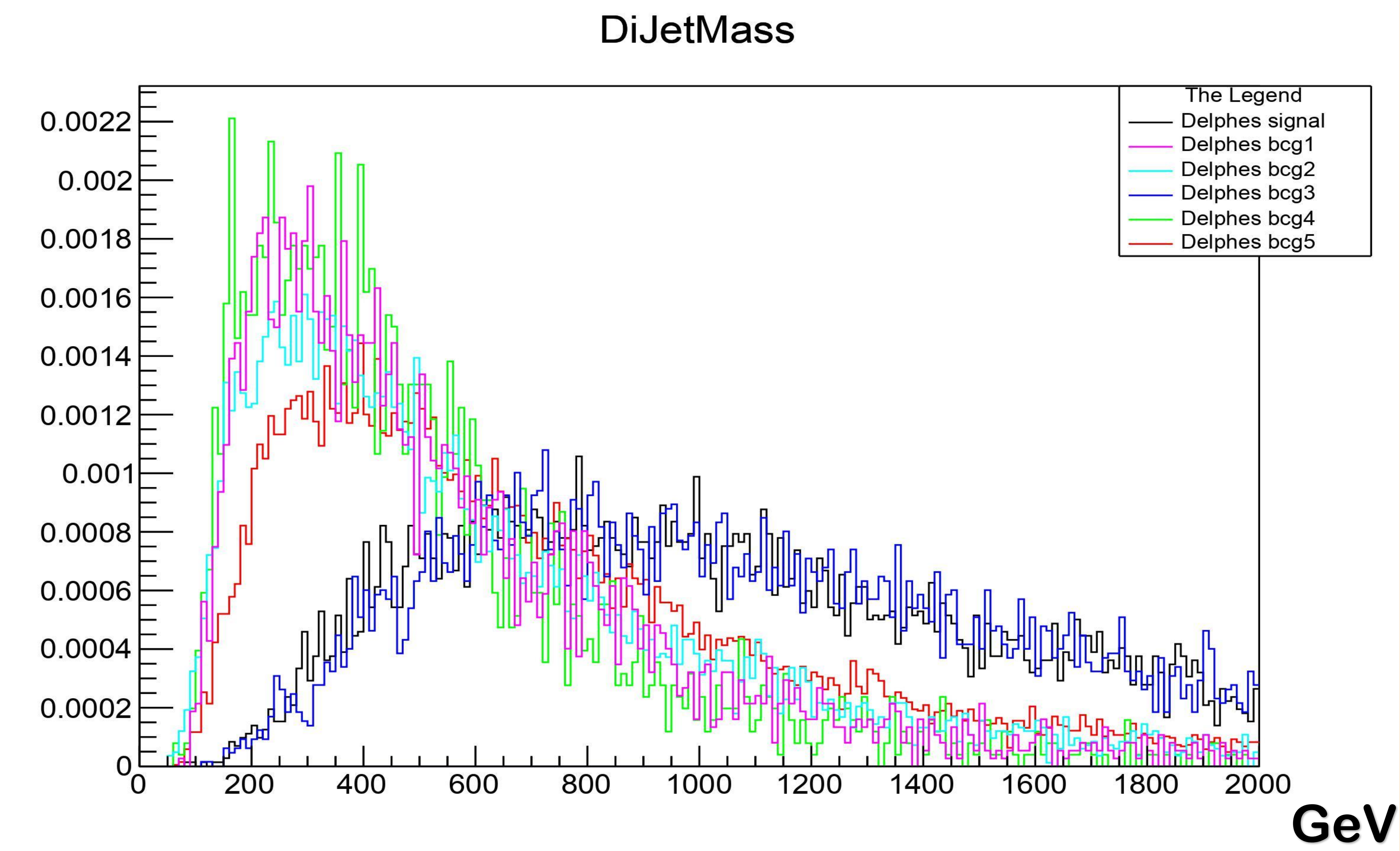


➢ DeltaEta



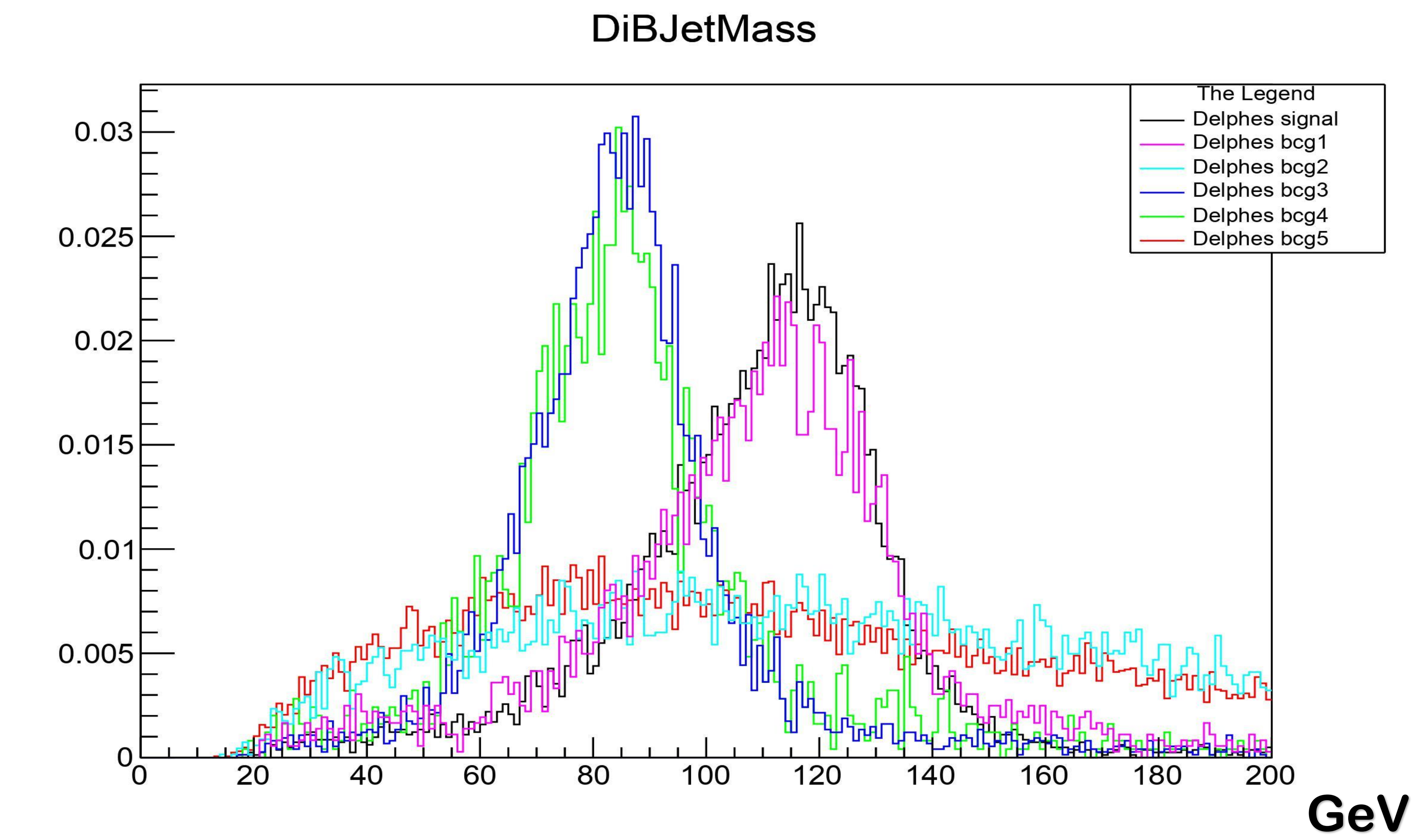
|η| VBF
The Legend
Delphes signal
Delphes bcg1
Delphes bcg2
Delphes bcg3
Delphes bcg4
Delphes bcg5
0.3
0.25
0.2
0.15
0.1
0.05
0
0
1
2
3
4
5
6
7
8
9
10

➢ DiJetMass



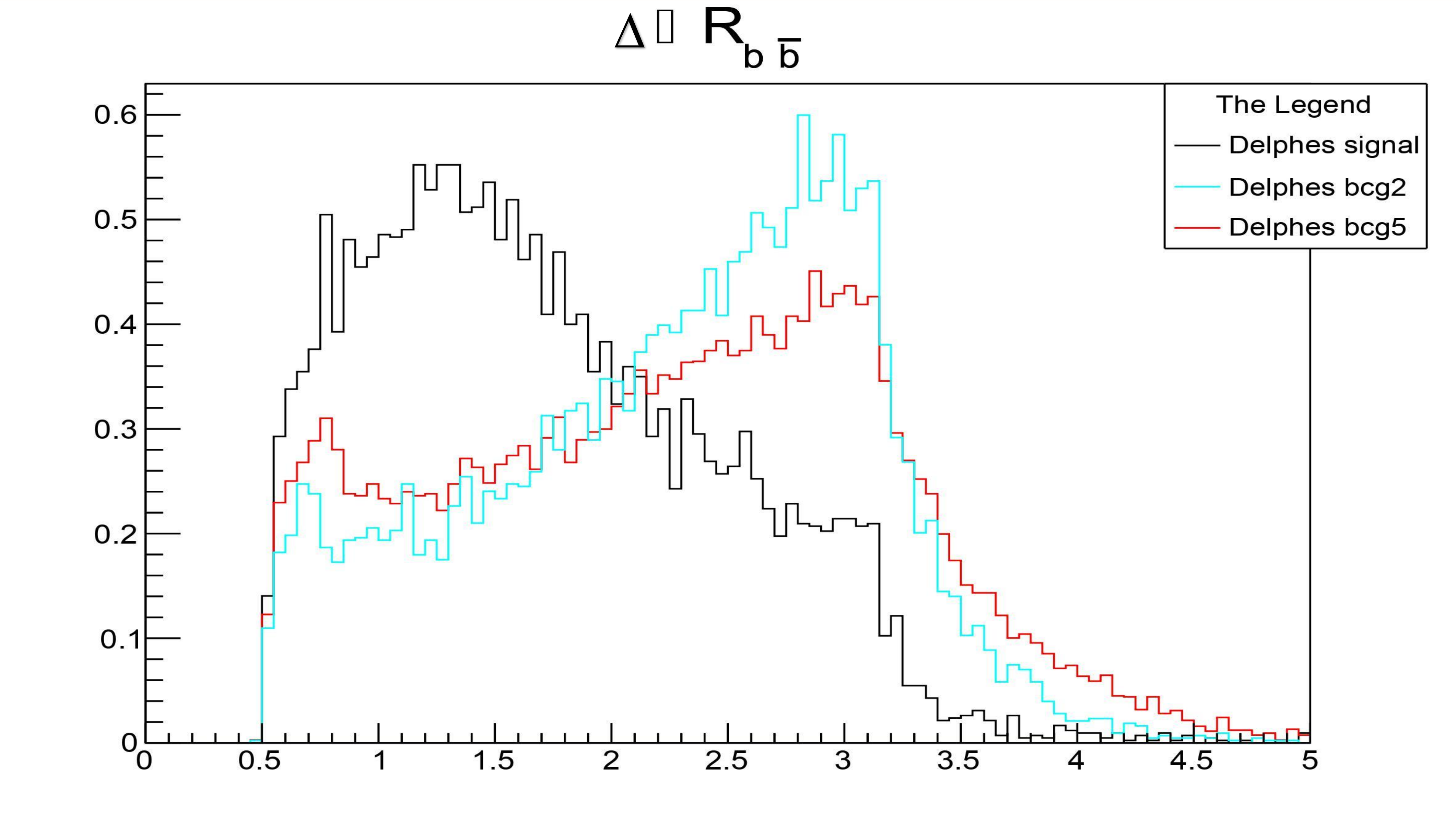
DiJetMass
The Legend
Delphes signal
Delphes bcg1
Delphes bcg2
Delphes bcg3
Delphes bcg4
Delphes bcg5
0.0022
0.002
0.0018
0.0016
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
GeV

➢ DiBJetMass



DiBJetMass
The Legend
Delphes signal
Delphes bcg1
Delphes bcg2
Delphes bcg3
Delphes bcg4
Delphes bcg5
0.03
0.025
0.02
0.015
0.01
0.005
0
0
20
40
60
80
100
120
140
160
180
200
GeV

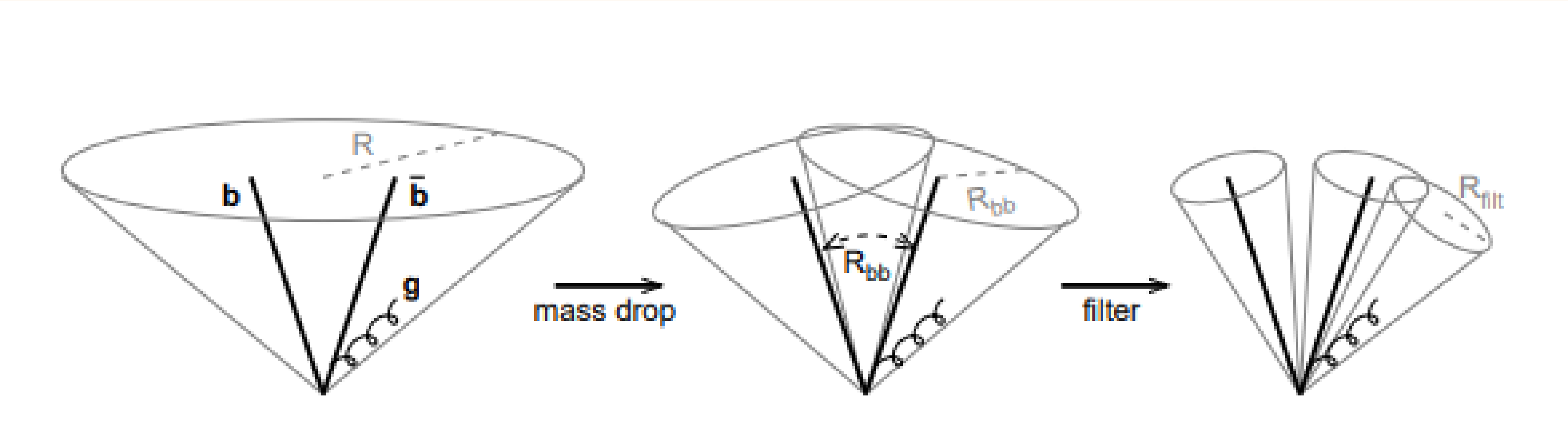
➢ $\Delta R^2_{b\,b} = |\Delta\eta|^2 + |\Delta\phi|^2$



➢ Boosted-Higgs search

- We employ the BDRS algorithm for boosted Higgs

- Use FastJet analysis framework for this purpose,
  with (px,py,pz,E) data of detected particles from Delphes



arXiv:0802.2470

➢ Semi-Final Cuts

Initial Cuts +

- VBF Cuts : |DeltaEta| >= 4 && DiJetMass >= 1000 GeV
- Missing ET < 50 GeV (For Bcg2)
- ΔR_{bb} <= 2 : Boosted Higgs cut,

  co-related with Higgs-pT & $\Delta\phi_{bb}$
- PT-Jet1 >= 100 GeV , PT-Jet2 >= 70 GeV , PT-Jet3 >= 50 GeV
- PT-B-Jet1 >= 55 GeV , PT-B-Jet2 >= 55 GeV

*Jets ordered from highest to lowest pT

➢ Improvement with FastJet

From the Delphes, we already have the DiBJetMass

& with FastJet we have Hmass

- Apply cut on DiBJetMass ~ (110,130) GeV : in Delphes
- Apply cut on Hmass ~ (110,130) GeV : in FastJet (FJ)
- Count the events selected for each case for the DiBJetMass & Hmass condition

➢ Final significance

Estimate significance with following formulas,

Where S = Signal Yield & B = Sum of Bcg Yields

σ :	Final Analysis:	If Only Delphes was used:
$\frac{S}{\sqrt{B}}$	1.86	1.4
$\frac{S}{B}$	0.25	0.1
$\frac{S}{\sqrt{(B + (\beta * B)^2)}}$	1.50	0.84

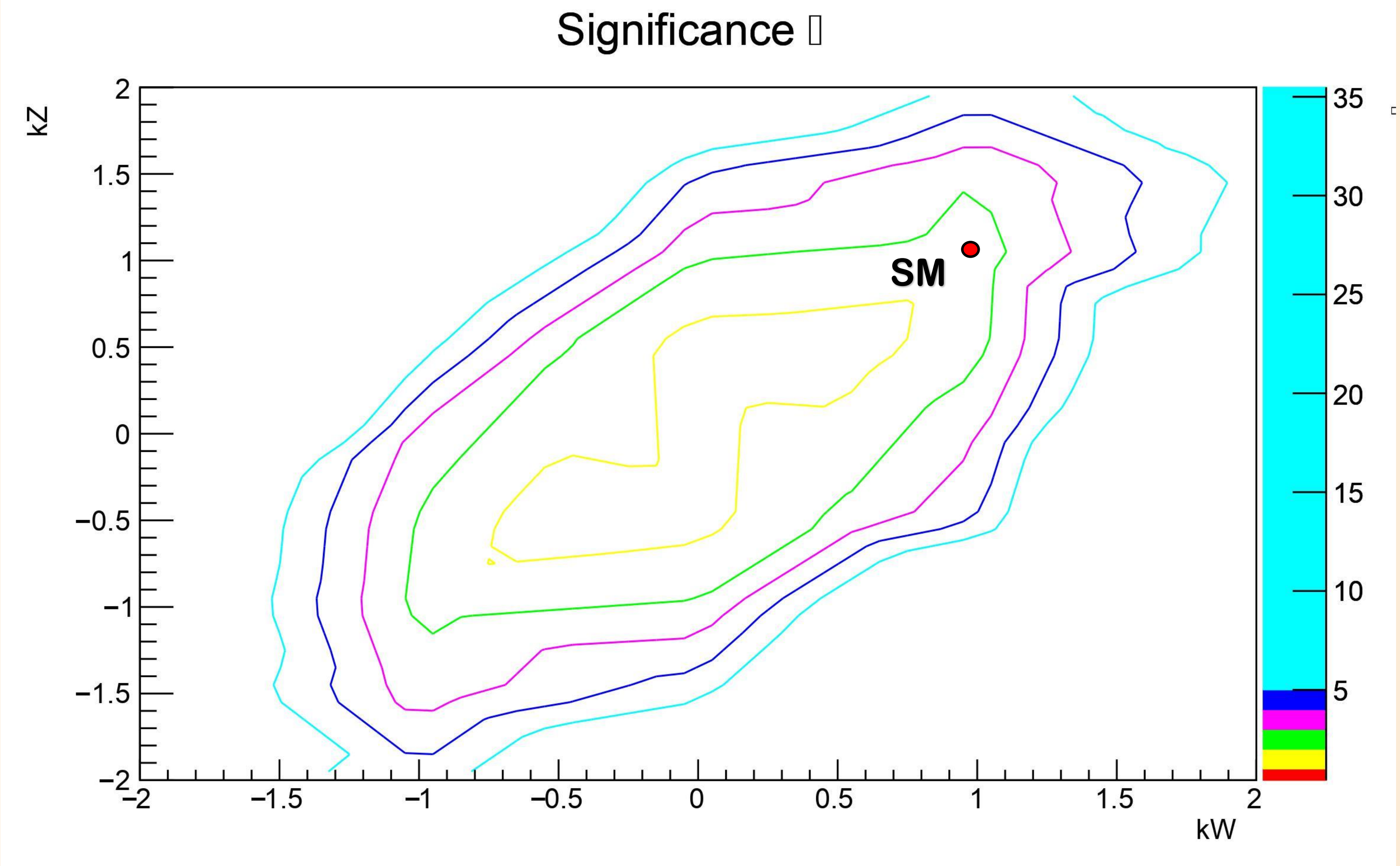
$^*\beta$ = 10%

➢ Run Analysis over a range of (kW, kZ) points

- Assume the background B to be approximately constant

- Therefore, Significance at (kW, kZ) is proportional to the factor with which Signal Yield increases

➢ Contour plot for σ (kW,kZ) plane



1σ - Yellow

2σ - Green

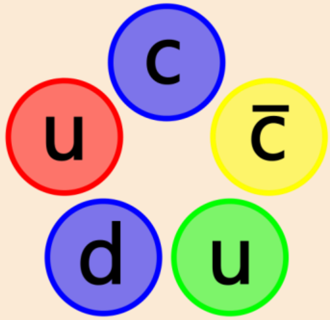
3σ - Pink

4σ - Violet

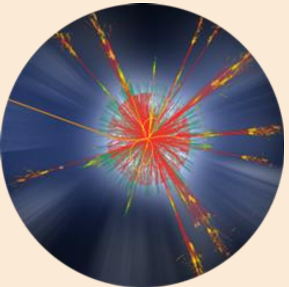
5σ - Cyan

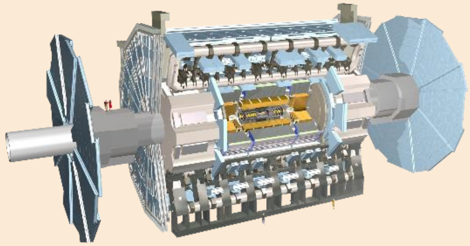
➢ Acknowledgement

- I am grateful to Prof. Daniel Stolarski for his invaluable guidance throughout the project and helping me keep focused despite the hardships faced during the project.
- I am thankful to Dr. Yongcheng Wu for his assistance during the project and helping me with technical difficulties.
- I am thankful to Mitacs organization for allowing me an opportunity to work with Canada’s top researchers



➢ **Thank you for listening !**



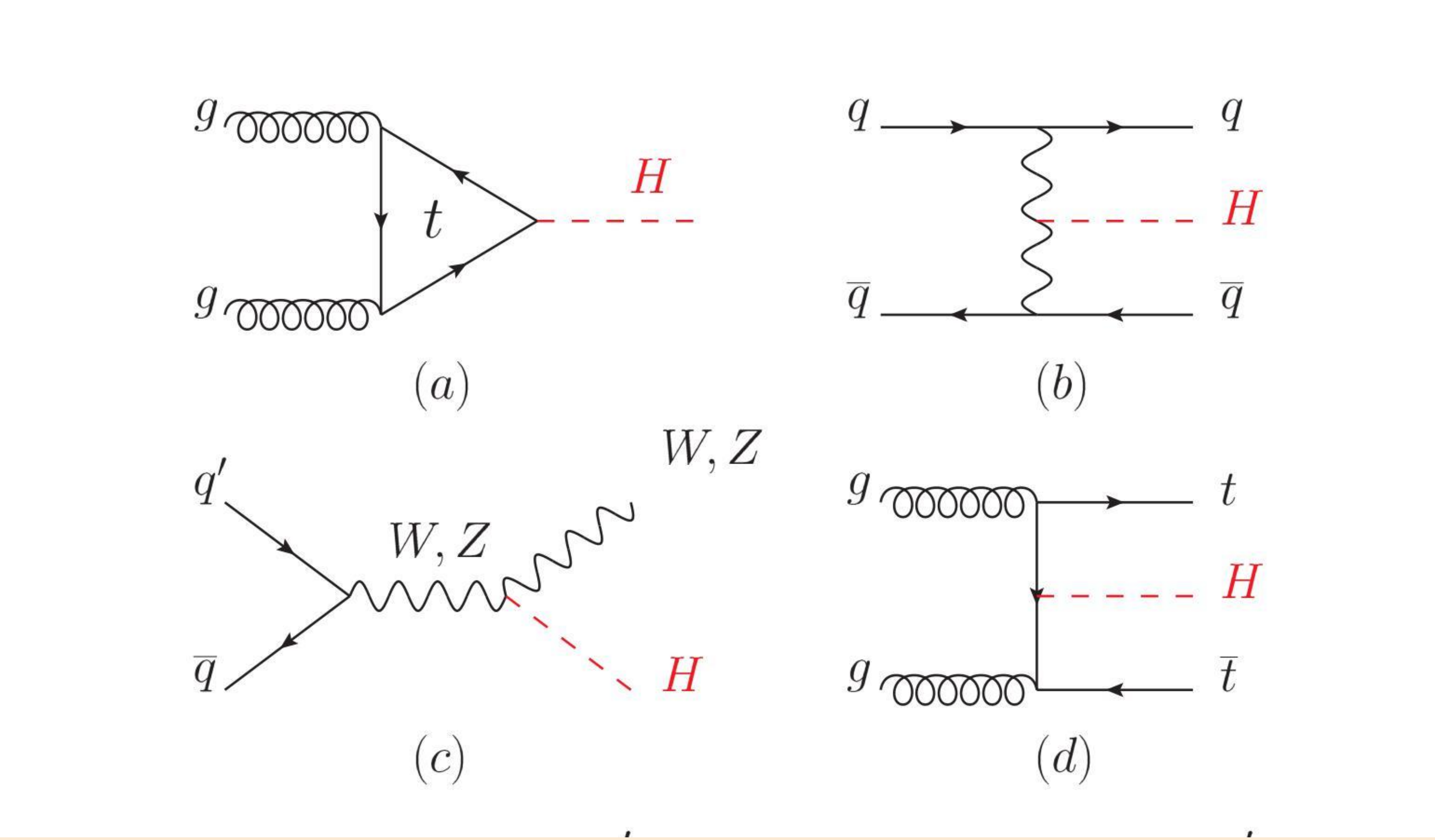


➢Introduction

4 Primary Higgs production channels

Gluon Fusion

Vector Boson Fusion (VBF)

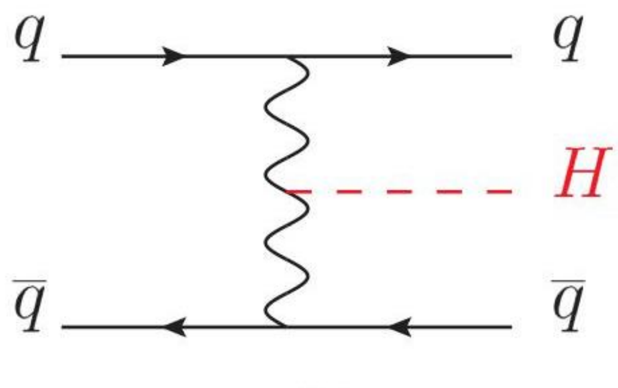


VH

t $\bar{t}$ H

➢ VBF Topology

VBF



(b)

VBF-ZH

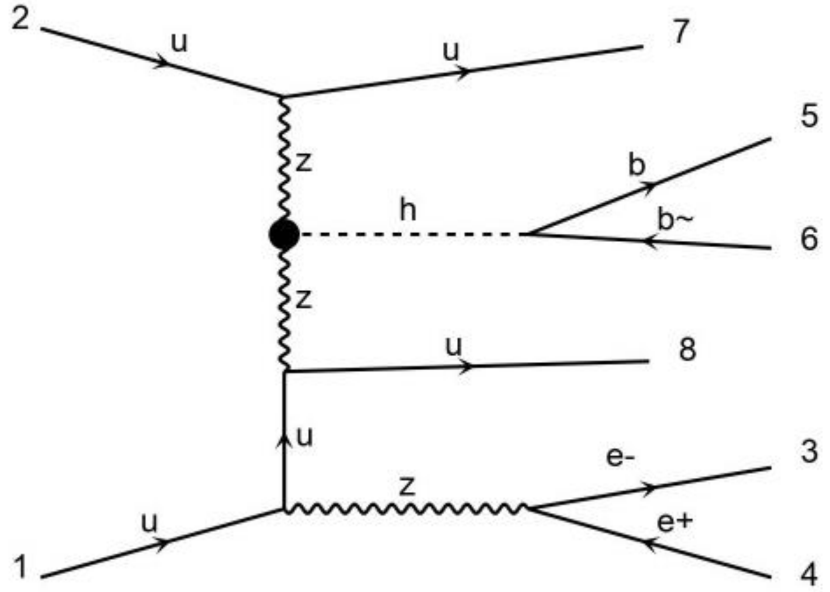


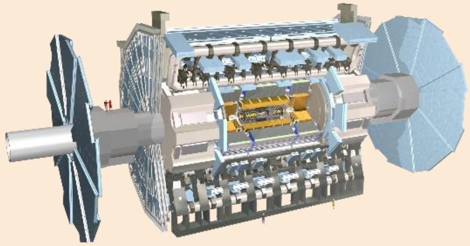
diagram 1 CHWW=0, CHZZ=1, QCD=0, QED

➢ Model with kW, kZ parametrized

- **Introduce kW, kZ as External parameters**
- **Modify the SM Lagrangian as follows :**

$$\mathcal{L} = \mathcal{L}_{SM} + h\Big\{(\kappa_W - 1) g m_W W^+_\mu W^-_\mu + (\kappa_Z - 1) g \frac{m_Z^2}{2m_W} Z_\mu Z_\mu\Big\}$$

g is SU(2) gauge coupling & In the SM, $\kappa_W = \kappa_Z = 1$.



➢ Simulation Framework

- Set up **MadGraph5-Pythia-Delphes** framework for simulation of processes at LHC
  MadGraph5 – Hard Scattering, Pythia – Shower, Delphes - Detector
- Use **FeynRules** to export our model as UFO Output & Import into MadGraph5
- Integrate **FastJet** with Delphes macros for analysis at later stage

➢ Initial Cuts

- For each jet under consideration :

  $pT >= 20$ GeV && $|\eta| <= 5$

- Number of Jets >= 4
- Number of VBF-B-Jets == 0
- Number of B-Jets >= 2
- OSSF Lepton Pair Invariant Mass ~ (81,101) GeV

*OSSF : Opposite Sign Same Flavour

➢ FastJet Analysis

- Events selected with the Semi-final cuts will be analysed again in FastJet, where the particles data (px,py,pz,E) is transferred from Delphes to FastJet
- Jet reconstruction with Anti-kt algorithm & R=0.5
- VBF Jet constituent particles and Isolated leptons are removed first

➢ FastJet Analysis

- Now, on the remaining particles, Apply Jet reconstruction

  with Cambridge-Aachen algorithm & R=2.0

- Obtain the leading jet in pT and apply

  Mass drop tagger with μ=0.667 & y_{cut} = 0.09

- The invariant mass of the 2 tagged pieces is the

  Higgs mass : Hmass

➢ Improvement with FastJet

Condition Satisfied by	For Signal - S	For Bcg5 – b5	S/b5
BOTH Delphes & FJ	503	9	~ 0.3
AT LEAST Delphes	698	35	~ 0.1
AT LEAST FJ	590	25	~ 0.1
NONE	434	308	---

Signal event count passing Semi-final cuts : 1219

Bcg5 event count passing Semi-final cuts : 350

➢ Final significance

- **Final Cuts : Semi-final cuts + DiBJetMass and Hmass ~ (110,130) GeV**

	Events selected:	Yield:
Signal :	503/100k	13.74
Bcg1 :	12/100k	0.69
Bcg2 :	3/5M	9.56
Bcg3 :	23/100k	0.84
Bcg4 :	1/100k	0.26
Bcg5 :	9/700k	42.93

8.

➢ Bcg5 & Bcg2

Yield ~ Cross-section * Event selection efficiency

- Bcg1 Yield = b1 , Bcg2 Yield = b2, …
- Signal Yield = S , Net Bcg Yield = B = b1 + b2 + b3 + b4 + b5
- In general, for a good analysis, we should try to achieve S/B ~ 1
- However, the cross-section for Bcg5 & Bcg2 is 1000 times larger than the signal cross-section

9.

➢ Bcg5 & Bcg2

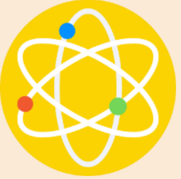
- Therefore, Event selection efficiency for signal must also be 1000 times larger than Bcg5 & Bcg2 (If we hope to achieve S/B ~ 1)
- Meaning that our computer needs to find the correct basketball,

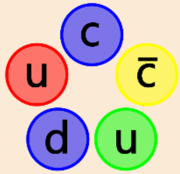
  even if the ground is filled with another 1000 look-alike basketballs !
- Investigate various distinctive features to separate signal & Bcg

➢ Bcg5 & Bcg2

- With the help of VBF constraints, Bcg1,3,4 are reduced within good bounds
- Bcg 1,3,4 are already of the order S/B ~ 1 to begin with
- Therefore, easy to achieve even S/B ~ 10 for the Bcg 1,3,4
- However, for Bcg2 & Bcg5, S/B ~ 10^{-3} to begin with.

Therefore, we need sharp enough event selection to compensate

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