Searches for new heavy resonances decaying into two Higgs bosons or a W/Z and a Higgs bosons at CMS

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on behalf of the CMS Collaboration
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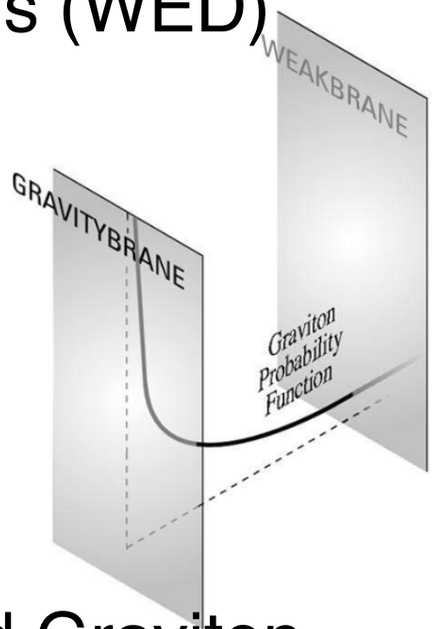
4th September 2017

Theoretical motivation

Warped Extra Dimensions (WED) models:

- solution to the hierarchy problem

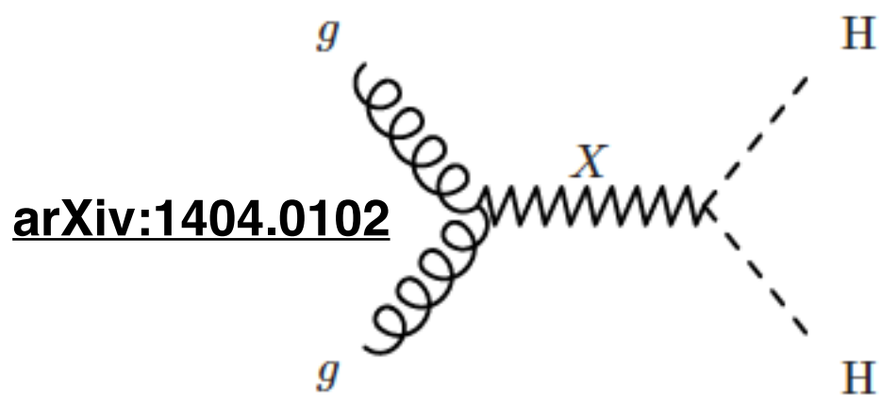


- Radion (spin 0) and Graviton (spin 2)
- New physics scale depends on warp factor $k/\bar{M}_{Pl} \sim 1$TeV
- sizable decay to HH (Radion 23% and Graviton 10%)

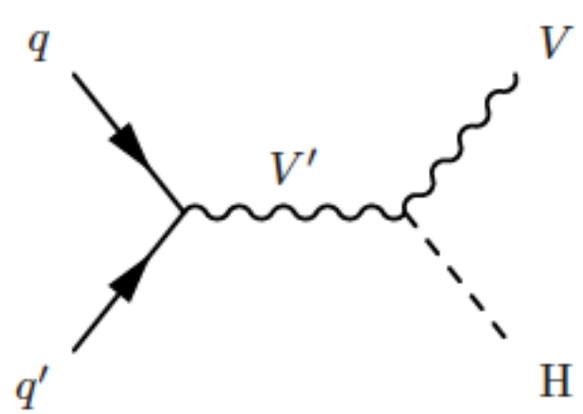
Heavy W' and Z' predicted by several models: Composite Higgs, Little Higgs

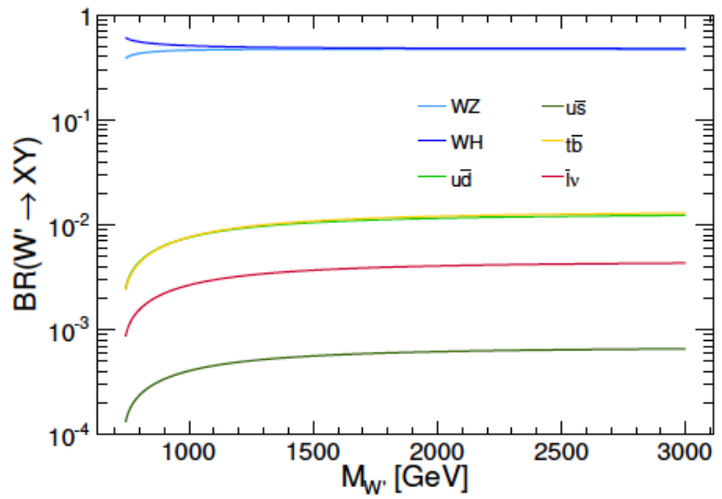
- generalized through the heavy vector triplet (HVT) simplified Lagrangian
- 3 fields: V'^{+}, V'^{-}, V'^{0}
- 2 scenarios for the coupling:
  -one to fermions dominating (Model A);
  -one to SM bosons enhanced (Model B);

JHEP09(2014)060



arXiv:1404.0102

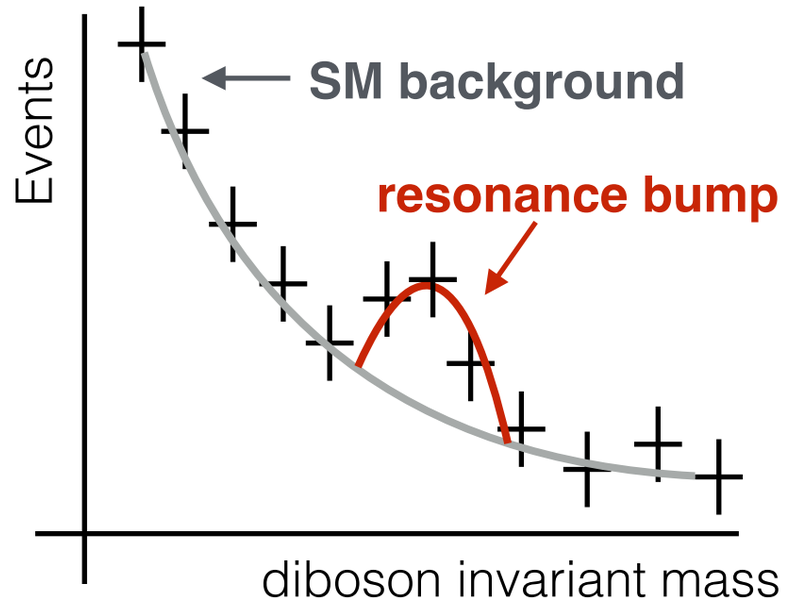




Search for diboson resonances

Common strategy of searches for narrow resonance:

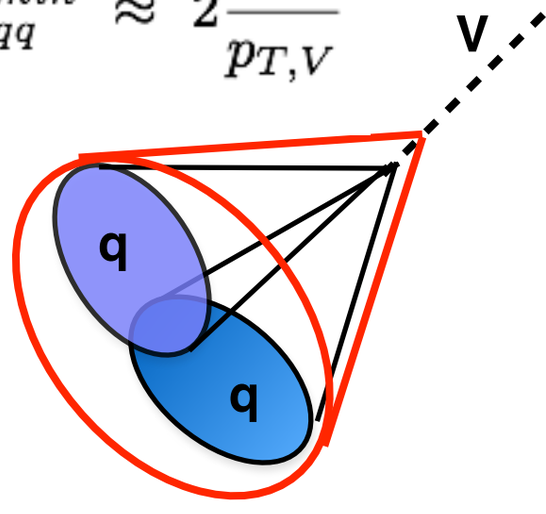
- identify the two bosons
- build the invariant mass of the system
- ➔ the new resonance would manifest as a “bump” on the smoothly decreasing standard model (SM) background



Experimental challenges:

- SM bosons decay preferably into quarks pairs
- For heavy resonances the SM bosons get high boost
- Their products can be collimated and merge into a single jet
  ➔ clustered within a large-cone jet (R = 0.8)
- Groomed jet mass to mitigate pileup contamination
- Investigation of the jet substructure to identify hadronic decays V→qq/H→bb

$$\Delta R_{qq}^{min} \approx 2\frac{M_V}{p_{T,V}}$$

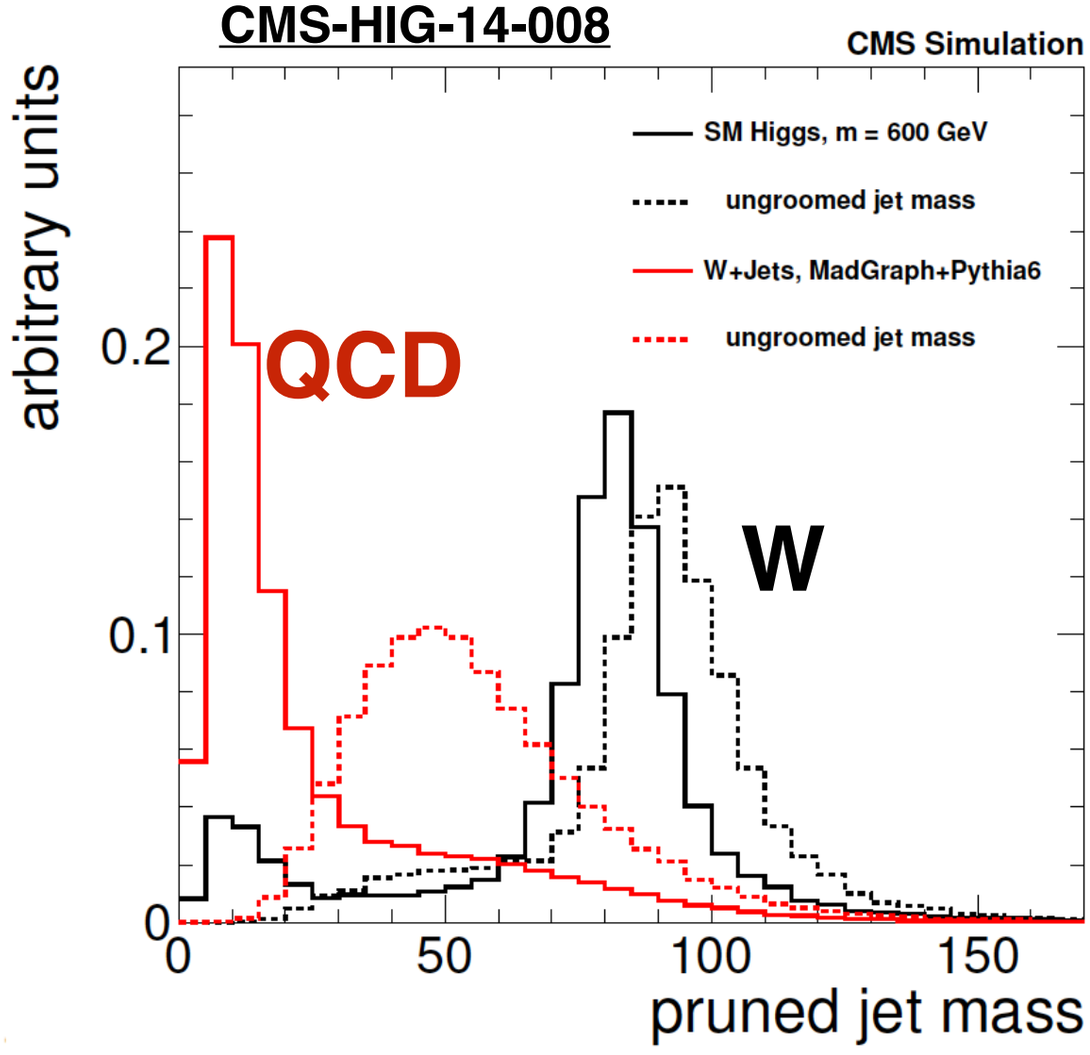


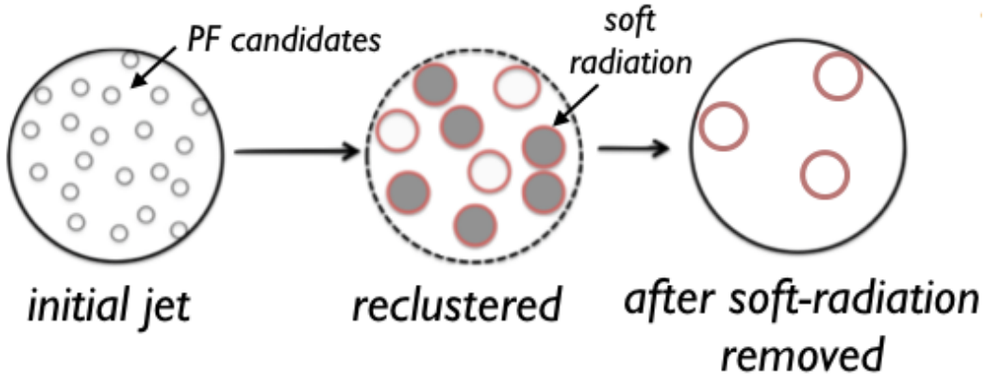
Groomed jet mass

Grooming techniques used to distinguish between jets originated:

- from single quark/gluons
- from boson→ quark pairs

soft and large angle emissions in the jets are filtered out and single quark/gluon- initiated jet masses are push towards zero





Groomed jet mass

The soft drop algorithm is used as grooming technique in combination with pileup mitigation by Pile Up Per Particle Identification (PUPPI) algorithm **JHEP05(2014)146**

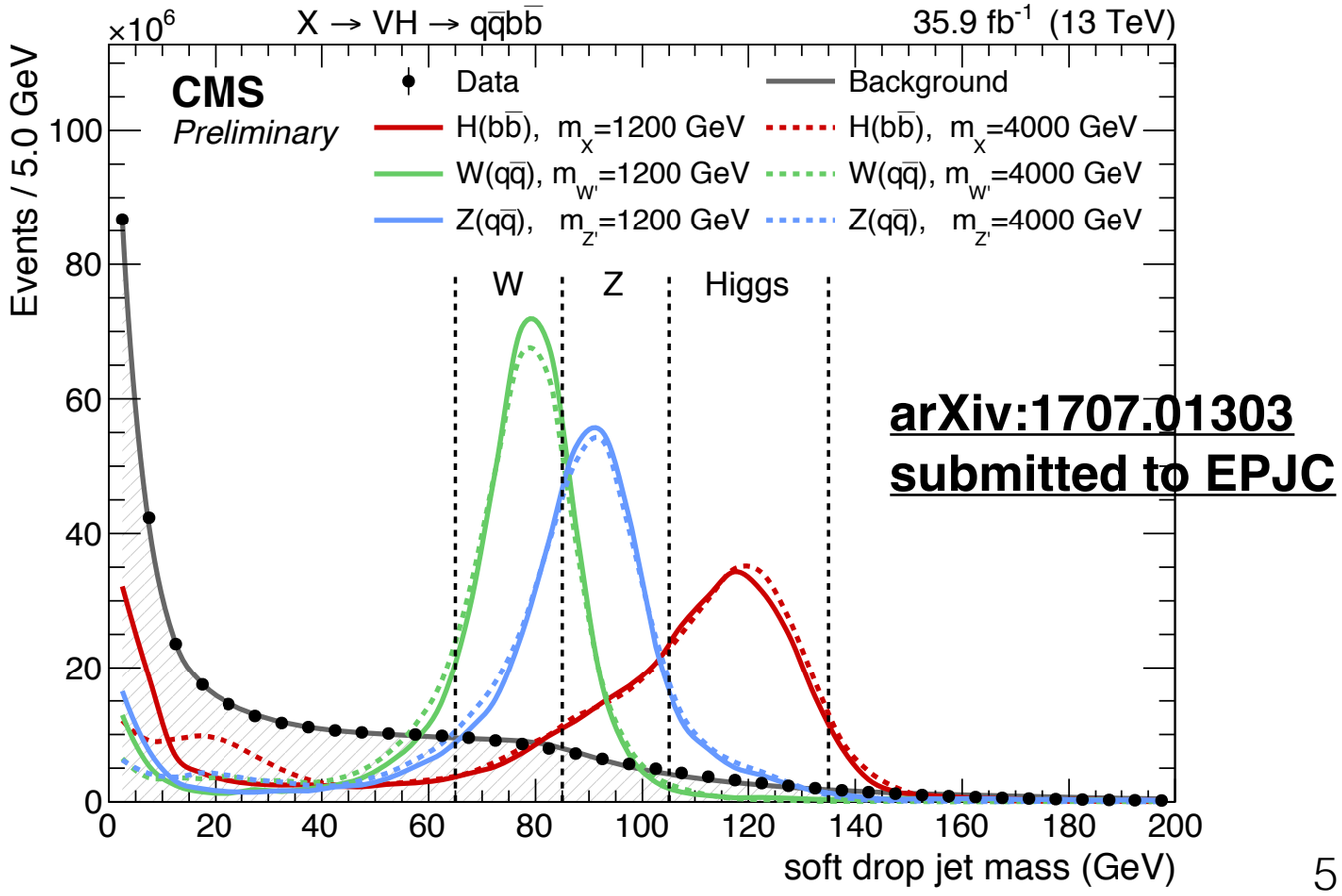
- combines event pileup properties, local shape information, and tracking information before the large-cone jet clustering **JHEP10(2014)059**

Soft drop + PUPPI combination:

- stable vs pileup
- good m_j resolution (10%)

Jet mass windows:

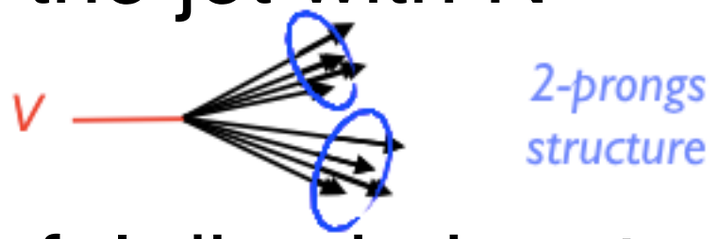
W-enriched 65 < mj < 85 GeV
Z-enriched 85 < mj < 105 GeV
Higgs-enriched 105 < mj < 135 GeV



Jet substructure

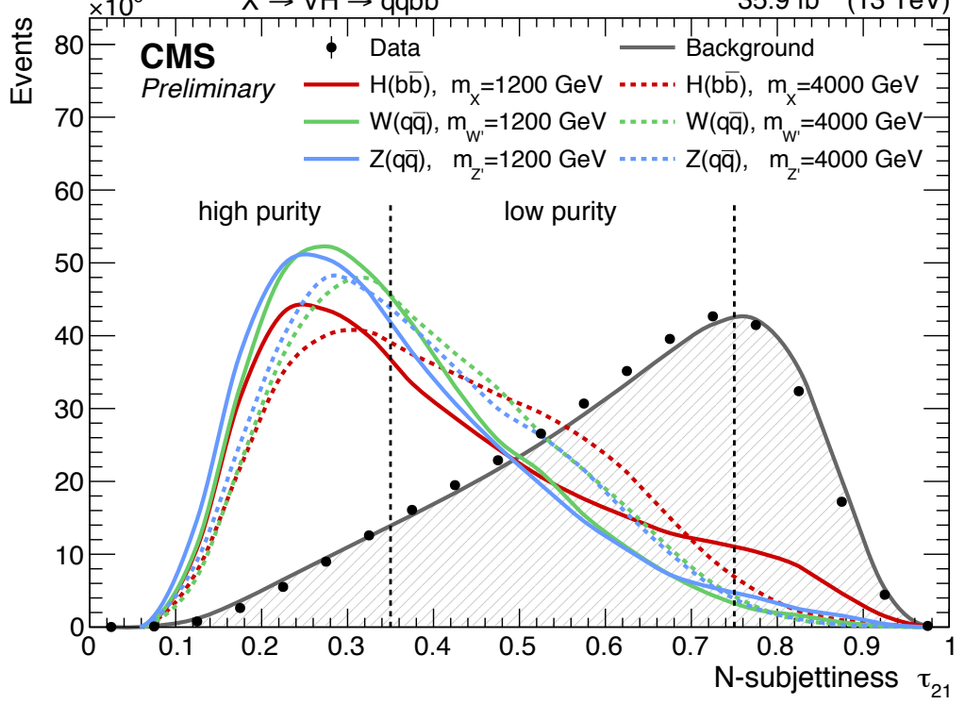
JHEP03(2011)015

N-subjettiness represents the compatibility of the jet with N sub-jets hypothesis



- the 2- over 1-subjettiness ratio (τ_{21}) powerful discriminant between single quark- or gluon- initiated jet and jets originated from two partons

arXiv:1707.01303
submitted to EPJC



Usually two categories are used by analyses:

- High signal purity (HP):
  $\tau_{21} < 0.35$
- Low signal purity (LP):
  $0.35 < \tau_{21} < 0.75$

The combination of the soft drop mass requirement and τ_{21} is referred as V-tagging : 50-55% signal efficiency at 1-2% mis-Id rate for jet p_T 1 TeV

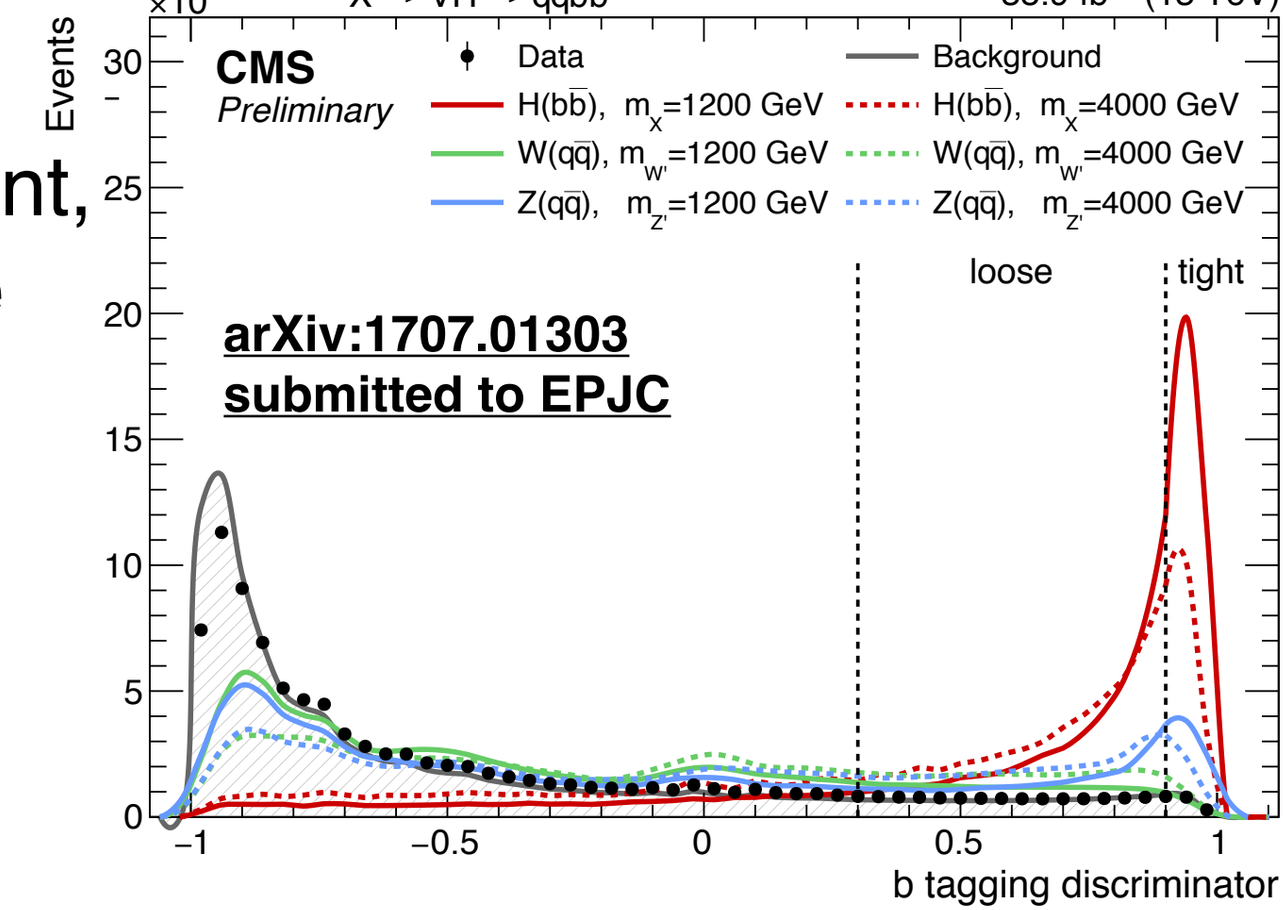
Higgs boson tagging

Double-b tagger algorithm based on multivariate approach:

- combines b-hadron specific information with substructure observables **CMS-BTV-15-002**
- exploits correlation between vertexing and tracking
  - b-hadron flight directions and the two N-subjettiness axis directions

Selection is analysis dependent, but usually two categories are used:

- Tight: eff ~30%, mis-id <1%
- Loose: eff ~80%, mis-id <10%

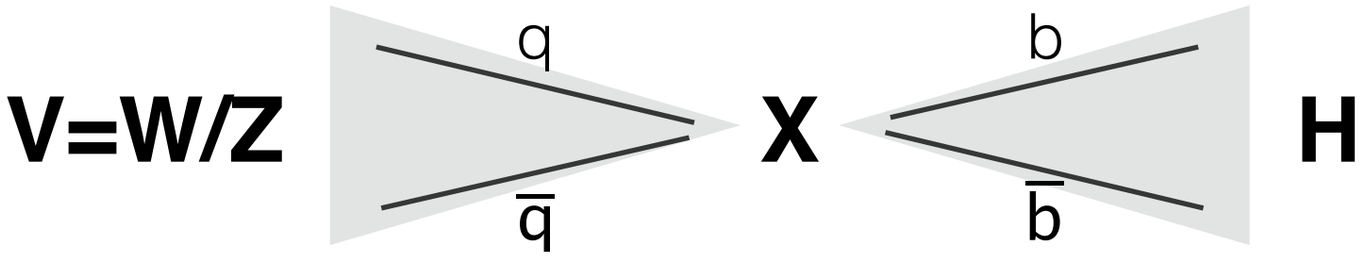


Analyses

The analyses presented in this talk are:

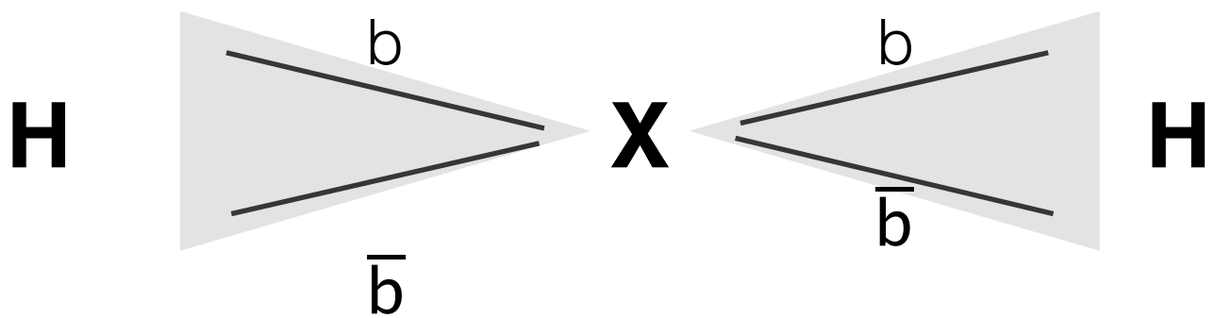
- $VH \rightarrow \bar{q}q\bar{b}b$

  CMS-B2G-17-002



- $HH \rightarrow \bar{b}b\bar{b}b$

  CMS-B2G-16-026



X→VH→q̄q b̄b

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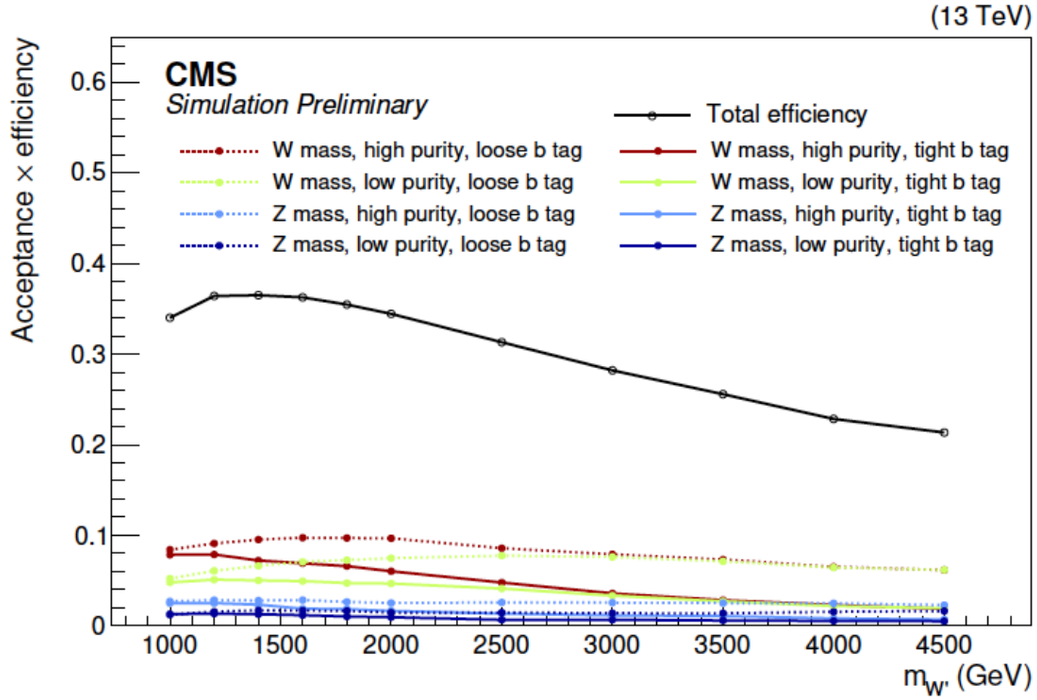
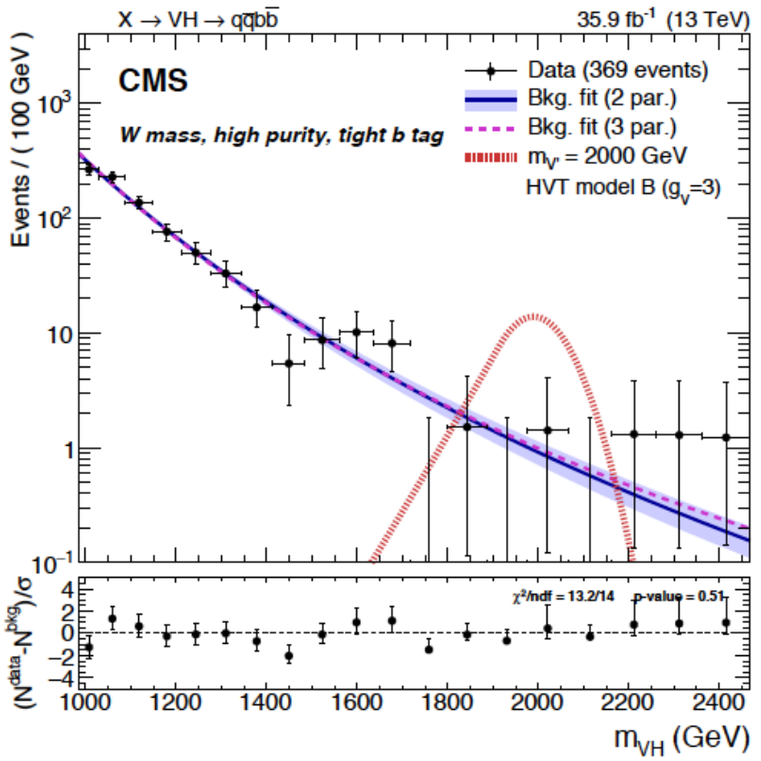
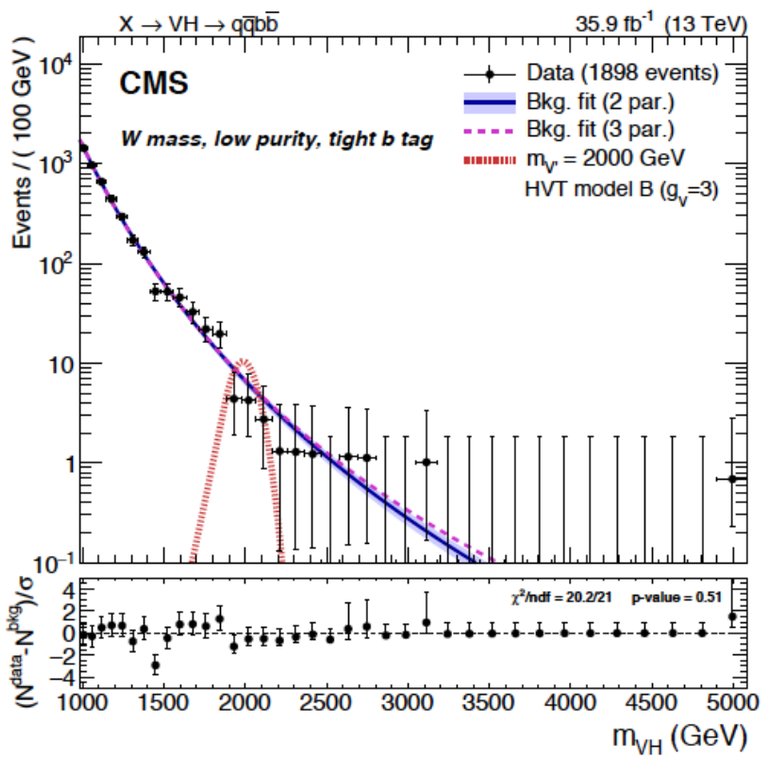
All hadronic search for V→q̄q and H→ b̄b resonances

- at least 2 large cone jets
  with p_T >200 GeV, |η|<2.5, |Δη|<1.3
- Require one V-tagged + one H-tagged jet
- Eight categories depending on:
  - the V mass windows (W or Z)
  - τ_{21} purity selection (HP or LP)
  - double b-tagger discriminator (loose or tight)



Bump hunt:
data are fit assuming for backgrounds smoothly functions





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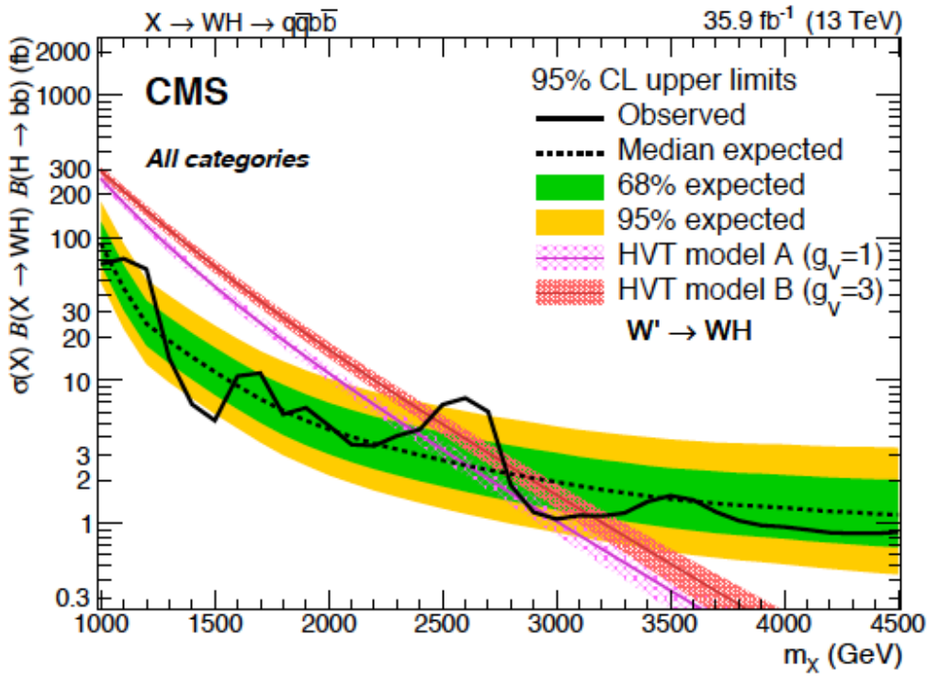
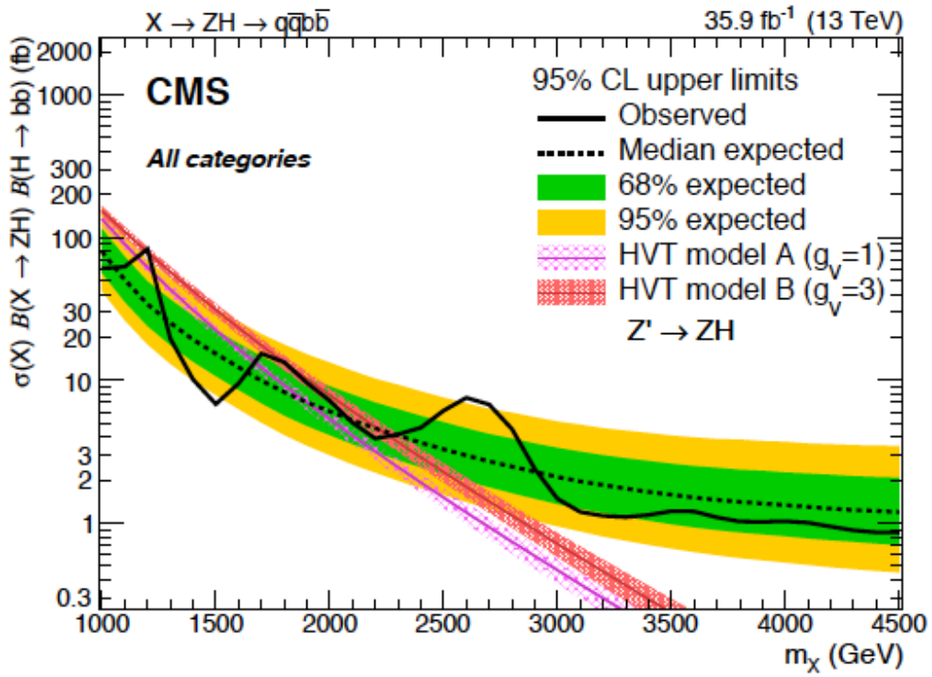
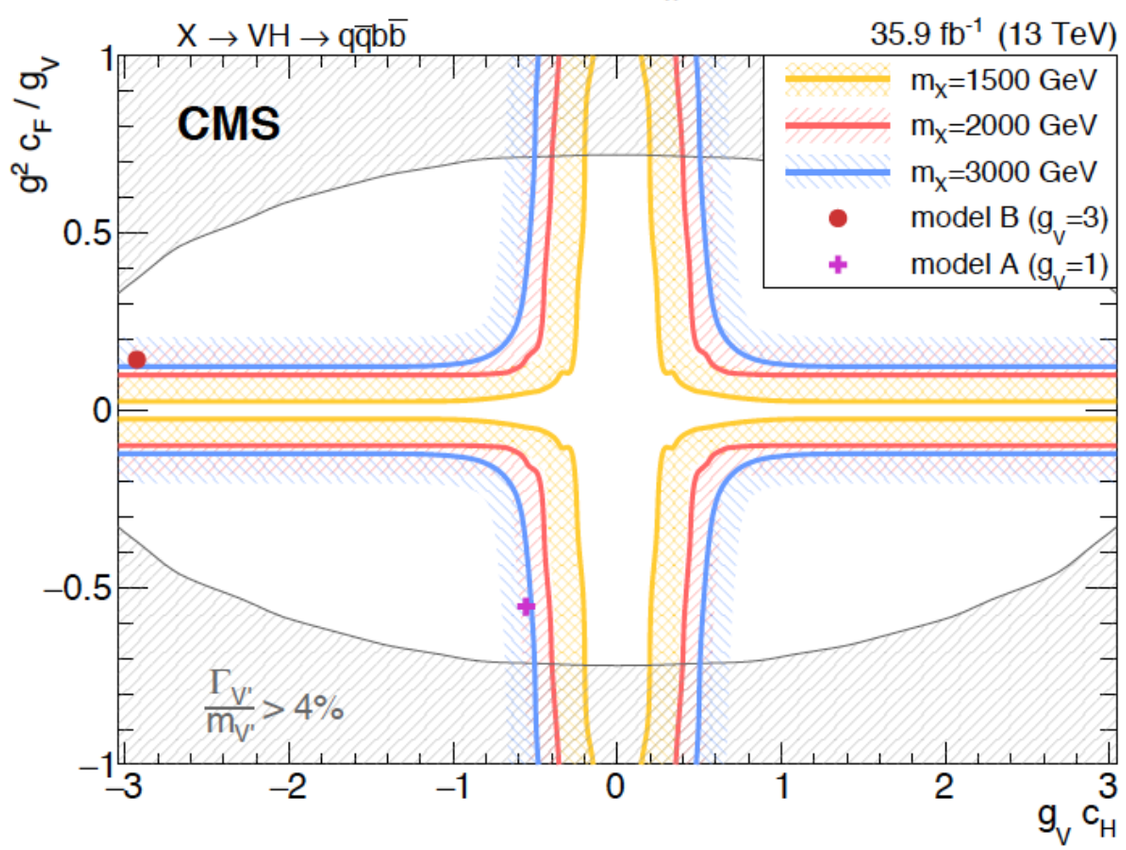




No significant excess is found in data

Combined exclusion in HVT triplet hypothesis ($M_{V'} < 3.4$ TeV)

Interpretation of model A and B in the HVT parameter space

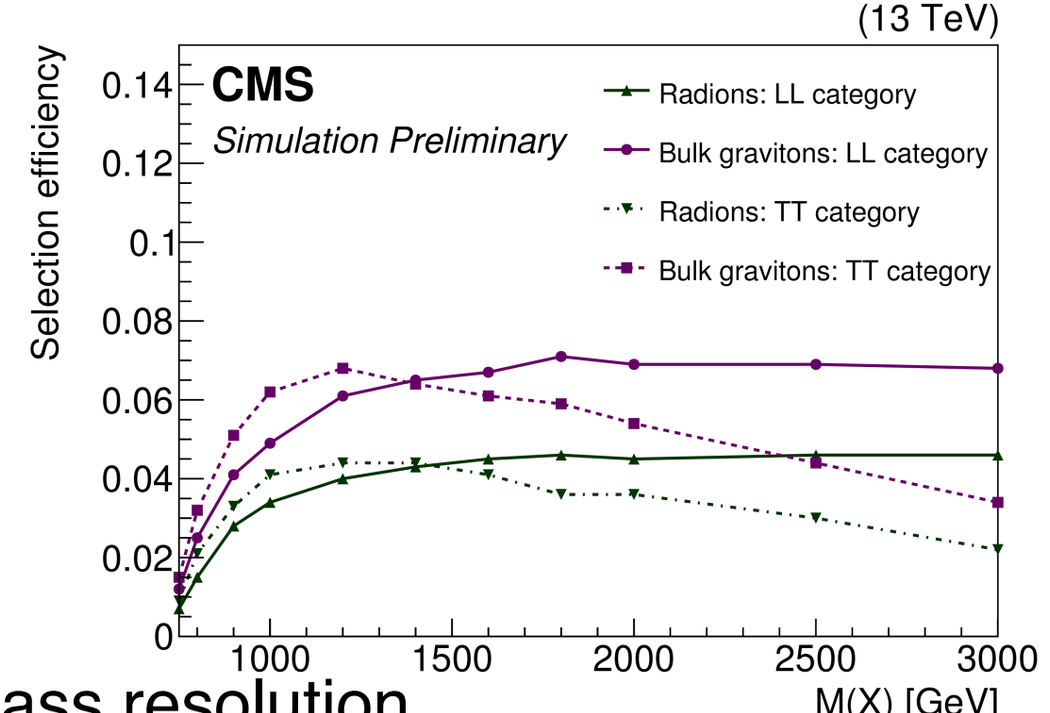


X→HH→ b̄b b̄b

CMS-B2G-16-026

All hadronic search for HH resonances

- Require two H-tagged jets:
  soft drop + N-subjettiness τ_{21}
- Categories based on double b-tagger discriminator for the two jets:
  Loose-Loose (LL) and Tight-Tight (TT)

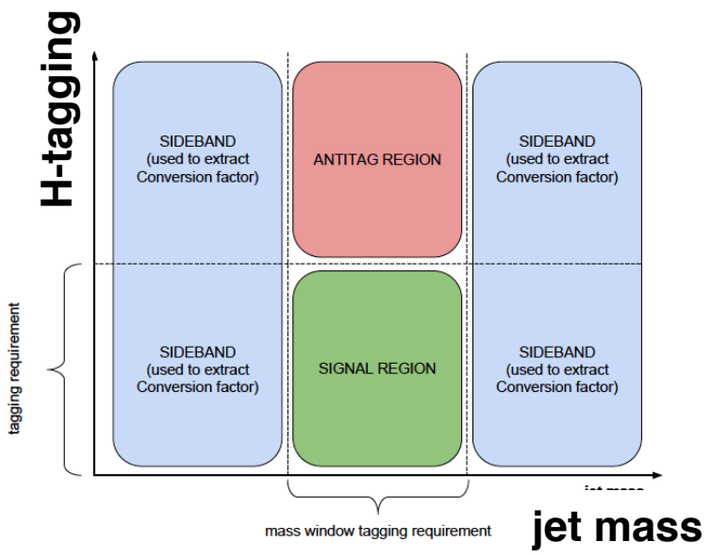


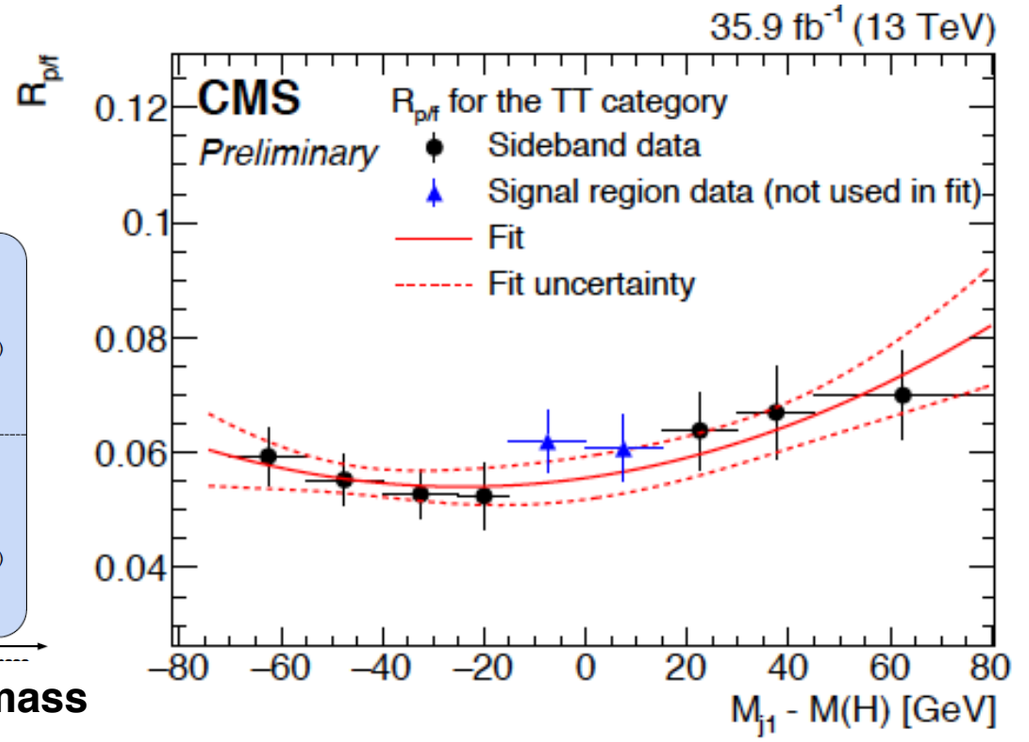
Reduced invariant mass to improve resonance mass resolution

$$M_{jj}^{red} = M_{jj} - (M_{j1} - M_H) - (M_{j2} - M_H)$$

Main background from multi-jet production

- Normalization from sideband in data defined from jet mass region and inverted b-tagging regions





X→HH→ b̄b b̄b

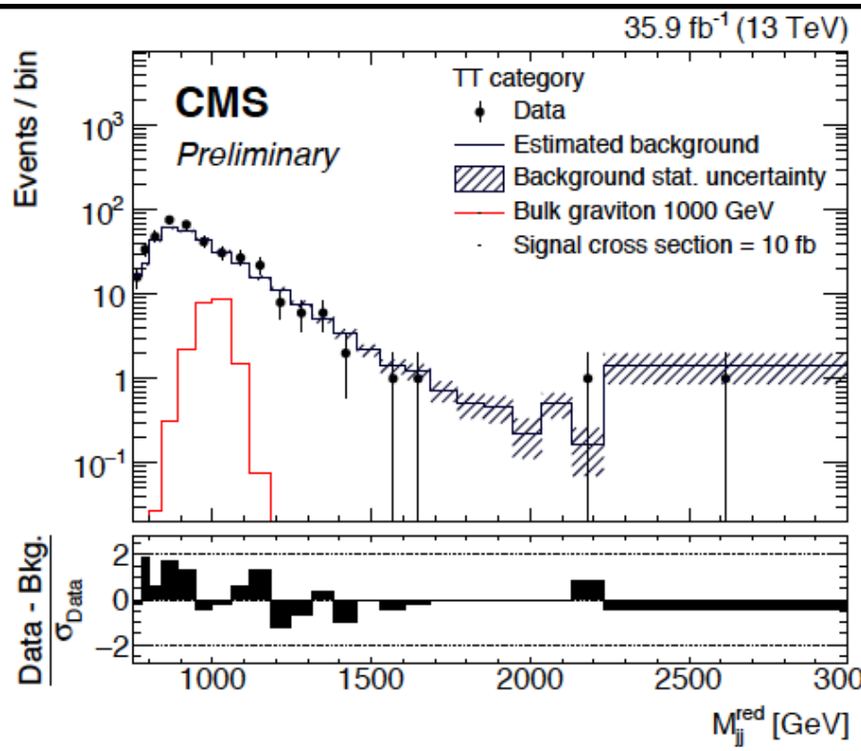
CMS-B2G-16-026

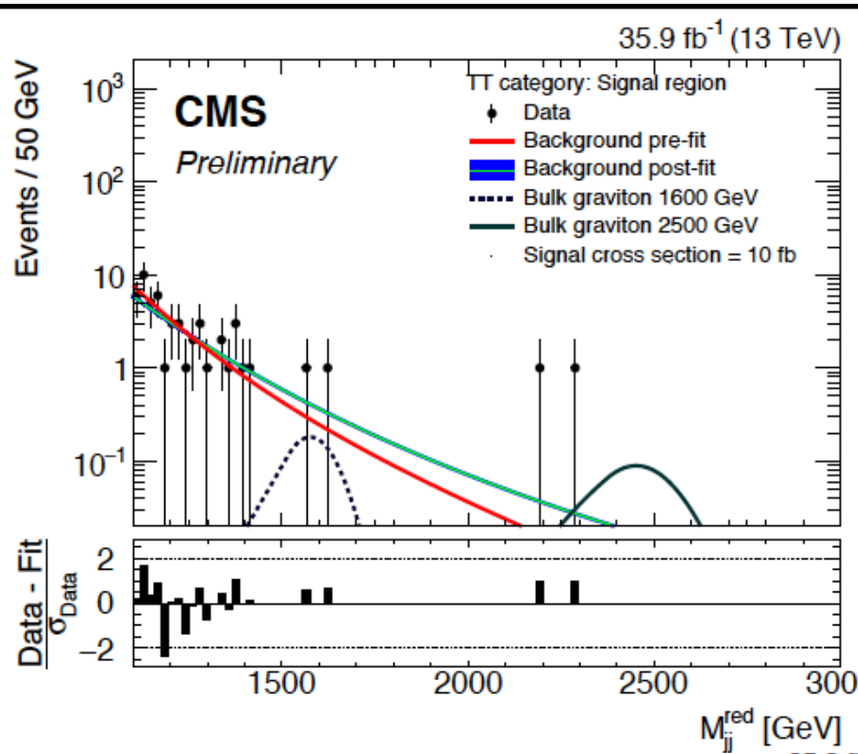
Alphabet method for M_{jj}^{red} <1.2 TeV

- Normalization from sideband
- Shape from anti-tagged events

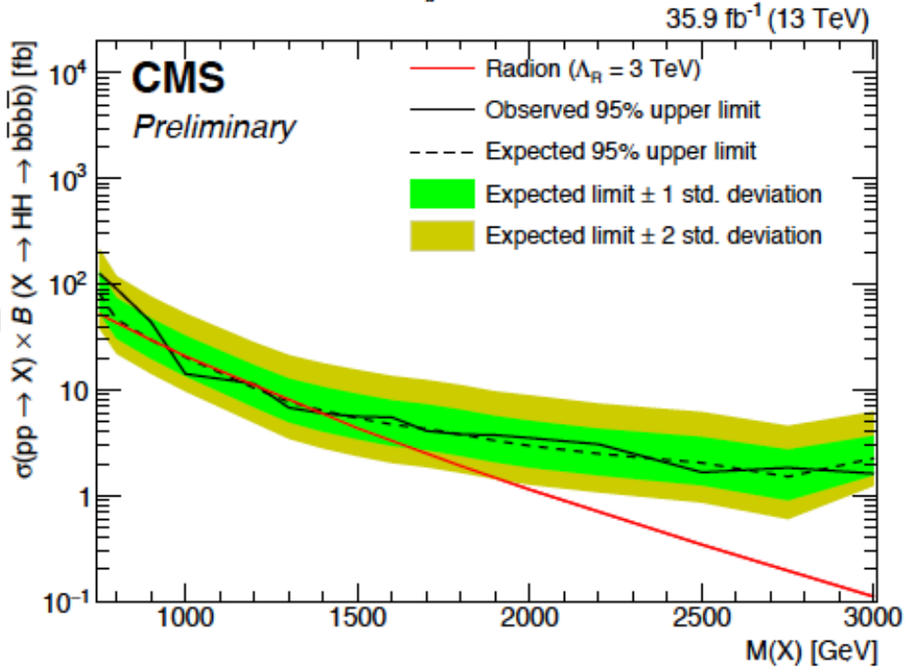
Smooth fit method for M_{jj}^{red} >1.2 TeV

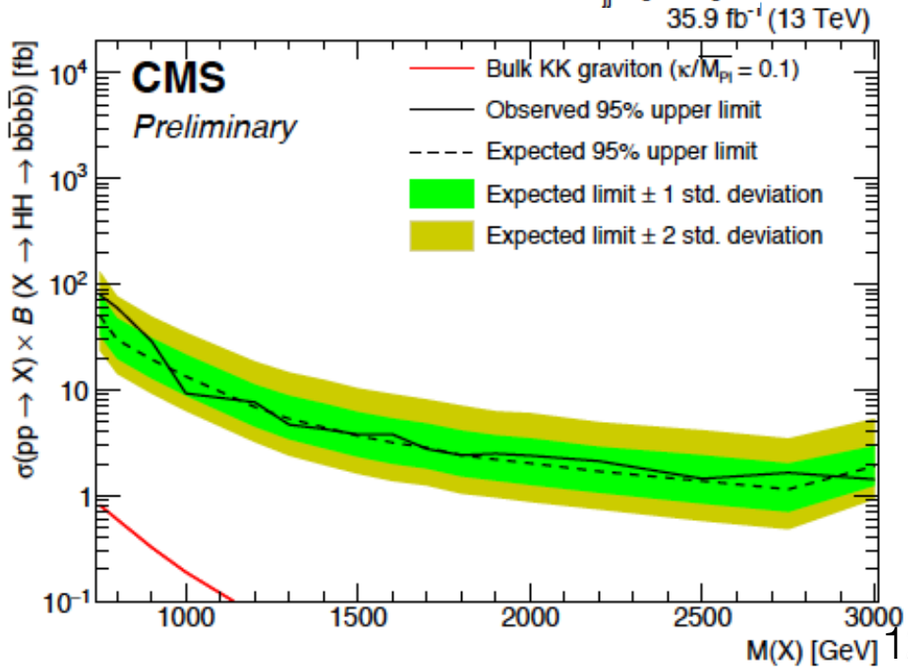
- Normalization from from sideband
- Simultaneous fit of signal and background in tagged and anti-tagged events





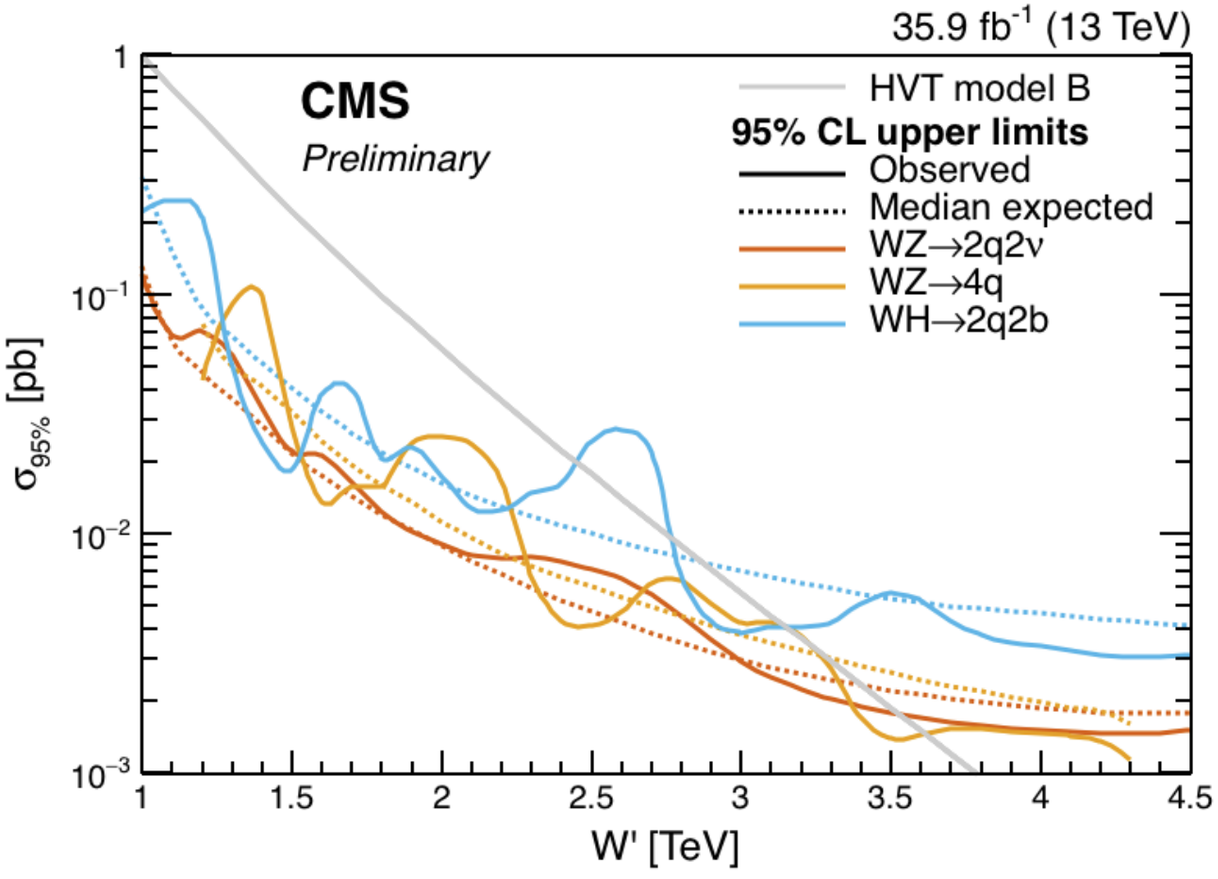
Limits on narrow spin-0 radion and spin-2 bulk graviton production cross sections

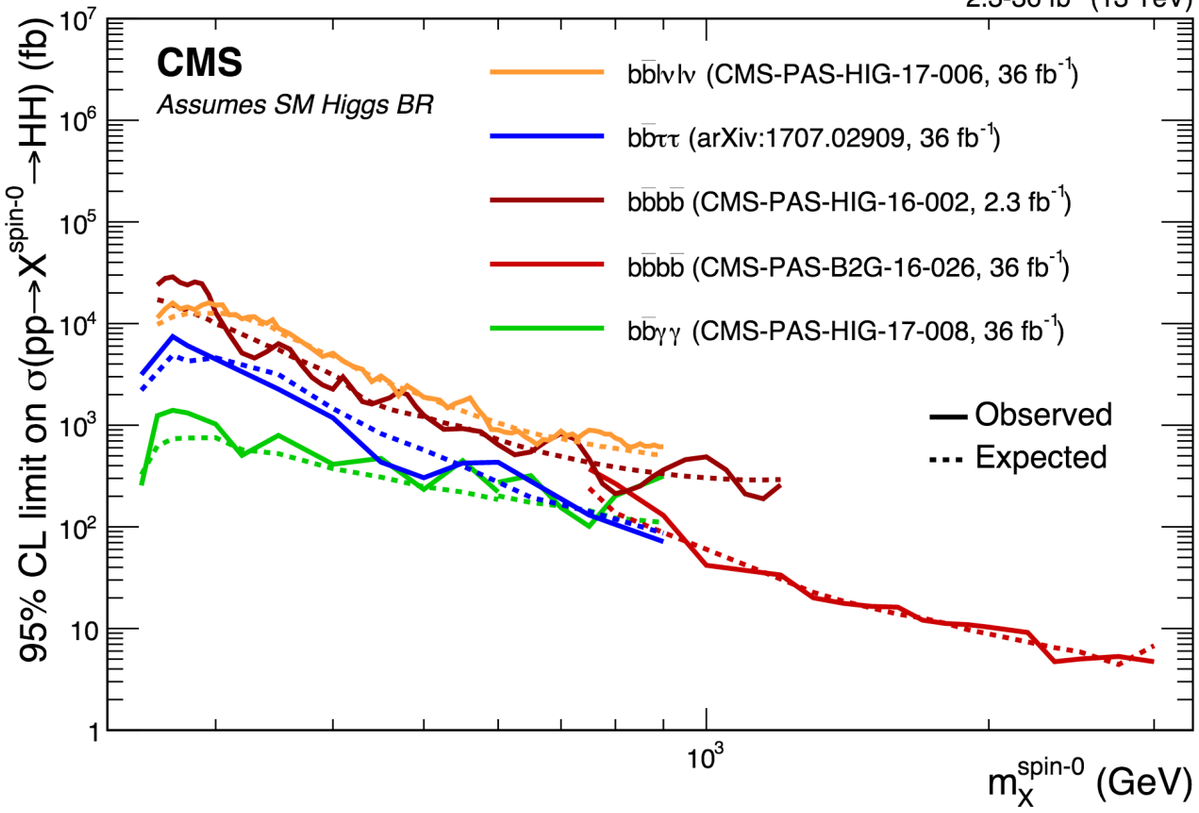




Comparison with other searches

X→HH→ $\bar{b}\bar{b}\bar{b}\bar{b}$ result nicely extends the mass spectrum to few TeV





X→VH→ $\bar{q}q\bar{b}\bar{b}$ shows similar sensitivity as other diboson searches

Final remarks and conclusion

Most recent CMS results of VH and HH searches have been presented

Many other searches of W, Z, H heavy resonances have been already performed and others are on their way

These searches use common reconstruction methods, selection on substructure variables and strategies

The analyses have similar sensitivities to common benchmark models and their combination will improve the current results

Thanks for your attention!!

Back up

W, Z, H reconstruction and identification

The soft drop algorithm filters out soft and large angle emissions
➔ The mass of a single quark/gluon-originated jet is pushed towards zero

JHEP05(2014)146

Contribution from pileup is not fully removed by soft drop so it is combined with pileup mitigation by Pile Up Per Particle Identification (PUPPI)

- combines event pileup properties, local shape information, and tracking information before the large cone jet clustering **JHEP10(2014)059**

Soft drop + PUPPI combination:

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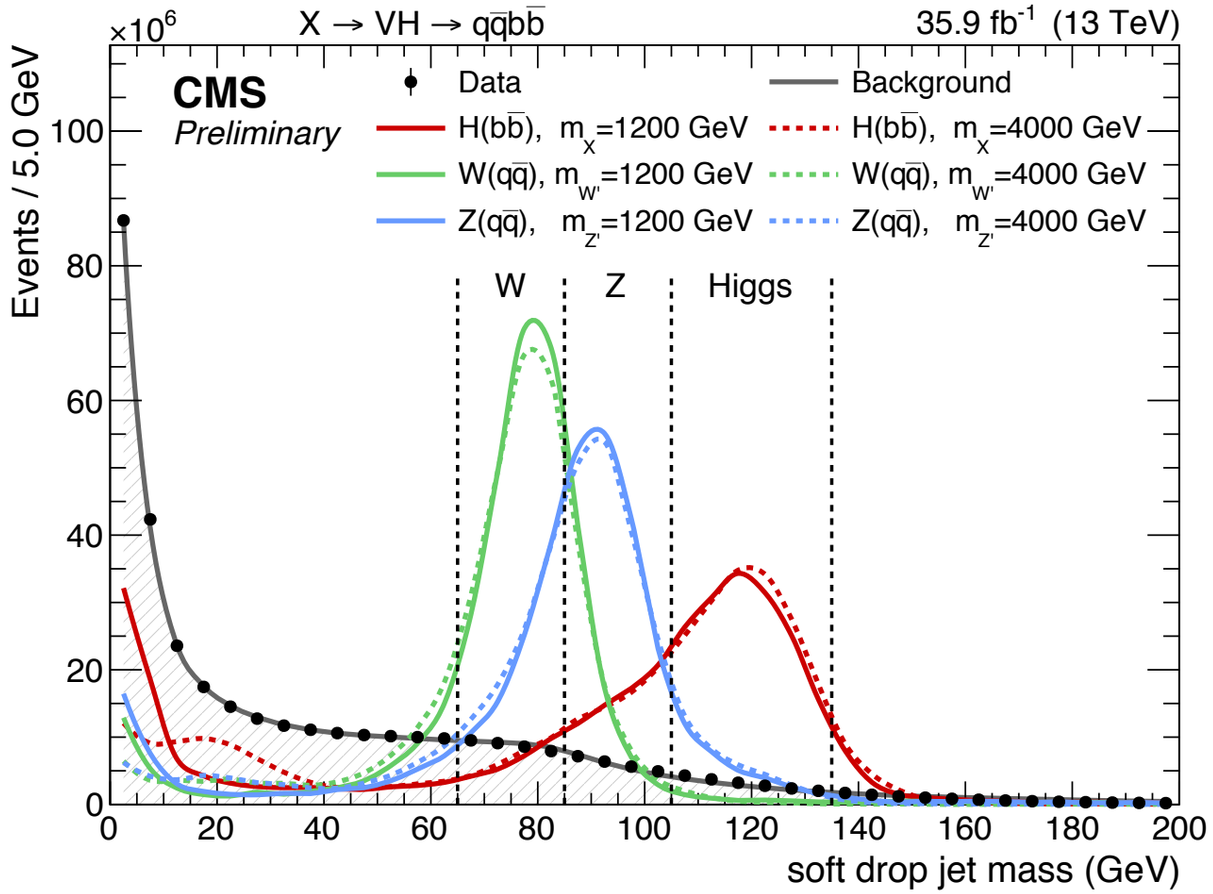

W, Z, H reconstruction and identification(II)

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JHEP03(2011)015

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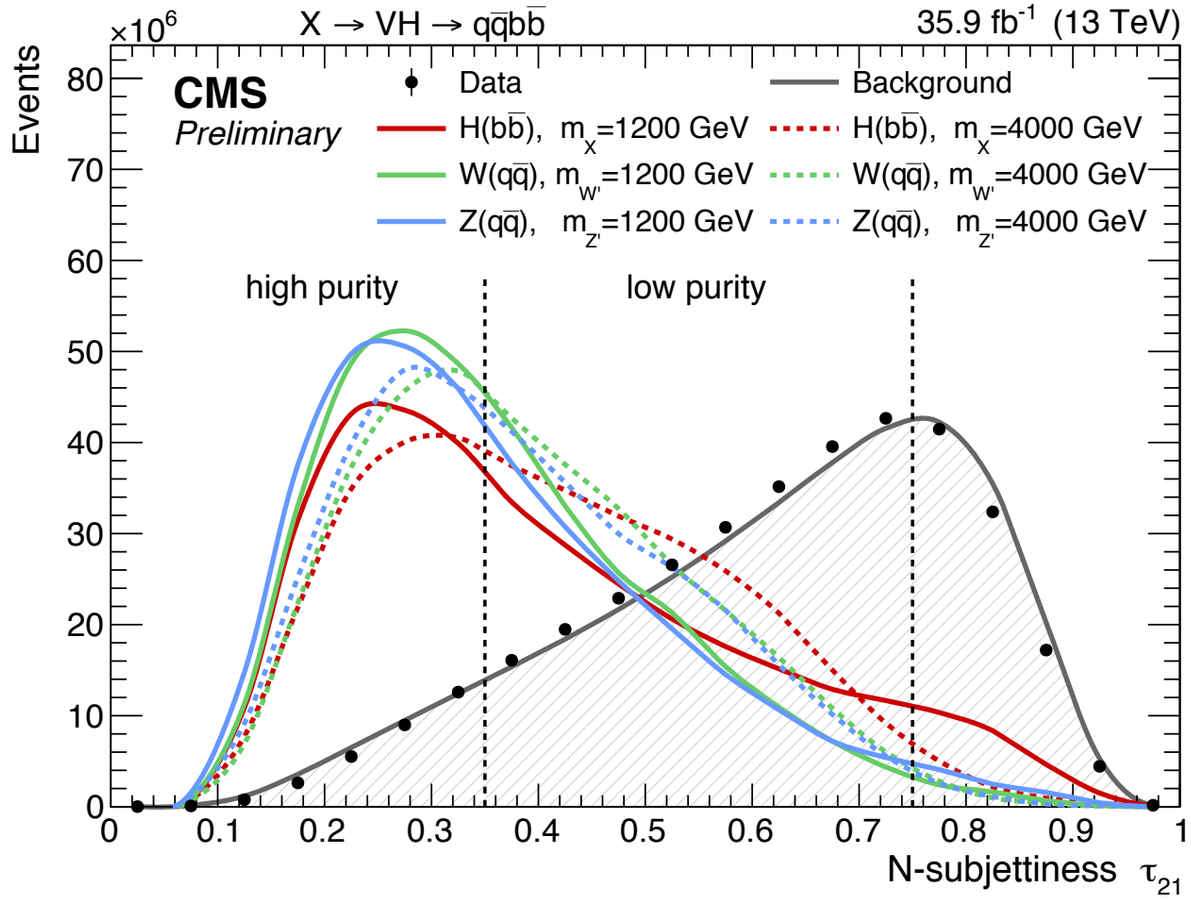

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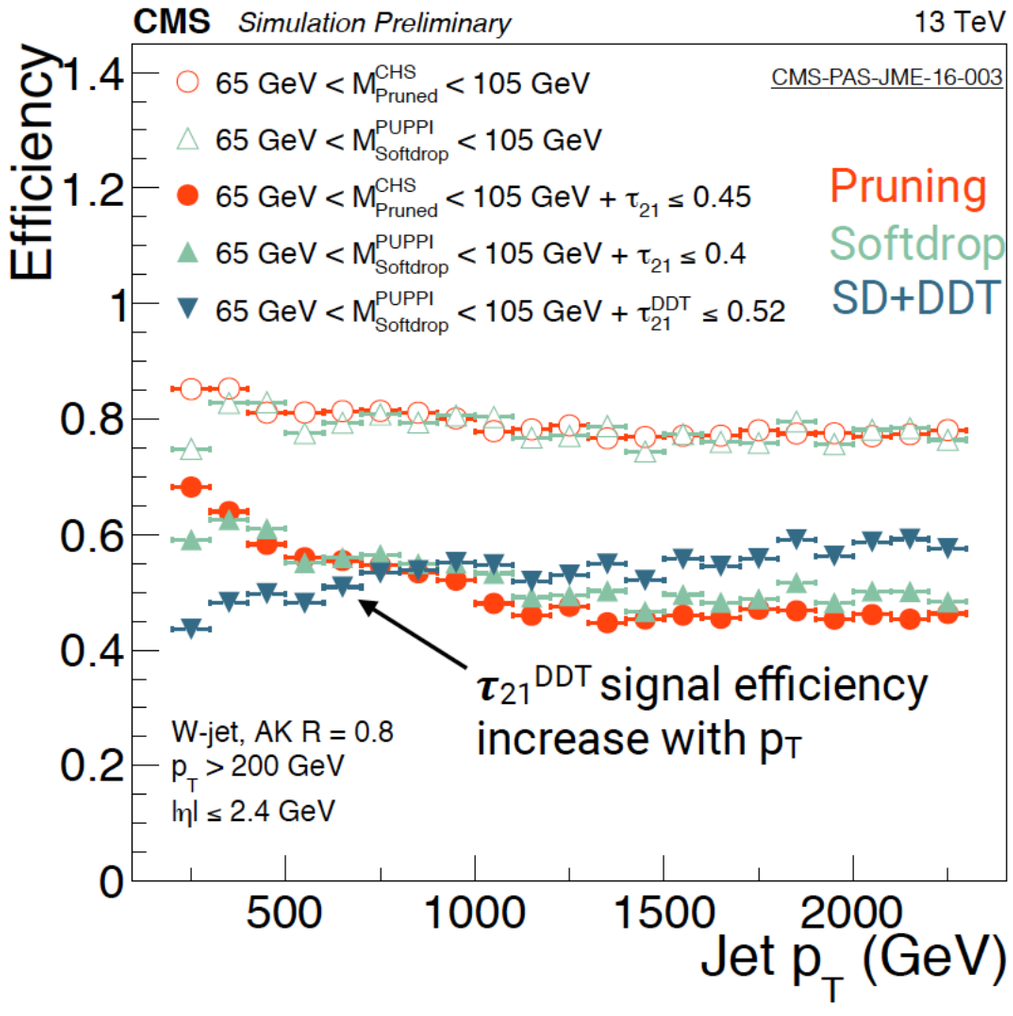
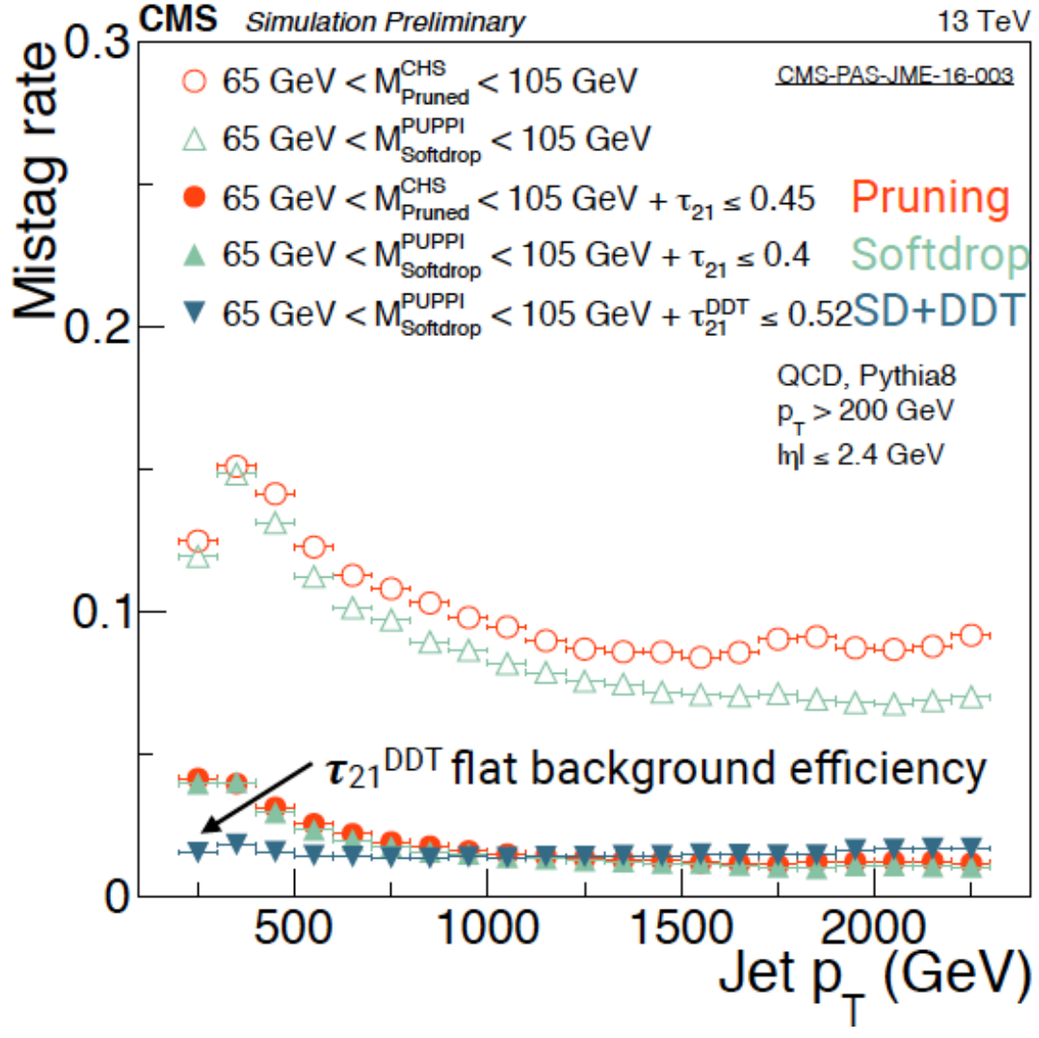
V-tagging





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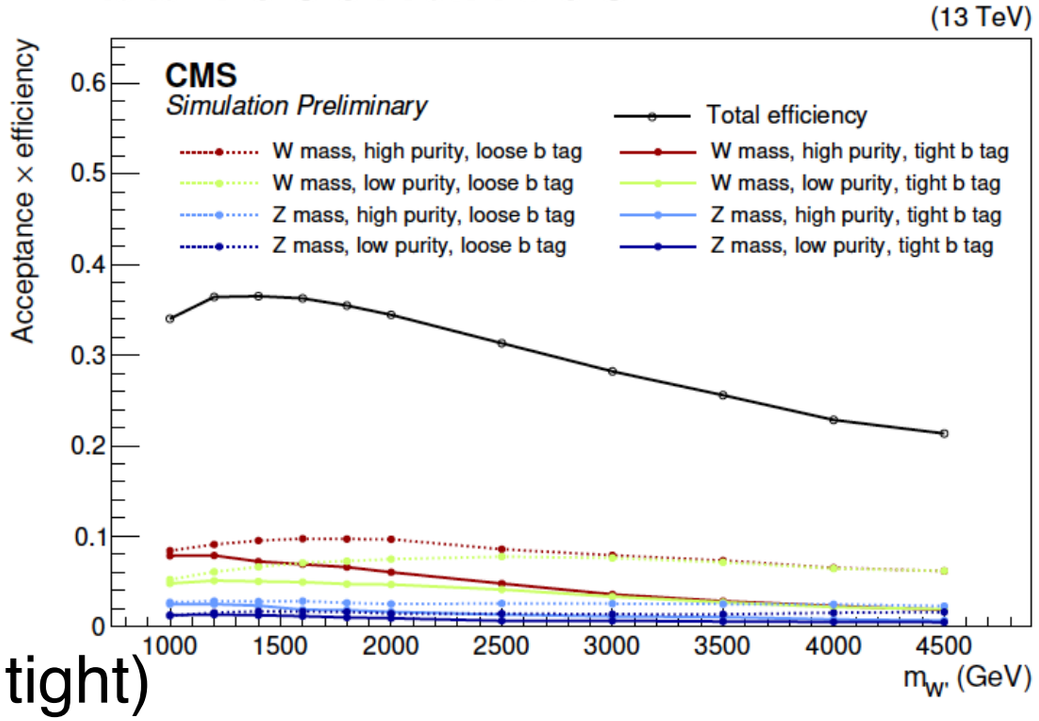
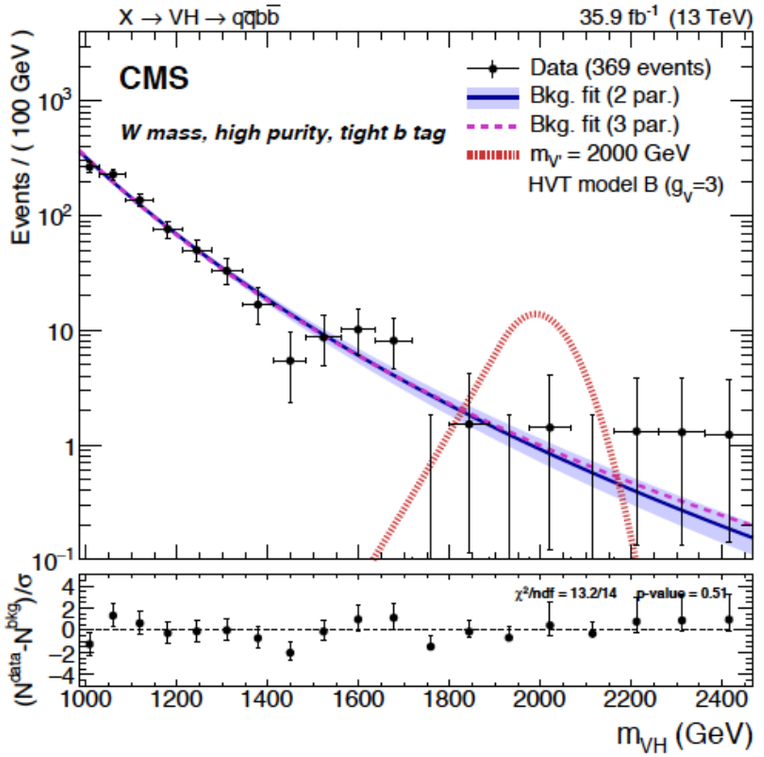
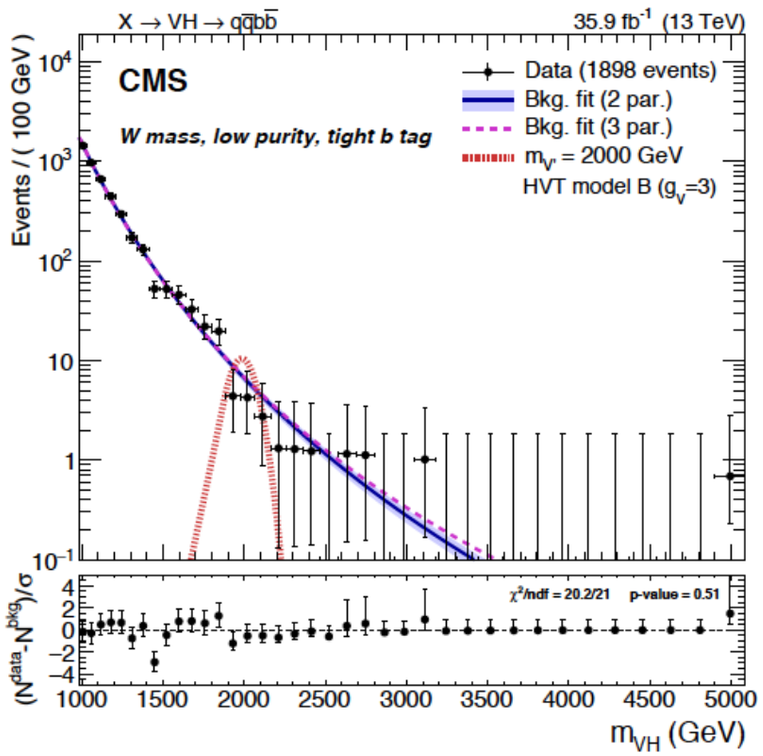
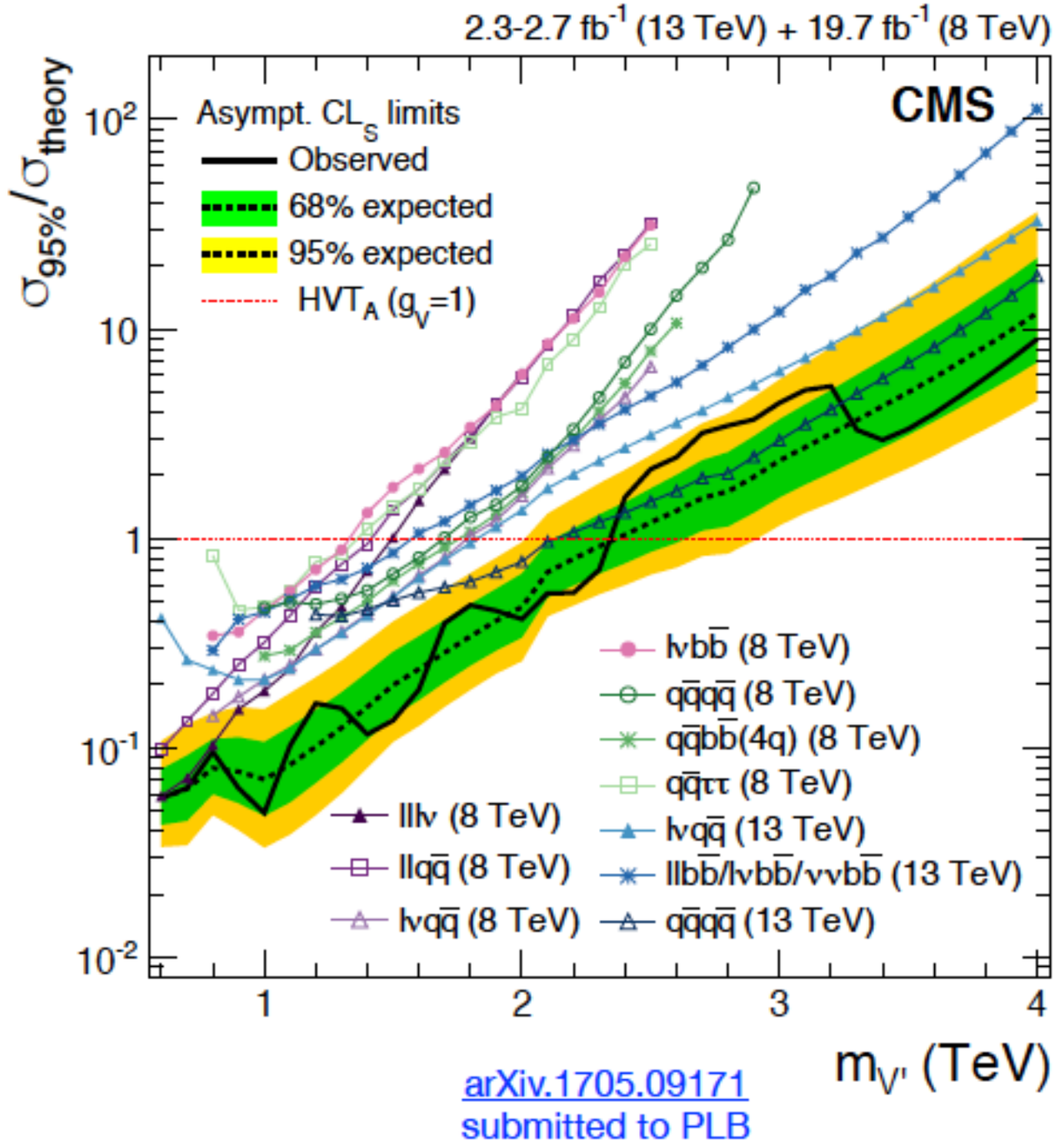


Bump hunt:
data are fit assuming for backgrounds smoothly decreasing power laws functions with 2-4 parameters (determined with Fisher test)





Combination



arXiv.1705.09171
submitted to PLB