Pseudoscalar Higgs Hunting at ATLAS 2015

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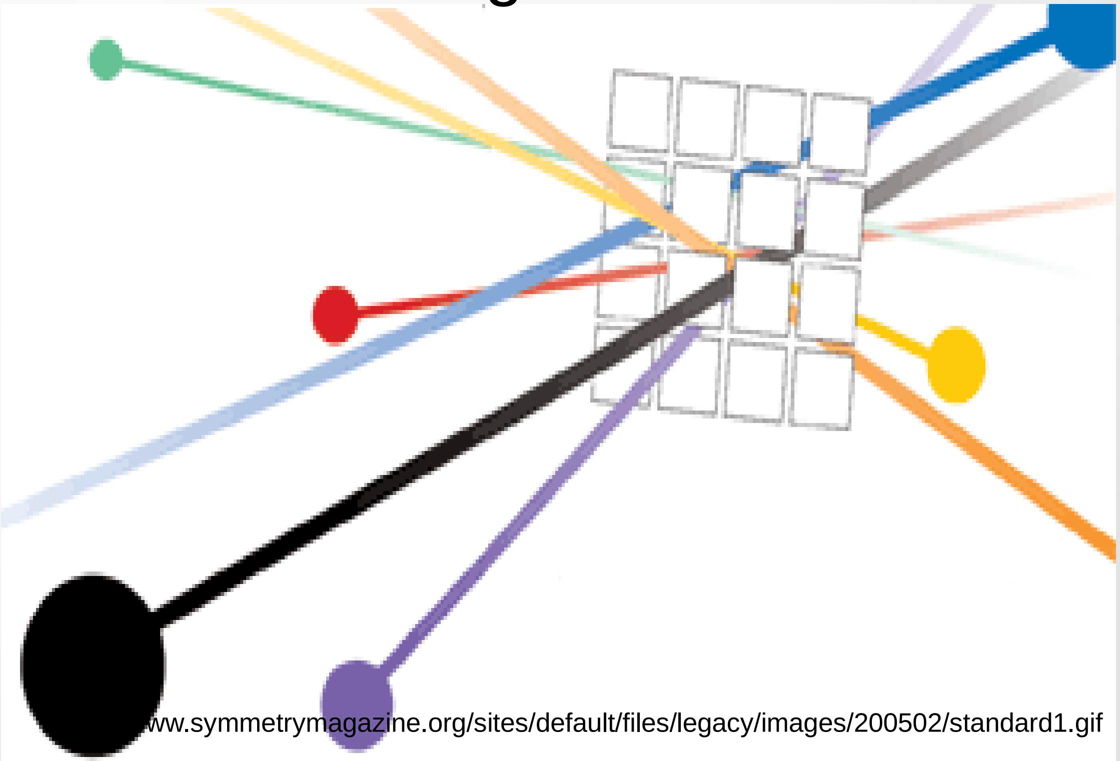
Outline

- Motivation - 2HDM Model
- Signal and Background Processes
- Sensitivity Study
- Results

Motivation

- Higgs discovery at LHC in 2012 – but there are more!
- 2 Higgs Doublet Model (2HDM) – source of CP violation and EWSB
- Type - 2 Doublets couple to fermions to give them mass
- Five Higgs: h, H, A, H±
- mass of A
- $\tan(\beta) = v_1/v_2$
- $\cos(\beta - \alpha)$

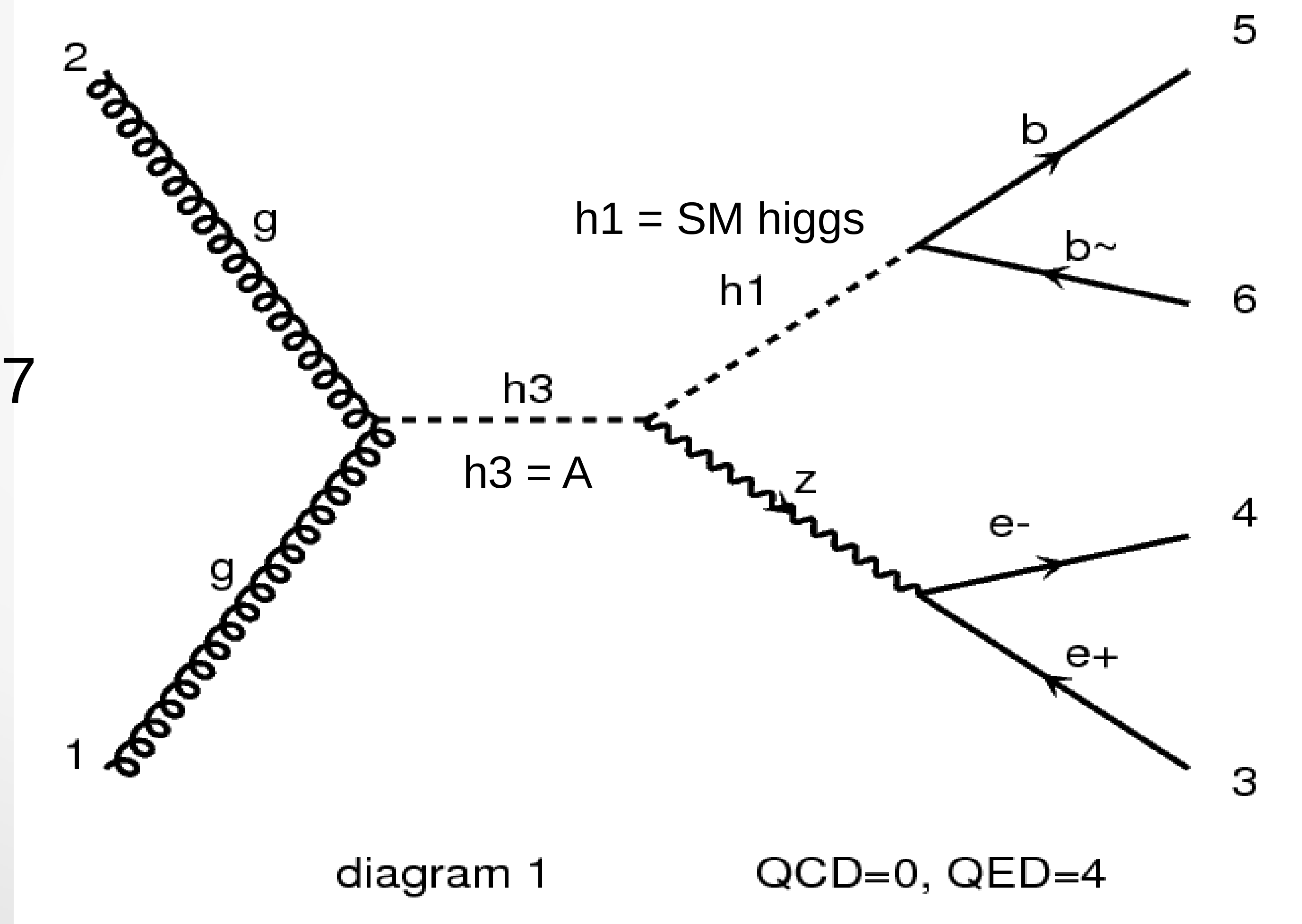


Particles involved

- A: pseudoscalar heavy higgs – What were looking for!
- Z : unstable force carrier boson - electroweak
- h : unstable boson - mass generation
- l: e+, e-, mu+, mu-
  - e+, e- = positron, electron
  - mu+, mu- = antimuon, muon
- quark-jet radiate particles as they accelerate, appear as a jet
  - heavy: b-jet (bottom), t-jet (top), b~ means anti-b quark
  - light: up down charm strange

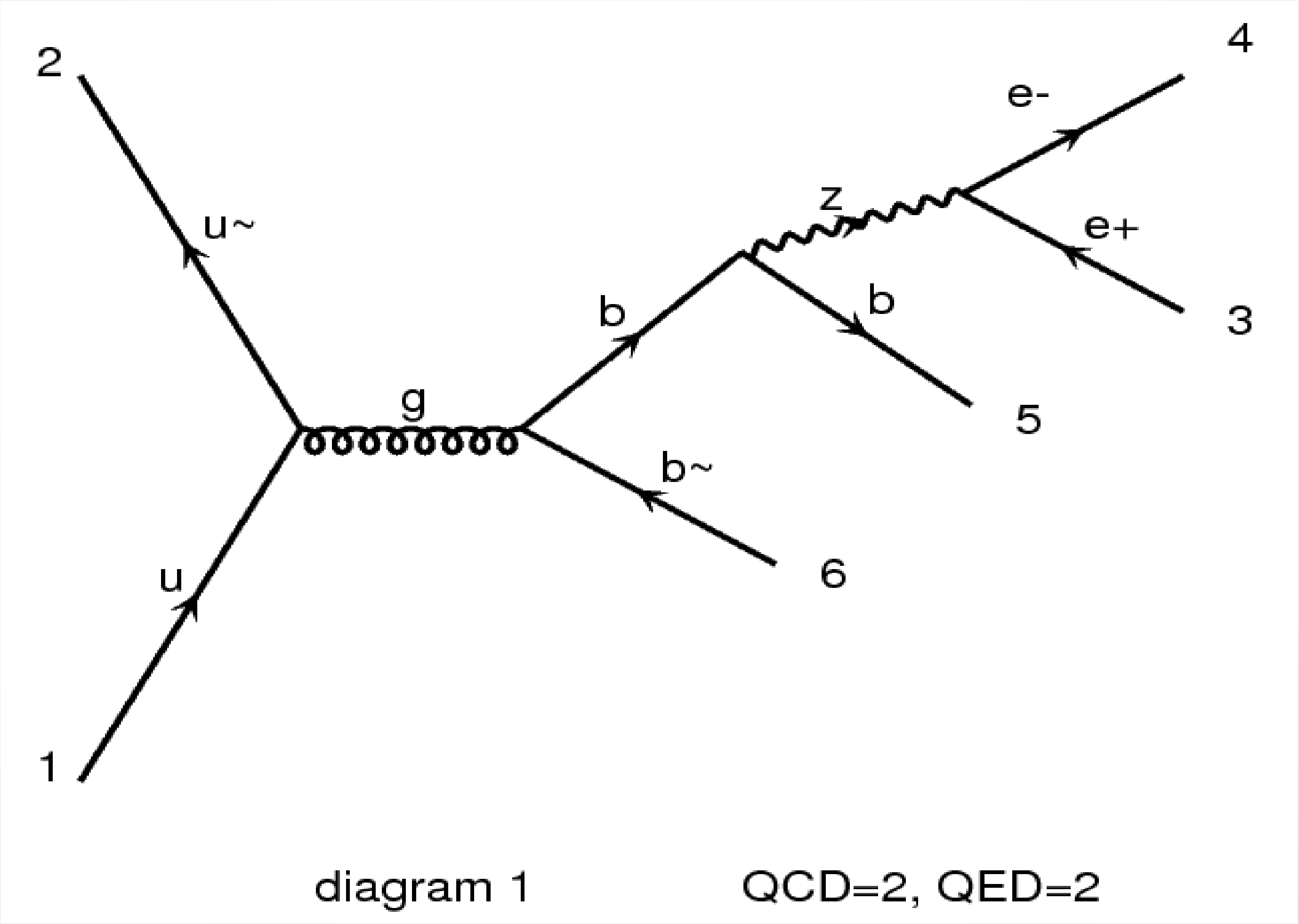
Signal Process – pp > A > Zh, Z > l+l-, h > bb~

- final products: 2 e+e-bb~ or mu+mu-bb~
- A, Z, h are unstable
- Br Z>ll = .0672
- Br h>bb~ = .577



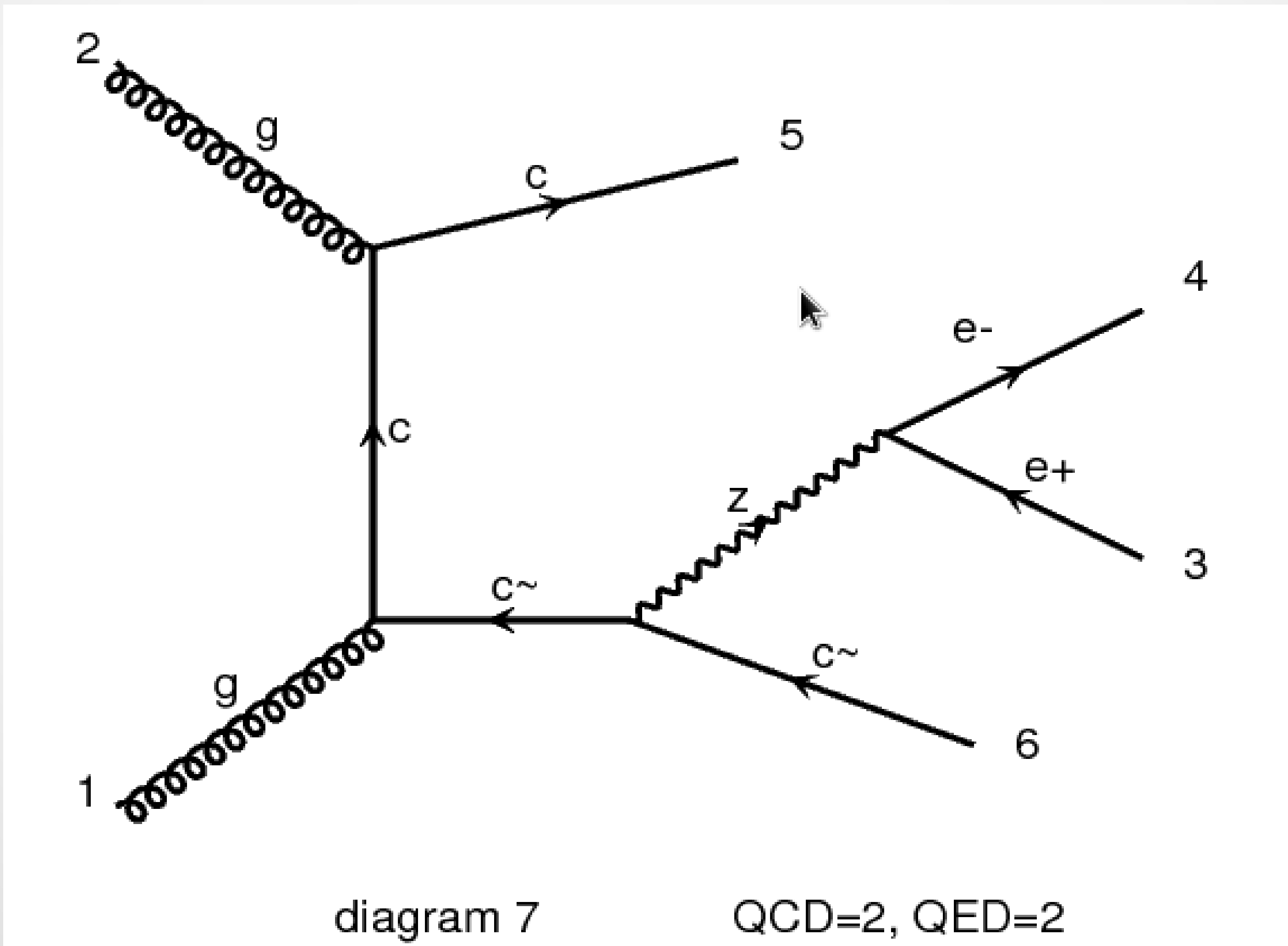
Background Process pp > Zbb~, Z > l+l-

- Same final Products but no A or h ever present



Background Process pp > Zjj, Z > l+l-

- Same final products. light jets can be mistagged



Motivation – other channels

- A > Zh investigated discovery channels

	$h \to WW^*$	$h \to ZZ^*$	$h \to \tau\tau$	$h \to \gamma\gamma$
$Z \to ll$	✓	✓	✓	✓
$Z \to qq$	X	✓	X	X
$Z \to \nu\nu$	X	✓	X	X

- A > Zh has high BR when mA < 350 GeV
- We like h > bb~ because of the large branching ratio 57.7%

https://indico.cern.ch/event/300048/session/13/contribution/54/material/slides/1.pdf

What is a Sensitivity Study - Yield

- Yield = unitless quantity describing how much of a process that we see after generation, detector, and cuts

$$Yield = L * xsec * (A * E)$$

- Luminosity (fb^{-1}) – how much data we have
  - After 2015: L = $5fb^{-1}$ for $\sqrt{s}$ = 13TeV
- Cross Section = xsec (pb) describes probability of a certain event occurring
- Acceptance = fraction of events the detector catches
- Efficiency = fraction of events filtered out by analysis cuts

What is a Sensitivity Study – Significance

- Background has Poisson Distribution so uncertainty

$$\sigma = \sqrt{Background\ Yield}$$

- We can calculate whether or not we will be able to see the signal process (if its really happening)

$$Significance = \frac{Signal\ Yield}{\sqrt{Background\ Yield}}$$

  - if Significance > 2 we will be able to see the process with 95% certainty.

Parameter Space Investigated

- Type II: H2 couples to up-type fermions, H1 couples to down-type fermions and leptons – gives them mass!!

- mA = 0.3TeV, 0.5TeV, 1TeV, 2TeV, 3TeV
  - mh = 0.125TeV
  - mA increases, xsec(A)*Br_A_Zh decreases

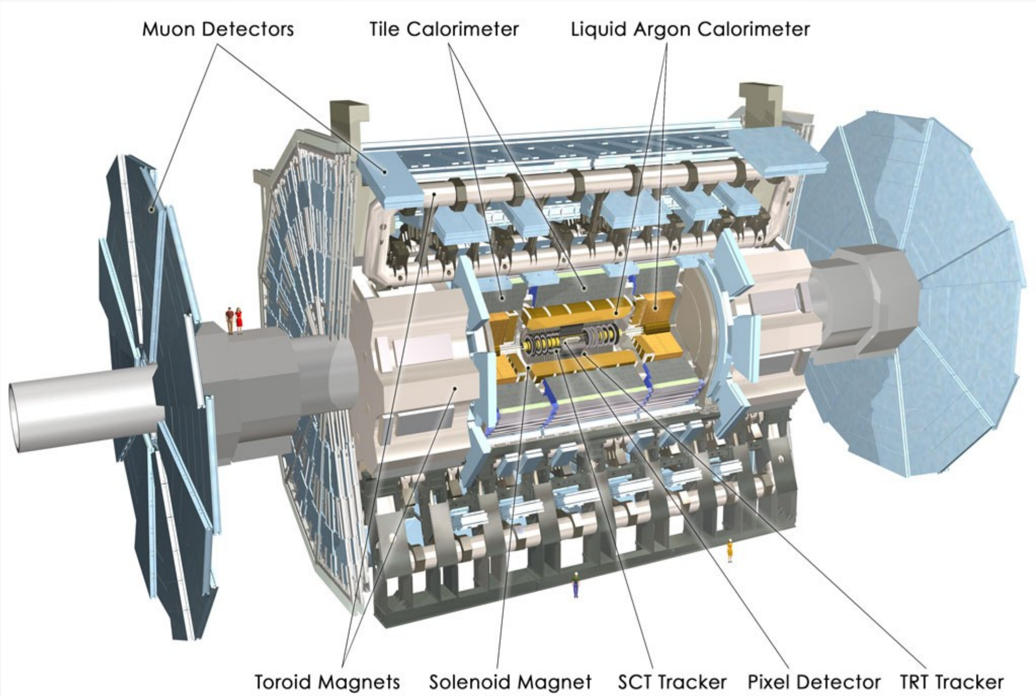
- $\tan(\beta) = 1, 10$ $\cos(\beta - \alpha) = 0, \pm 0.4$
  - tan(β) increases. xsec(A)*Br_A_Zh decreases

Process Simulation

- Events generated based on various regions of parameter space
- Collide beams of protons at energies of 6500GeV
- MadGraph – process simulator
- Delphes – detector simulator

Detection

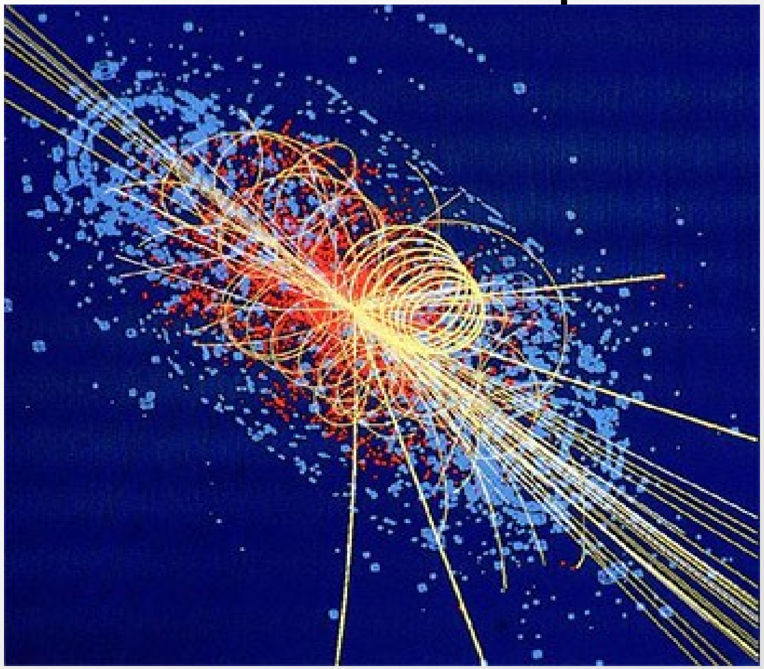
- ATLAS Detector
  - Detect electron, muons, jets
  - tag jets with quark



http://www.atlas.ch/photos/atlas_photos/selected-photos/full-detector/ATLAS_Silver_White_MK.jpg

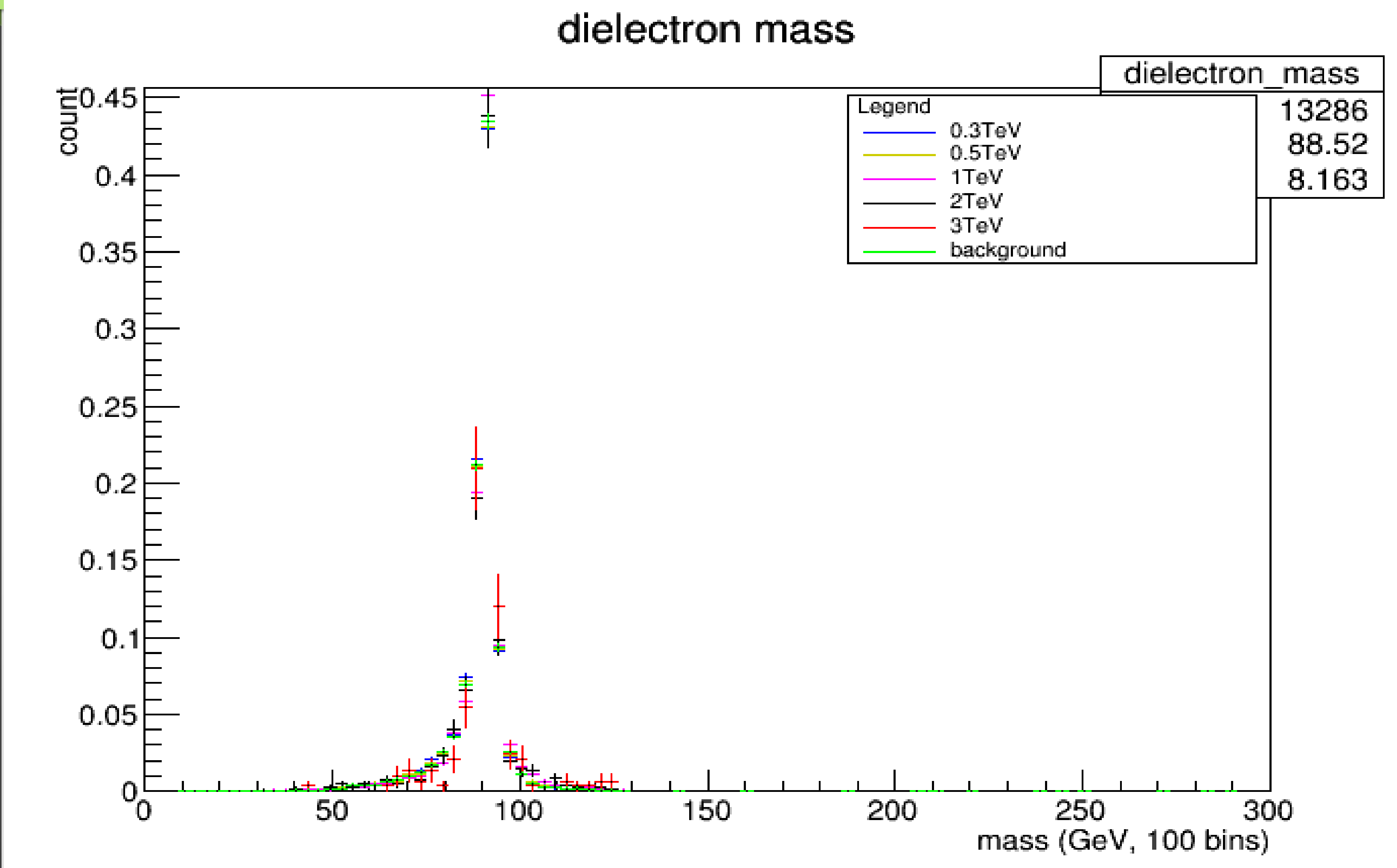
Kinematics – Differences

- Look at the kinematic distributions for signal and background
  - Look for major differences
  - Perform analysis to remove events that do not pass cuts to remove background
- PT
- bb reconstructed mass
- llbb reconstructed mass

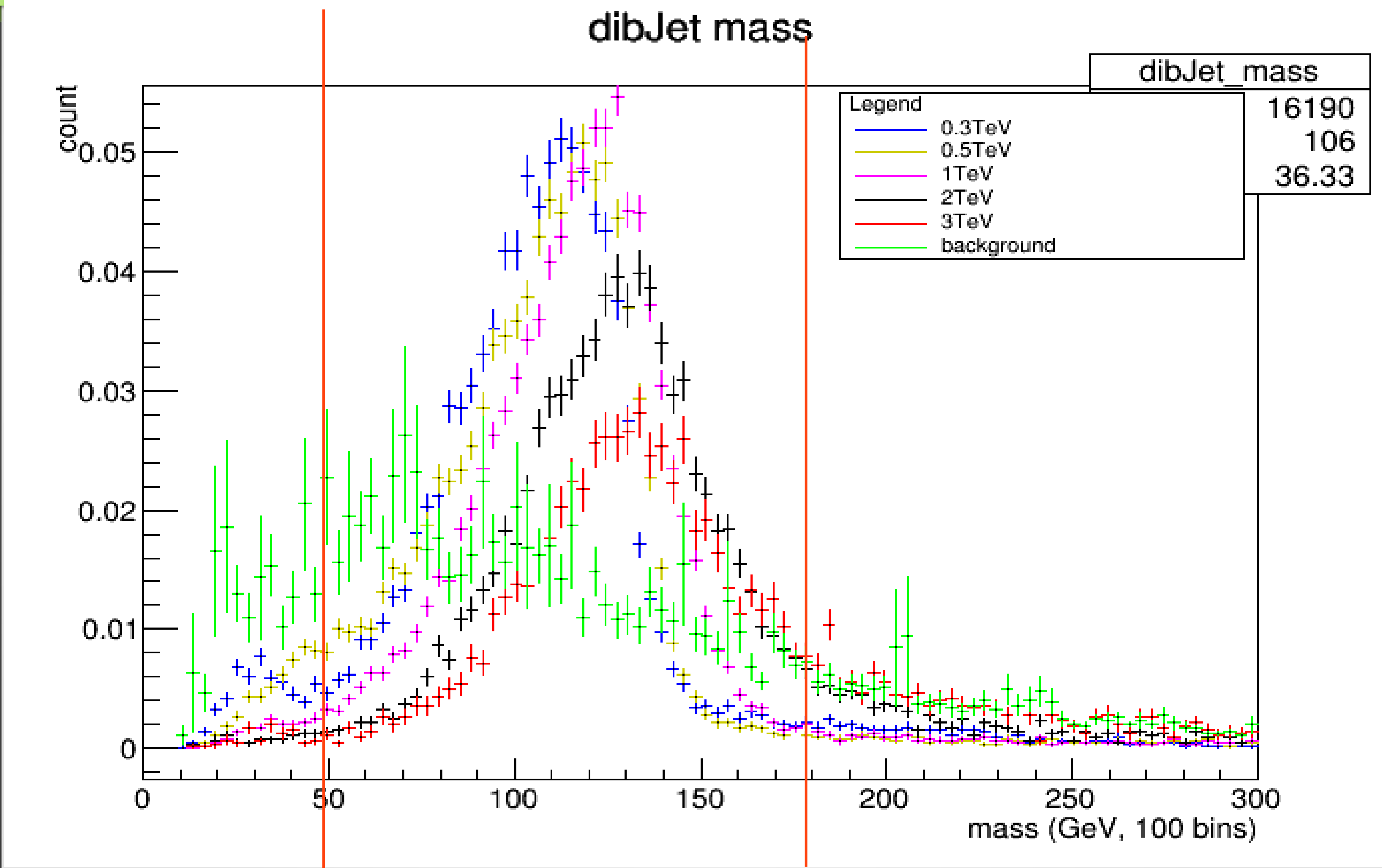


http://blackmaps.files.wordpress.com/2009/12/higgsboson350px.jpg

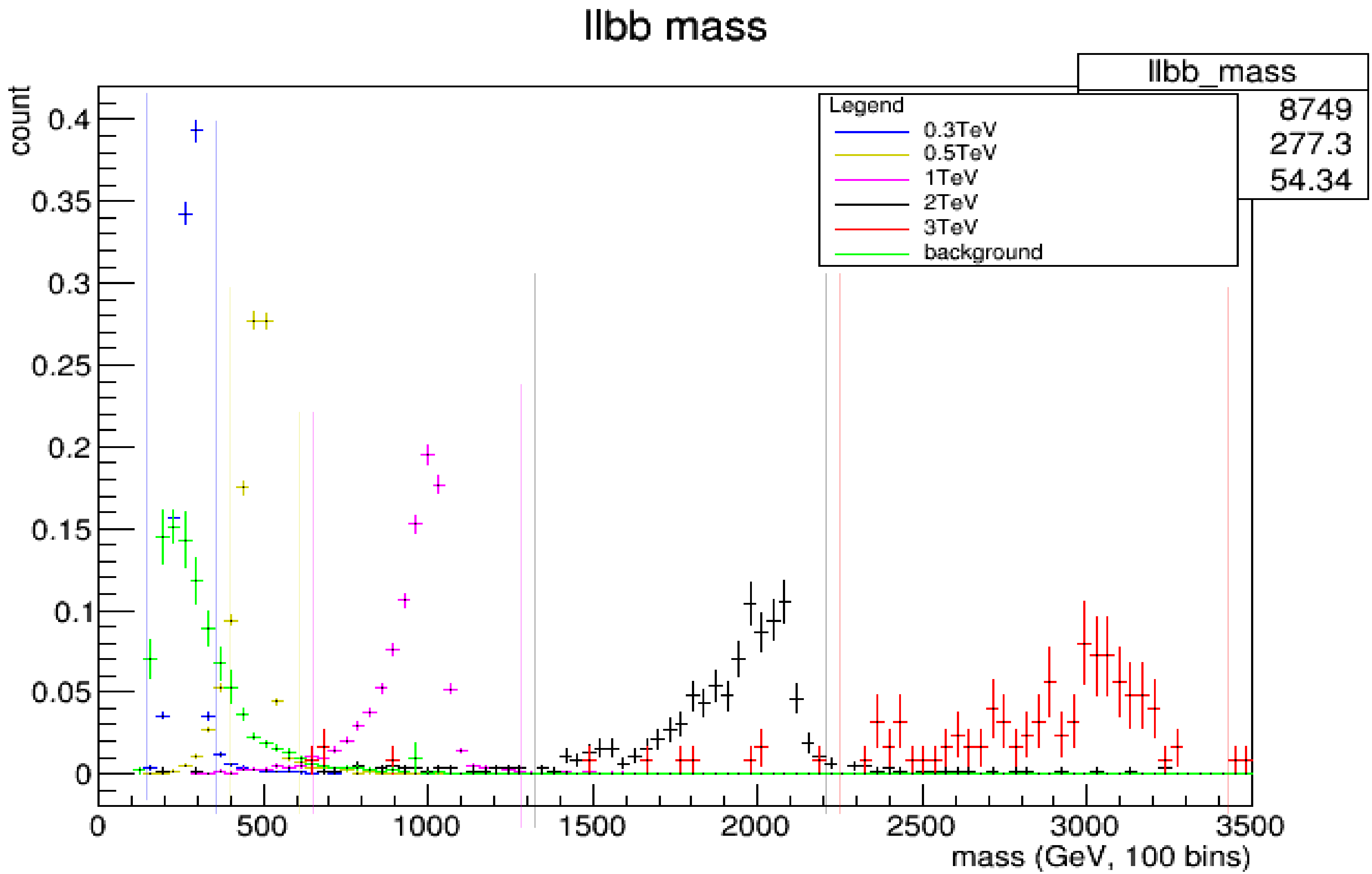
ee mass cos(β – α) = 0, tan(β) = 10



bb~ mass   cos(β – α) = 0, tan(β) = 10



llbb~ mass cos(β – α) = 0, tan(β) = 10

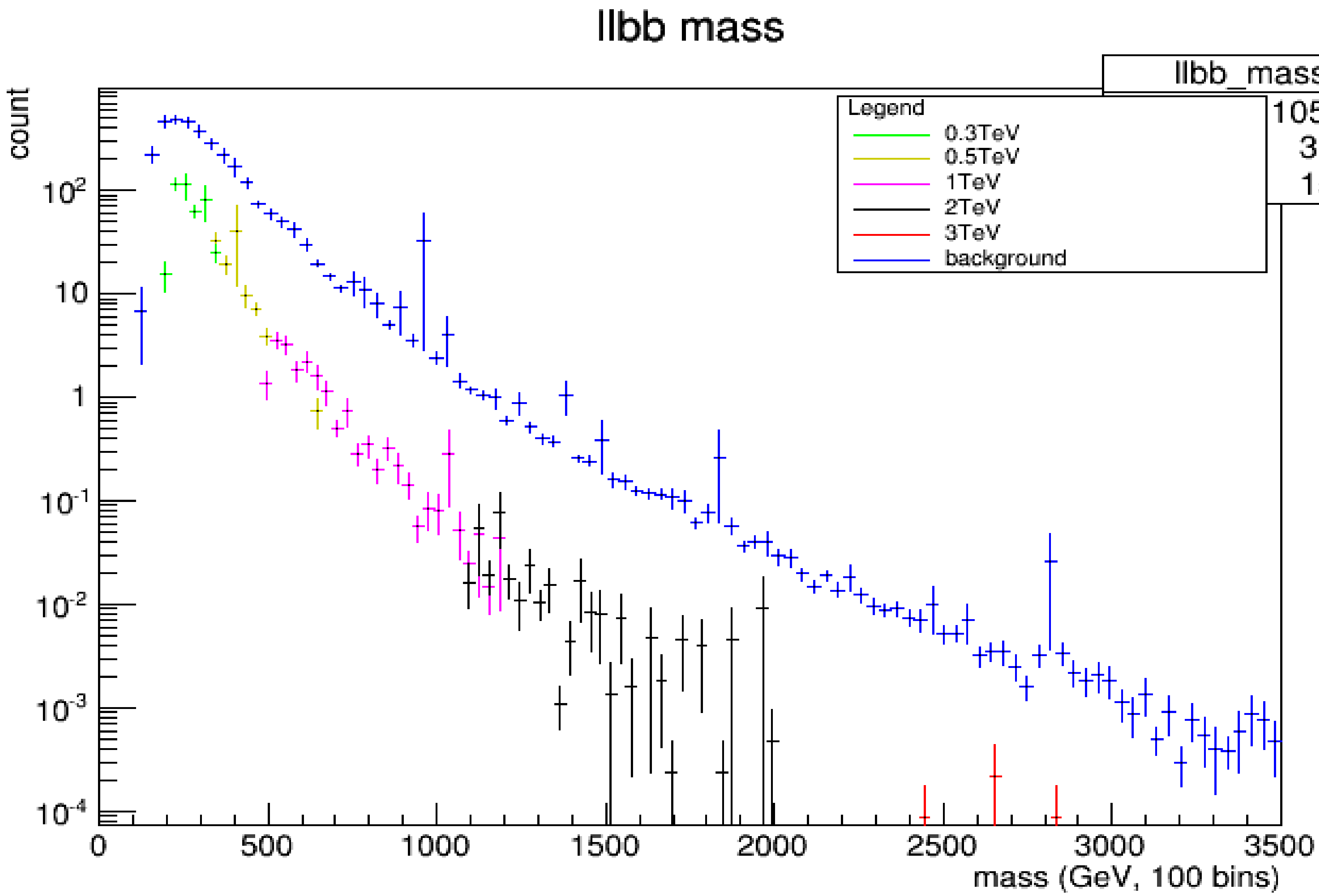


Cuts

- lepton and jet PT > 30.0GeV
- 50 GeV < bb~ mass < 150 GeV for mA = 0.3TeV, 0.5TeV, 1TeV
- 50GeV < bb~ mass < 200 GeV for mA = 2TeV, 3TeV
- llbb mass

mA (TeV)	min llbb~	max llbb~
0.3	200	350
0.5	200	700
1	500	1200
2	1000	2500
3	2000	3500

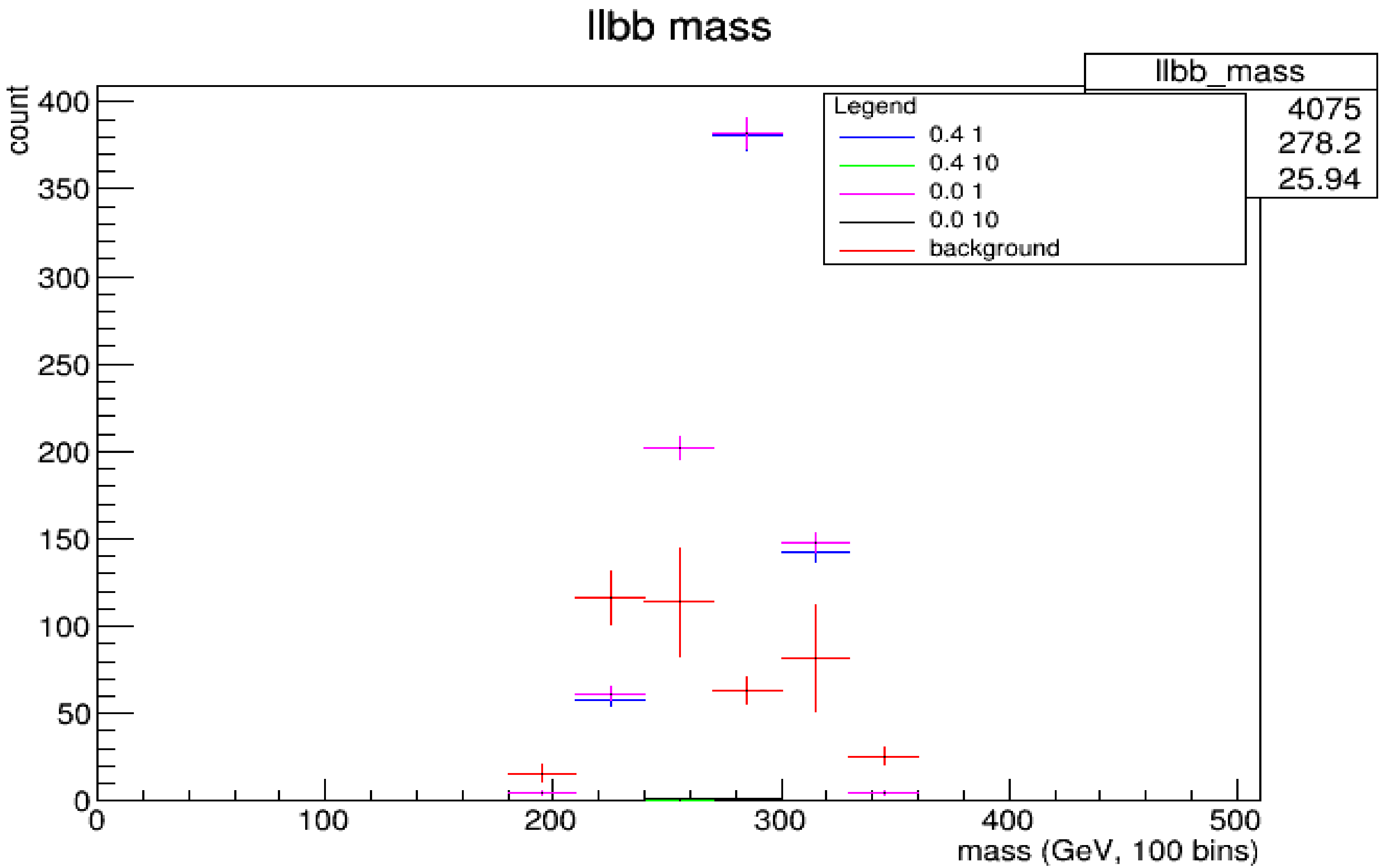
Background Reduction



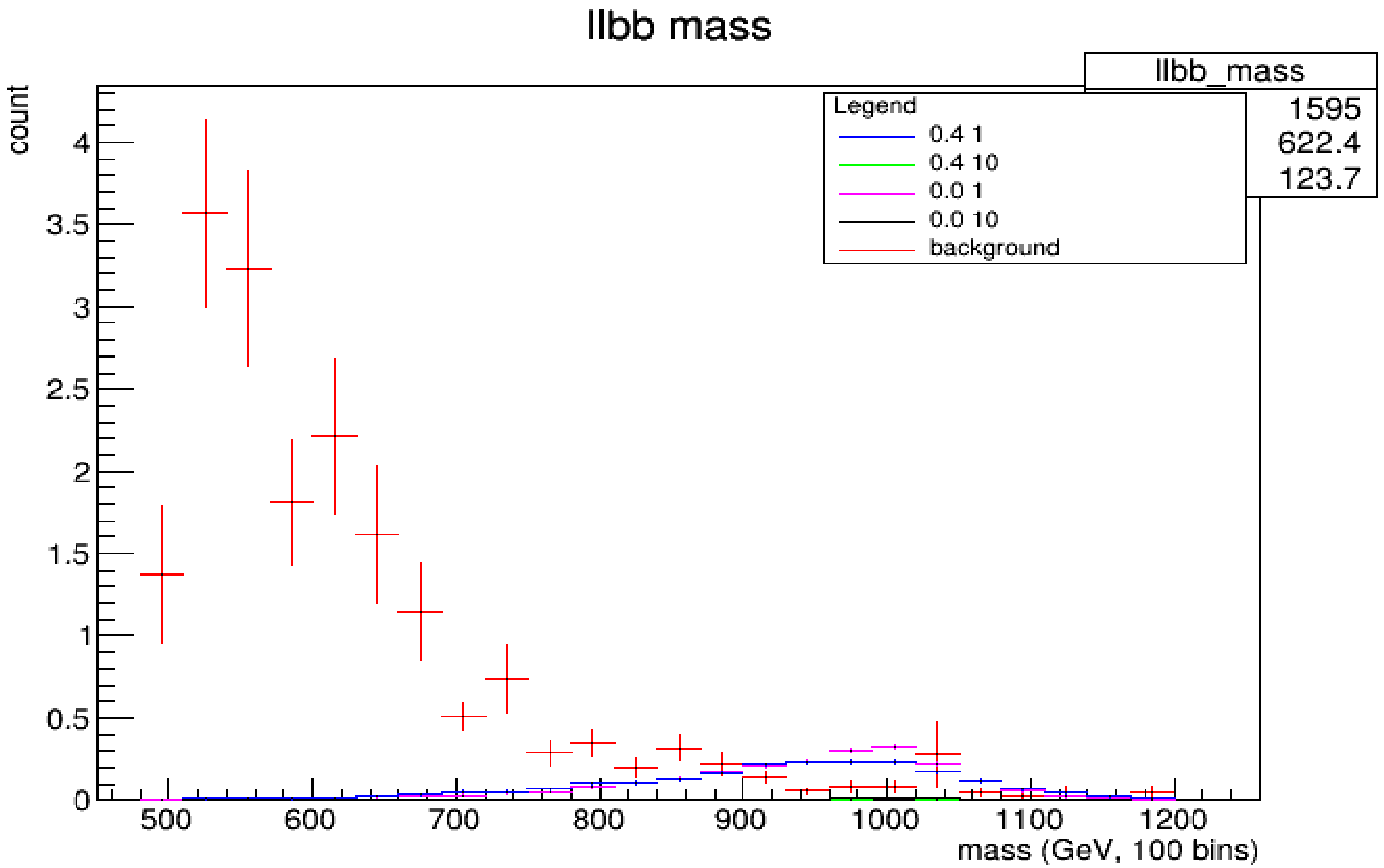
Background Yields

Backgrounds	xsec	Yield	Entries	A*E%
mA300	348.45	415.82	78.2	0.1564
mA500	348.45	207.15	23.7	0.0474
mA1000	348.45	18.418	212.8	0.4256
mA2000	348.45	0.32579	28.22	0.05644
mA300	348.45	4.70E-004	4.42	0.00884

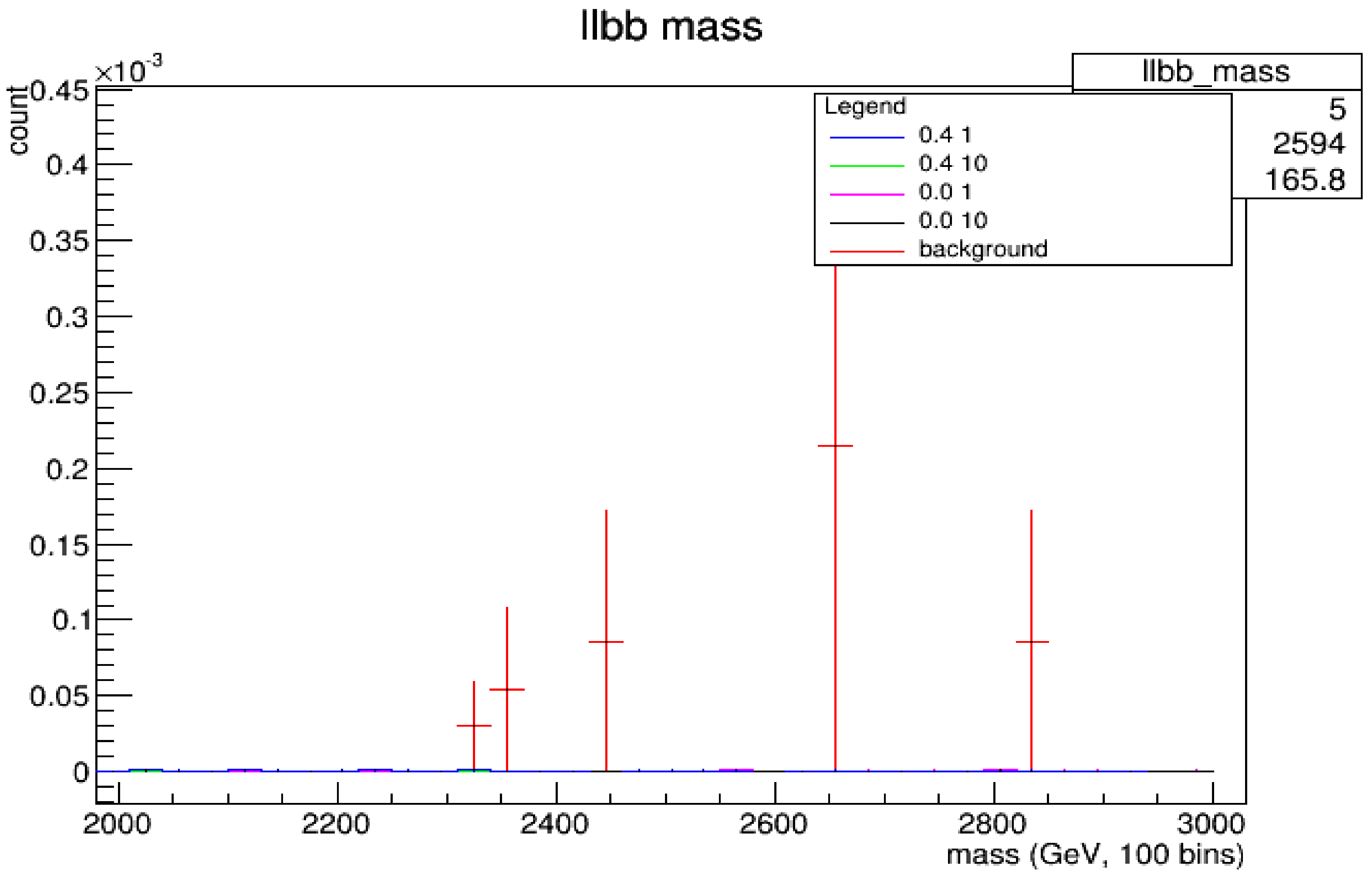
0.3TeV llbb~ mass



1TeV llbb~ mass



3TeV llbb mass



Yields mA = 0.3TeV, 0.5TeV

mA300	xSec*BrA_Zh (pb)	Yield	A*E(%)	Signficance
0.4-1	28.9341	792.33	8.15	3.89E+001
0.0-1	28.9341	802.247	8.252	3.93E+001
0.4-10	0.124497	3.49956	8.366	1.72E-001
0.0-10	0.124497	3.48282	8.326	1.71E-001
mA500				
0.4-1	1.4471	77.6602	15.972	5.40E+000
0.0-1	1.4471	79.0313	16.254	5.49E+000
0.4-10	0.102696	5.73272	16.614	3.98E-001
0.0-10	0.102696	5.69614	16.508	3.96E-001

Yields mA = 1TeV, 2TeV, 3TeV

mA1000	xSec*BrA_Zh (pb)	Yield	A*E(%)	Significance
0.4-1	0.0733473	2.15247	8.734	5.02E-001
0.0-1	0.0733473	2.22937	9.046	5.19E-001
0.4-10	0.00233568	0.0694536	8.85	1.62E-002
0.0-10	0.00233568	0.0692337	8.822	1.61E-002
mA2000				
0.4-1	0.00251921	9.48E-003	1.12	1.66E-002
0.0-1	0.00251921	8.48E-003	1.002	1.49E-002
0.4-10	1.76748E-005	6.52E-005	1.098	1.14E-004
0.0-10	1.76748E-005	5.33E-005	0.898	9.34E-005
mA3000				
0.4-1	2.98308E-005	1.80E-005	0.18	8.32E-004
0.0-1	2.98308E-005	1.78E-005	0.178	8.23E-004
0.4-10	5.13346E-007	2.73E-007	0.158	1.25E-005
0.0-10	5.13346E-007	2.83E-007	0.164	1.30E-005

So What?

- If mA = 0.3TeV or mA = 0.5TeV
  - if tan(β) = 1, we will be able to see after next year at the LHC
    - mA = 0.3TeV, significance ~ 40
    - mA = 0.5TeV, significance ~ 5
  - if tan(β) = 10, the signal will be too small to see
- If mA > 0.5TeV the signal will be too small to see

Thanks

- Thank you:
  - Professor Hsu
  - Nikolas Whallon
  - Deep, Alejandro, Gray, Linda, Janine
  - NSF for funding
- Questions?

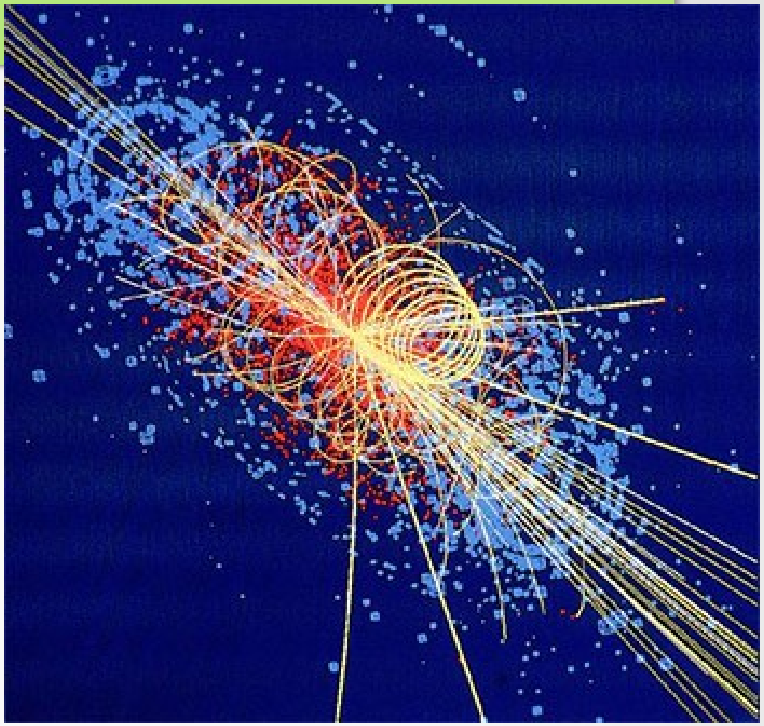
Parameter Space with Cross Section

mA300	xSec*BrA_Zh (pb)	mA1000	xSec*BrA_Zh (pb)	mA3000	xSec*BrA_Zh (pb)
0.4-1	28.9341	0.4-1	0.0733473	0.4-1	2.98308E-005
0.0-1	28.9341	0.0-1	0.0733473	0.0-1	2.98308E-005
0.4-10	0.124497	0.4-10	0.00233568	0.4-10	5.13346E-007
0.0-10	0.124497	0.0-10	0.00233568	0.0-10	5.13346E-007
mA500		mA2000			
0.4-1	1.4471	0.4-1	0.00251921		
0.0-1	1.4471	0.0-1	0.00251921		
0.4-10	0.102696	0.4-10	1.76748E-005		
0.0-10	0.102696	0.0-10	1.76748E-005		

Improvements

- Me:
  - Optimize cuts, make more cuts
  - Better Statistics at high PT for background
- CERN:
  - More Data, increase Luminosity
  - More energetic LHC to increase cross-section
  - More efficient detector

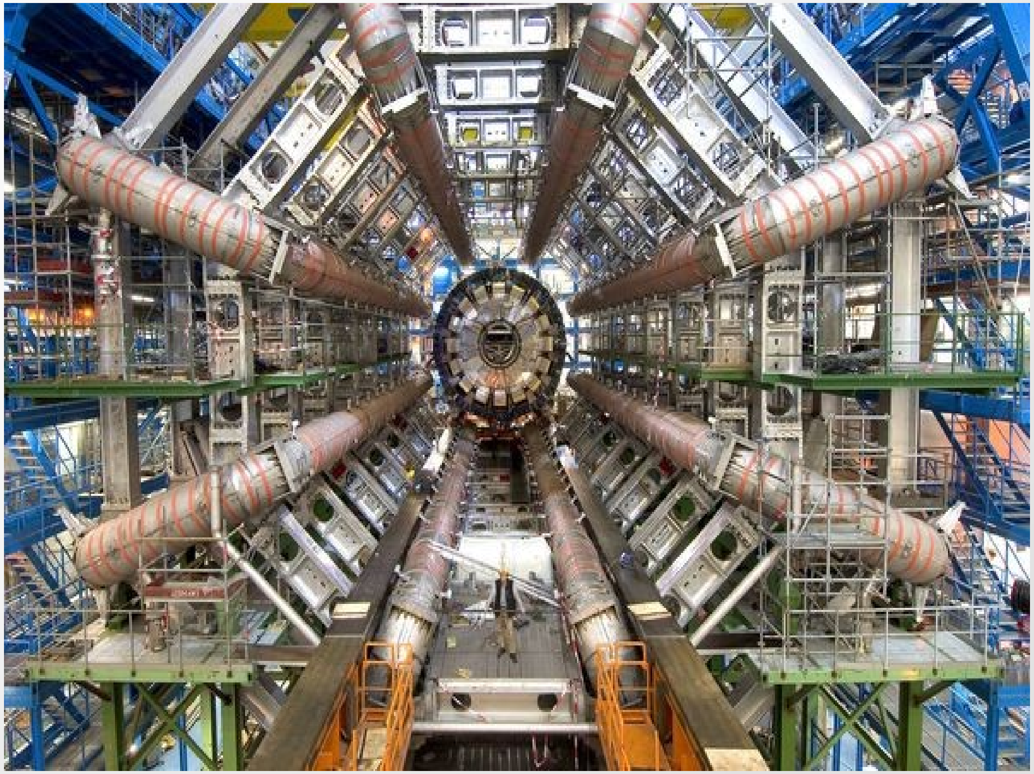
Sample Production



- Samples produced using
  - MadGraph5 v1.5.14
  - Delphes 3.0.12
  - Pythia 2.2.0
- run_card.dat: 13TeV, drjj = drll = 0
- param_card.dat: used width A based on parameter space
- delphes_card.dat: b-tagging = 0.7,
  lepton DeltaRmax = 0.5

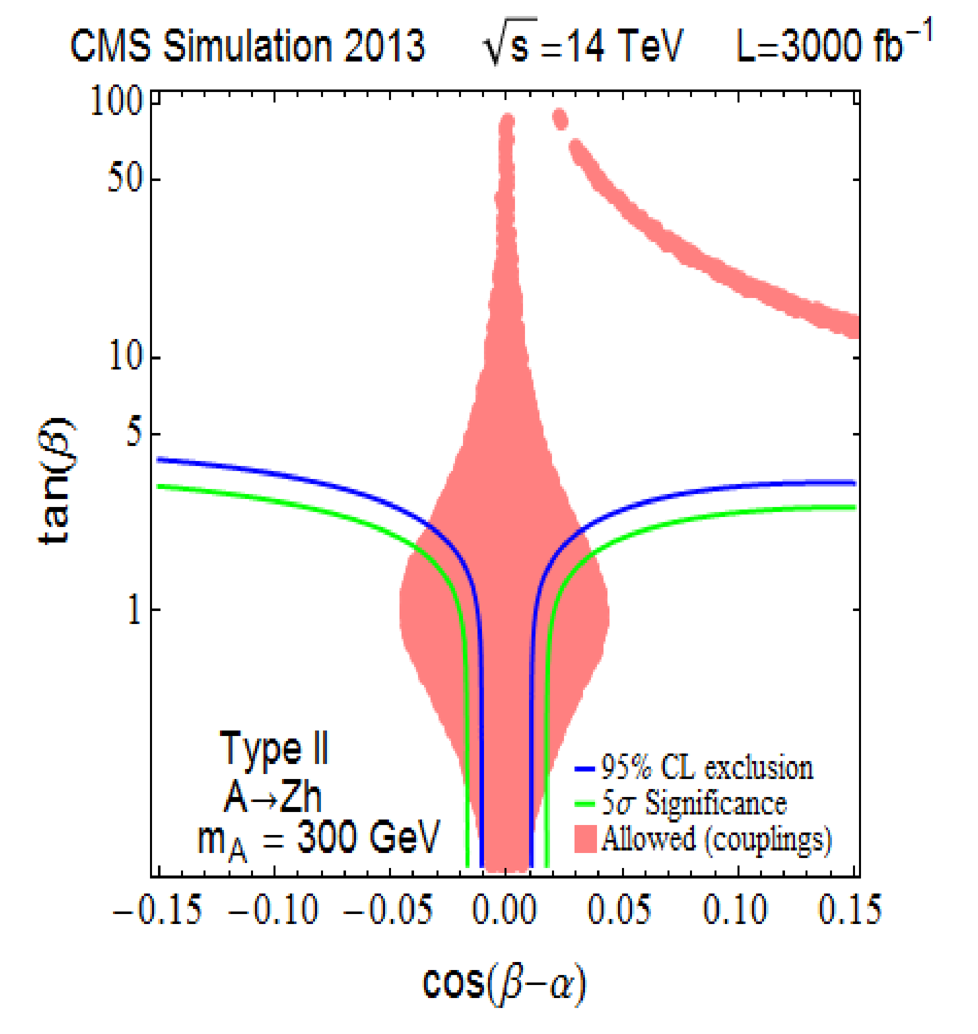
Signal and Background Samples

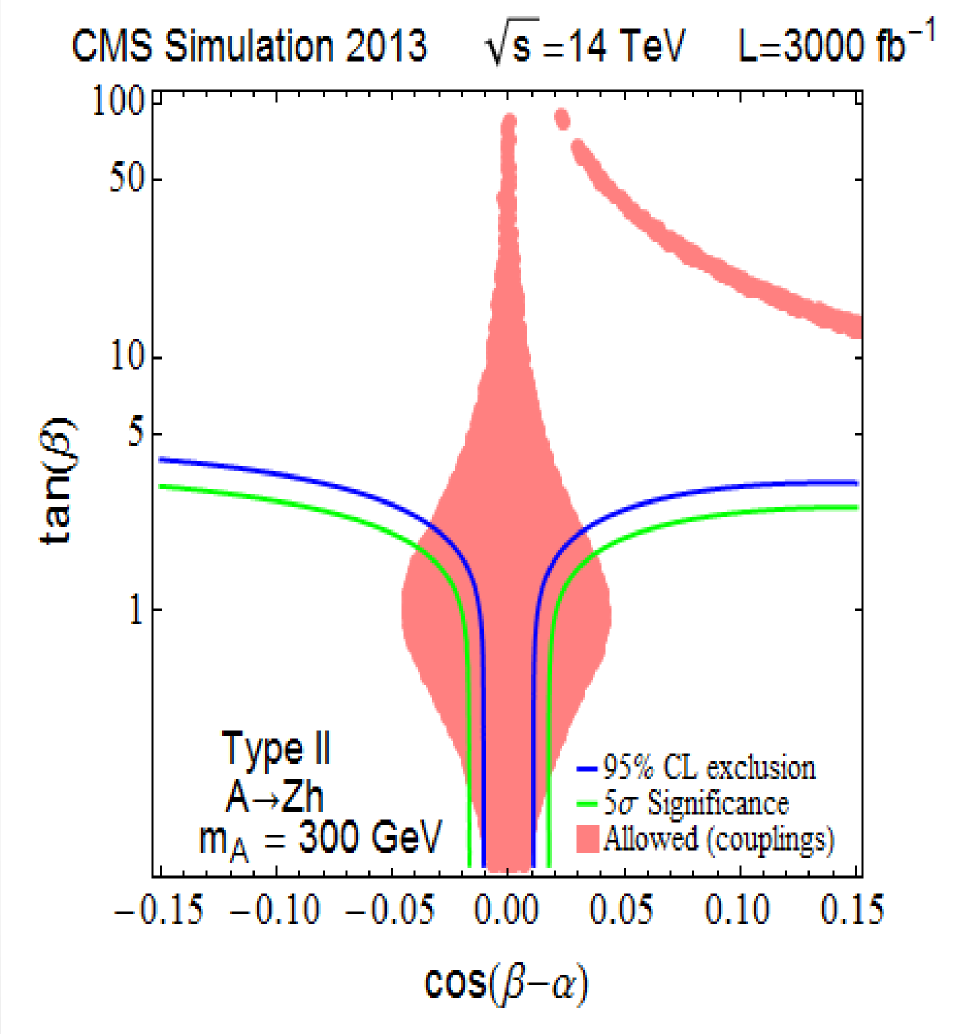
- Signal – 50k events for each point in parameter space
  - 20 signal runs total
- Background – generated 5.5M events for each background process, 5000
- at 11 different PT levels
  - Normalized for better statistics at high PT



Other studies

- Results agree with studies of other decay channels





http://cds.cern.ch/record/1637776/files/HIG-13-025-pas.pdf