Reunión Red LHC

Madrid, May 7th, 2019

Combination of CMS Searches for Heavy Diboson Resonances at 13 TeV

(CMS B2G-18-06)

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Phenomenological Models

Heavy narrow resonances:

- width much smaller than mass experimental resolution.

Spin 1:

- **Heavy Vector Triplet (HVT)** model. Two working points:
- **Model A**: g_V = 1; weakly coupled scenario. BR to fermions and EWK bosons similar; sensitivity dominated by EXO dilepton analyses.
- **Model B**: g_V = 3; strongly coupled scenario, typical of Composite Higgs Models; BR to EWK bosons dominant; sensitivity dominated by diboson analyses.

Spin 2:

- **KK-Graviton** from Bulk Warped Extra Dimension model; k_tilde = 0.5.
- BR to top, Higgs and longitudinal components of EWK bosons dominant.

Ingredients: Individual Analyses

Hadronic channels:

B2G-16-26	HH to 4b	PL B 781 (2018) 244
B2G-17-01	VV to 4q	PRD 97 (2018) 072006
B2G-17-02	VH to 2q 2b	EPJ C 77 (2017) 636
B2G-17-19	HH to 4b	JHEP 01 (2019) 40

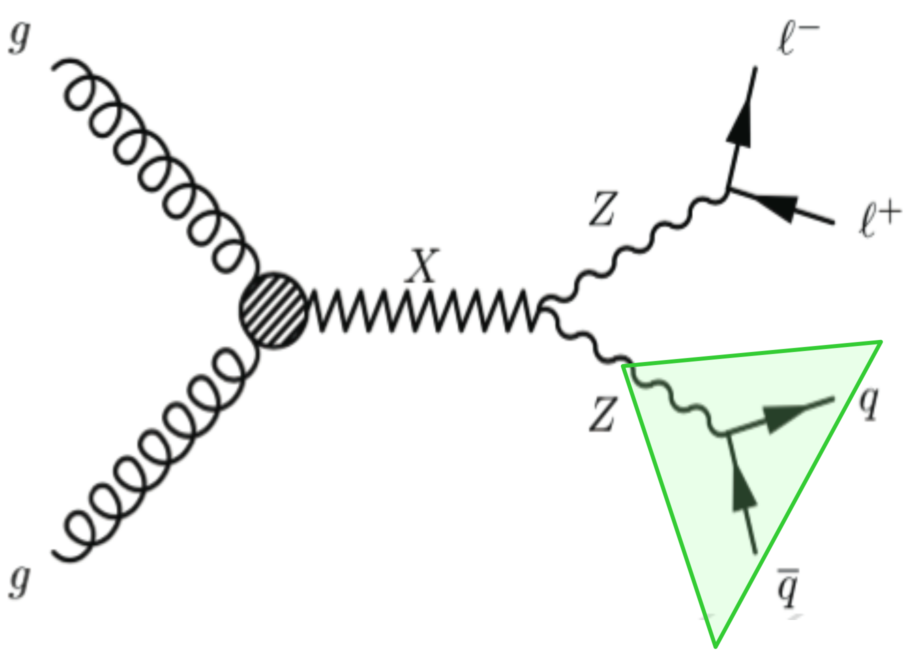
Semileptonic channels:

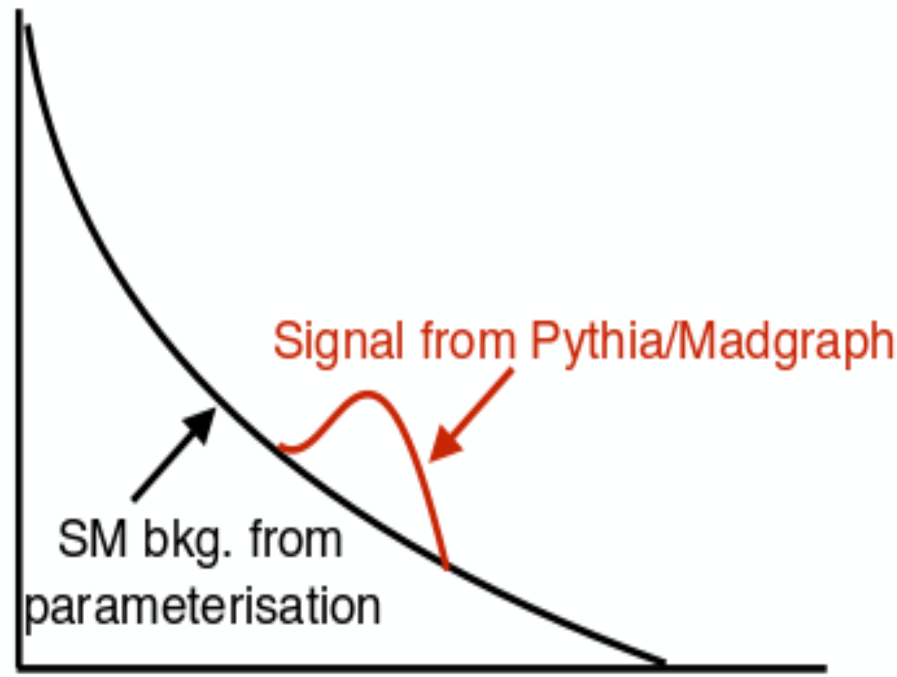
B2G-16-29	WV to lnu 2q	JHEP 05 (2018) 88
B2G-17-05	ZV to 2nu 2b	JHEP 07 (2018) 75
B2G-17-13	ZV to 2l 2q	JHEP 09 (2018) 101
B2G-17-04	VH to lnu/2l 2b	JHEP 11 (2018) 172
B2G-17-06	VH/HH to 2tau 2q/2b	JHEP 01 (2019) 51

Leptonic channels:

B2G-16-23	ZZ to 2l 2nu	JHEP 03 (2018) 3

Hadron Z / W / H Resonances



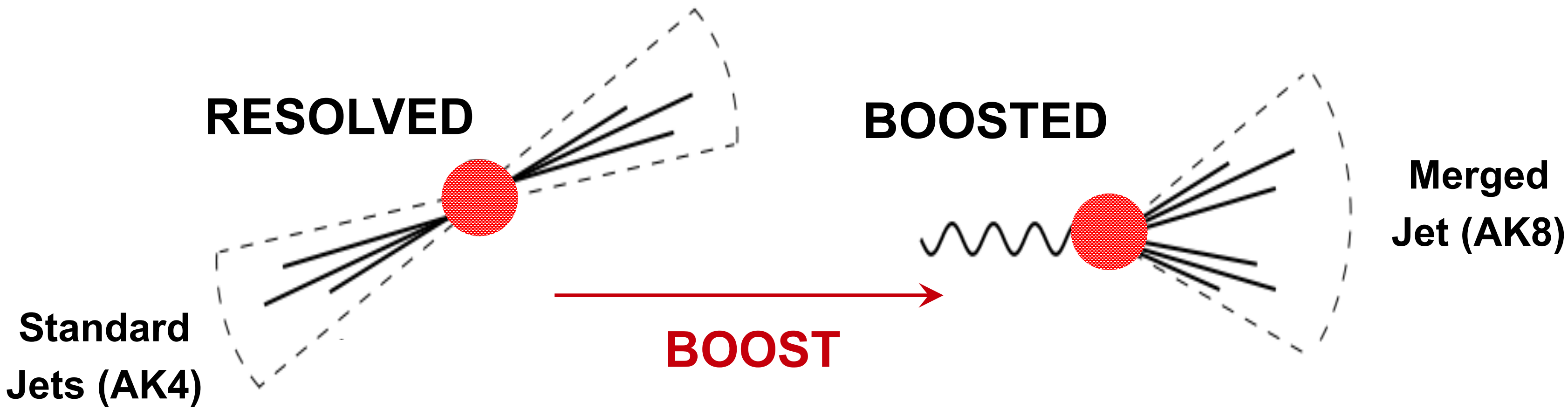


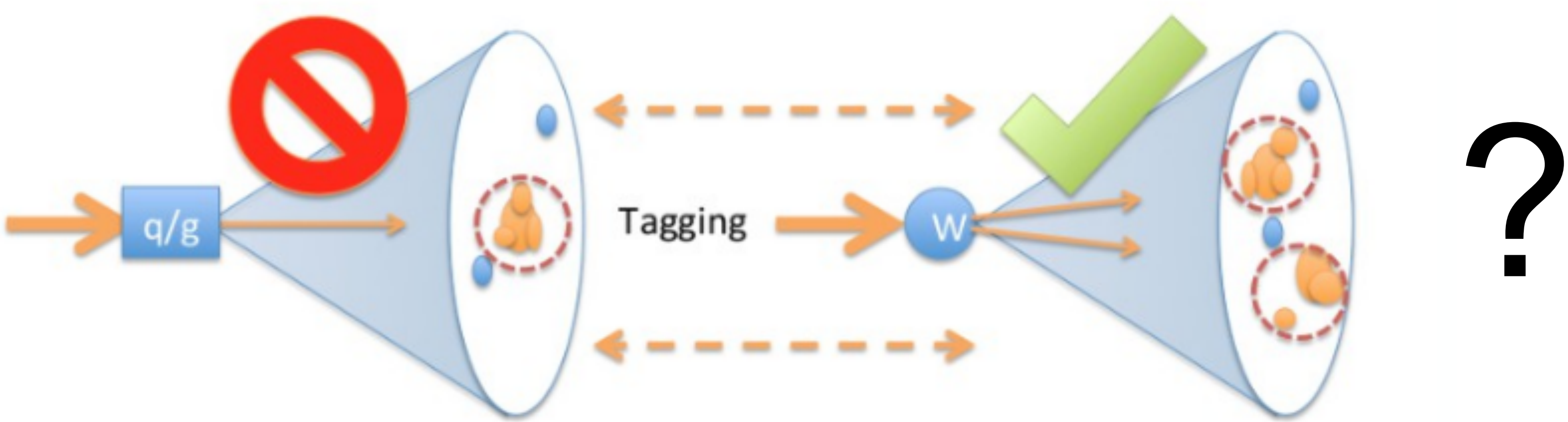
Pros: Large Branching Fractions

Cons: Large backgrounds from V+jets, QCD.

- Estimate via NLO QCD and/or sideband (SB) data.

Heavy Resonance = Boosted Regime





Z / W / H-tagging vs. QCD

- Standard discrimination against QCD in CMS uses:

1. PU mitigation: CHS: Charged Hadron Subtraction, (Hybrid) Jet Area Subtraction: pT offset/area, PUPPI.

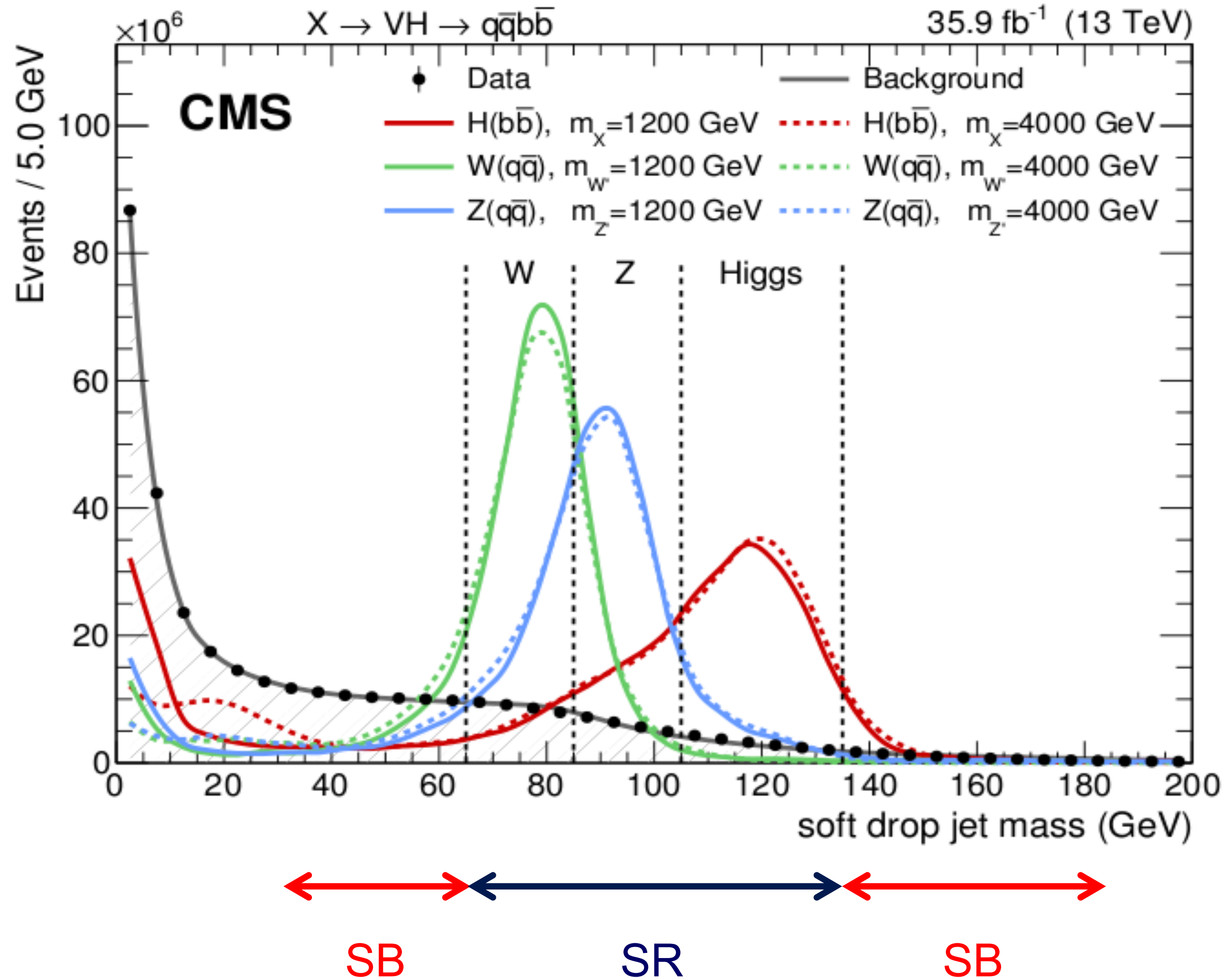
2. Jet Grooming: Recluster jet removing soft and wide angle constituents (PU, ISR, UE). Main observable is the groomed M(J); grooming pushes QCD to lower M(J) values and improves signal mass resolution. Pruning, Soft Drop.

3. Jet Substructure: N-subjettiness quantifies consistency of jet energy flow aligned along N directions / subjets. Ratio of 2-subjettiness over 1-subjetiness discriminate from single quark- or gluon-initiated jets.

4. B-tagging in boosted topologies: Subjet CSV: Combined Secondary Vertex on SD subjets for Z-tagging; Double-B: Double b-tagging (mostly) dedicated to boosted H decays.

Grooming: Merged Jet Mass

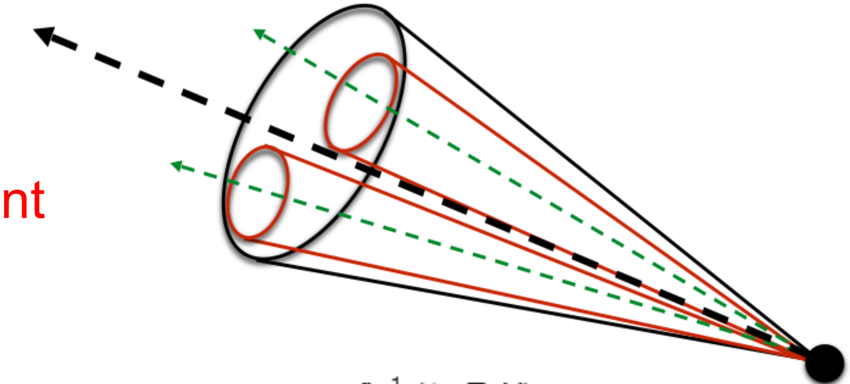
2016



Resolution M(J) ~ 9 - 10%; Resolution M(2lJ) ~ 3 - 4%

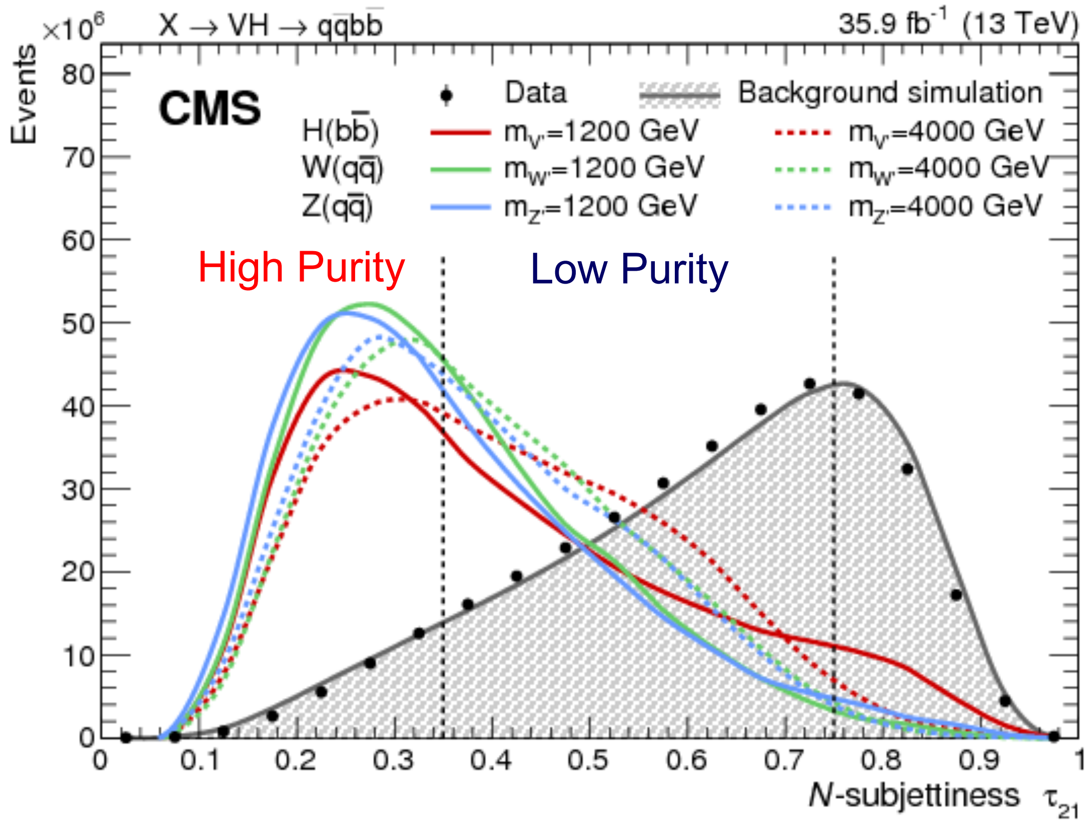
Substructure: N-Subjetiness

$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \min(\Delta R_{1,k}, \Delta R_{2,k}, \ldots, \Delta R_{N,k}),$$

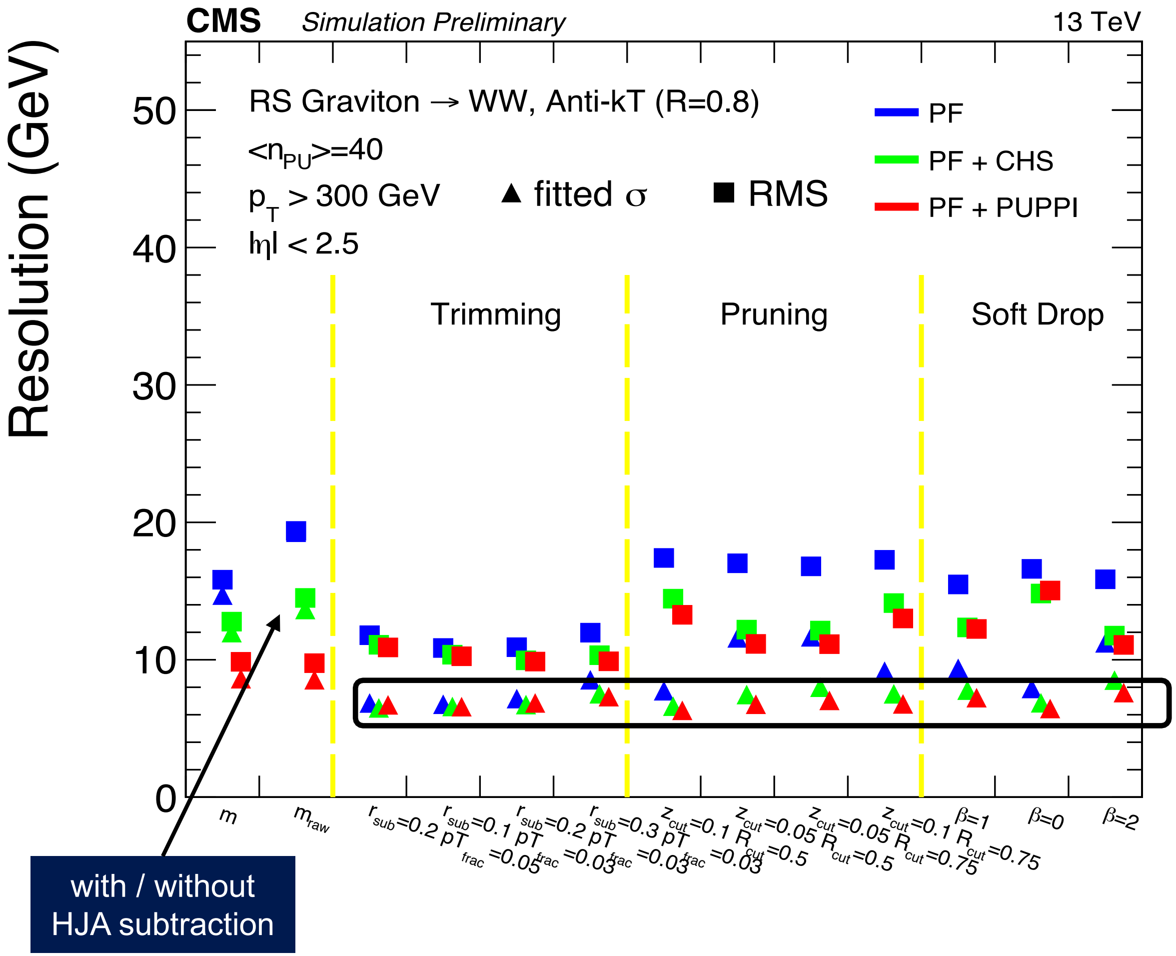


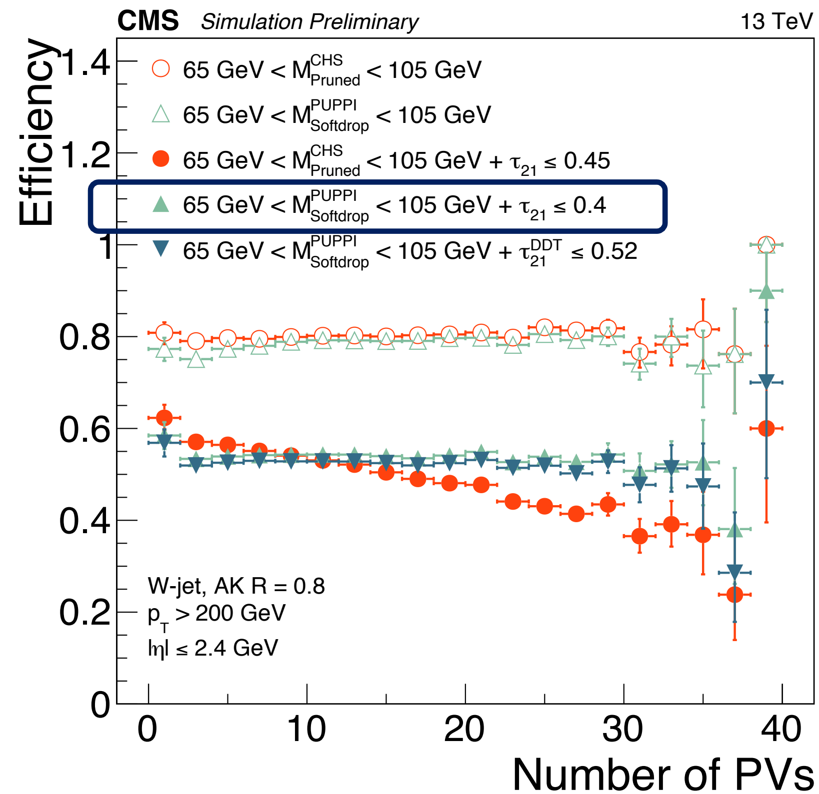
τ_2 / τ_1 is found a very powerful discriminant for boosted two-prong decays

2016



Pileup Mitigation + Grooming Performance





2016: PF + PUPPI, Soft Drop (z_{cut} = 0.1, beta = 0). Improved M(J) resolution and V-tagging efficiency stability vs. number of PVs and pT(J).

Pile Up Per Particle Identification (2014)

- Per particle pileup mitigation technique: "redefinition" of PF event content.
- Examine particle density around PU charged tracks; get distributions for alpha using leading vertex (LV) charged tracks and others.

$$\alpha_i = \log \sum_{j \in \text{event}} \xi_{ij} \times \Theta(R_{\min} \le \Delta R_{ij} \le R_0),$$

$$\text{where } \xi_{ij} = \frac{p_{Tj}}{\Delta R_{ij}}.$$

Charged :

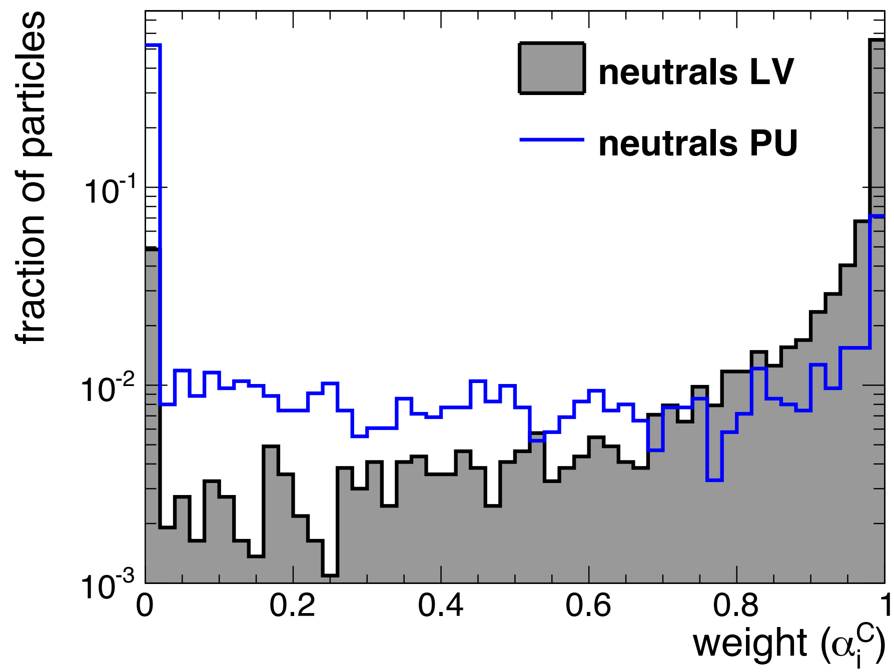
$$\alpha_i^C = \log \sum_{j \in \text{Ch,LV}} \xi_{ij}\, \Theta(R_{\min} \le \Delta R_{ij} \le R_0),$$

Forward :

$$\alpha_i^F = \log \sum_{j \in \text{event}} \xi_{ij}\, \Theta(R_{\min} \le \Delta R_{ij} \le R_0).$$

- Calculate the median and the width of event-by-event alpha distributions.
- Neutral particle 4-momentum weighted, based on 1D chi-squared probability using:

$$\chi_i^2 = \Theta(\alpha_i - \bar{\alpha}_{\text{PU}}) \times \frac{(\alpha_i - \bar{\alpha}_{\text{PU}})^2}{\sigma_{\text{PU}}^2},$$

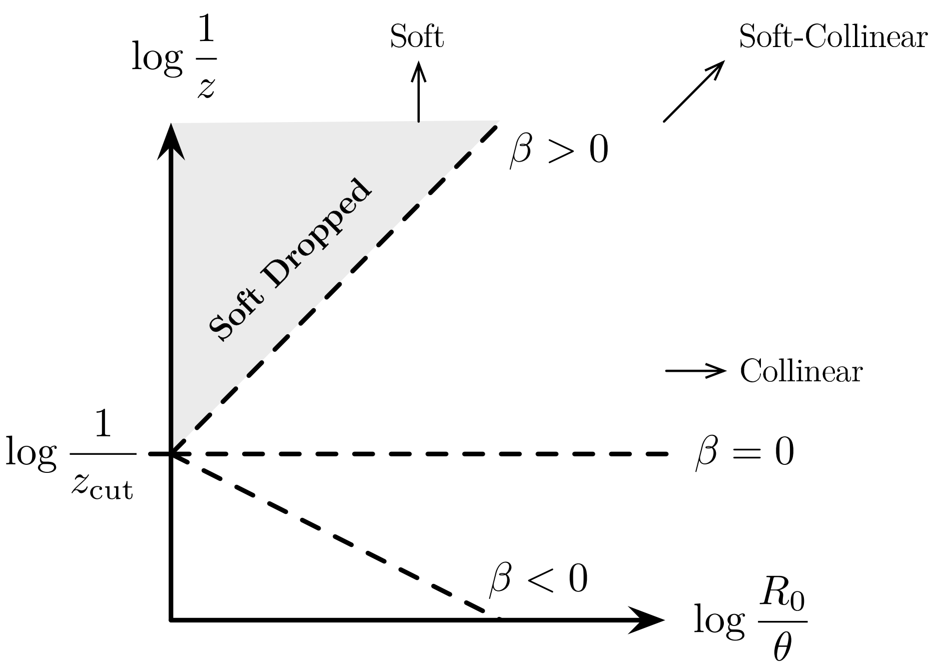


D. Bertolini, P. Harris, M. Low, N. Tran, JHEP 1410 (2014) 059

Soft Drop Grooming (2014)

- Undo last stage of C/A jet clustering into subjets 1 and 2.
  - If $\frac{min(p_{T1}, p_{T2})}{p_{T1} + p_{T2}} > z_{cut} \left(\frac{\Delta R_{12}}{R_0} \right)^{\beta}$, declare SD jet is defined;
  - else, drop softer subjet and iterate on harder one.

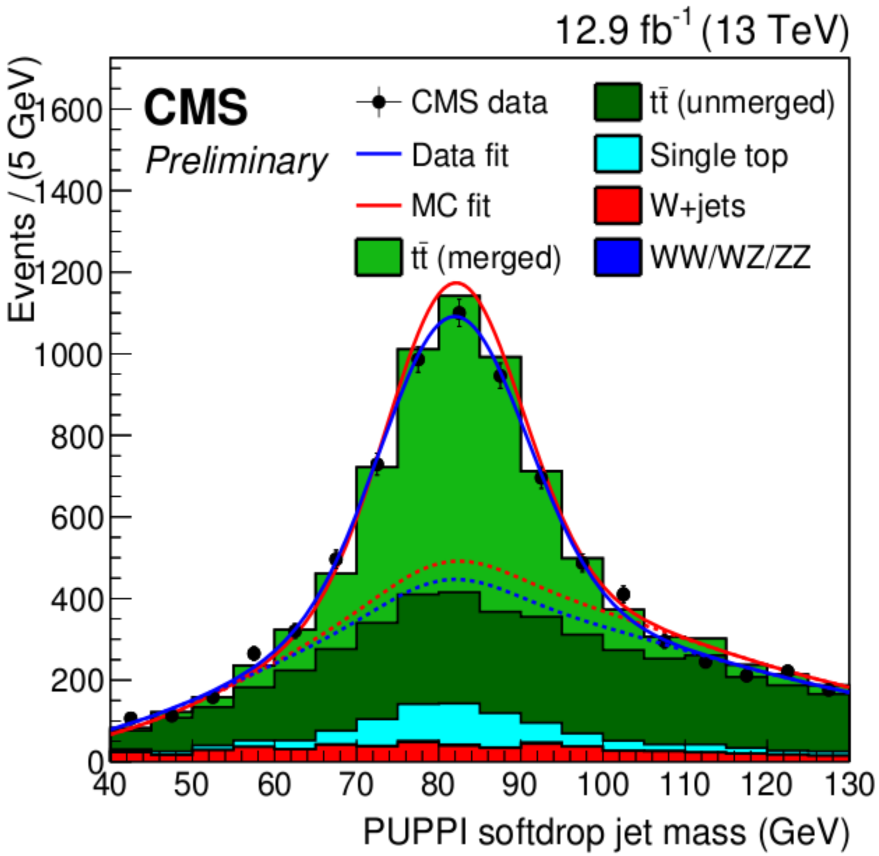
- For beta = 0, soft radiation removed (aka modified mass drop tagger).



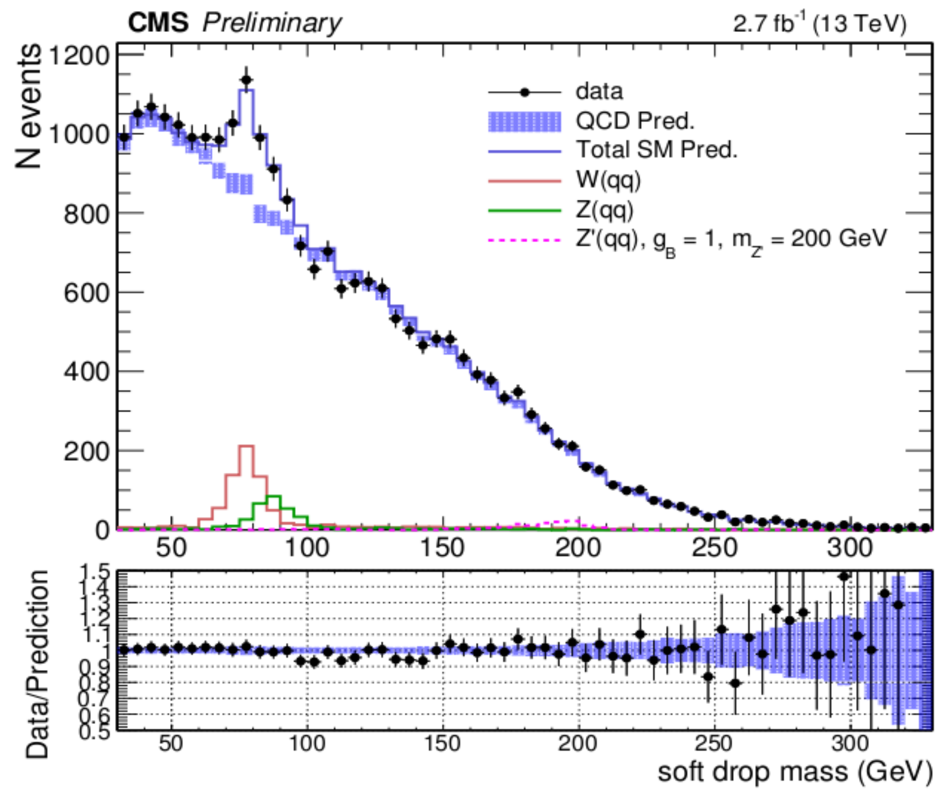
A. Larkoski, S. Marzani, G. Soyez, J. Thaler, JHEP 1405 (2014) 146

Boosted W/Z Tagging Calibration

2016



2015



Lepton + jets top-enriched data sample.

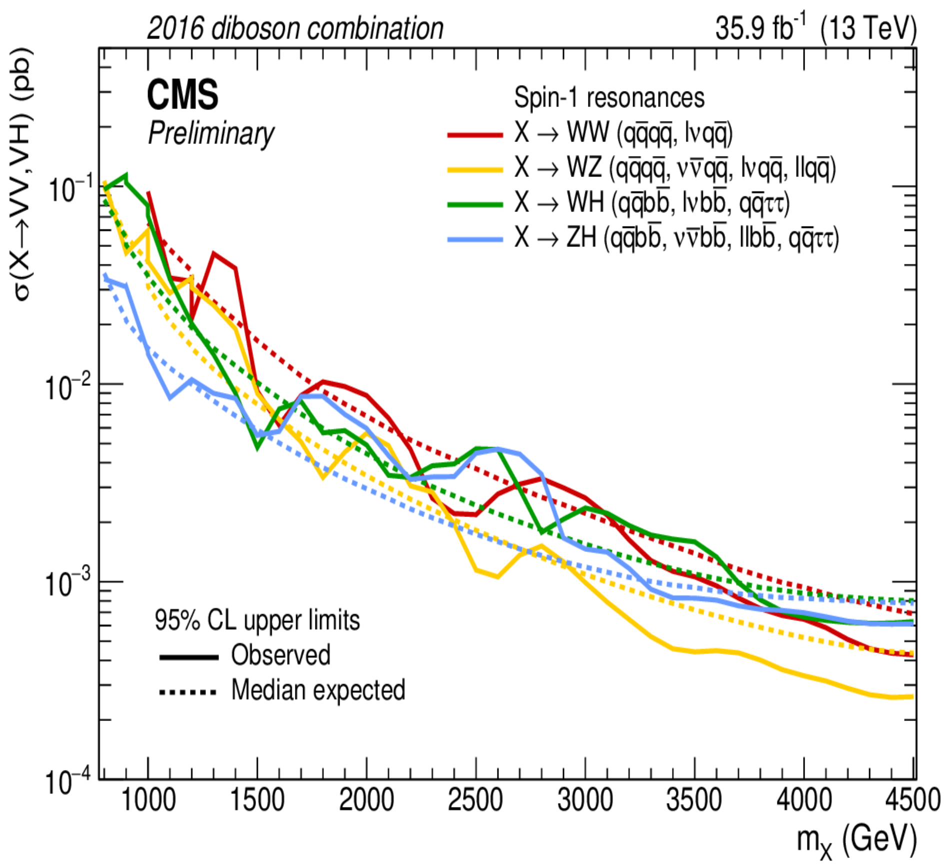
- W signal used to extract V-tagging data/MC scale factors

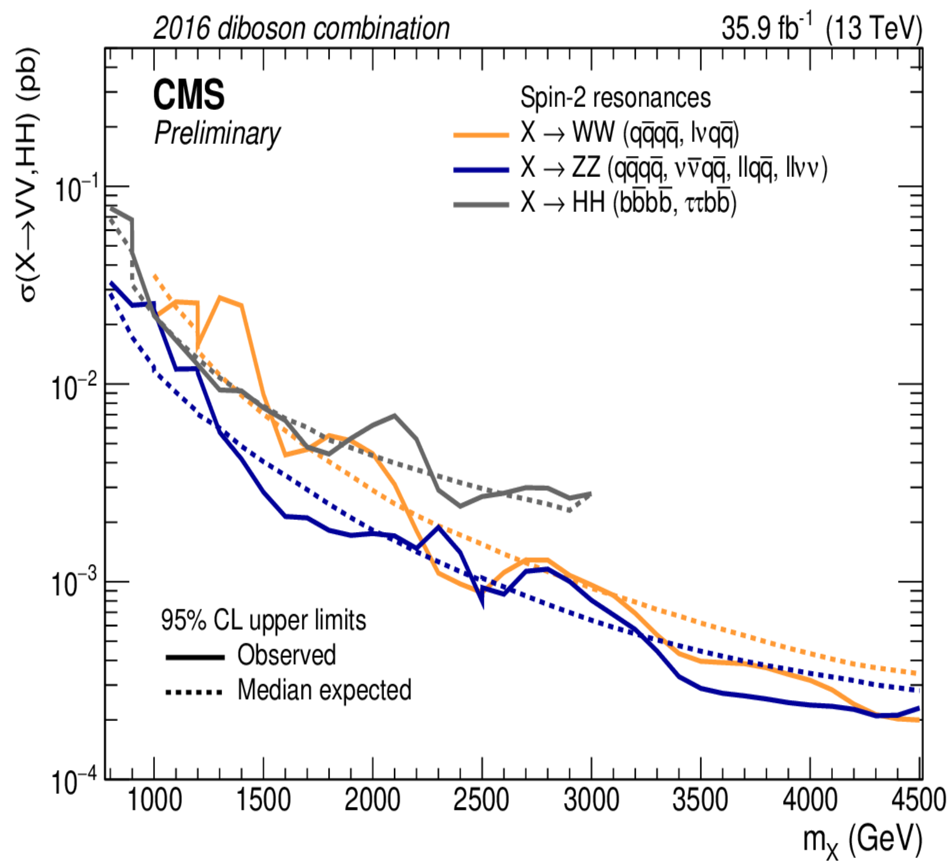
Inclusive high-pT AK8 jet data sample.

- Very clear Z/W bump above QCD continuum in M(J) distribution.

Limits per Spin and VV Channel

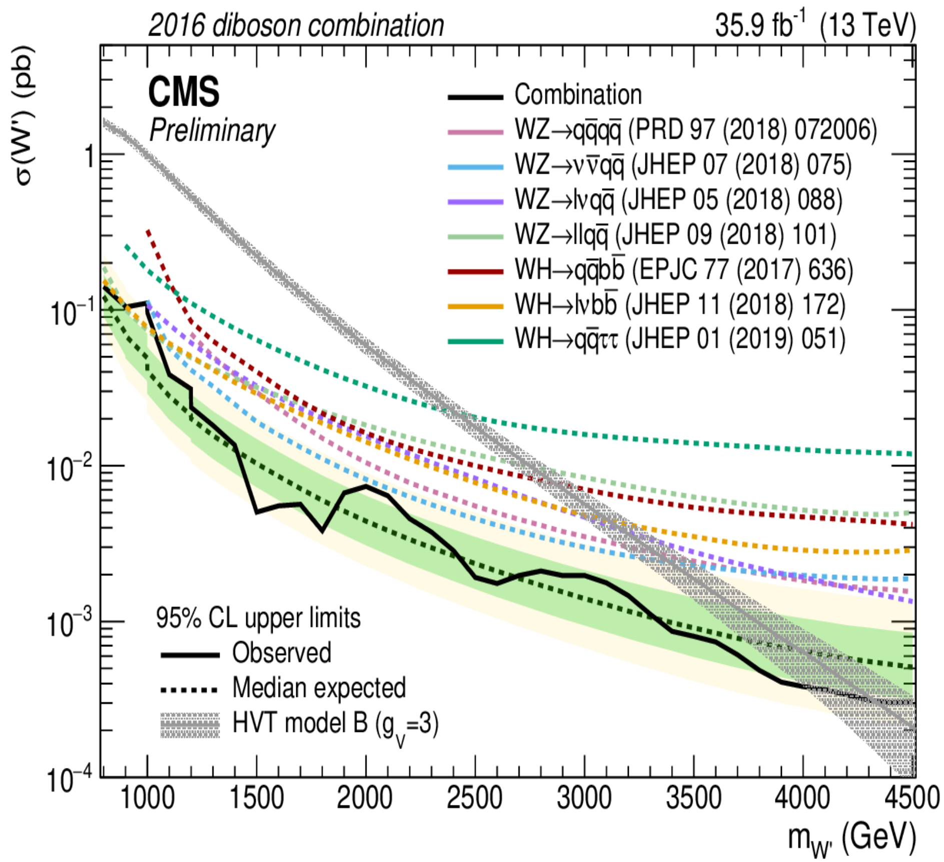
2016: Integrated luminosity 35.9 / fb; (~26% of the Run 2 complete sample).

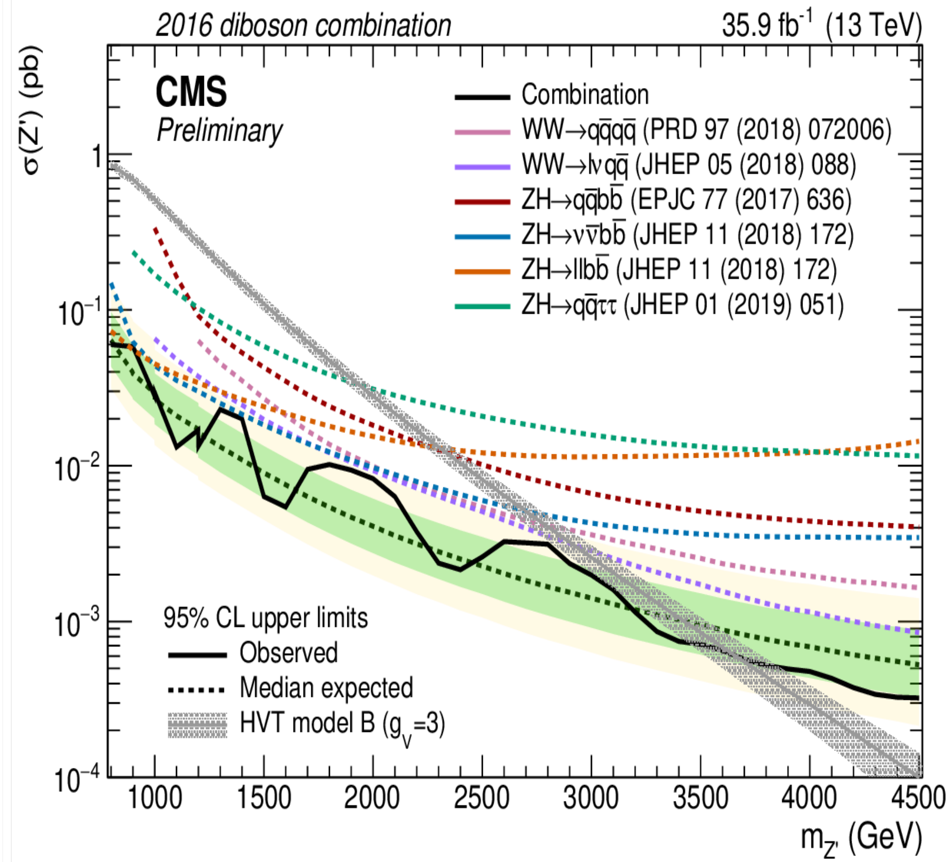




Limits on HVT W' / Z' "Singlet" Production

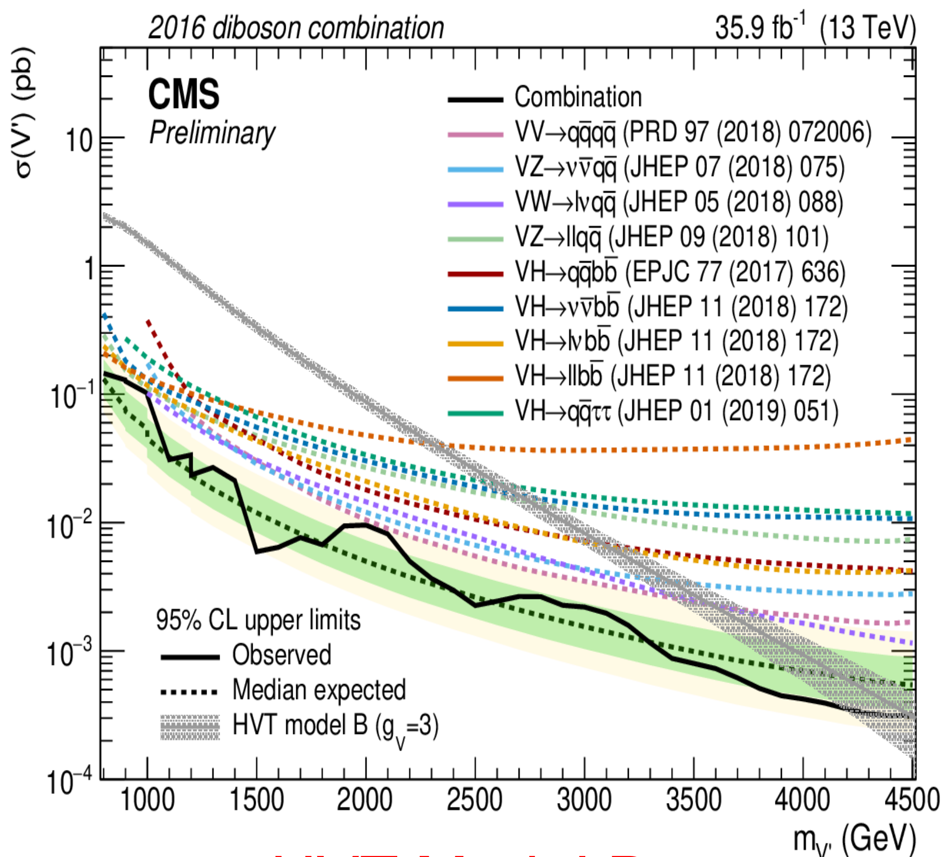
2016: No significant excess; largest excesses are 2.8 local (1.3 global) and 2.6 (0.7) sigmas. M(W') > 4.3 TeV; M(Z') > 3.7 TeV @ 95% CL.



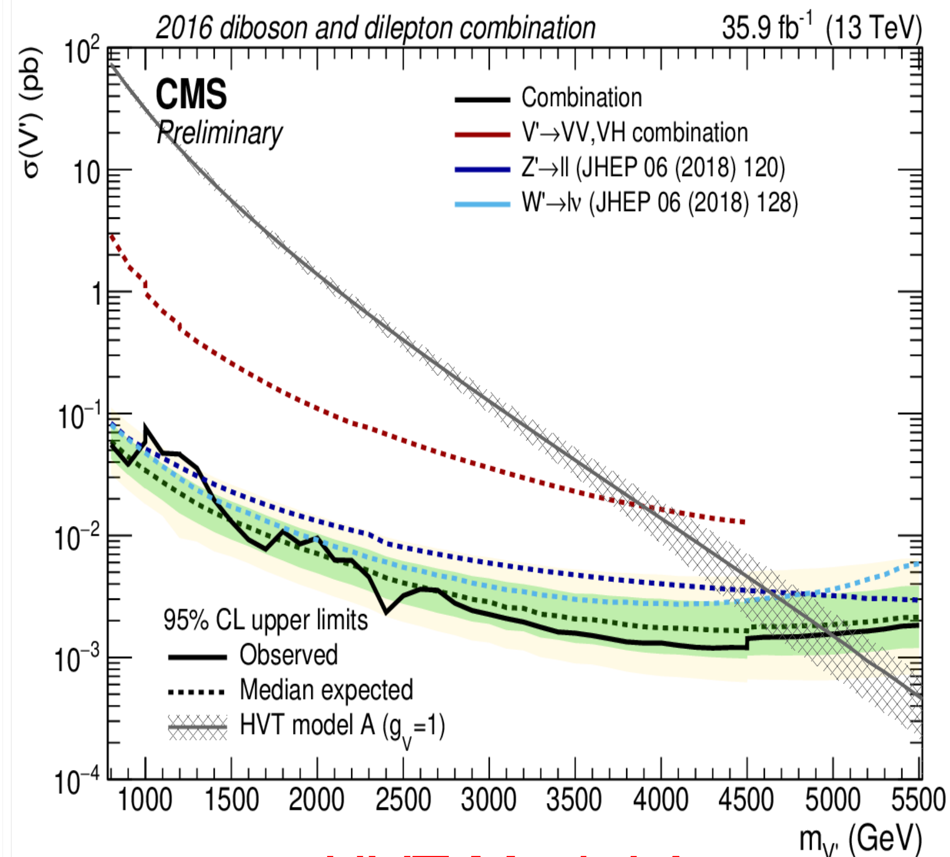


Limits on HVT V' Production

2016: No significant excess; largest excess is 2.4 local (0.5 global) sigmas. M(V') > 4.5 (5.0) TeV for HVT Model B (A) @ 95% CL.

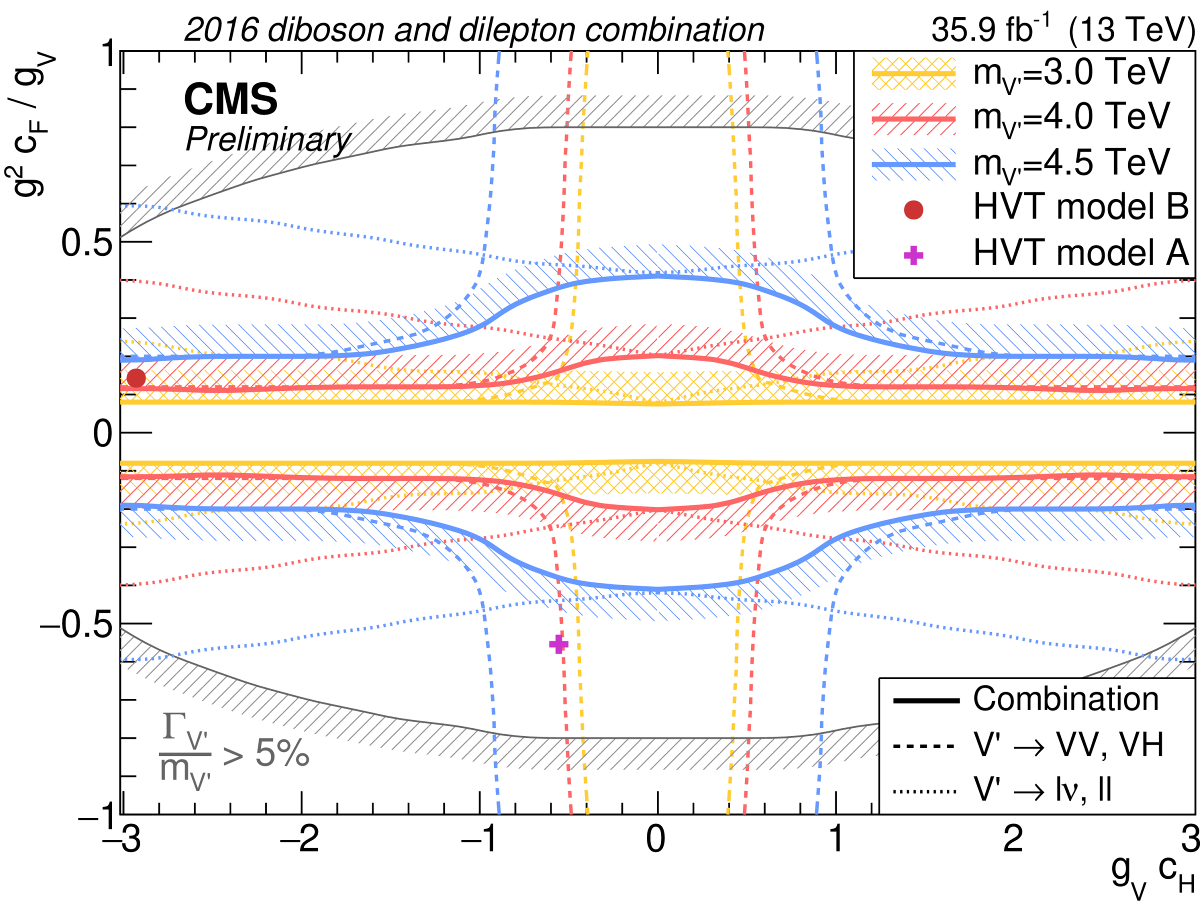


HVT Model B



HVT Model A

Limits on HVT Model Couplings



Limits on Bulk Graviton Production

2016: No significant excess; largest excess is 2.2 local (0.7 global) sigmas. M(G) > 0.85 TeV @ 95% CL.