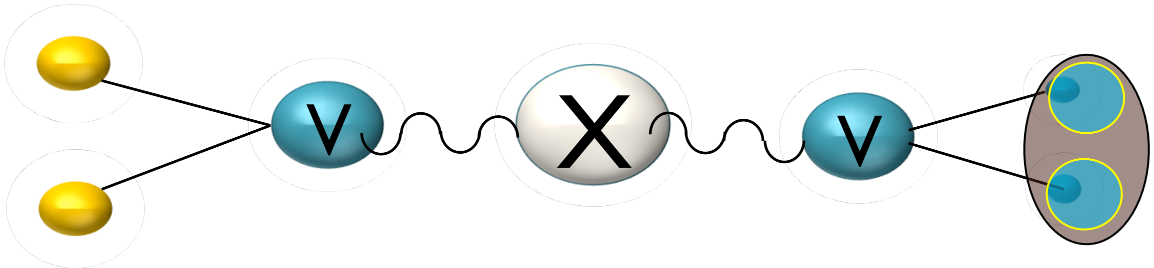

Search for Heavy VV Resonances in Semi-Leptonic Final State

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On behalf of the CMS Collaboration

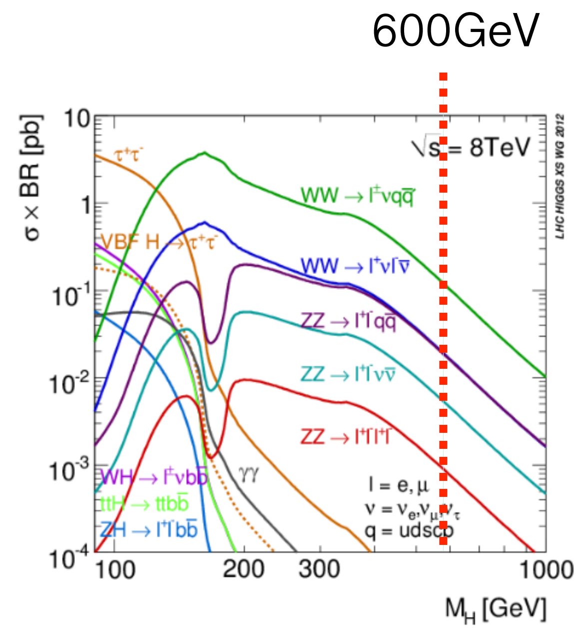
Boston Jet Physics Workshop 2014

Outline

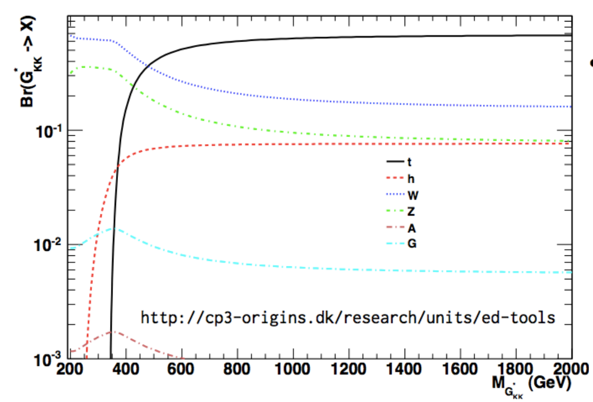
- Introduction
  - $H \to WW \to l\nu$ + fat-jet: CMS PAS HIG-13-008
  - $X \to WW \to l\nu$ + fat-jet: CMS PAS EXO-12-021
  - $X \to ZZ \to ll$ + fat-jet: CMS PAS EXO-12-022
  - *$X \to VV \to$ Dijet: Petar's talk*
- Event Reconstruction and Selection
  - Leptonic W/Z;
  - **Hadronic W/Z, V-Tagging** CMS PAS JME-13-006 James's talk
- Analysis Strategy
- Systematic Uncertainties
- Statistical Interpretations
- Summary

Introduction(1)

- Heavy Higgs(600-1000GeV)
  - H→WW→lvqq'
  - BSM: a heavy electroweak singlet
    - A heavy Higgs and the 125GeV one complete unitarization; $C'^2 + C^2 = 1$
    - The heavy Higgs has a non-SM-like decay modes;
    - generic in width and cross-section
      $\Gamma' = (C'^2/(1-BR_{new})) \times \Gamma_{SM}$
      $\mu' = C'^2 \times (1 - BR_{new})$



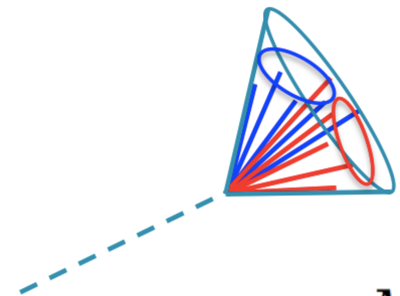
- Bulk Graviton
  - G→WW→lvqq' (800-2500GeV)
  - G→ZZ→llqq' (600-2500GeV)
  - Production process at LHC similar to SM Higgs decays preferentially to t, then W, Z and H



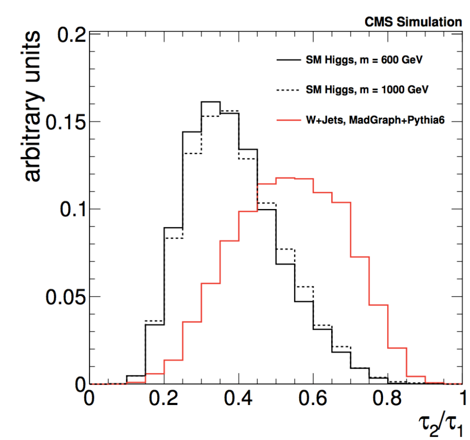
NB: Higgs is a wide resonance, while G is narrow;

Introduction(2)

- W/Z are highly boosted:
  - decay productions are very collimated in space.
- Jet Grooming:
  - Significantly improved jet mass
  - Remove constituents inside a fat-jet for reducing soft process contaminant;
- Jet substructure:
  - Provide additional information for discriminating QCD-jet and V-jet;
  - N-subjettiness, mass drop, Qjet…

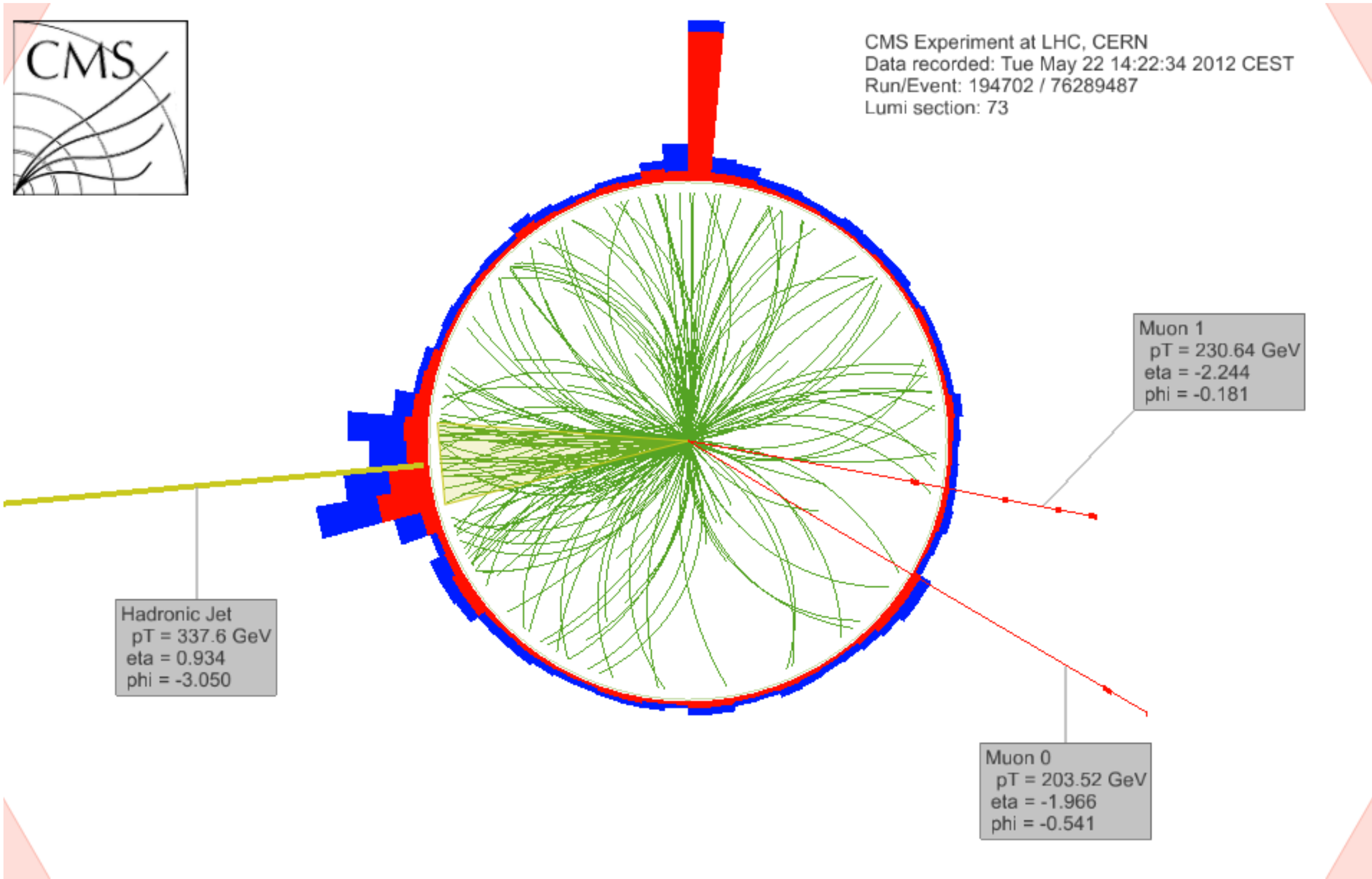


$$\Delta R \approx 2 \cdot \frac{M}{p_{\mathrm{T}}}$$



CMS PAS HIG-13-008

Event Display: 2μ + jets



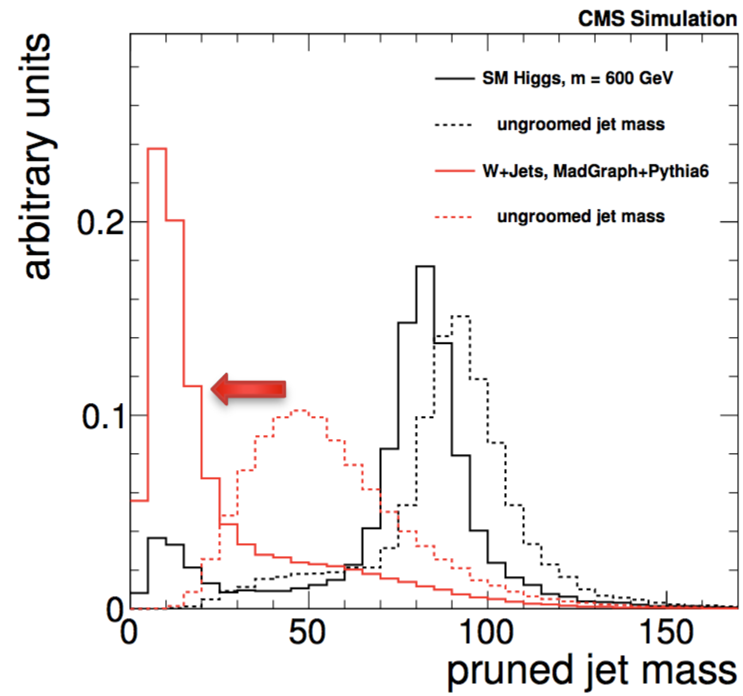
Leptonic W/Z

- W:
  - One good lepton; No additional loose ID lepton;
  - large MET;
  - W_{lep} pT > 200 GeV
- Z:
  - Same flavor but opposite charge di-leptons;
  - M(ll) in [70,110];
  - Z_{lep} pT > 80 GeV

More details in James's talk

Hadronic W/Z: V-Tagging(1)

- A high pT CA8 jet.
  - In WW analysis, need to be back-to-back with leptonic objects;
  - V_{had} pT>200(80)GeV for W(Z)
- Jet mass:
  - M(QCD-jet) ~ 0;
  - M(V-jet) ~ M(V_{PDG});
  - Main observable in analysis;
  - Improved by jet **pruning**: soft and large angle radiation removed; Especially for QCD-jet
  - [65,105]GeV for W;
  - [70,110]GeV for Z;



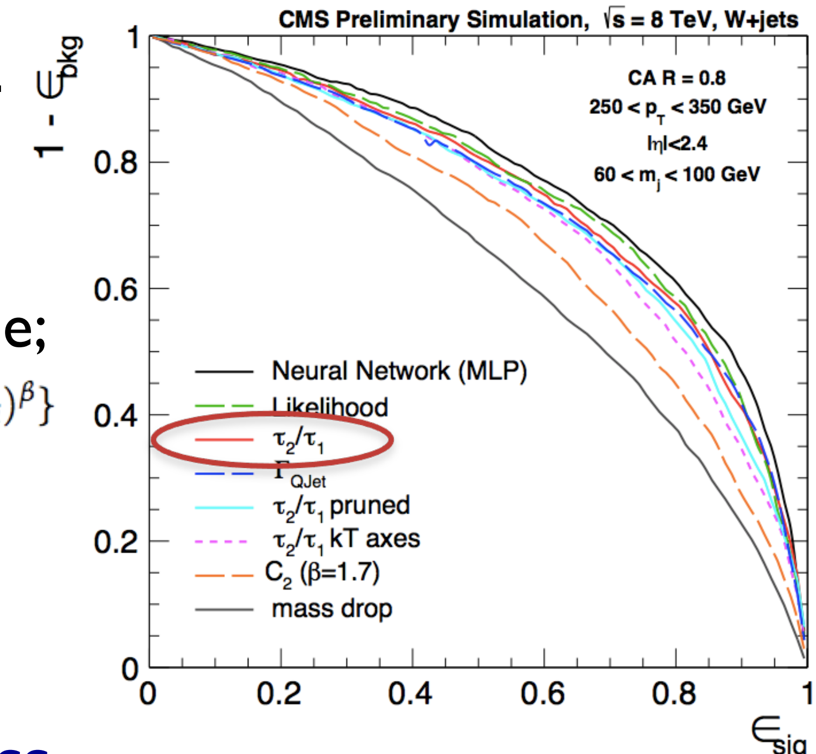
CMS PAS HIG-13-008

More details in James's talk

Hadronic W/Z:V-Tagging(2)

- N-subjettiness
  - Jet compatibility with N-pronged substructure.
  - τ2/τ1 is the best performing single variable;

$$\tau_N = \frac{1}{d_0}\sum_i p_{T,i}\min\{(\Delta R_{1,i})^\beta, (\Delta R_{2,i})^\beta, ..., (\Delta R_{N,i})^\beta\}$$



CMS PAS JME-13-006

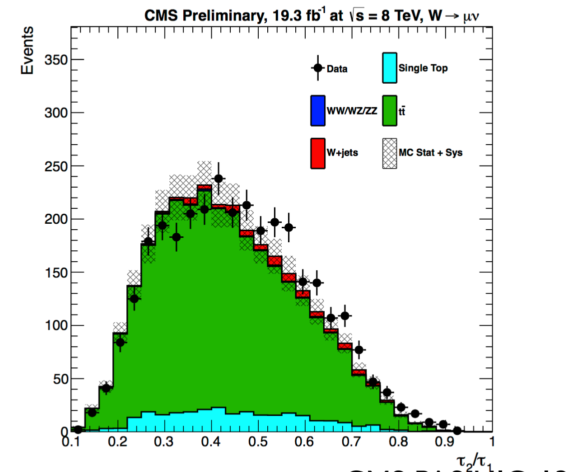
- **V-tagging**:

  Jet Mass + N-subjettiness

More details in Petar's talk

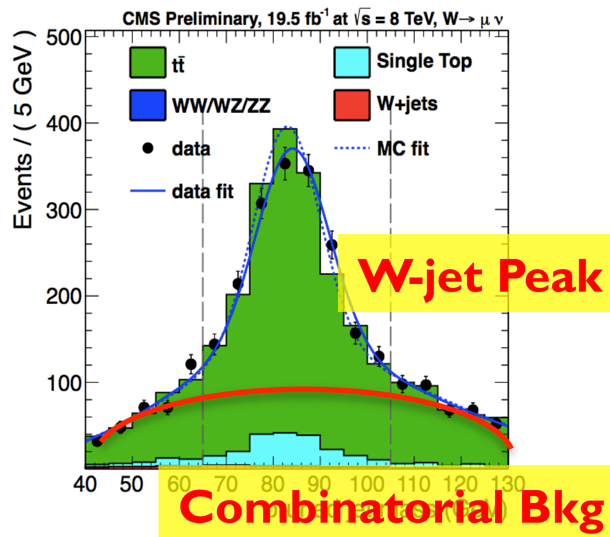
Hadronic W/Z: V-Tagging in TTbar sample

- TTbar selection:
  - W_{Lep}+ W-Tagged jet+ B-Tagged jet
- Tag-And-Prob:
  - Fit samples passed and failed W-Tagging in Data and MC
  - Scale factor for W-tagger efficiency of real W-jet;
  - W-jet mass bias and resolution corrections



CMS PAS HIG-13-008

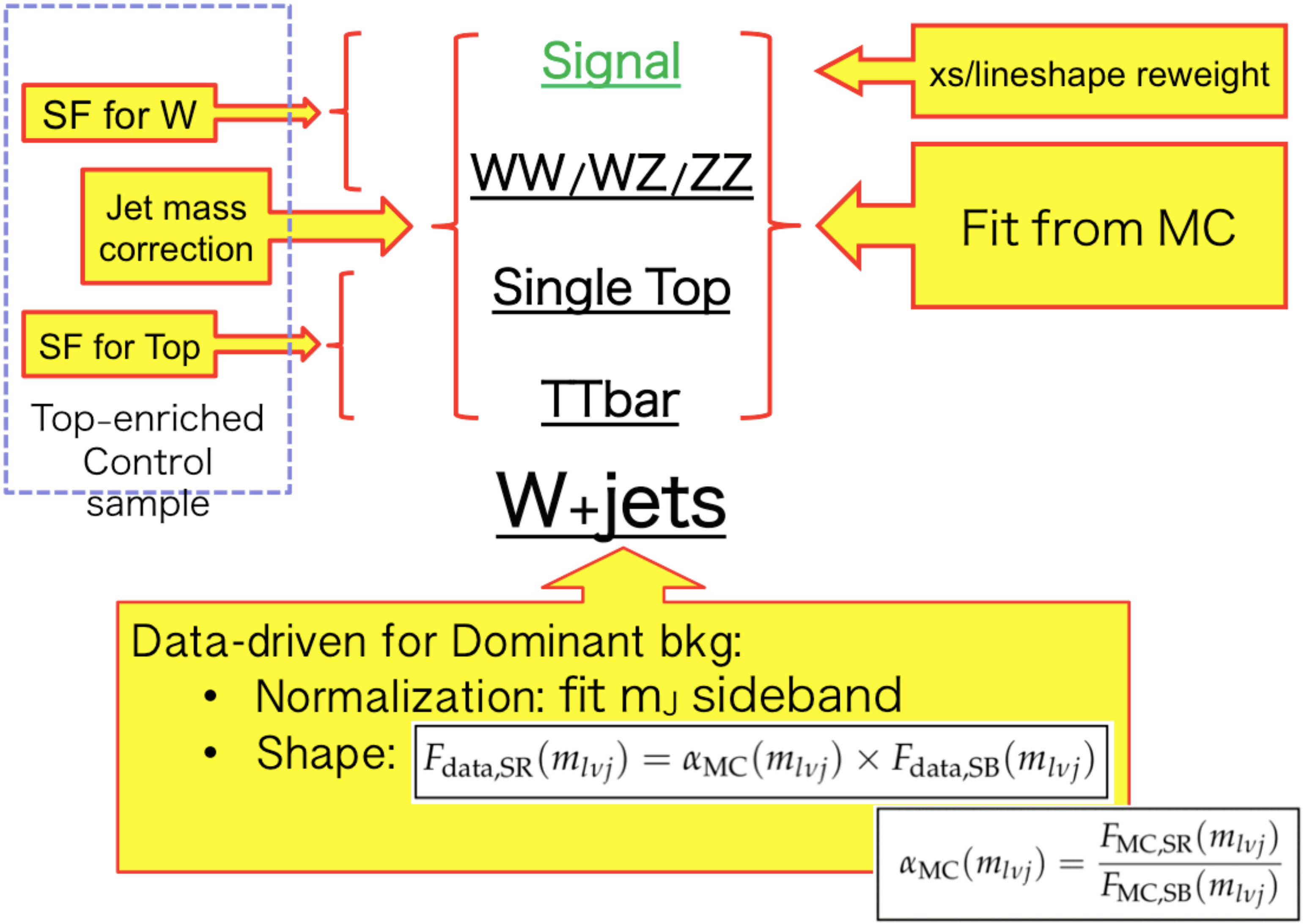
After τ2/τ1



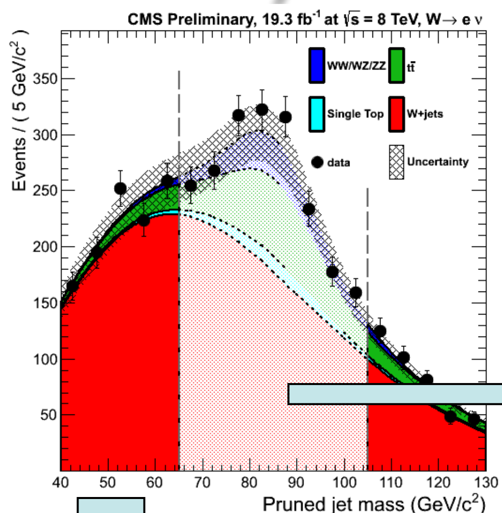
CMS PAS JME-13-006

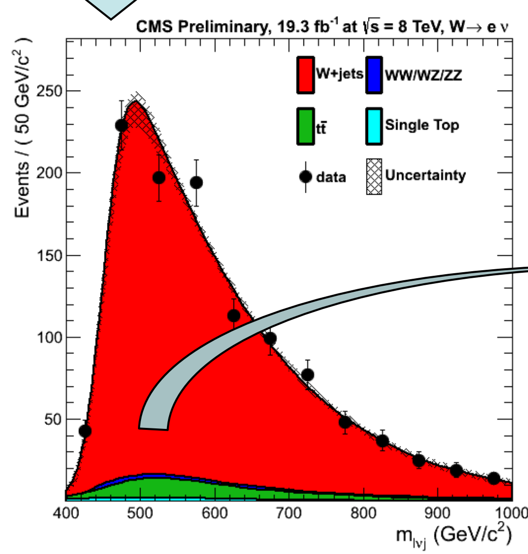
	data	MC	scale factor / shift
efficiency 200<p_T<265 GeV			* 0.96 +- 0.08
efficiency 265<p_T<600 GeV			* 0.89 +- 0.10
mass peak position	84.5 +- 0.4 GeV	83.4 +- 0.4 GeV	+1.1 +- 0.4 GeV
mass peak width	8.7 +- 0.6 GeV	7.5 +- 0.4 GeV	+16% +- 9%

Analysis Strategy: WW(1)



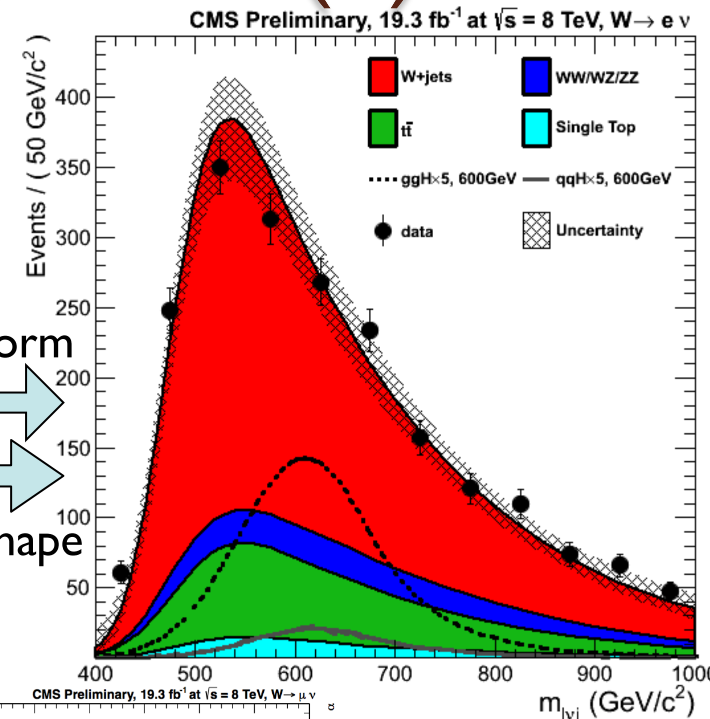
Analysis Strategy: WW(2)

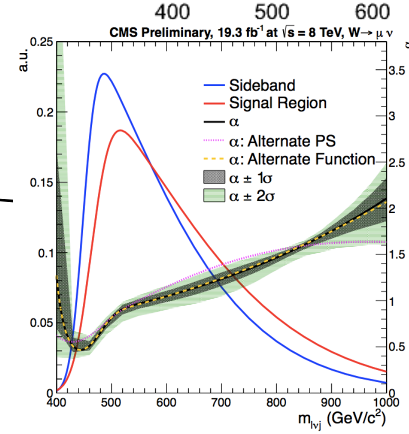




W+jets Norm

W+jets Shape

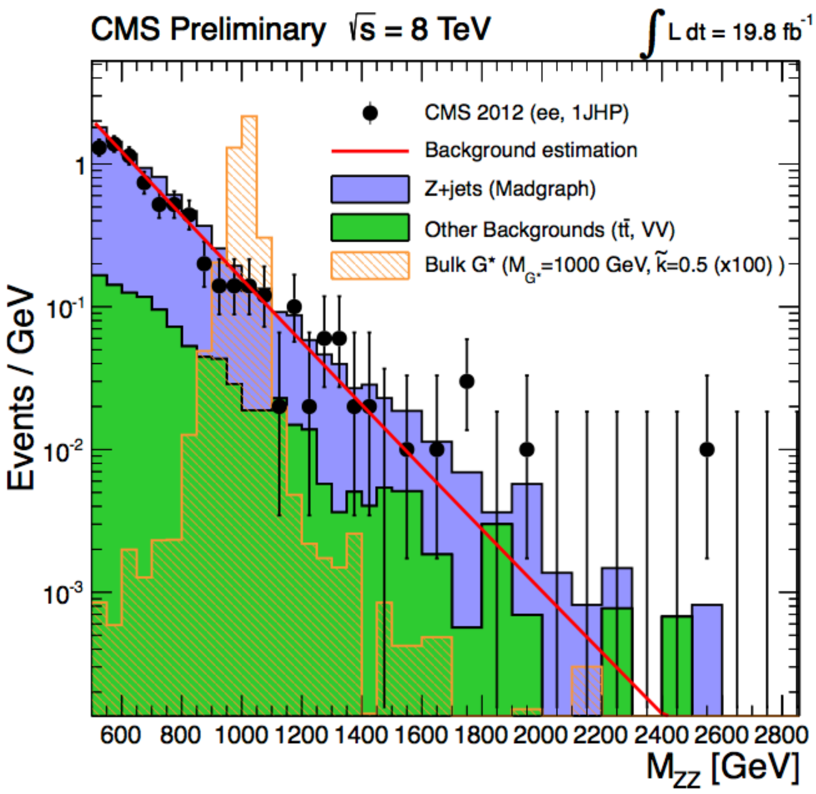


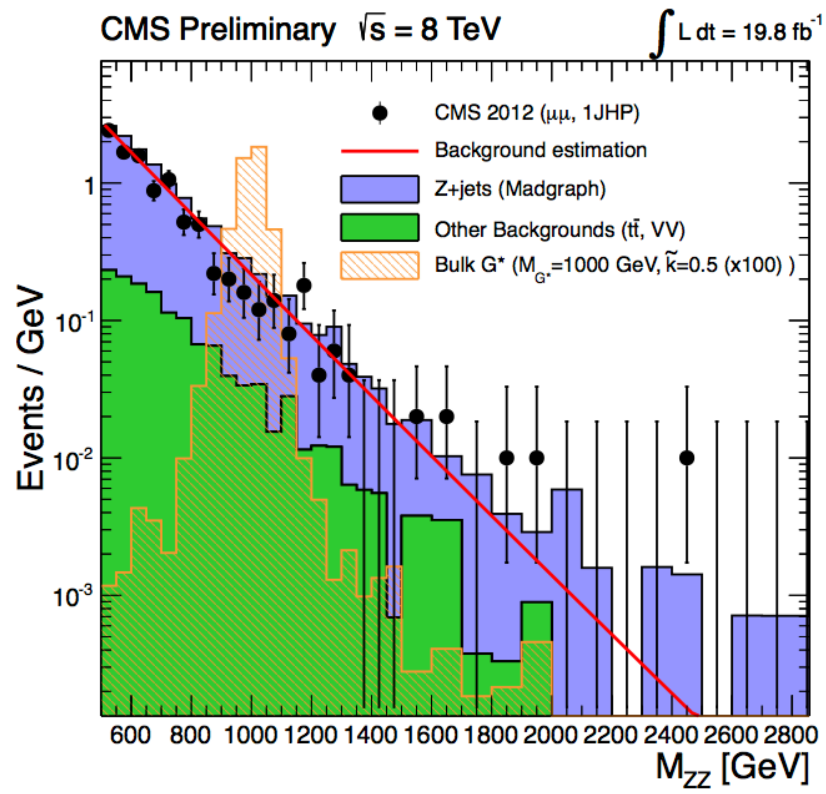


$$F_{\text{data,SR}}(m_{l\nu j}) = \alpha_{\text{MC}}(m_{l\nu j}) \times F_{\text{data,SB}}(m_{l\nu j})$$

Analysis Strategy: ZZ

$$\alpha = \frac{N^{\text{MC-Bkg}}_{\text{Sig-Reg}}}{N^{\text{MC-Bkg}}_{\text{SB-Reg}}} \qquad N^{\text{DATA-Bkg}}_{\text{SIG-Reg}} = \alpha \cdot \left[N^{\text{DATA-Bkg}}_{\text{SB-Reg}} \cdot (1 - r_{\text{VV}})\right] + N^{\text{MC-VV}}_{\text{Sig-Reg}}$$





Systematic Uncertainties

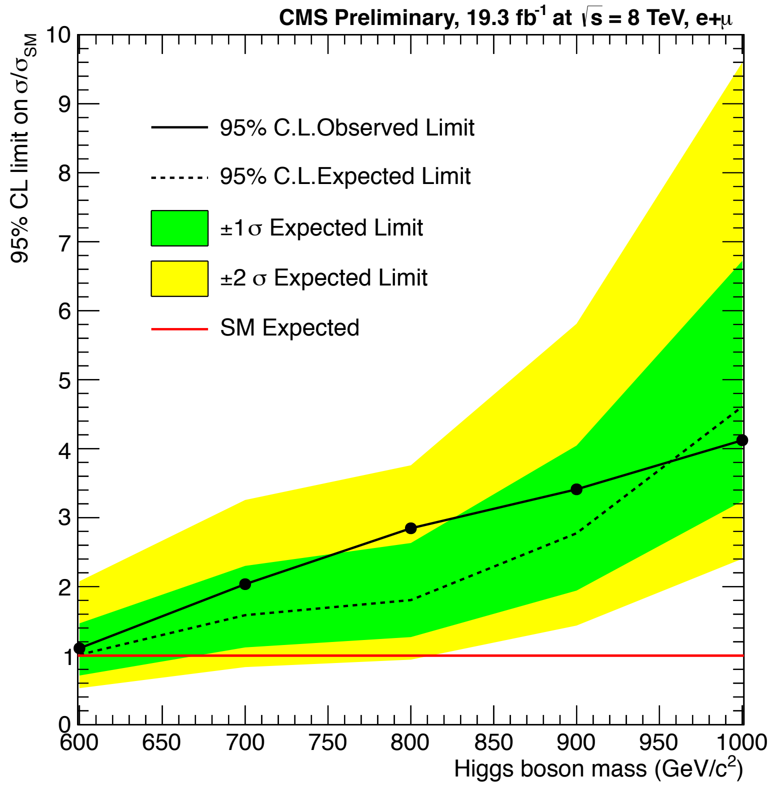
HWW: Signal + Background

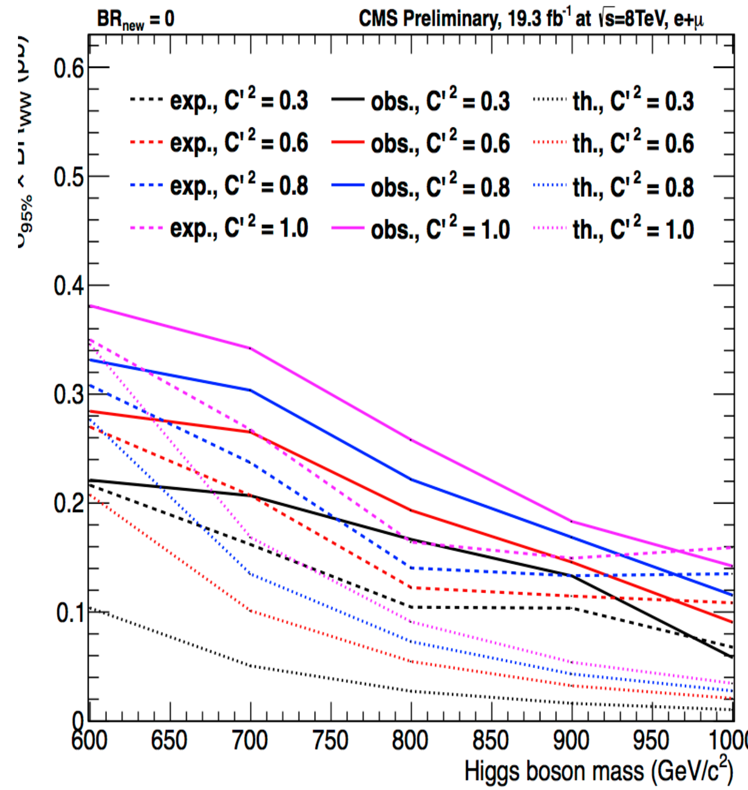
Syst. uncertainty	sig, ggH	sig, VBF	W+jets	$t\bar{t}$	single t	WW/WZ
lumi	4.4%	4.4%	-	4.4%	4.4%	4.4%
Higgs QCD scale	6.5% †	1.3% †	-	-	-	-
Higgs PDF+α_s	12.1% †	5.9% †	-	-	-	-
Intf (sig/bkg)	10.0%	50.0%	-	-	-	-
Bkg cross-section	-	-	-	-	30.0%	30.0%
W+jets norm.	-	-	8%	-	-	-
W-tagging	10.0%	10.0%	-	-	-	10.0%
$t\bar{t}$ norm	-	-	-	6.0%	6.0%	
Jet mass/energy scale	2%	2%	-	2%	2%	2%
W+jets shape	-	-	see Sec. 6	-	-	-
b-tagging	2.5%	2.5%	-	-	2.5%	2.5%
Trigger (e & μ)	1%	1%	-	-	1%	1%
Selection Eff. (e & μ)	2%	2%	-	-	2%	2%

XZZ: Signal normalization

Source	Value	Comment
Muons (trigger and ID)	5%	Tag-and-probe study
Electrons (trigger and ID)	~3%	Tag-and-probe study
Muon scale	2%	Scale and resolution of the muon
Electron scale	$< 0.5\%$	Scale and resolution of the electron
Jet reconstruction	1%	JES uncert., JER uncert. negligible
Pile-up	0.5%	
Z-tagging	8% (1JHP)	From $t\bar{t}$ control sample,
	30% (1JLP)	anti-correlated between categ.
Proton PDFs	$< 0.5\%$	PDF4LHC, acceptance only
Luminosity	4.4%	

SM and BSM Higgs Limits

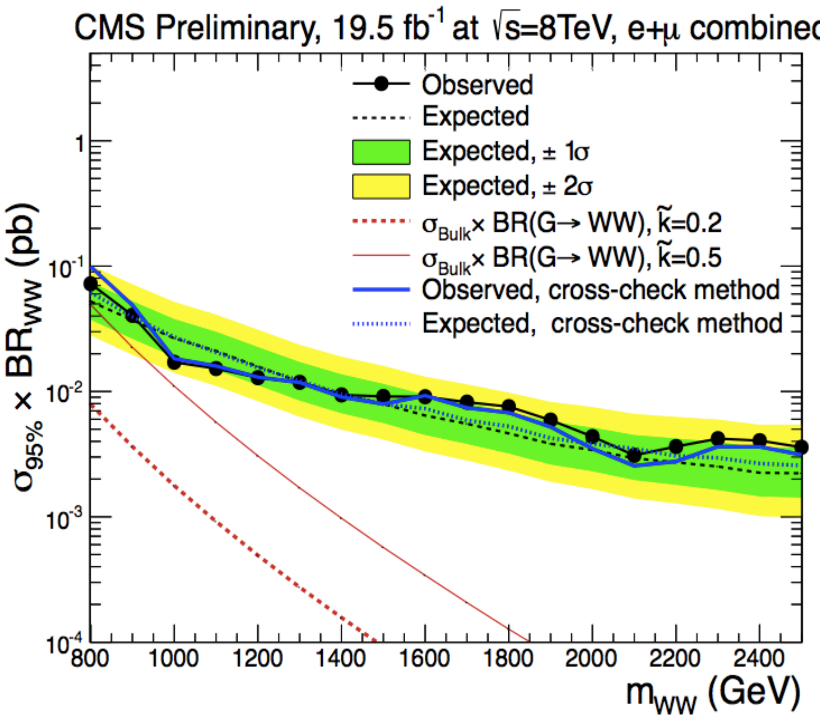


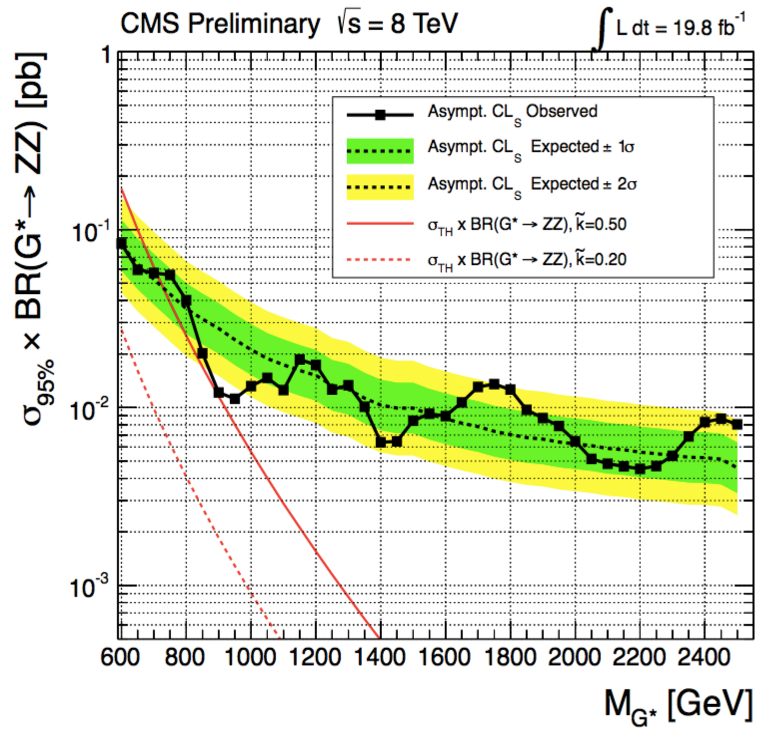


No significant excess is observed:

- Exclude at 1.1 (4.1) times the SM Higgs cross-section for a mass of 600 (1000) GeV hypothesis.
- The typical upper limit on the σ 95% × BRWW ranges from ~60 to 400 fb when BRnew=0 and C'2 ranges from 0.3 to1.0.

Graviton to WW and ZZ Limits

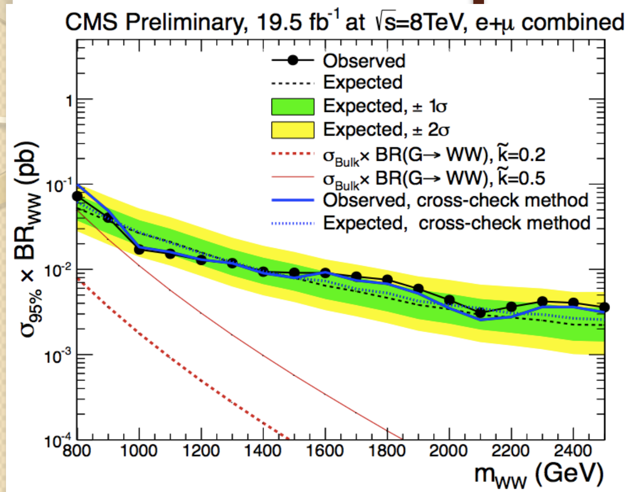


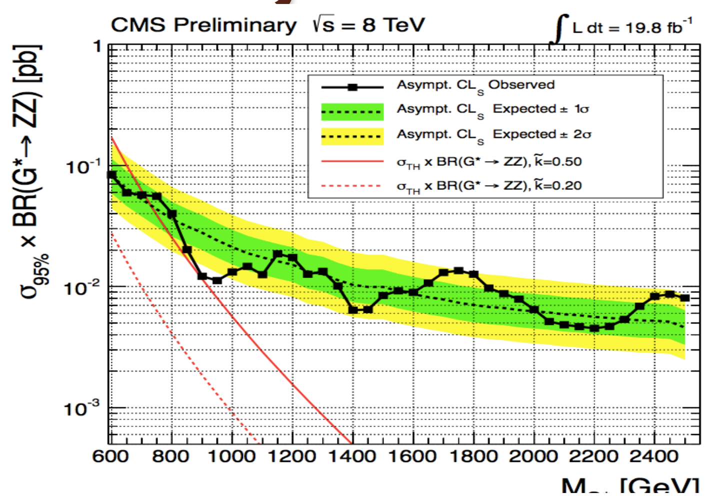


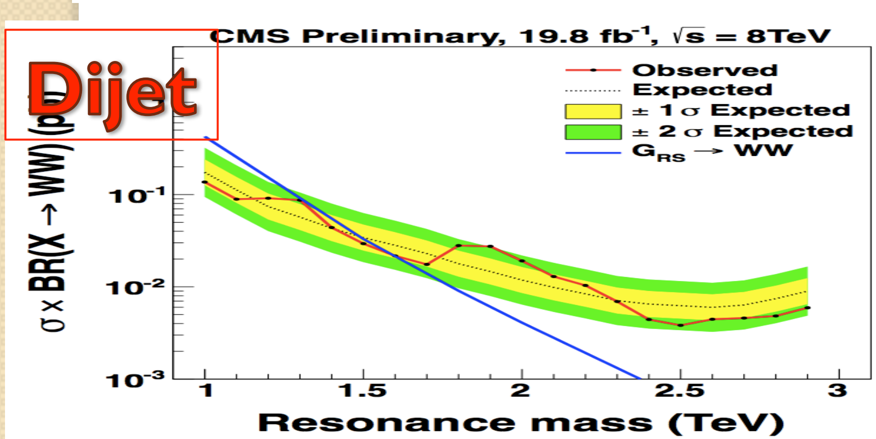
No significant excess is observed:

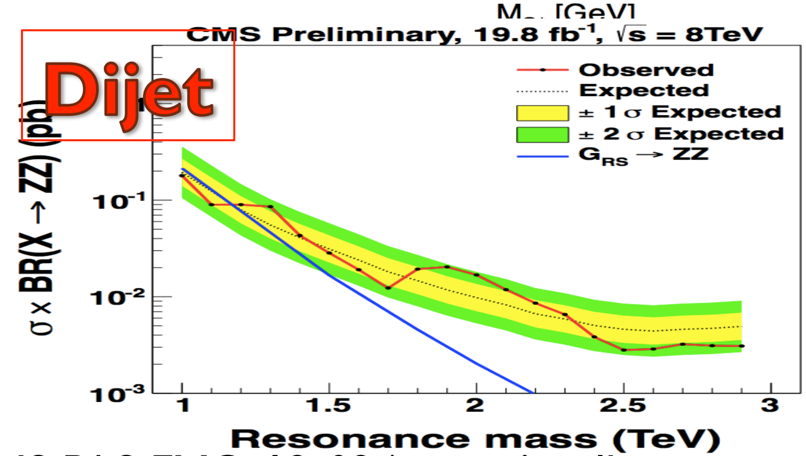
- WW: upper limits at 95% CL on σ*BR(WW) are set in the range from 70 fb to 3 fb for masses between 0.8 and 2.5 TeV, respectively;
- ZZ: a lower mass limit M>710GeV for a bulk graviton with coupling k = 0.5

Semi-leptonic V.S. Dijet









CMS PAS EXO-12-024, petar's talke

Dijet search goes to higher masses;
Semi-leptonic search gives stronger limits;

Conclusion

- Search for X to VV in semi-leptonic final state has been performed with ~20fb^{-1} data of p-p collisions at $\sqrt{s}$=8TeV from CMS;
- No Significant excess has been observed;
- Novel techniques for V-tagging are employed;
- Benchmark for future analysis at high mass regime.

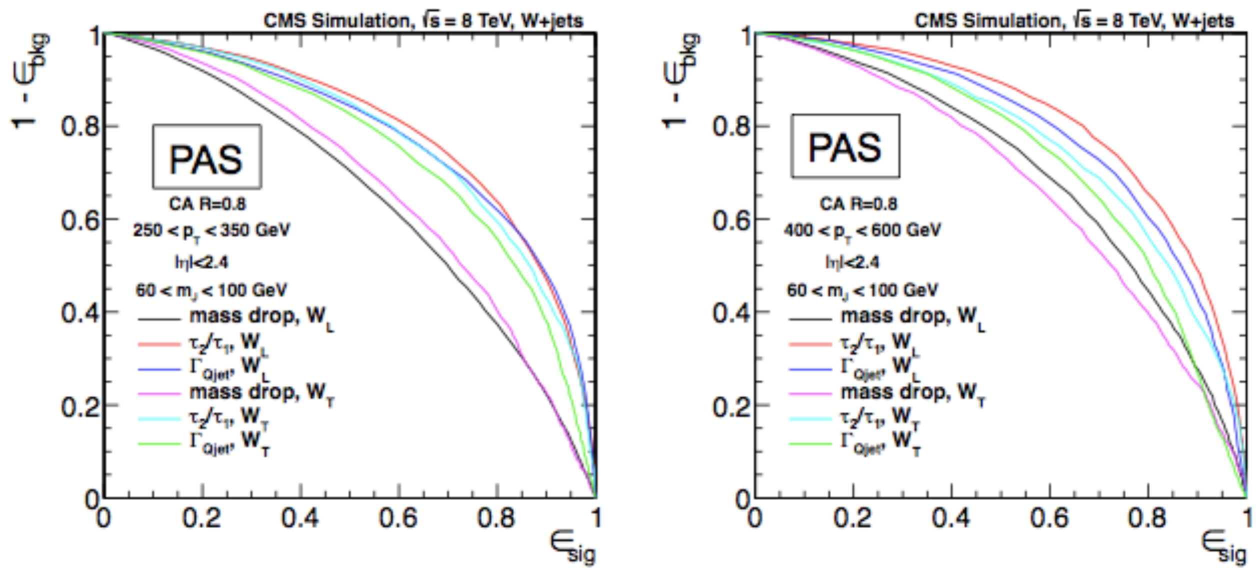
Backup

Effect of W polarization

Effect of W polarization

250 < pT < 350 GeV

400 < pT < 600 GeV



Test performance vs. W polarization

Performance is slightly degraded in all cases for W_T w.r.t W_L.

Mass drop seems to least sensitive to W polarization

Polarization effects become more important at higher pT

Event Selection for EXOZZ

Summary of Selections

Selection	Value	Comments
Lepton selections		
Leading lepton p_T	$p_T > 40$ GeV	Electrons and muons.
Subleading lepton p_T	$p_T > 40$ GeV	For electrons.
Subleading lepton p_T	$p_T > 20$ GeV	For muons.
Electron η	$\|\eta\| < 2.5$	
Electron fiducial	$\|\eta\|_{SC}$ out of [1.4442, 1.566] range	Avoid the ECAL gap.
Muon η	$\|\eta\| < 2.4$	
Jet selections		
Jet p_T	$p_T > 30$ GeV	
Jet η	$\|\eta\| < 2.4$	
Boson selections		
m_{LL}	$70 < m_{LL} < 110$ GeV	
m_{JJ} (resolved case, signal)	$70 < m_{JJ} < 110$ GeV	
m_J (merged case, signal)	$70 < m_J < 110$ GeV	
m_{JJ} (resolved case, sideband)	m_{JJ} in range $[60, 70] \cup [110, 130]$ GeV	
m_J (merged case, sideband)	m_J in range [50, 70] GeV	
Leptonic Z p_T	$p_T > 80$ GeV	
Hadronic Z p_T	$p_T > 80$ GeV	
Diboson selections		
Diboson mass M_{ZZ}	$M_{ZZ} > 180$ GeV	
2- to 1-subjettiness ratio (high purity)	$\tau_{21} < 0.50$	
2- to 1-subjettiness ratio (low purity)	$0.50 \le \tau_{21} < 0.75$	

When applying final V- tagging selection, only one candidate per event is retained.
We pick the one with Z masses closest to PDG value.

Event Selection for EXOWW

Event Selections :

1) High Boosted Leptonic W : $p_T^{WLep} > 200\,GeV$
2) **High Boosted Hadronic W = CA8 hardest Jet:** $p_T^{CA8} > 200\,GeV$
3) pfMET > 40 (80) GeV for muon (electron) channel
4) Lepton pT > 50 (90) GeV for muon (electron) channel.
5) back to back topology : $\Delta R_{lJ} > \pi/2$ $\Delta\varphi_{J,WLep} > 2.0$ $\Delta\varphi_{J,MET} > 2.0$
6) **btag veto** : no btagged AK5 jets, with $p_T > 30\,GeV$, according to CSV med.

(Optimized to have the best Punzi's significance)

Analysis Strategy: G->WW