Search for high mass resonances in ATLAS and CMS

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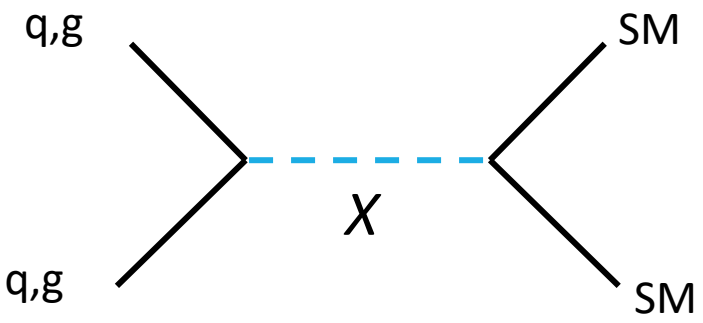
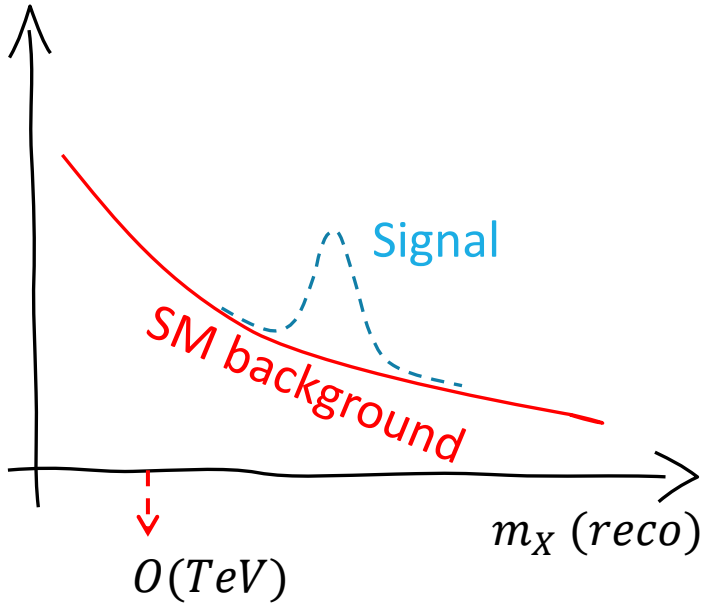
(ON BEHALF OF THE ATLAS AND CMS COLLABORATIONS)

Search for new resonances

- High mass resonances:
  - Predicted by many Beyond Standard Model (BSM) theories:
    - GUT, compositeness, warped extra dimension
    - Mediators of interaction between SM and Dark Matter (DM) particles

- Resonance search:
  - Full reconstruction of resonance mass from decay products
  - Clear experimental signature: peak over smooth background





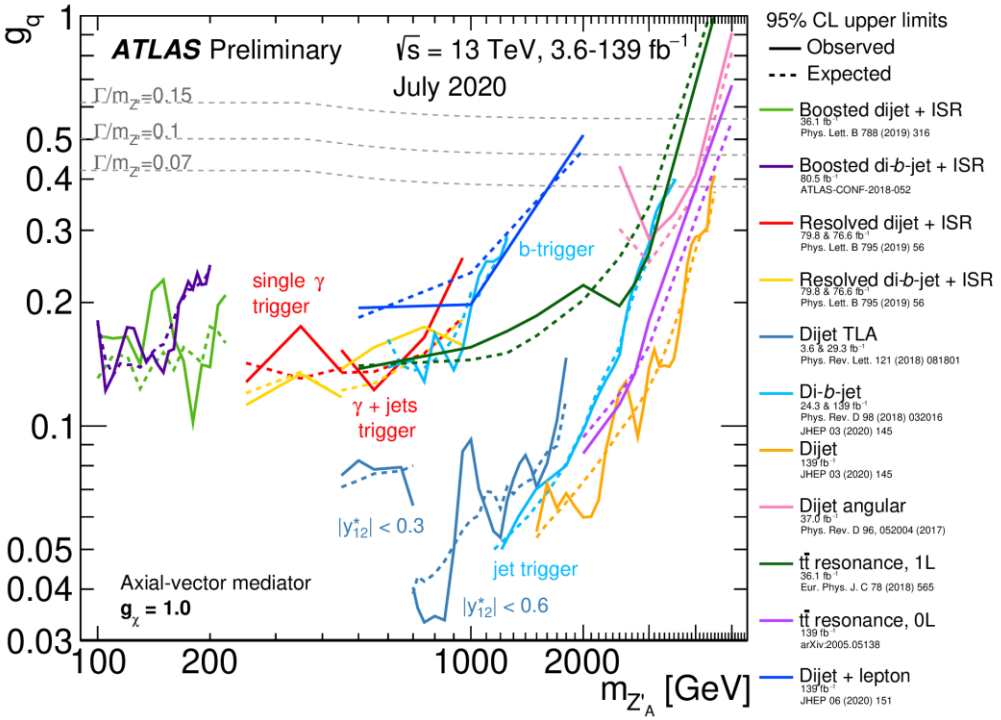
Summary of resonance searches

Many efforts from ATLAS and CMS collaborations:

- cover wide range of final states and resonance masses
- No evidence for new physics BSM, even with full Run 2 dataset

Channel	Latest results
$X \to jj$	JHEP 03 (2020) 145 (ATLAS) JHEP 05 (2020) 033 (CMS)
$X \to ll$	PLB 796 (2019) 68 (ATLAS) arXiv:2103.02708 (CMS)
$X \to t\bar{t}$	JHEP 10 (2020) 61 (ATLAS) JHEP 04 (2019) 031 (CMS)
$X \to lv$	CMS-PAS-EXO-19-017 (CMS) PRD 100 (2019) 052013 (ATLAS) More in Tadej Novak talk
$X \to diboson$ γ, Z, W, H	Antonis Agapitos talk

Overview of dijet resonance searches



Beyond standard searches

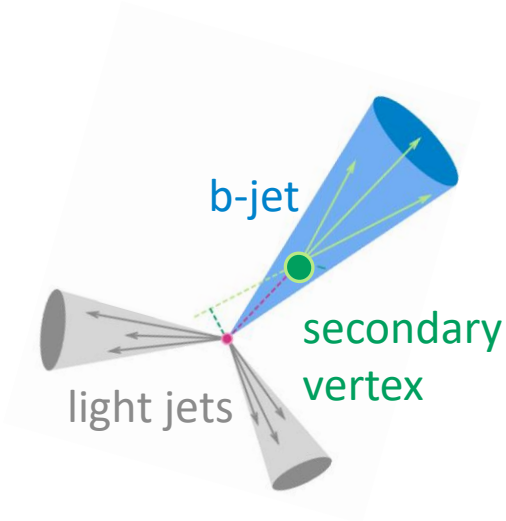
In this phase of the LHC, ATLAS and CMS activity is focused on analysis upgrades

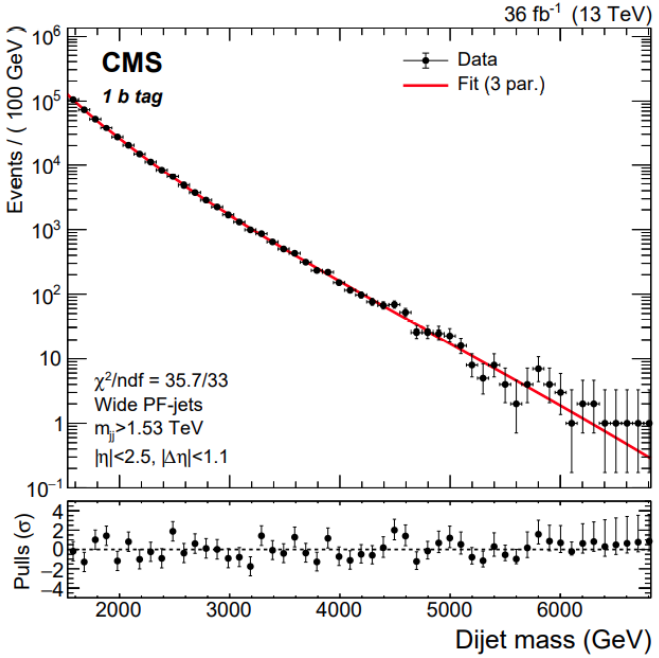
- Extend searches to low resonance mass: Silvio Donato's talk
- New theoretical interpretation of results
- Explore new experimental signatures

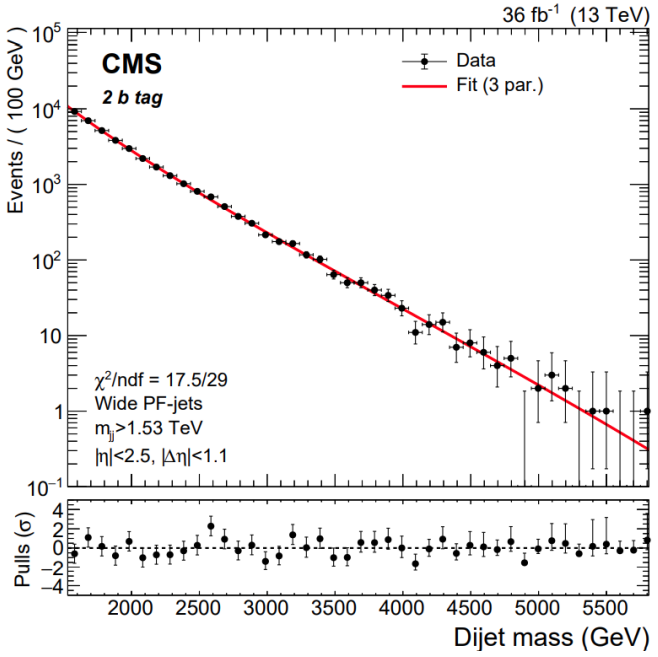
Final state	Process	Links
2 b-jets	$Z' \rightarrow bb$	(to be confirmed) CMS;
Dijet + l	$X \rightarrow jj + l$	JHEP 06 (2020) 151 (ATLAS)
Jets + E_T^{miss}	$X \rightarrow E_T^{\mathrm{miss}} + VV$	PRL 126 1218 02 ATLAS
Trijet	$X \rightarrow Y + j \rightarrow 3j$	(approved) CMS;

Resonances decaying to b-jets

- Some new physics models foresee new resonances decaying mostly to b quarks
  - $Z' \to b\bar{b}$
  - $b^* \to bg$
- Suppression of QCD multijet background by requiring b-jet in the final state
  - Enhance sensitivity to new physics

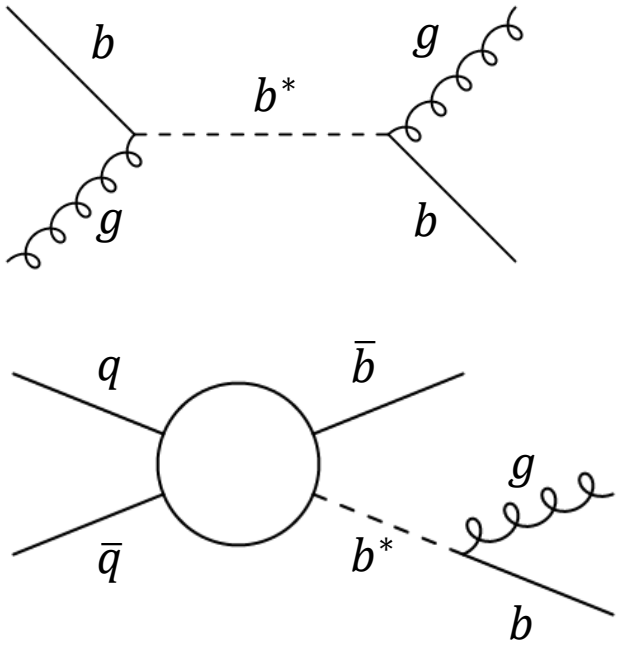


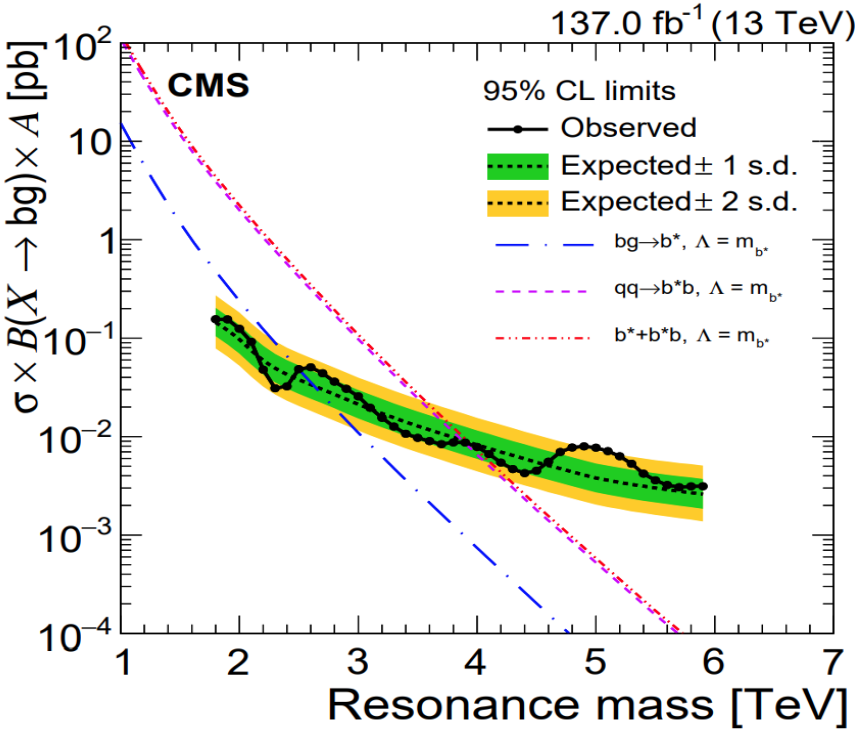




New limits on excited quarks (b^*)

- 2 production processes
  - $bg \rightarrow b^*$ (s-channel, pdf suppression due to initial state b quark)
  - $q\bar{q} \rightarrow b^*\bar{b}$ (contact interaction, dominant) → **NEW**
- Excluded $m_{b^*} < 4.0\ TeV$ → Large increase in mass limit thank to new interpretation

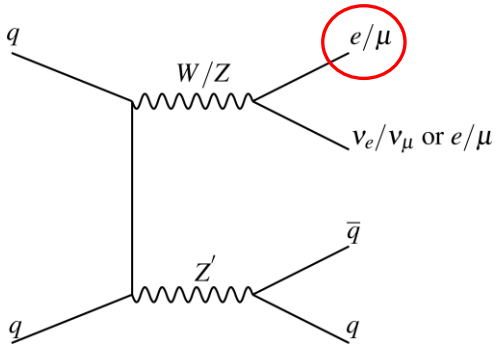




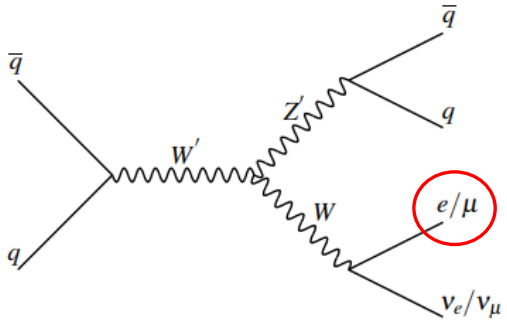
Dijet + lepton final state

- Extension of standard dijet bump search
  - Require additional isolated high-p_T lepton in the final state
- Strong reduction of QCD multijet background
  - Enhance sensitivity to new physics signals with additional lepton in the final state

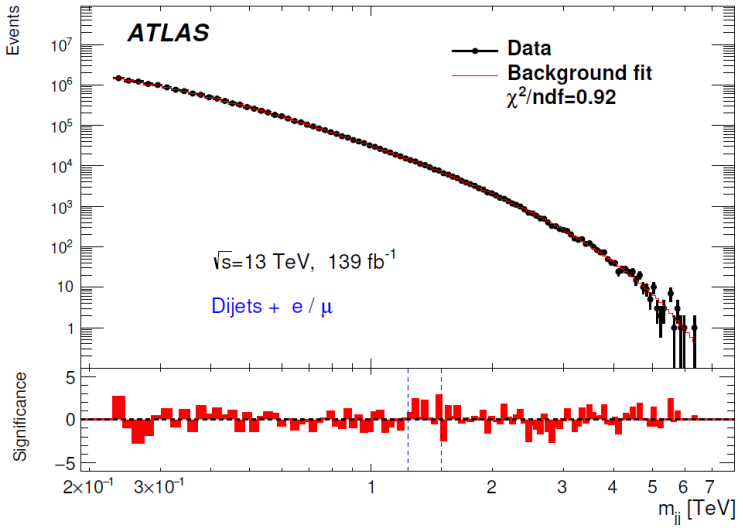
Dijet + ISR W/Z



$W' \rightarrow Z' + W$



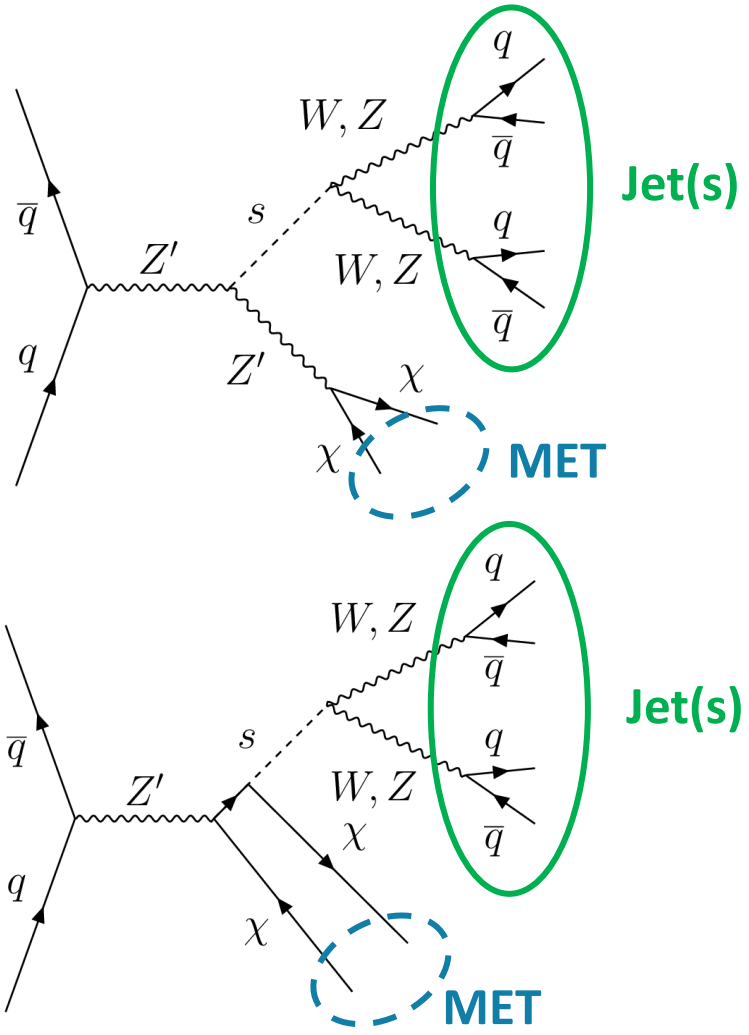
Model	Mass limit
$Z' + \text{ISR W} \rightarrow qqlv$	$m_{Z'} < 1.2\ TeV$
$W' \rightarrow Z' + W \rightarrow qqlv$	$m_{Z'} < 2\ TeV$



Dark Matter + VV resonance

- Existing searches for Dark Matter (χ) consider many $E_T^{miss} + X$ final states (Varun Sharma's talk):
  - $E_T^{miss} + q$ (monojet, monotop)
  - $E_T^{miss} + \gamma$ (monophoton)
  - $E_T^{miss} + V$ (mono-Z, mono-W)
  - $E_T^{miss} + H$ (mono-Higgs)

- $E_T^{miss} + VV$: unexplored final state
  - $Z' =$ mediator of interaction between quark and Dark Matter
  - $s =$ Dark Higgs (couples to χ and Z')
  - s decays to two vector bosons (focus on hadronic final states)



Jet substructure from VV decays

- Several final state topologies considered

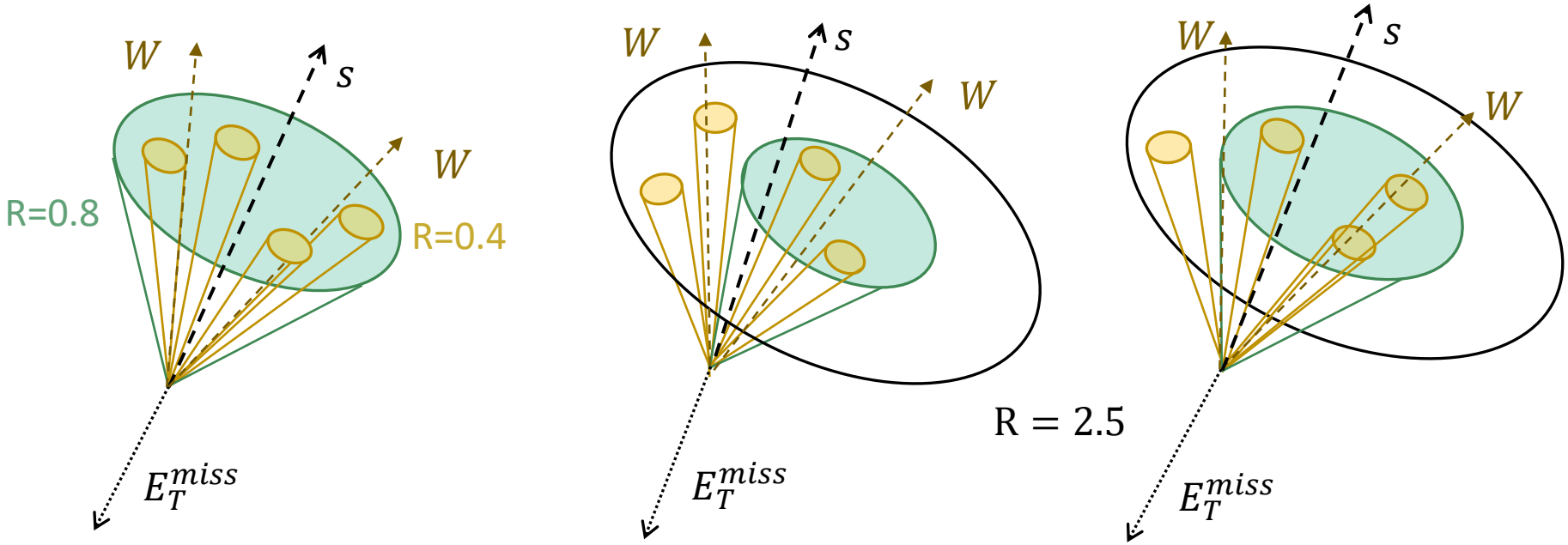
Merged

$E_T^{miss} > 300\ GeV$
1 jet with 4-prong topology
(using $\tau_{43}; \tau_{42}$
N-subjettiness ratios)

Intermediate

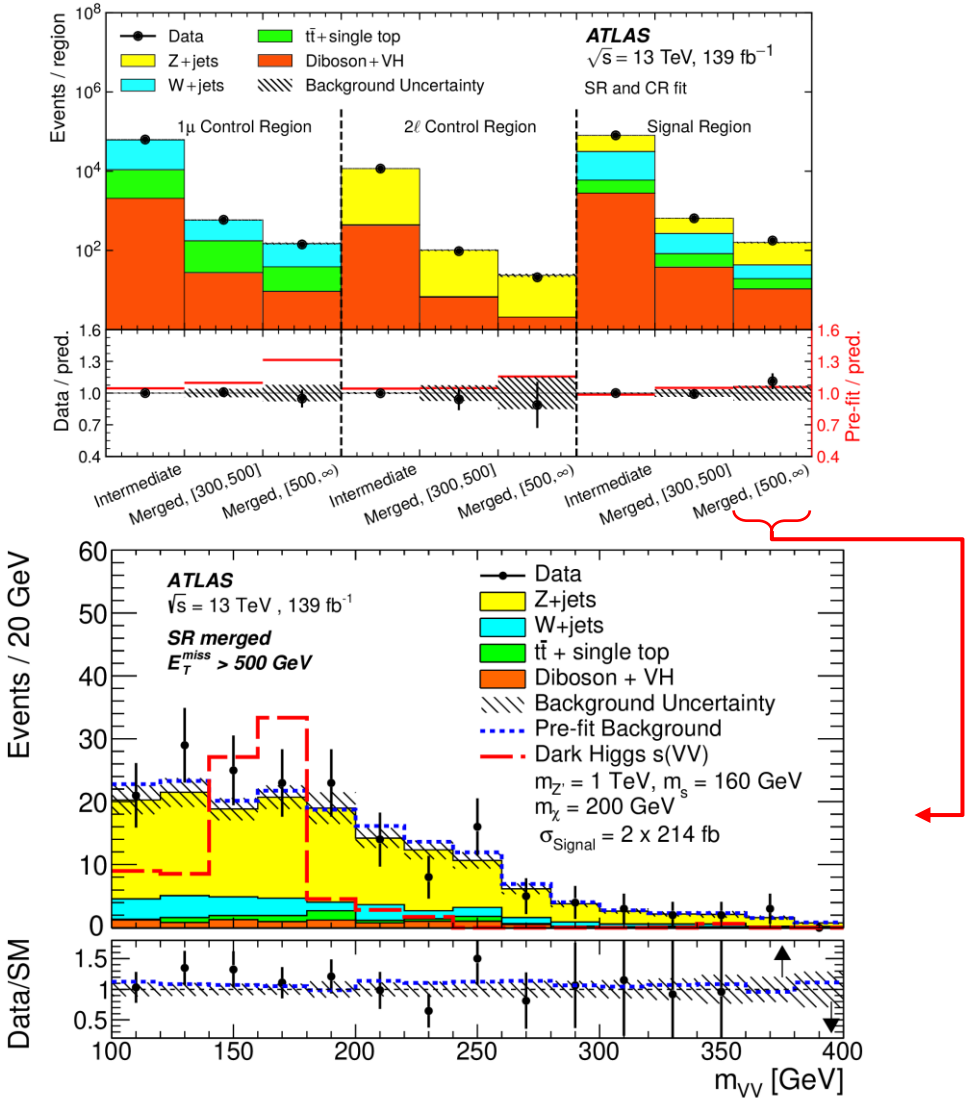
$E_T^{miss} > 200\ GeV$
1 large jet
$60 < m^{jet} < 100\ GeV$
+2 small-R jets: $m_{jj} \approx m_W$

$E_T^{miss} > 200\ GeV$
1 large jet
$100 < m^{jet} < 400\ GeV$
+1 small-R jet



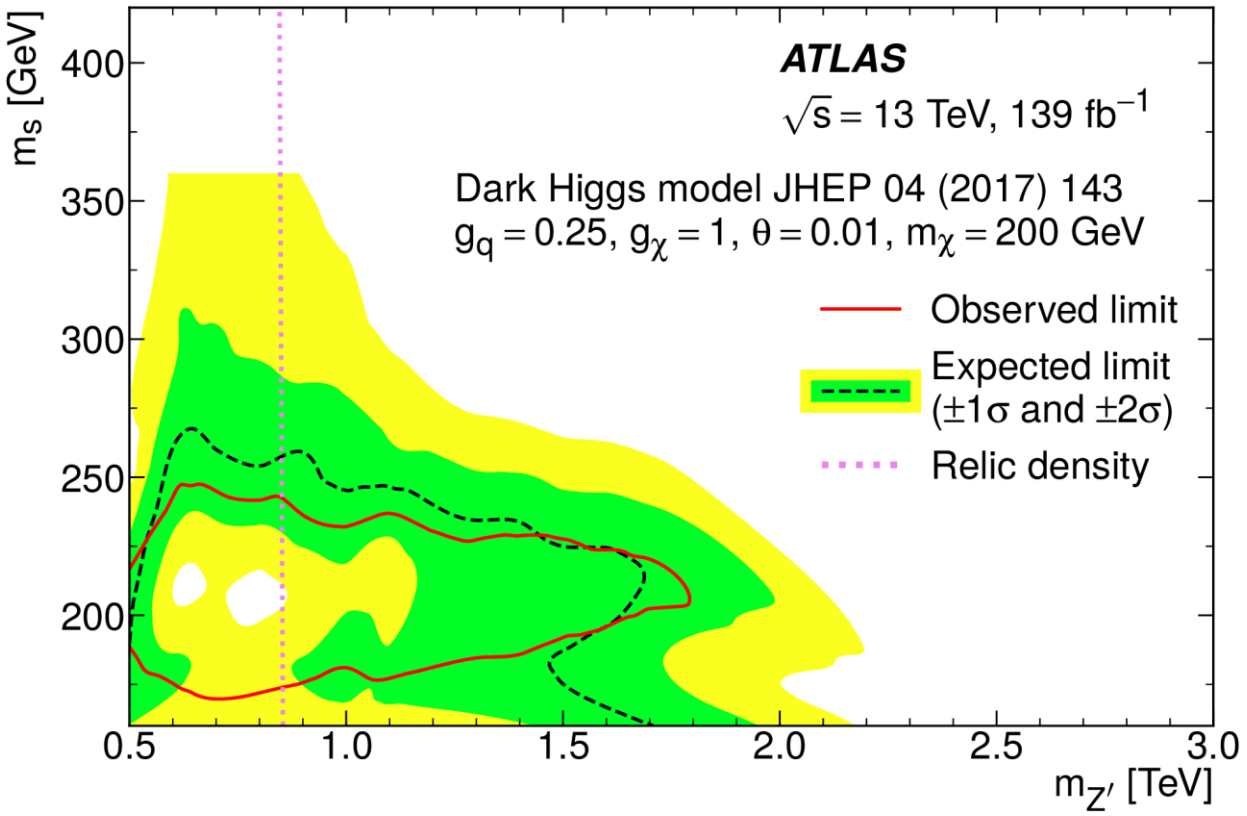
Results

- Main SM background: $V + jets$
  - Modeled using Control Regions (CR) in data requiring 1 or 2 additional leptons
- Main observable:
  - reconstructed mass of the VV system (m_{VV})
- Simultaneous fit to m_{VV} distributions in all categories and regions
  - No evidence for new resonances



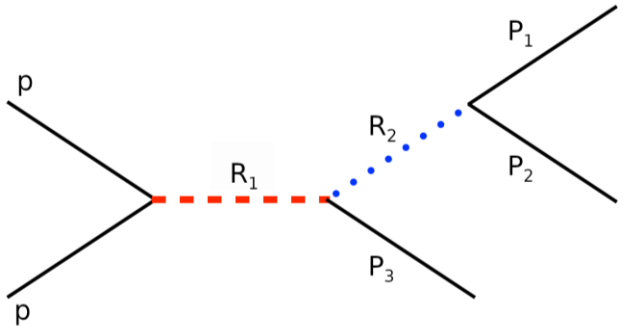
Limits for Dark Higgs model

- Model with 3 particles of unknown mass: $m_{Z'}$, m_s, m_χ
- Limits in 2D: $m_\chi = 200\ GeV$; $m_{Z'} \in [0.5; 2.5]\ TeV$; $m_s \in [160; 360]\ GeV$



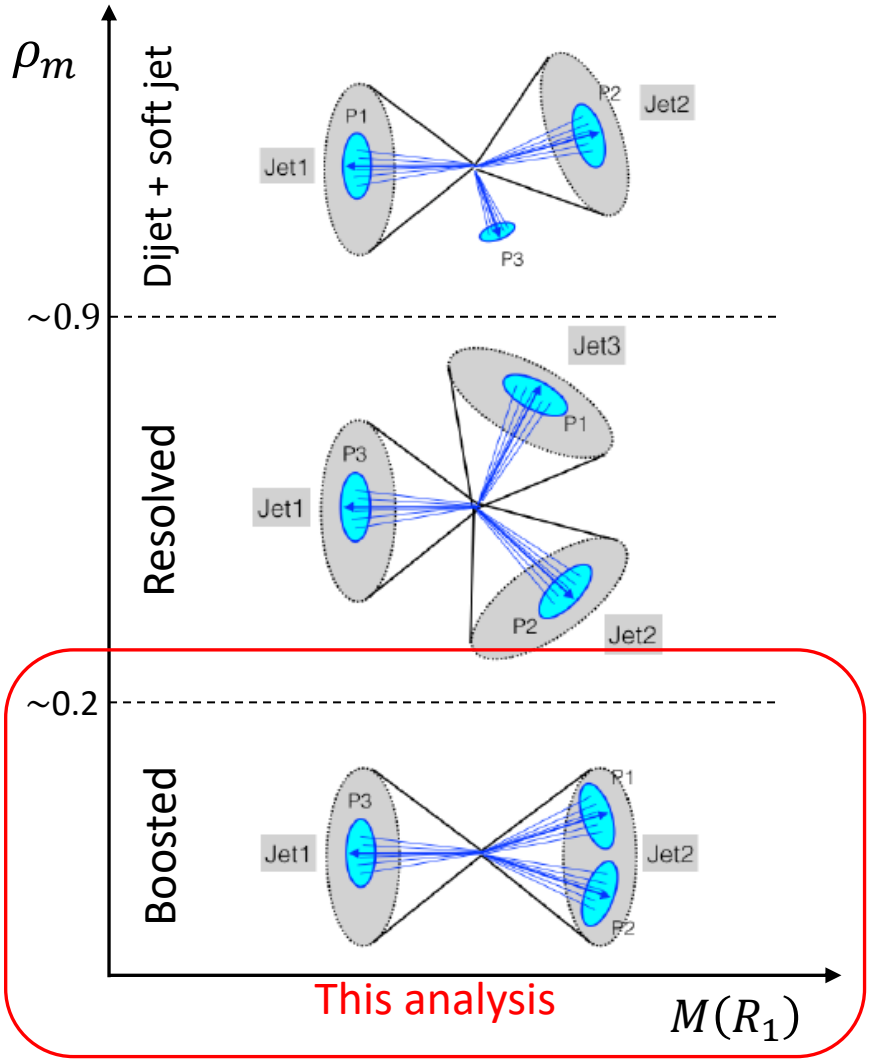
Trijet resonances

- New unexplored signature at the LHC

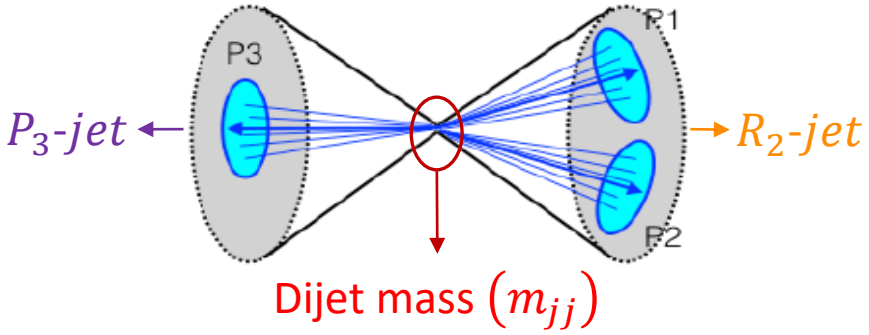


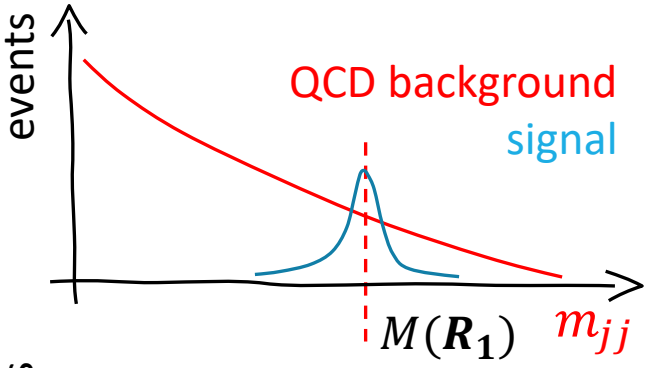
- Cascade decay with 2 new resonances:
  - P_1, P_2, P_3 are q/g producing jets
  - Different hadronic final state topologies

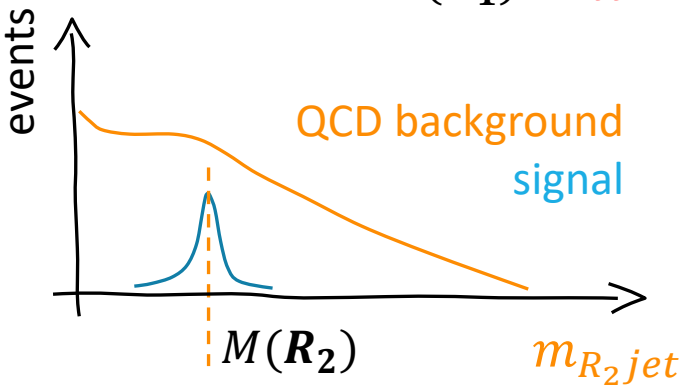
- Boosted regime $\rho_m = \frac{M(R_1)}{M(R_2)} < \sim 0.2$:
  - P_1, P_2 jets merged
  - Exploit jet substructure and cascade decay properties

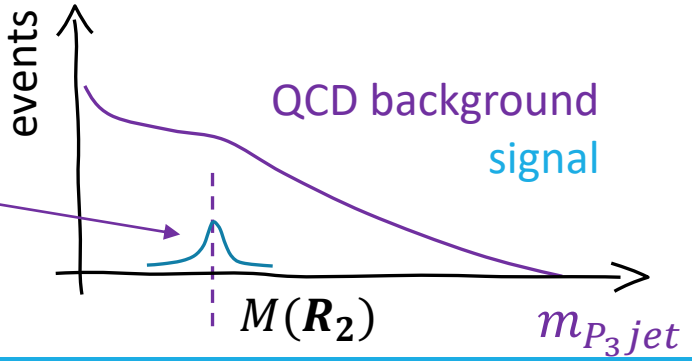


Jet identification and observables





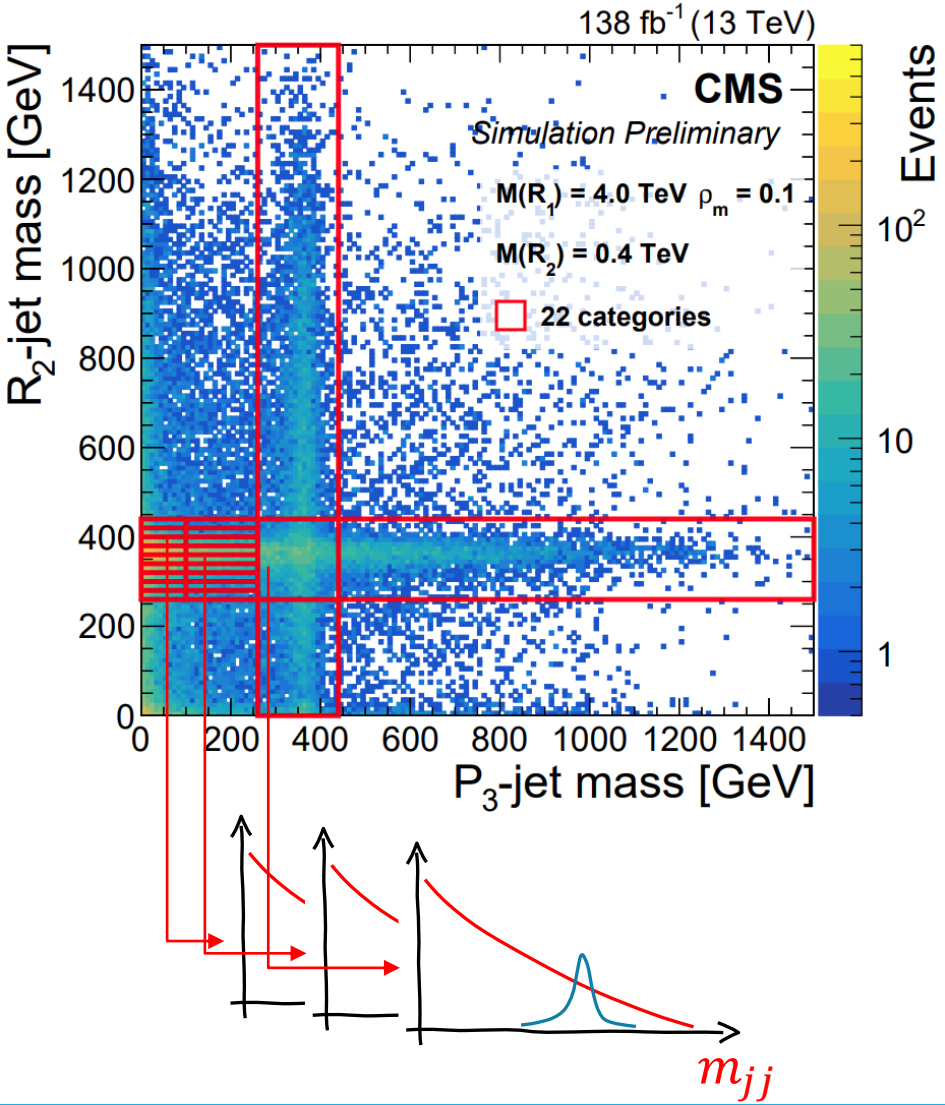




- R_2-jet:
  - jet with the smallest N-subjettiness ratio (τ_{21})
- Expected Signature:
  - 2 peaks in m_{jj} and $m_{R_2 jet}$ spectra
- Errors in jet identification (~30% of events):
  - Small peak in $m_{P_3 jet}$ spectrum from R_2-jet identified as P_3-jet

Event categories definition

- **Signal events:**
  - Cross-shaped area in plane ($m_{R_2 jet}$ vs $m_{P_3 jet}$)
  - Cross centered @ M_{Res2}
  - Vertical band: wrong jet ID
- **Strategy:**
  - Divide cross in 2D categories
    - Recover events with misID jets
    - Categories change according to M_{Res2} (sliding window)
  - Simultaneous fit to m_{jj} distributions for each category



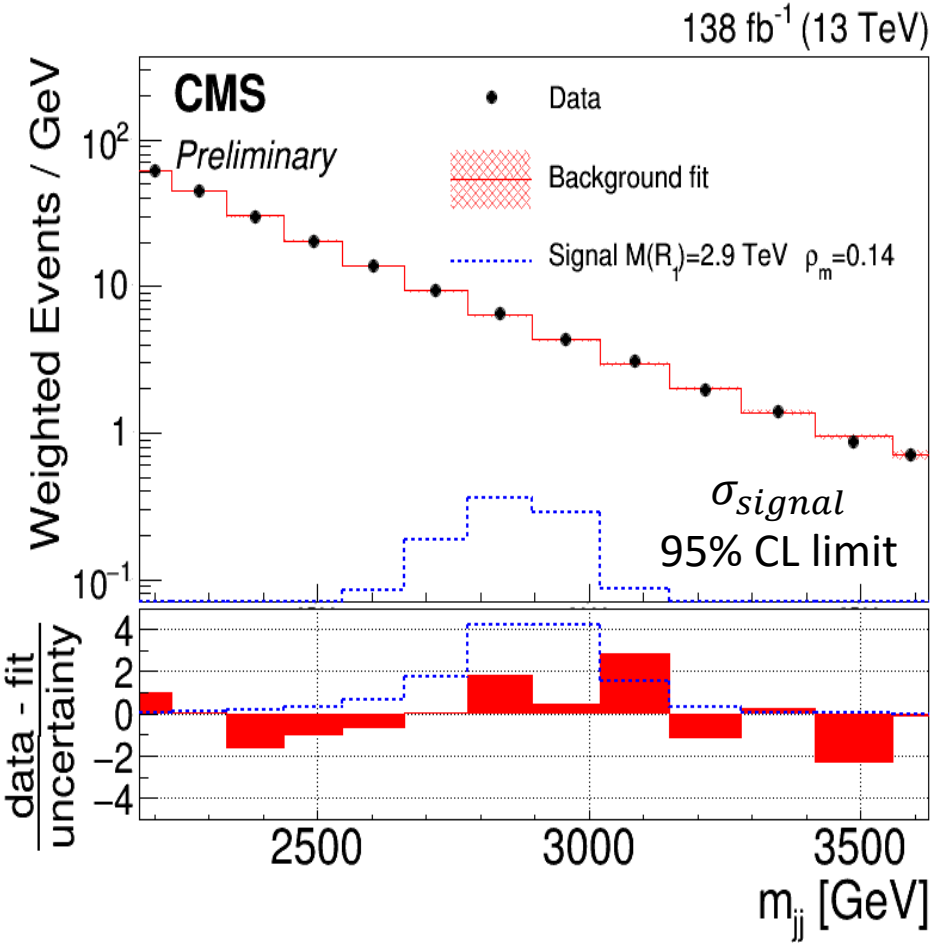
Combined dijet mass spectrum

- Wide range of signal hypotheses tested:
  - $M(R_1) \in [2; 9]\ TeV$
  - $\rho_m \in [0.1; 0.2]$
- No evidence for new resonances found
- Largest excess:
  - loc. significance 3.2 std. dev.
  - Glob. significance $< \sim$1.8 std.dev
- Combined m_{jj} plot (weighted):

$$w_i = \frac{S_i}{S_i + B_i}$$

$$S_i = \#\ signal\ events\ in\ cat.\ i$$

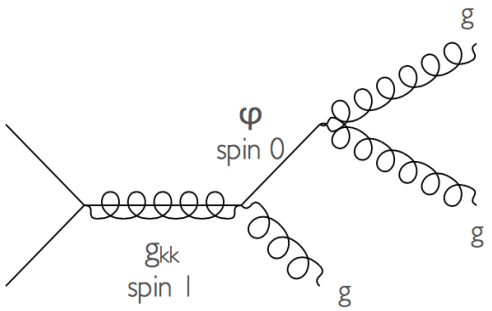
$$B_i = \#\ background\ events\ in\ cat.\ i$$



Limits on Extra dimension model

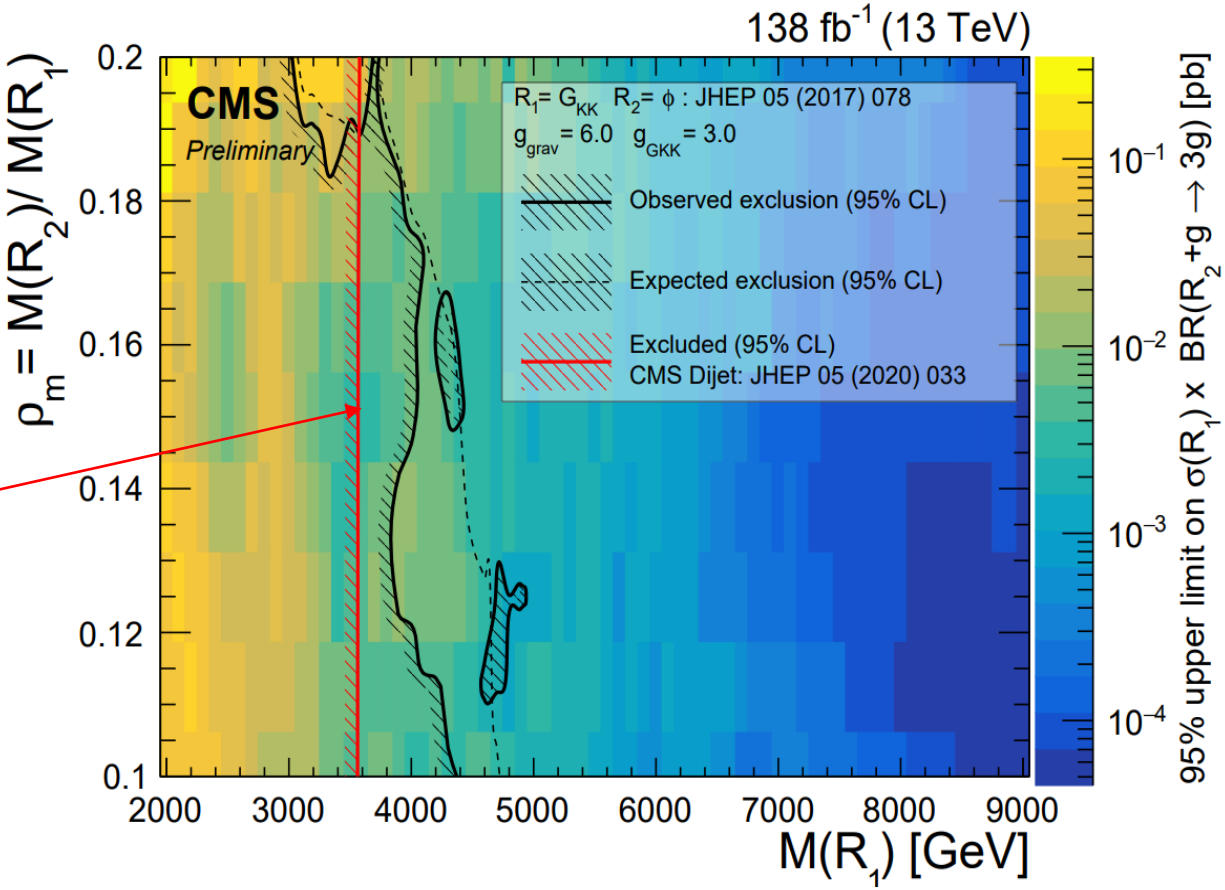
- Results interpreted in Warped Extra Dimension model (Agashe et al. JHEP 05 (2017) 078)

$q\bar{q} \rightarrow g_{KK} \rightarrow \phi g \rightarrow 3g$ (g_{KK} = *Kaluza-Klein gluon;* ϕ = *radion)*



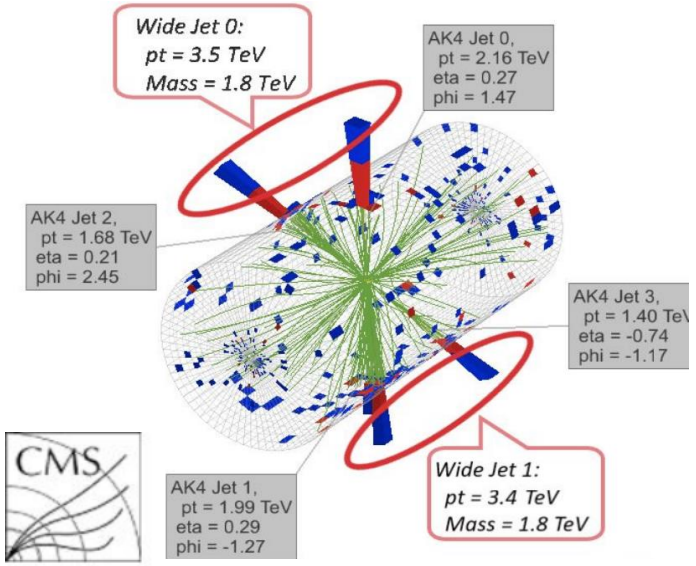
CMS Dijet search constraints
JHEP 05 (2020) 033
$qq \rightarrow g_{KK} \rightarrow qq$

Significant increase in sensitivity to this model of new physics



Future prospects

- The LHC Run 3 will start in 2022:
  - Expect similar integrated luminosity as Run2
  - Center-of-mass energy $\sqrt{s} = 13\text{-}14\ TeV$
- Mild improvement expected from the increment of data sample size
- Increase of energy will have considerable impact on sensitivity only for very high masses ($> 6 - 7\ TeV$)
- The collection of new data must proceed in parallel with analysis improvements:
  - Exploration of new final states (including boosted objects)



CMS dijet event with second highest invariant mass ($8\ TeV$)