Triboson resonance Phenomenology and Prospects at CMS

(- on going feasibility study)

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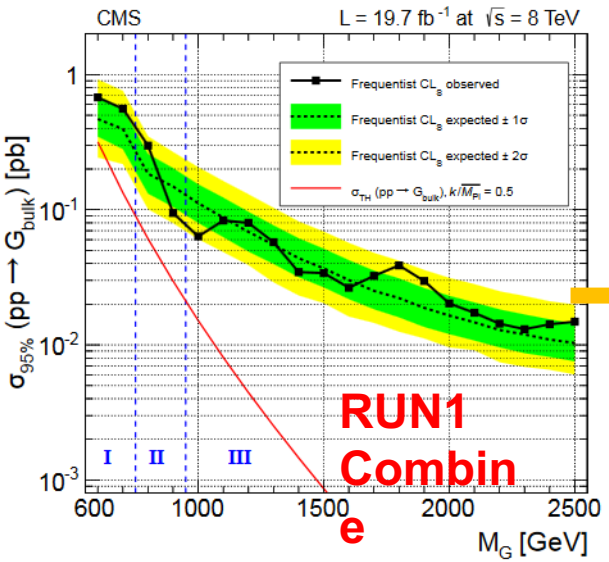
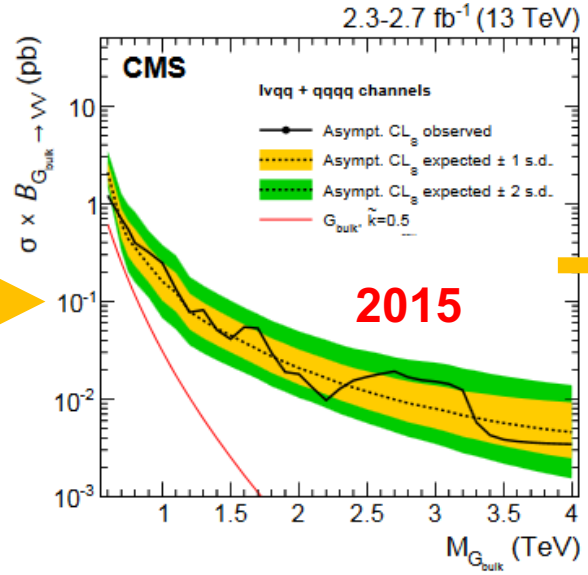
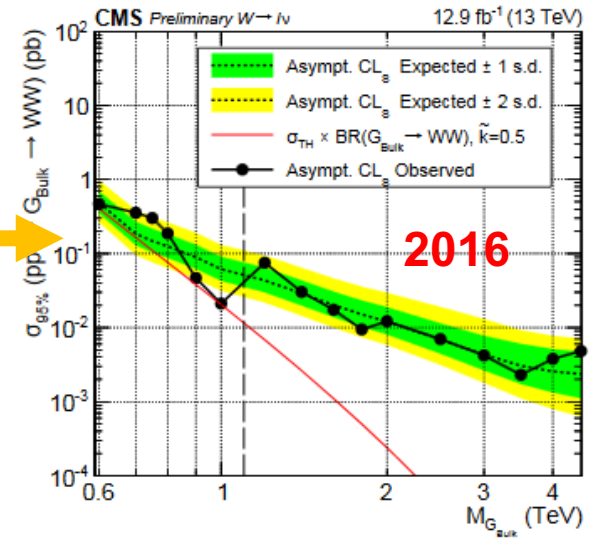
Outline

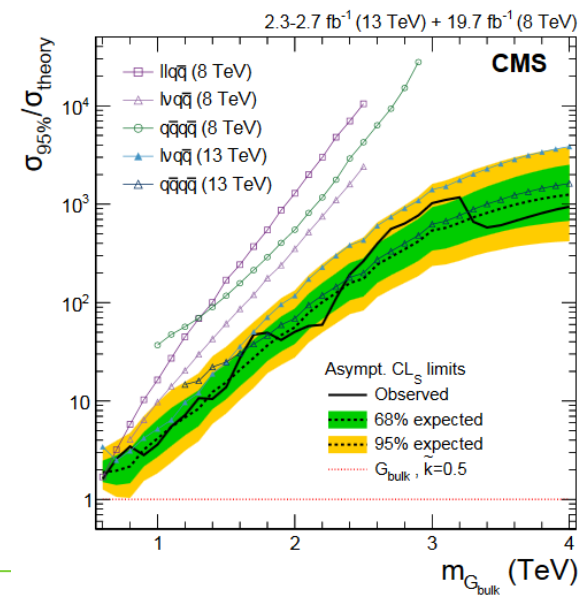
- Motivation
- Particle and Interaction
- Particle and Parameters
- Decay Channels
- Plans
- Distribution Plots at LHE and SIM level
- Summary

PKU Diboson Analysis





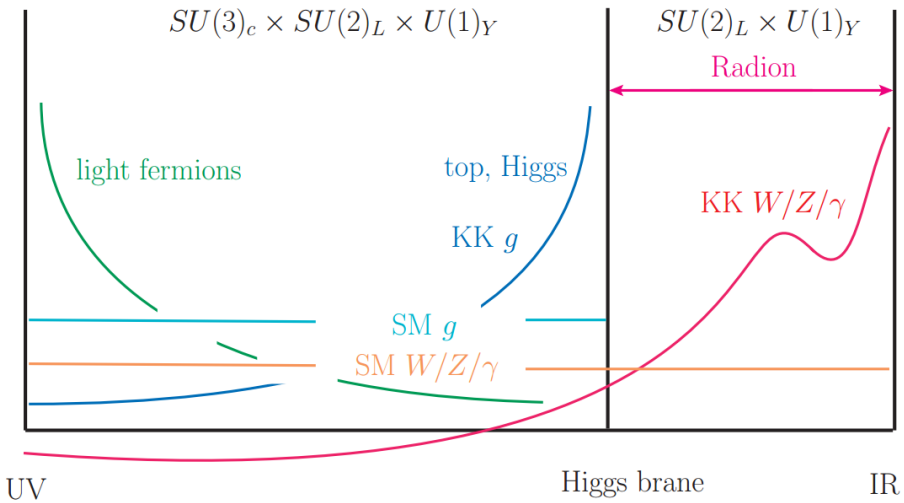




- PKU CMS Group has made crucial contributions on diboson analysis and given stricter limits on new physics search.
- Analyse: **JME-13-006 EXO-15-002 B2G-16-004 B2G-16-007 B2G-16-020→B2G-16-029**
- 6 analyses and 5 papers, from 5 years long journey

Motivation

- The usual framework of warped higher dimensional compactifications involves fields corresponding to all SM particles propagating in the bulk of a warped extra dimension
- It is modified by the inclusion of one such extra brane, located very close to the IR brane.
- The SM matter and Higgs fields are allowed to propagate only in the subspace from UV to this “intermediate" brane
- We have close contact with the authors



Introduction of an intermediate brane (henceforth called, “Higgs brane”), which helps to avoid experimental bounds so that **new particles lie within reach of the LHC**!

Higgs brane scale is chosen to be >= O(10) TeV, i.e., same as the IR brane scale of the standard scenario.

https://arxiv.org/pdf/1711.09920.pdf

Particle and Interaction

➢ Lagrangian of WKK:

- **WKK,fermions coupling:** $$\frac{g_V^2}{g_{V_{\rm KK}}} V_{\rm KK}^{\mu} J_{V\mu}$$

  where $J_{V\mu}$ is SM W current and gw is SM W coupling. This gives the production of WKK via quarks and part of WKK decay.

- **WKK,R,W coupling:** $$\epsilon \frac{g_{\rm grav}}{g_{V_{\rm KK}}^2} g_{V_{\rm KK}} g_V V_{\mu\nu} V_{\rm KK}^{\mu\nu} \frac{\varphi}{m_{\rm KK}}$$

  where $V_{\rm KK}^{\mu\nu}$ is the field strength of KK (SM) W.

- **R, SM EW gauge boson coupling:**

$$-\frac{1}{4} \frac{g_{\rm grav}}{g_{V_{\rm KK}}^2} g_V^2 V_{\mu\nu} V^{\mu\nu} \frac{\varphi}{m_{\rm KK}}$$

  where g_V is SM Z (photon) coupling.

Lagrangian expression:

$$\mathcal{L}_{\rm warped}^{\rm EW} \ni \frac{g_V^2}{g_{V_{\rm KK}}} V_{\rm KK}^{\mu} J_{V\mu} + \left(-\frac{1}{4} \frac{g_{\rm grav}}{g_{V_{\rm KK}}^2} g_V^2 V_{\mu\nu} V^{\mu\nu} + \epsilon \frac{g_{\rm grav}}{g_{V_{\rm KK}}^2} g_{V_{\rm KK}} g_V V_{\mu\nu} V_{\rm KK}^{\mu\nu} \right) \frac{\varphi}{m_{\rm KK}}$$

Particle and Parameters

- **Particles in MG5 model:**

KK W/Z/A : WKK/ZKK/AKK, Radion: R, SM particles are the same as usual.

a) External Parameters:

· Mass: (KK scale and the mass for WKK)MKK,(Radion mass)MR;
· Couplings:
  - ggrav : composite coupling in gravity sector;
  - gWKK : composite coupling in for KK W;
  - gZKK : composite coupling in for KK Z;
· epsilon: one parameter in the WKK,R,W coupling coupling

b) Internal Parameters:

$$g_{AKK} = g_{WKK}\sqrt{1-(g_{WKK}/g_{ZKK})^2}$$

Particle and Parameters

c)Allowed Parameter ranges:

ggrav : 1~6

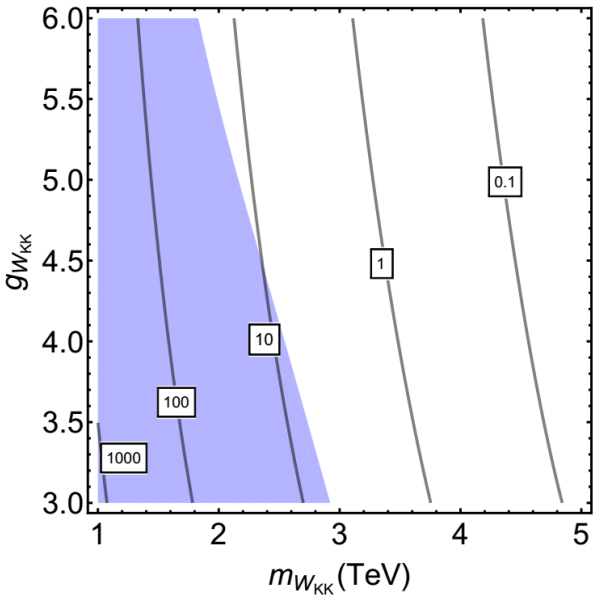
gWKK : 3~6

gZKK : $\sqrt{g_{WKK}^2 + 3^2} \sim \sqrt{g_{WKK}^2 + 6^2}$

(Just like SM, $g_{ZKK} = \sqrt{g_{WKK}^2 + g_{BKK}^2}$, where gBKK is the KK U(1)_Y coupling. We demand that gBKK is within 3~6, this gives the parameter range for gZKK, which is correlated with gWKK.)

epsilon : 0.3~0.5

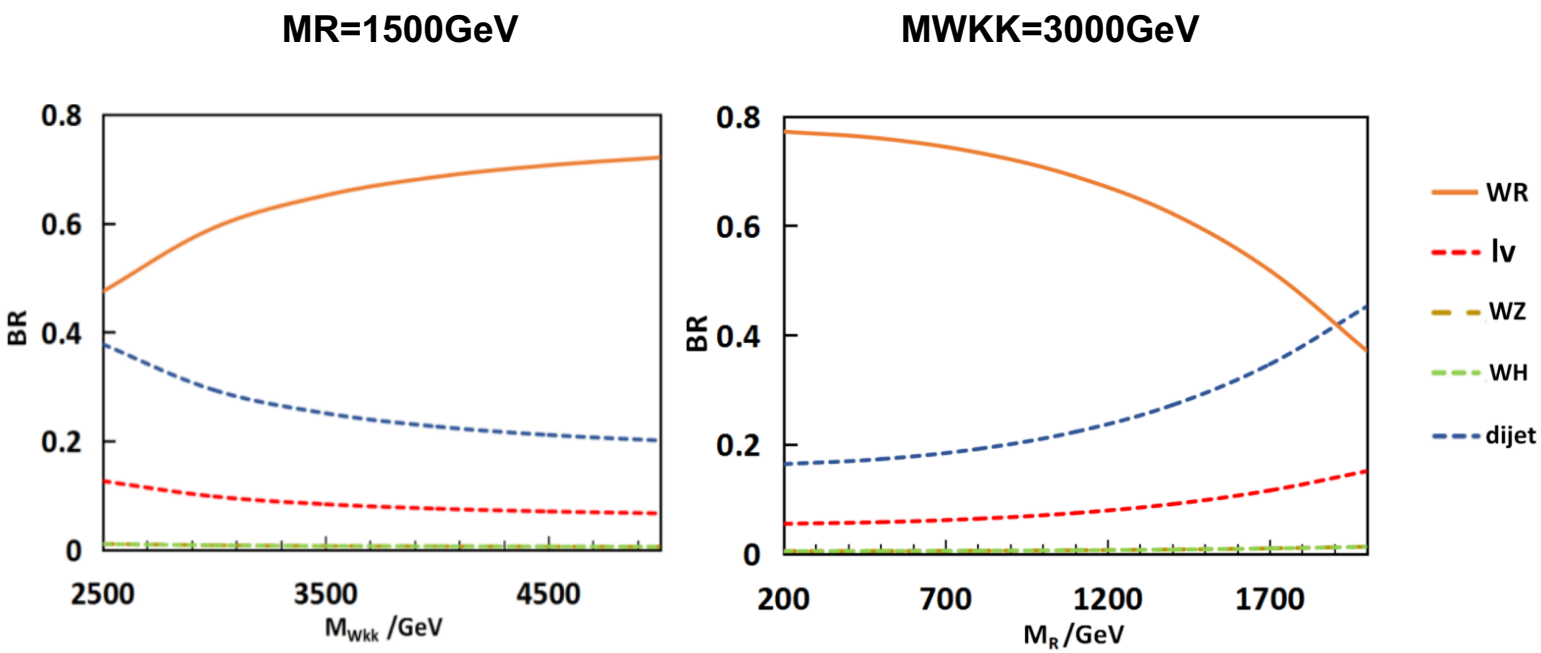
MR : >=200GeV



Model	Name	Current search	Allowed mass values [TeV]
EW model	KK W	$\ell + E_T^{\text{miss}}$	$m_{W_{KK}} \gtrsim 2.5$ for $g_{W_{KK}} \sim 4$ $m_{W_{KK}} \gtrsim 3$ for $g_{W_{KK}} \sim 3$
	KK Z	$\ell\ell$ resonance	$m_{Z_{KK}} \gtrsim 2$ for $g_{Z_{KK}} \sim 5$ $m_{Z_{KK}} \gtrsim 2.5$ for $g_{Z_{KK}} \sim 3$
	KK γ	$\ell\ell$ resonance	$m_{\gamma_{KK}} \gtrsim 2$ for $g_{\gamma_{KK}} \sim 4$

Decay Channels

- **Decay channels of WKK**



The branching ratio of WKK as a function of MWKK and MR

Decay Channels

- **Decay channels of R**

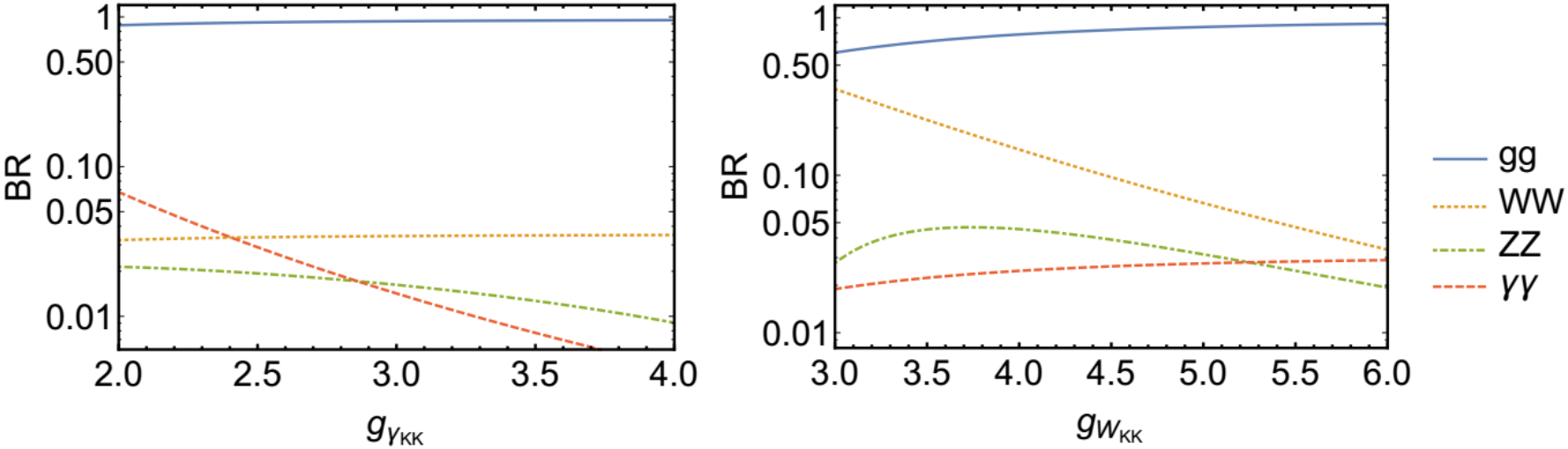
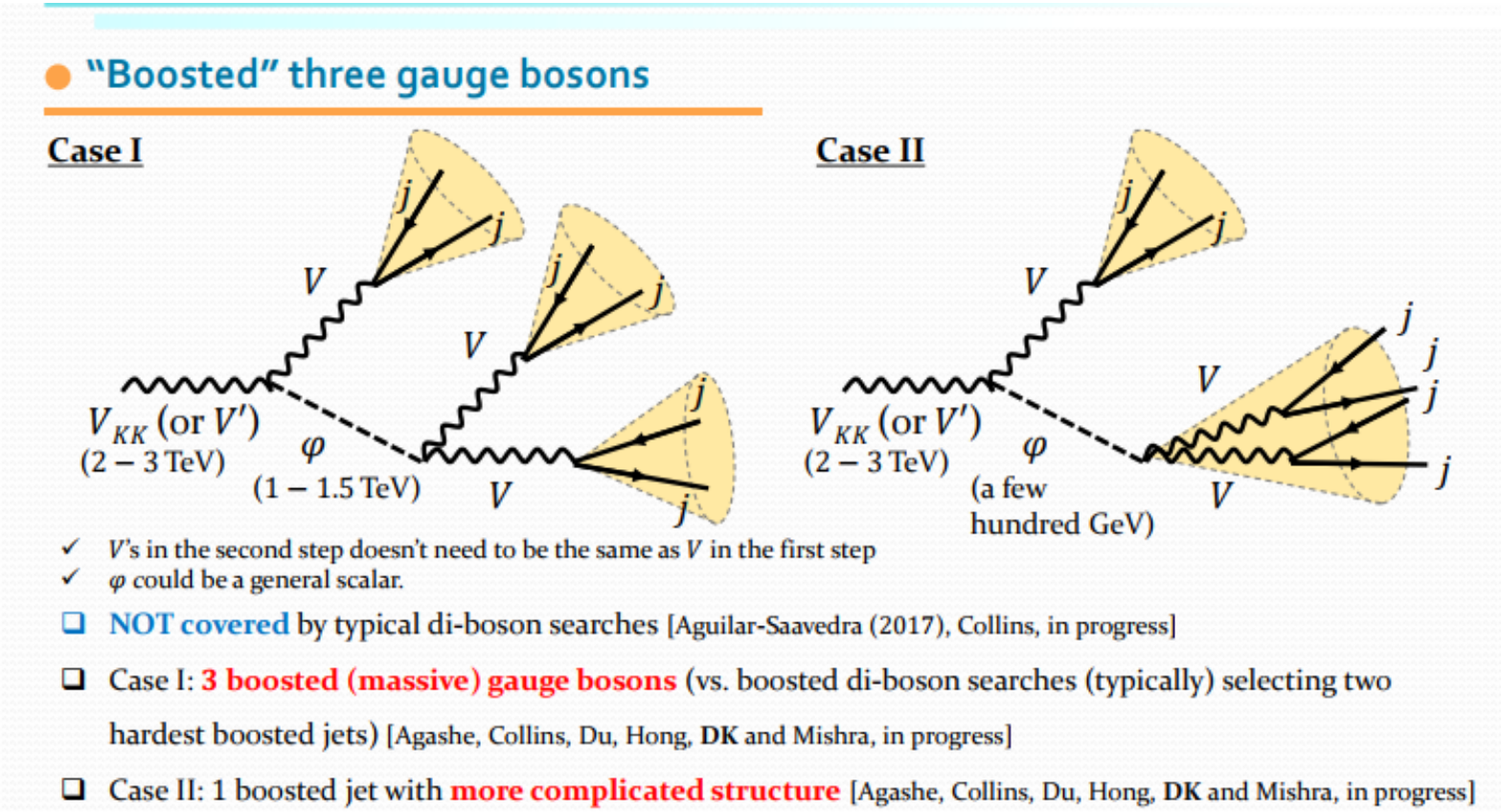


Figure 5. The left panel shows BR of radion as a function of $g_{\gamma_{KK}}$, keeping $g_{W_{KK}} = 6$. The right panel shows BR as a function of $g_{W_{KK}}$, keeping $g_{\gamma_{KK}} = 2.5$. In both cases we choose $g_{g_{KK}} = 6$.

https://arxiv.org/pdf/1612.00047.pdf

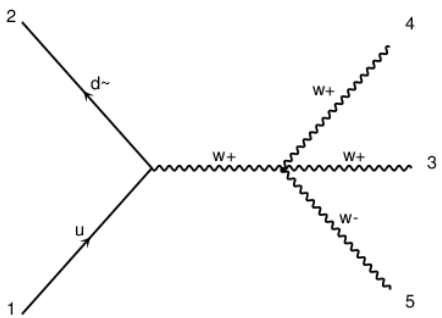
Our Plans

- **Process 1:** p p → $wkk \rightarrow R\,V, R \rightarrow$ V V (2 resonances)

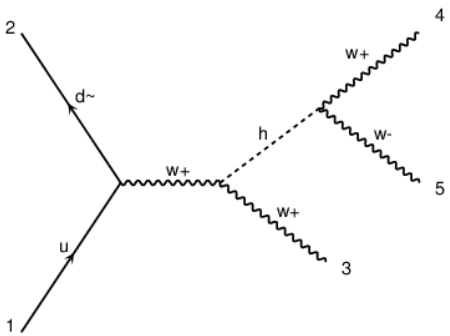


Our Plans

- **Process 2:**
  - p p → X → V V V (1 resonance, simple)



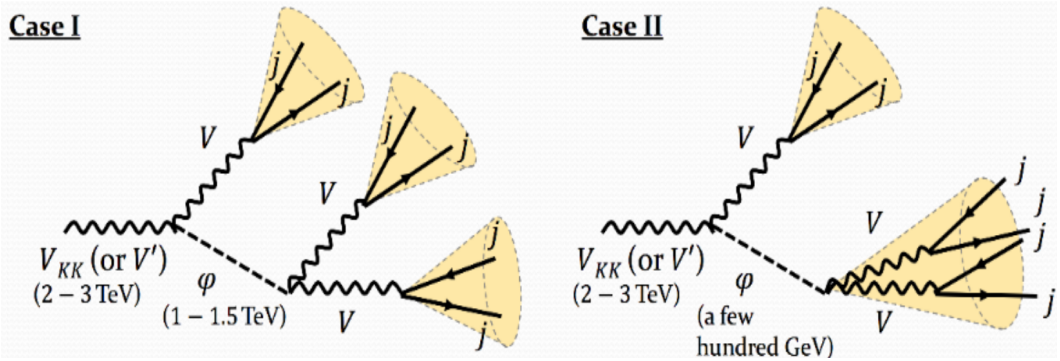
- **Process 3:**
  - p p → $V\ H$, H → V V (1 resonance)
  - heavy Higgs with anomalous coupling
  - Inspired by Prof. Yuping Kuang
  - CPC40(2016)-023101



- **Process 4:**
  - p p → V V V (0 resonance)
  - aQGC, in refer to SMP-13-008

Samples of Two Cases for Process 1

- **Process: p p > wkk+ > w+ r, r > w+ w- and p p > wkk- > w- r, r > w+ w- ;**
- **Parameters: gWKK=3, gZKK=6.708, ggrav=6, epsilon=0.5, MWKK>2500, MR>200 ;**
- **Cross-section @ 13 TeV LHC : 2.73 fb MR=1500**
  3.34 fb MR=200



- **Bkg samples are same as the normal EXOWW analysis**: B2G-16-029
- **Data:**
  2016 data with lumi: 35.861 /fb

Distribution Plots

PT (R=0.1)

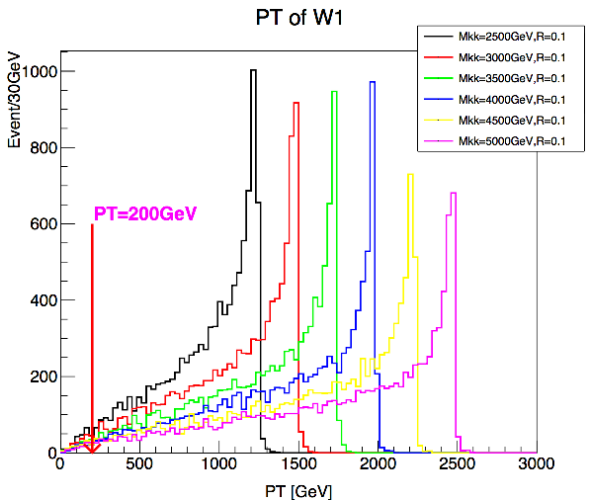
LHE level

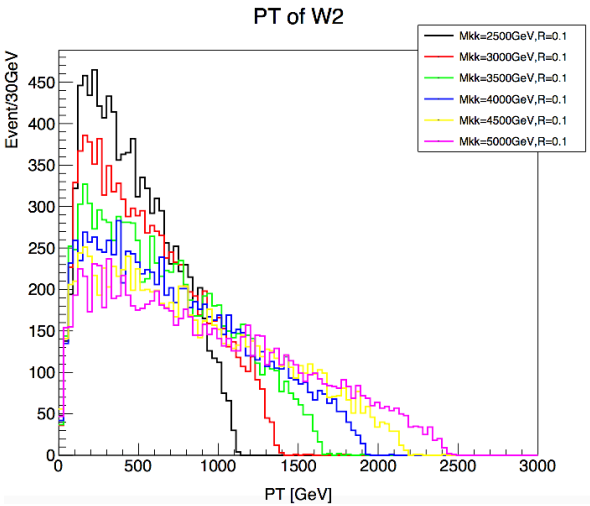
- **process: p p > wkk+ > w+ r, r > w+ w- and p p > wkk- > w- r, r > w+ w-**

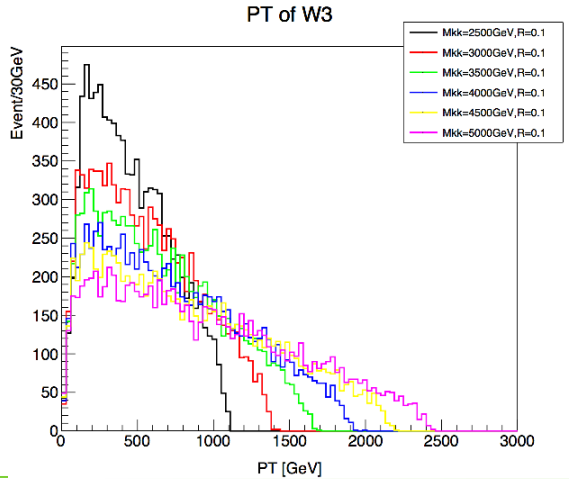
$$R = \frac{M_r}{M_{wkk}}$$

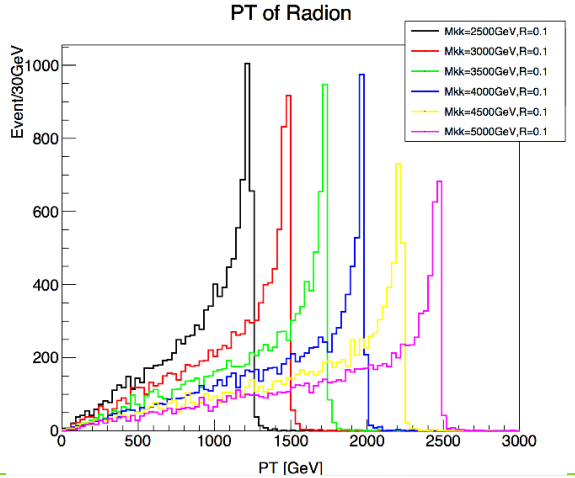
$wkk \rightarrow W_1 r$

r$\rightarrow W_2\ W_3$







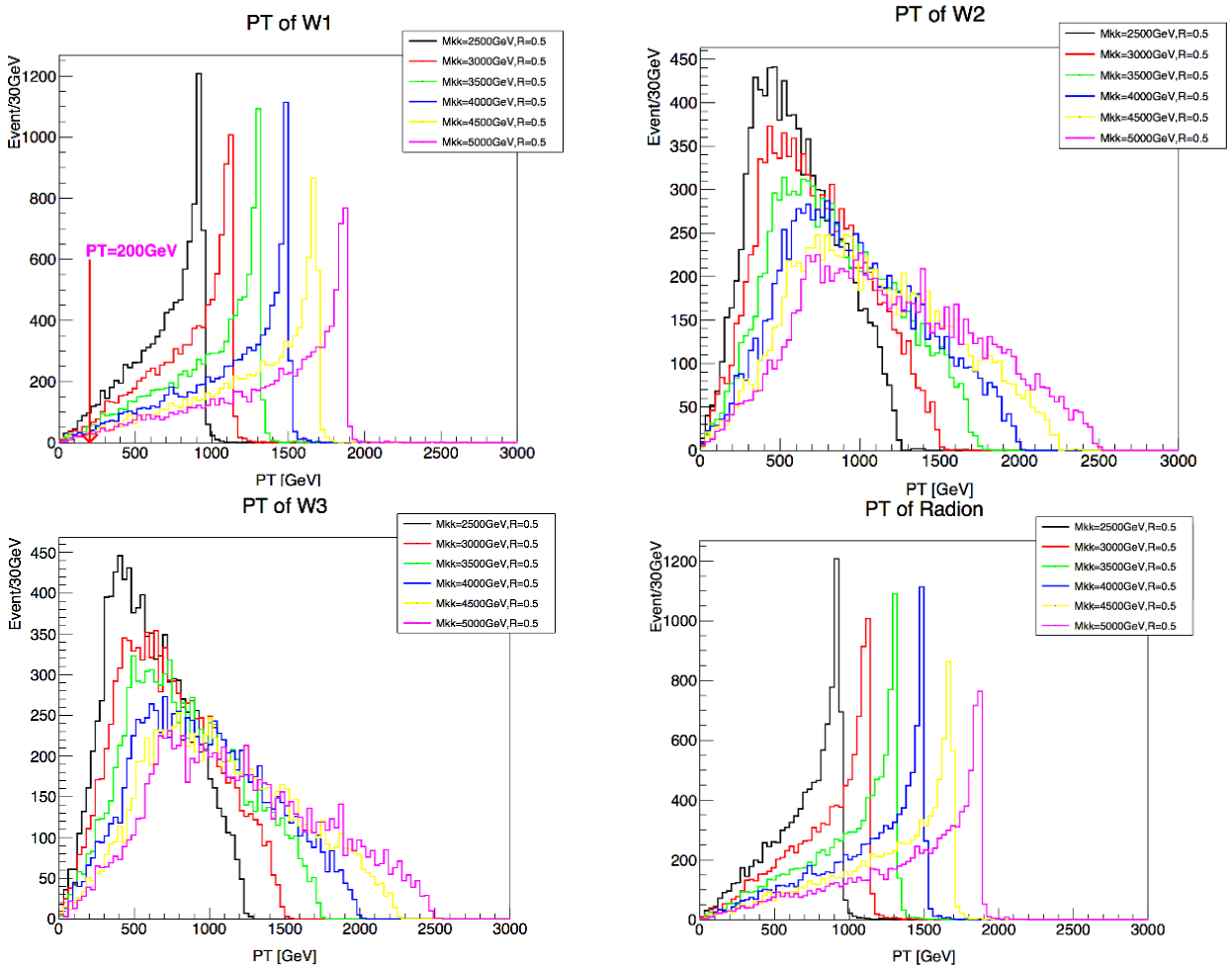


Distribution Plots

PT (R=0.5)

LHE level

- **process: p p > wkk+ > w+ r, r > w+ w- and p p > wkk- > w- r, r > w+ w-**

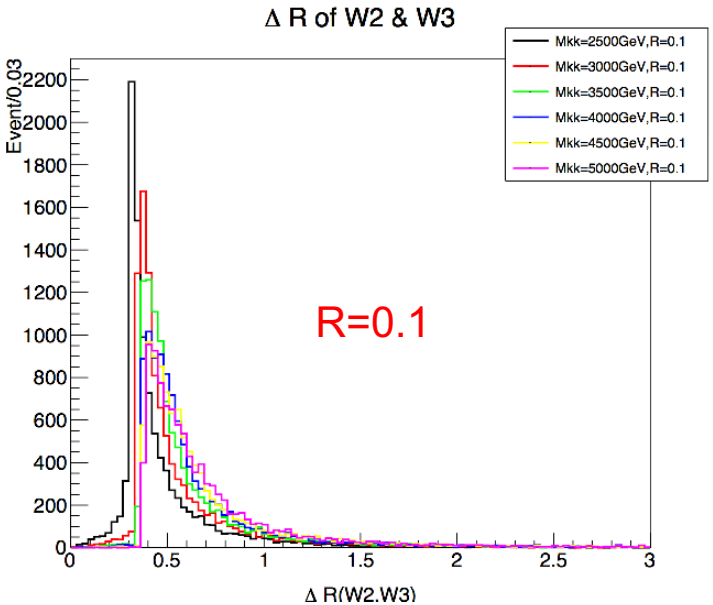


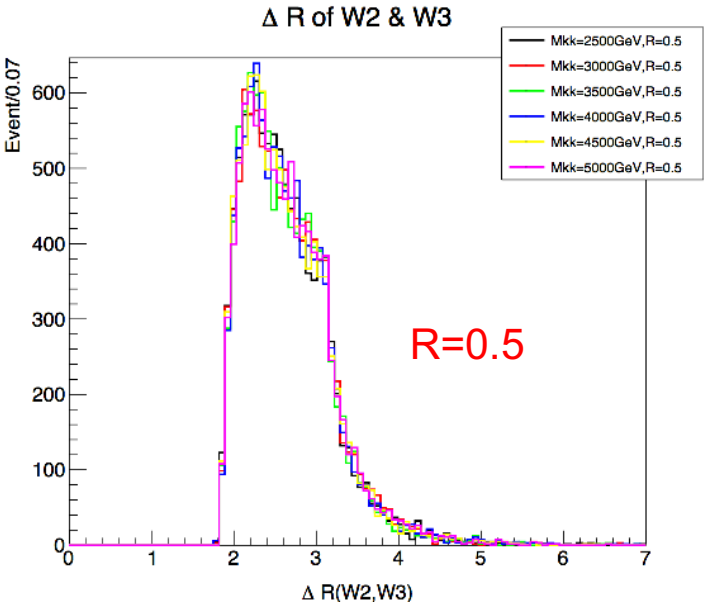
Distribution Plots

$\Delta R\ (W_2, W_3)$

LHE level

- **process: p p > wkk+ > w+ r, r > w+ w- and p p > wkk- > w- r, r > w+ w-**





- angle between W_2 and W_3 depends only on R, independent of M_{Wkk}
- For small R values (such as R ~ 0.1), W_2 and W_3 can be reconstructed in an **AK8 jet**

Distribution Plots

casel &case II

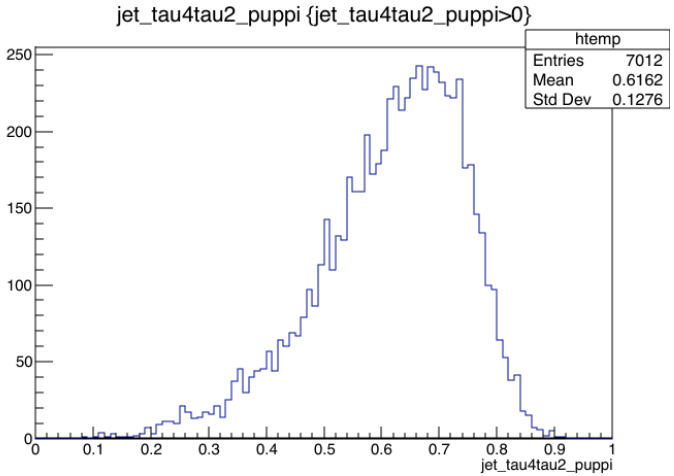
SIM level

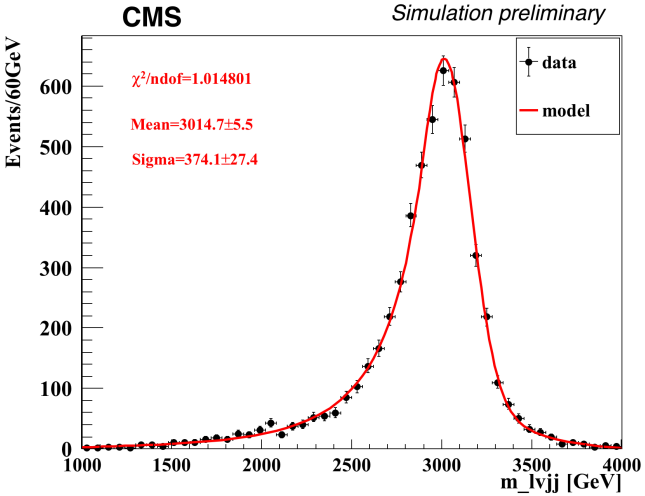
Leading jet_tau42

Mass_wkk

Case I

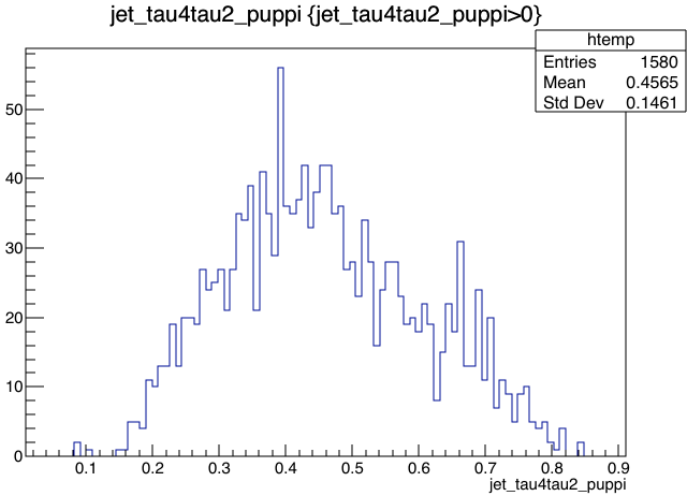
M_R=1500TeV

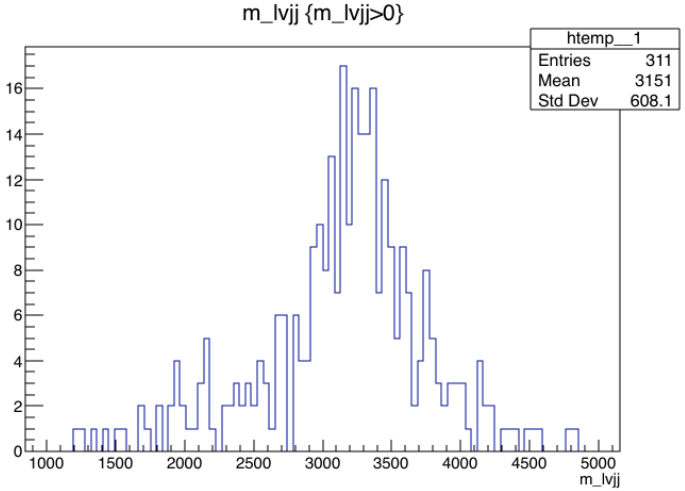




Case II

M_R=200TeV



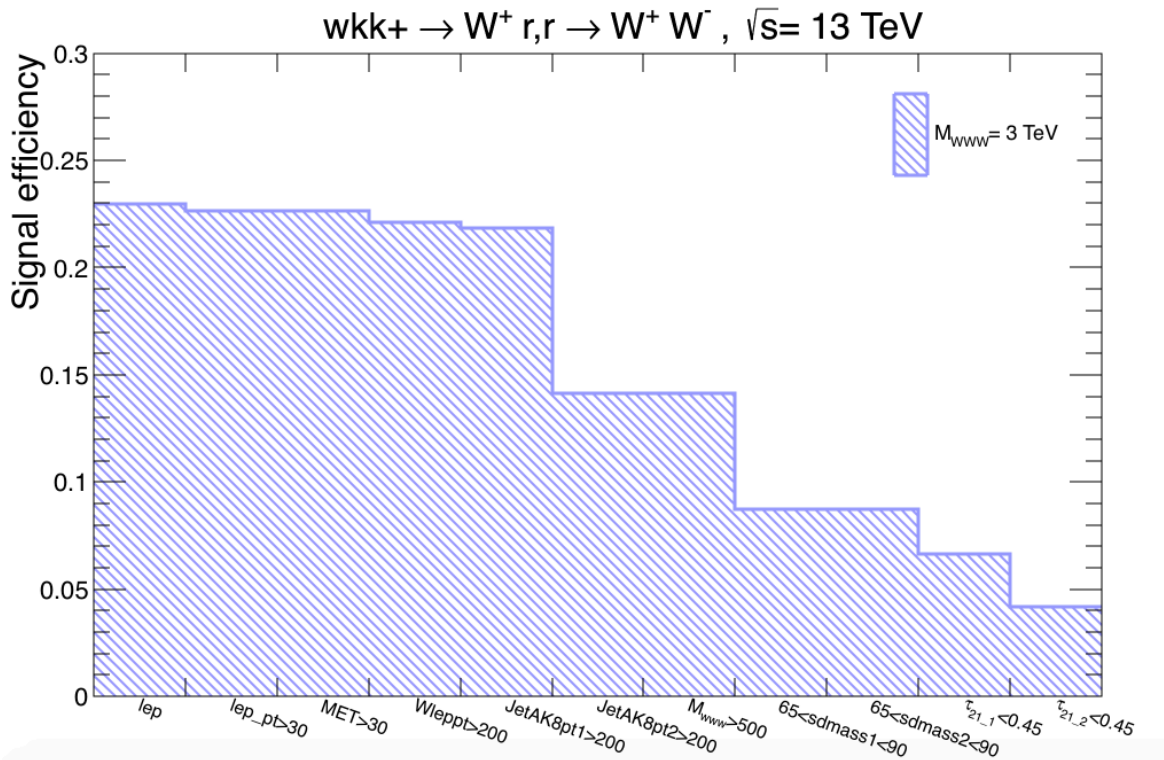


Cut Flow

case I

- Cuts:

lepton (μ), lepton Pt>30, MET>30, Wlep Pt>200, JetAK8Pt1>200, JetAK8Pt2>200 , M_vvv>500, 65<sdmass1<90, 65<sdmass2<90, tau21_1<0.45, tau21_2<0.45

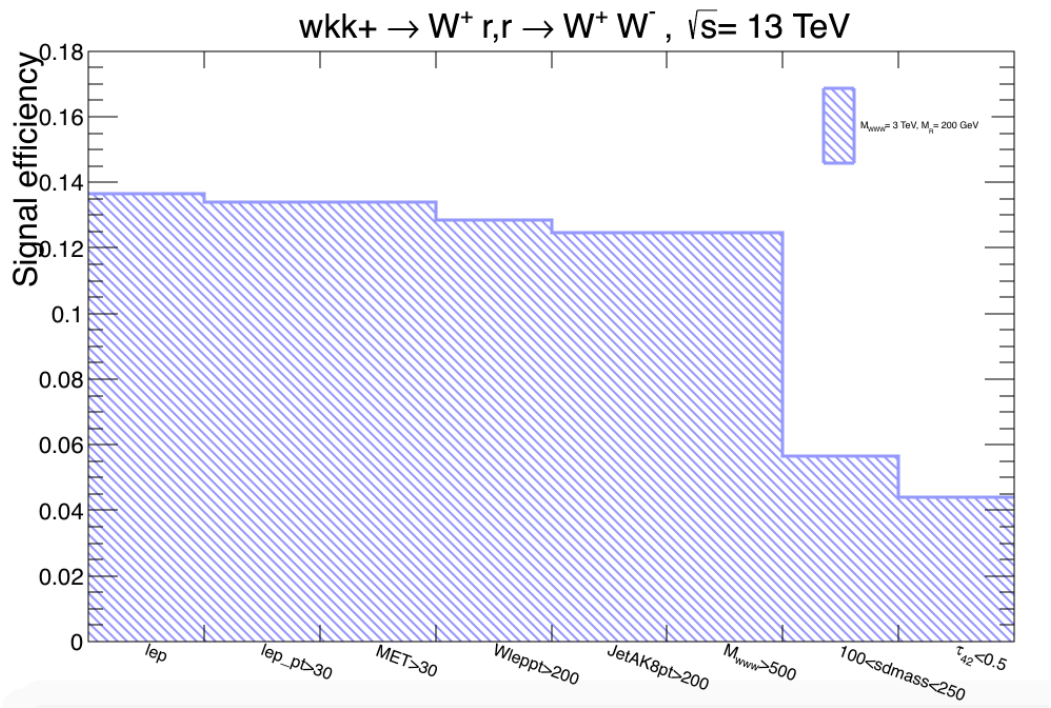


Cut Flow

Case II

➢ Cut:

lepton (μ), lepton Pt>30, MET>30, Wlep Pt>200, JetAK8Pt>200, M_vv>500, 100<sdmass<250, tau42<0.5



Background Estimation

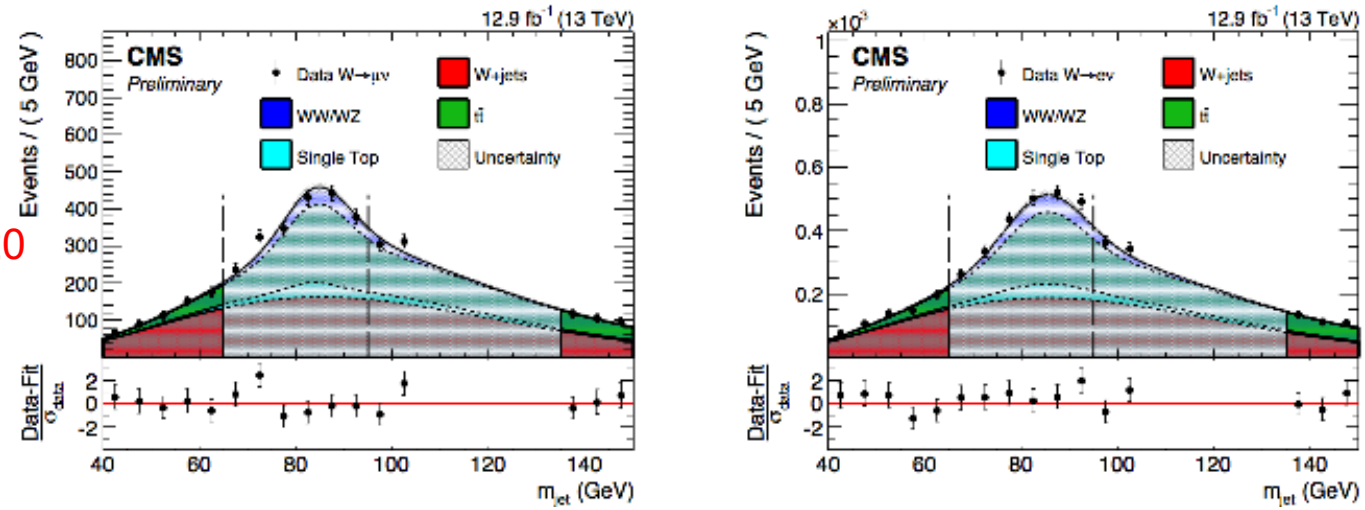
- Dominant bkgs from TTbar and WJets, as in diboson analysis
- TTbar will be corrected in TTbar control region
- Wjets: from alpha method

Data-driven for Dominant bkg:

- Normalization: fit m_J sideband
- Shape: $F_{\mathrm{data,SR}}(m_{l\nu j}) = \alpha_{\mathrm{MC}}(m_{l\nu j}) \times F_{\mathrm{data,SB}}(m_{l\nu j})$

$$\alpha_{\mathrm{MC}}(m_{l\nu j}) = \frac{F_{\mathrm{MC,SR}}(m_{l\nu j})}{F_{\mathrm{MC,SB}}(m_{l\nu j})}$$

B2G-16-020



- Process II is easier as the 3 W-bosons behave similarly, and we plan to go first with this case.
- There are 2 jets, and we needs to consider SB*SR and SB*SB in jet mass distributions.

Summary

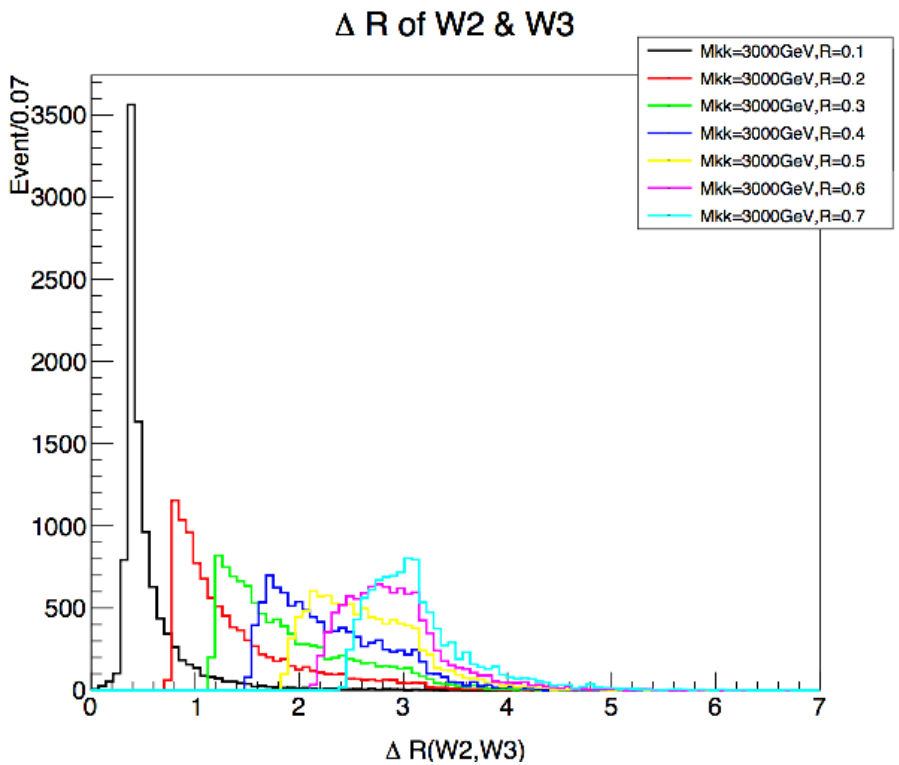
- Two resonance case is more complicated, although supported more by the modified Bulk Extra Dimension model.
- We plan to go on with the one resonance case, with which also to set up the analysis machine with alpha method
- We will also consider the aQGC case with no resonance (process 4)
- New analysis coming soon, keep tuned

backup

Distribution Plots

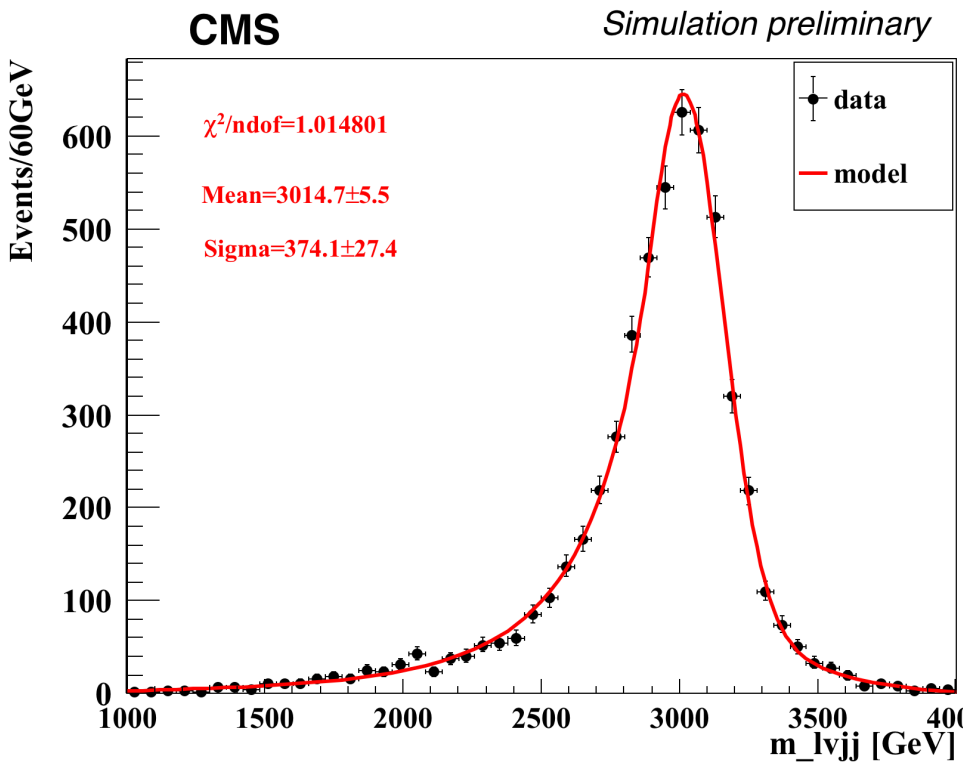
dR

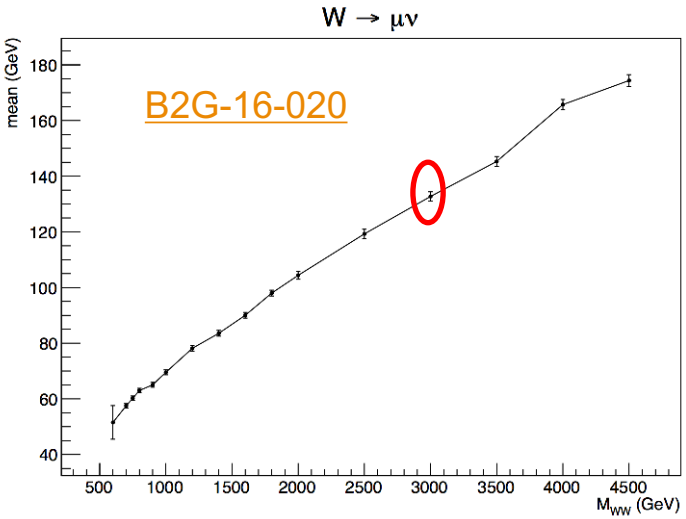
- **process: p p > wkk+ > w+ r, r > w+ w- and p p > wkk- > w- r, r > w+ w-**



Signal Modelling

Fit pdf: Double Crystal Ball (case I)



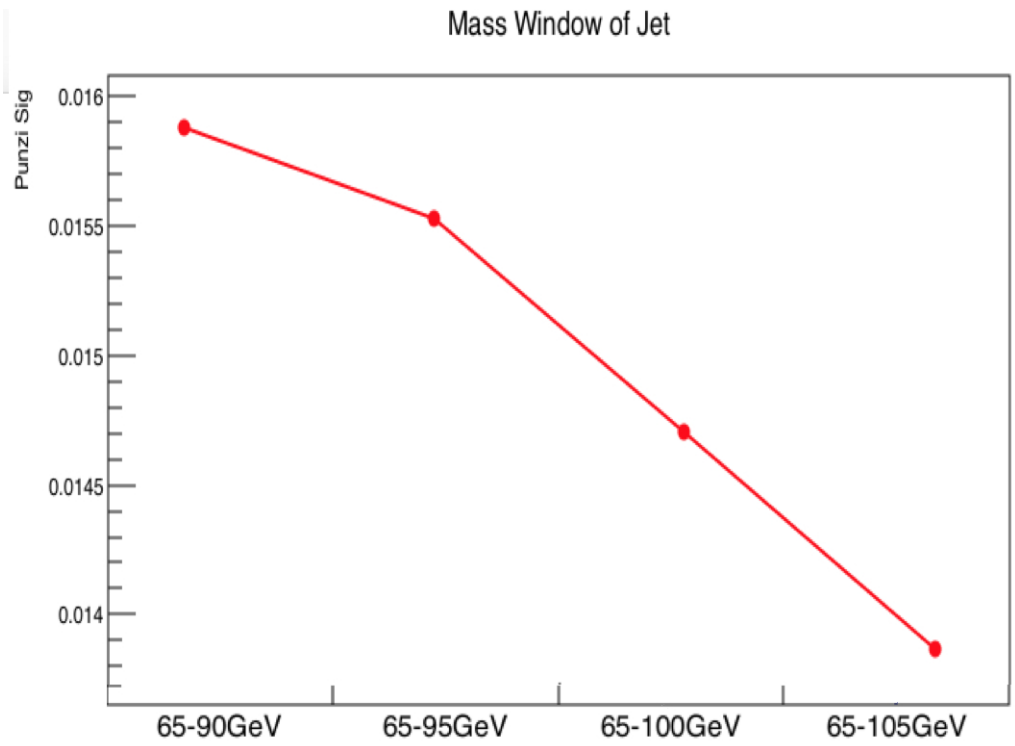


For mass_WWW, sigma is 374 GeV @3TeV;
Comparing with the previous study of WW, sigma is about 135 GeV @3TeV.

JetMass Window Optimization

Punzi significance: $P = \varepsilon_S \frac{1}{1+\sqrt{B}}$

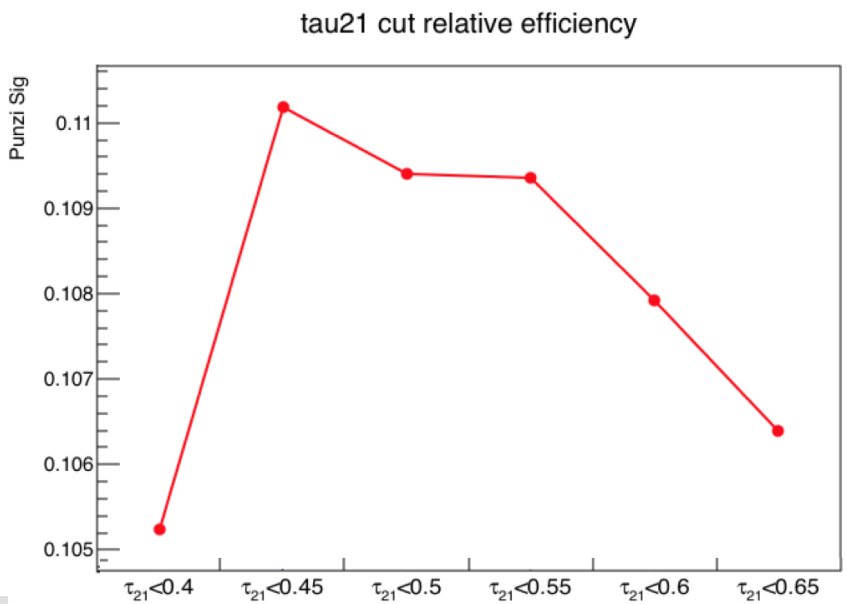
case I

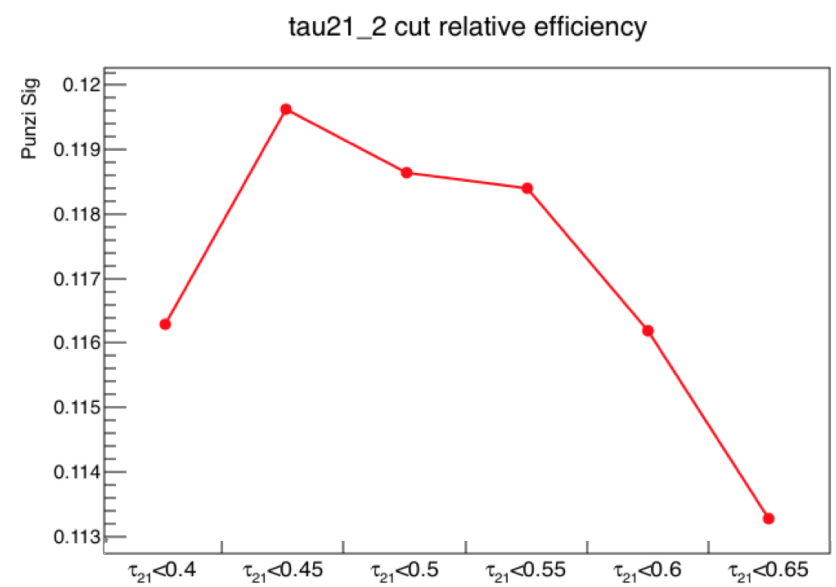


- The best cut of the two jet masses is 65-90GeV.

Tau21 Optimization

case I



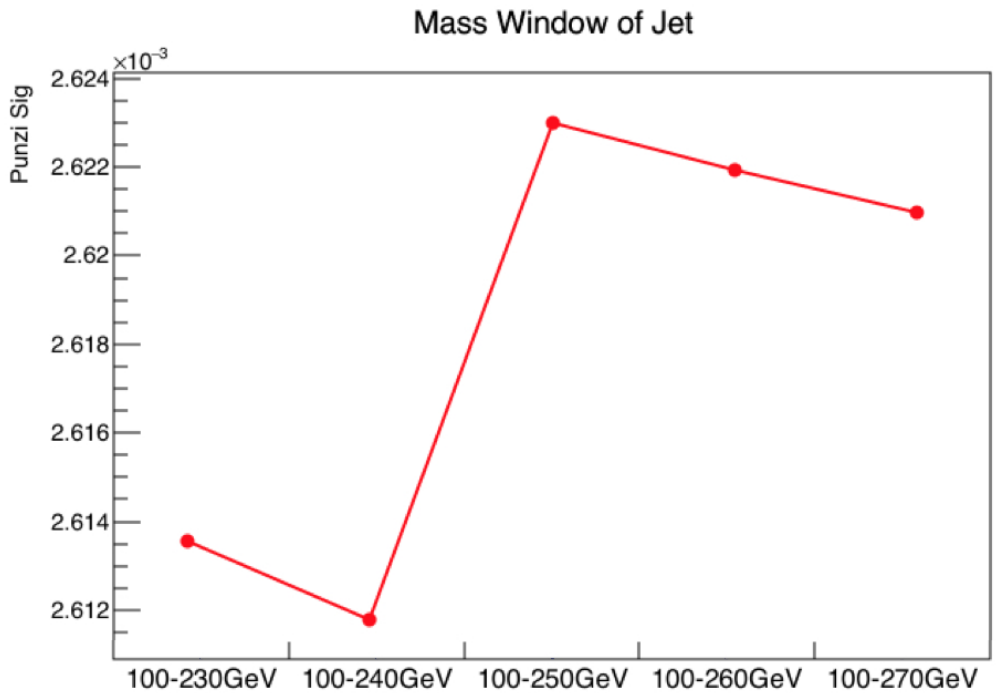


- The best tau21 cut value of the two AK8Jets are both 0.45.

Case II

JetMass Window Optimization

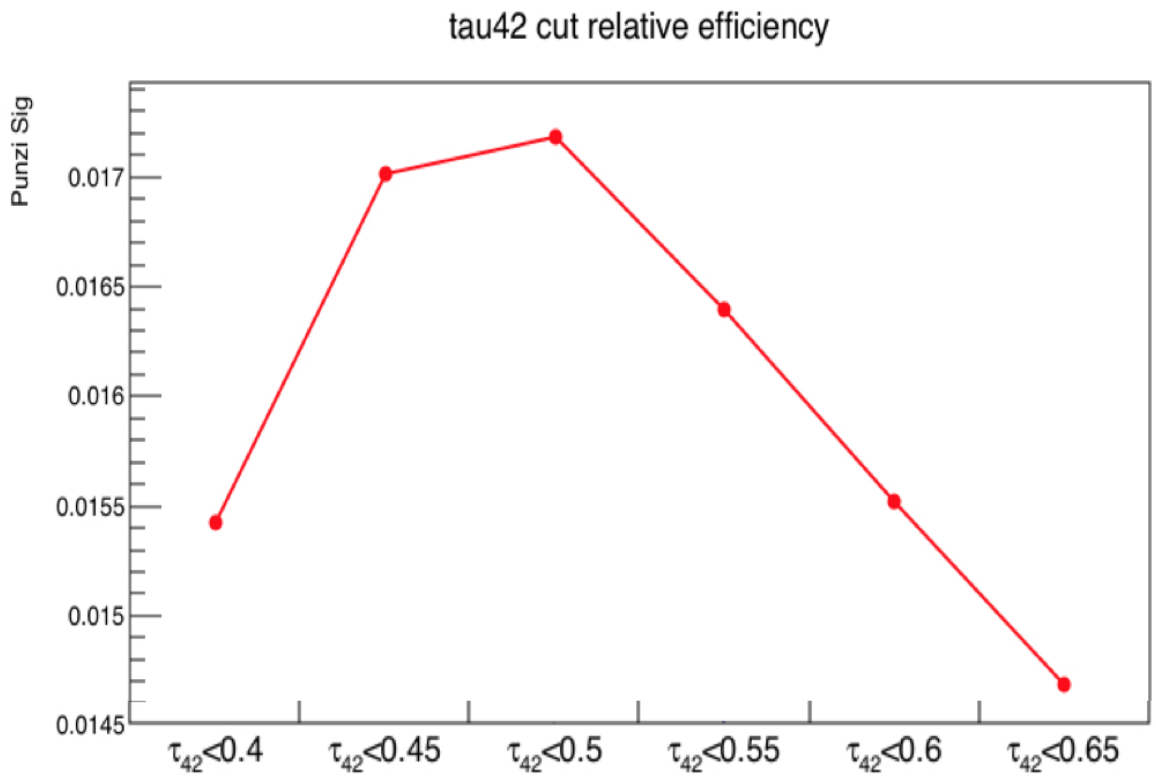
Punzi significance: $P = \varepsilon_S \frac{1}{1+\sqrt{B}}$



- The best cut of the jet mass is 100-250GeV.

Case II

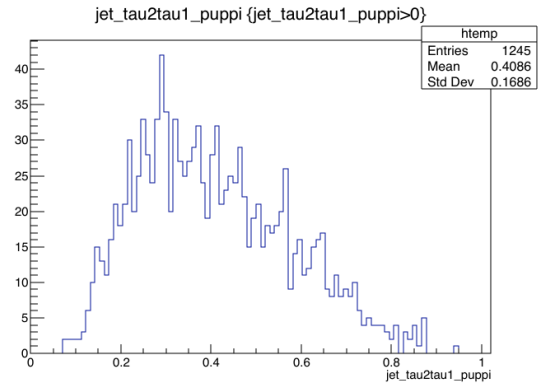
Tau21 Optimization



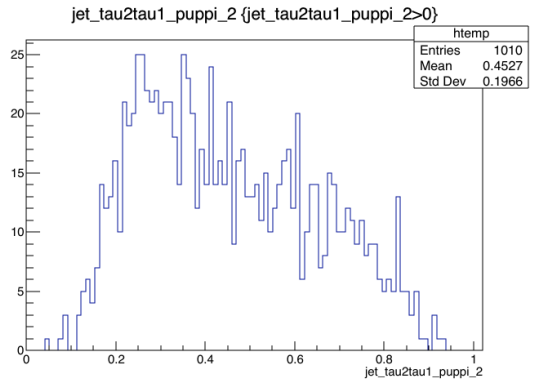
- The best tau42 cut value of the AK8Jet is 0.5.

case III

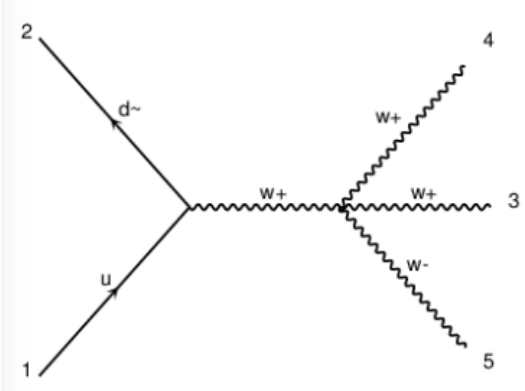
jet1_tau21



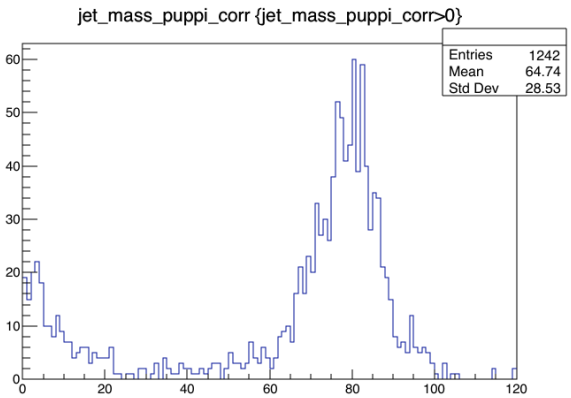
jet2_tau21



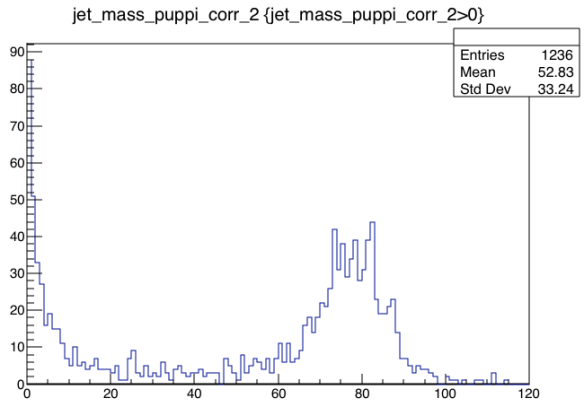
Feynman diagram



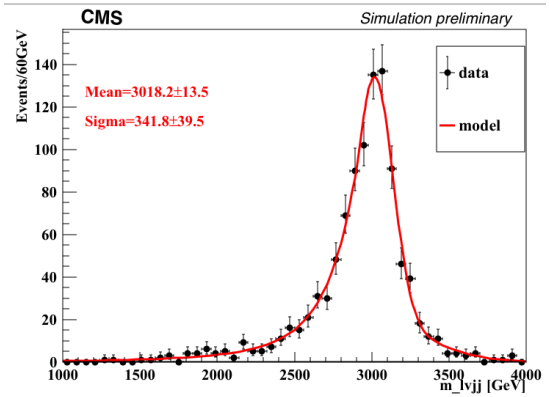
jet1_mass



jet2_mass



Signal modelling



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