Search for heavy resonances decaying to two Higgs with a 4 b final state with the CMS detector

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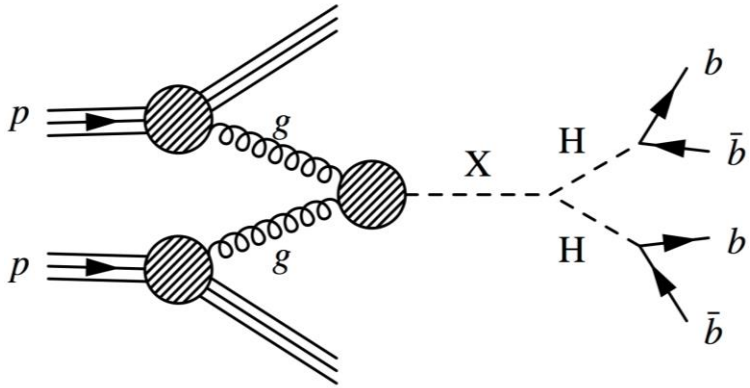
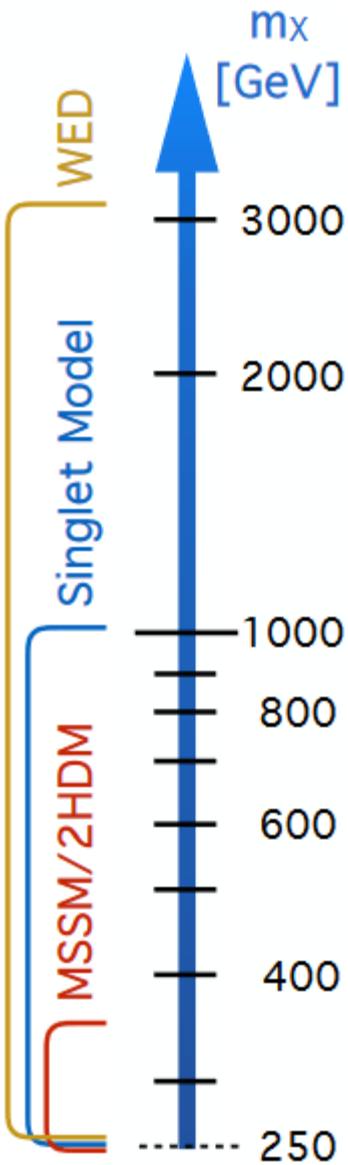
Introduction

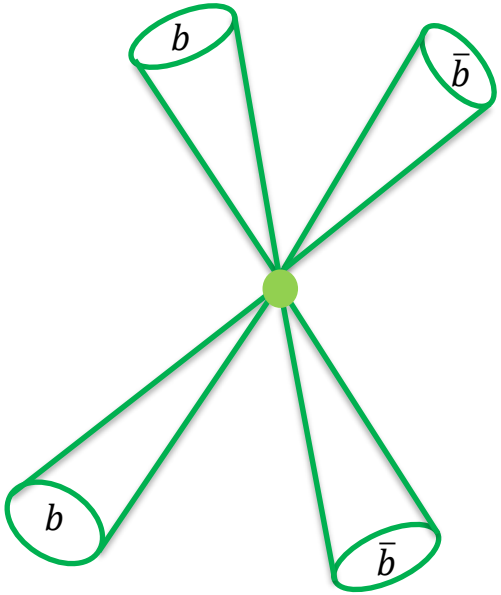
- Resonant HH production would be evidence of a new state, not predicted by the Standard Model
- Multiple beyond the standard model models predict this process
  - Minimal Supersymmetric Standard Model
  - 2 Higgs Doublet Model
  - Warped extra dimensions
    - Spin-0 Radion
    - Spin-2 Kaluza-Klien Graviton

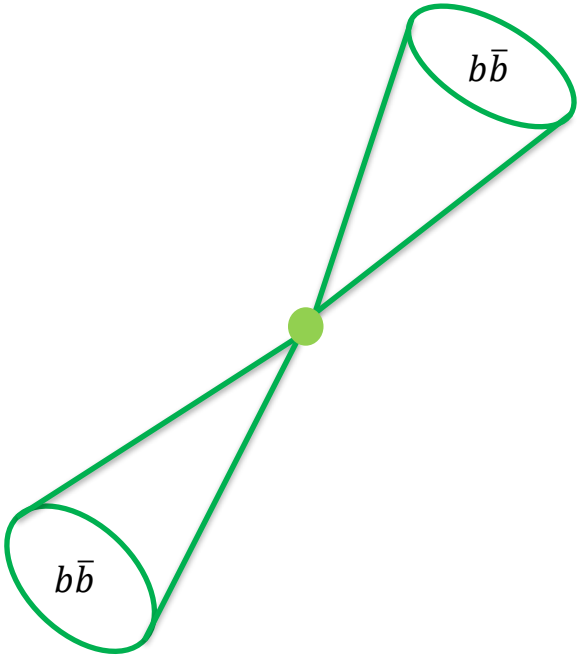




4b Final State

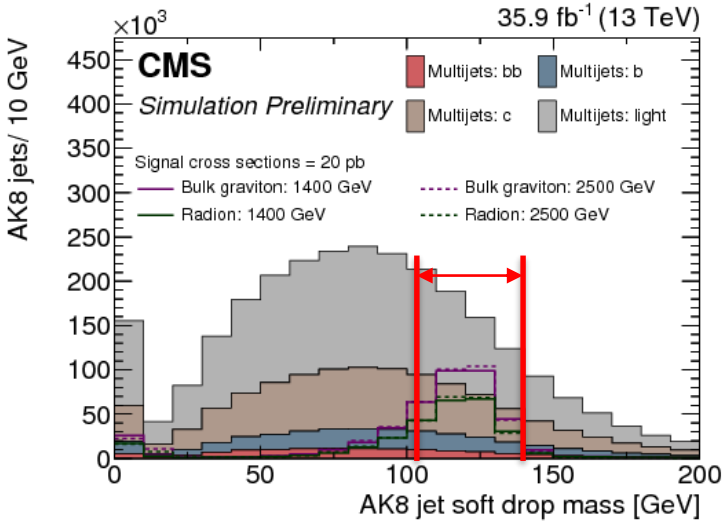
- H→bb is the largest branching fraction, ~58%
  - Hadronic production is the dominant process in pp collisions
- 2 event topologies
  - Resolved: each b quark is reconstructed as a separate $\Delta R = 0.4$ b jet ($\Delta R = \sqrt{\Delta\eta^2 + \Delta\theta^2}$)
  - Boosted: each Higgs is reconstructed as a separate $\Delta R = 0.8$ Higgs jet



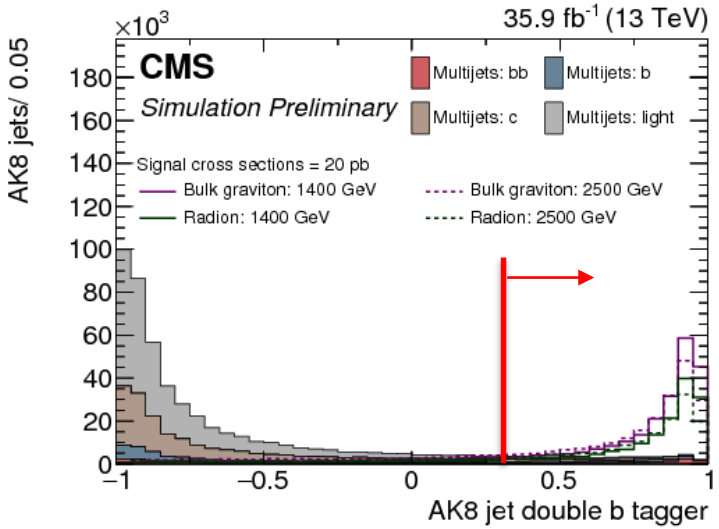


Higgs Jet Tagging

- Mass
  - Soft drop: recursively remove soft wide-angle radiation from a jet



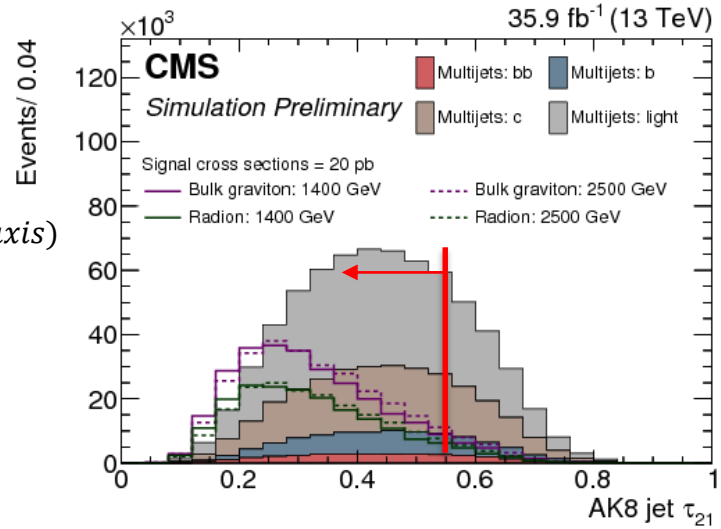
- b-tagging
  - Double-b tagger: holistically tag jets with 2 b quarks



- Substructure
  - N-subjettiness:

$$\tau_N \sim \sum p_T \times (Distance\ to\ nearest\ subjet\ axis)$$

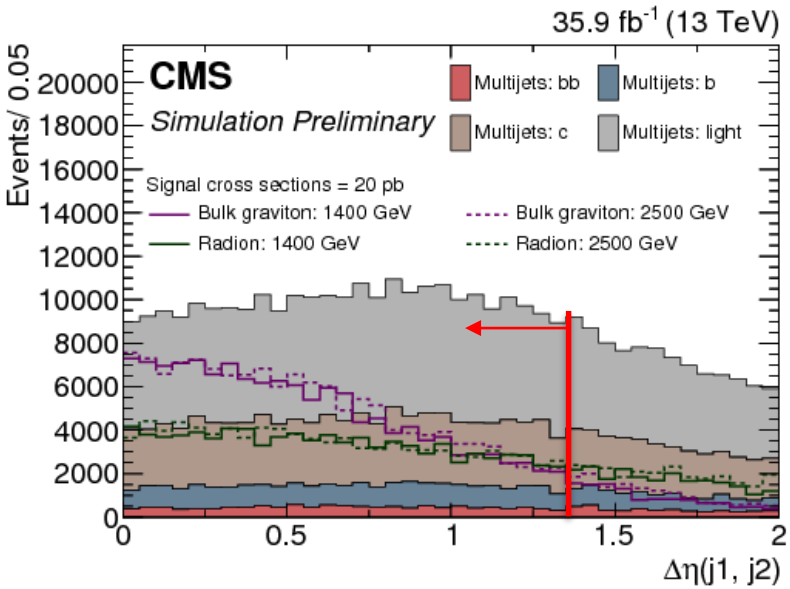
sum over all jet constituents



  - τ_2/τ_1 discriminates jets with 2 prongs from jets with 1 prong

Initial Selection

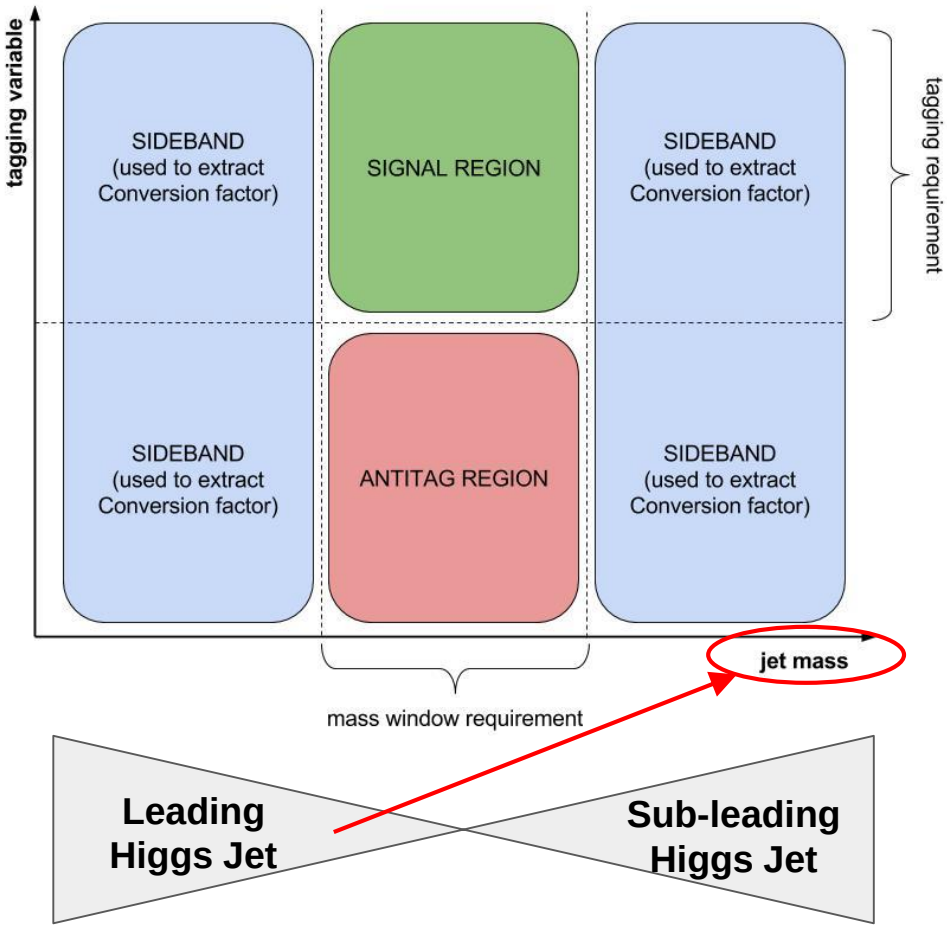
- Jet $p_T > 300$ GeV – approximately the threshold where two b quarks merge into a single fat jet
- $|\eta| < 2.4$ – the coverage of the CMS tracker
- $|\Delta\eta| < 1.3$ – QCD jets usually have a large angular separation



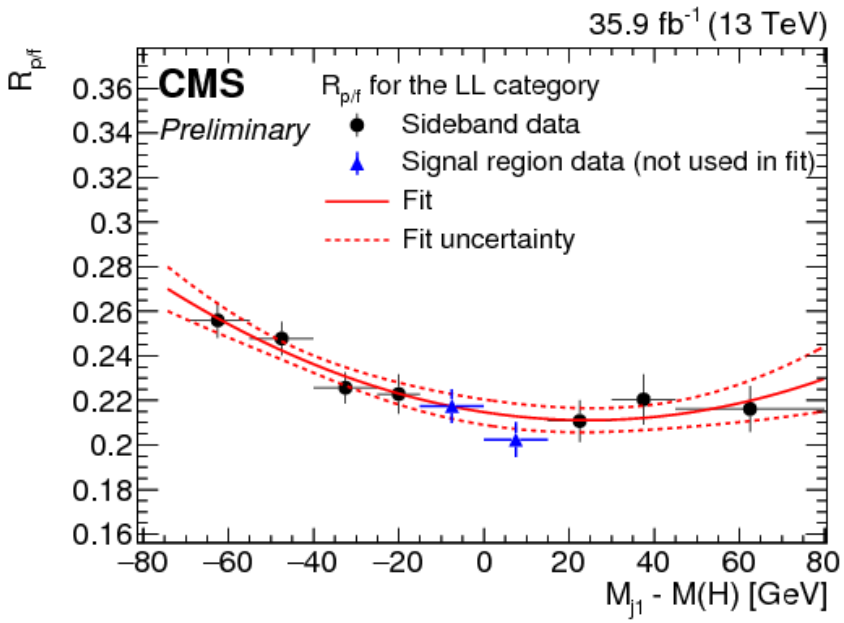
- Dijet mass > 750 GeV – We are only interested in searching for heavy resonances
  - $M_{jj}^{red} = M_{jj} - (M_{jet1} - M_H) - (M_{jet2} - M_H)$
- Veto any events containing a lepton– due to the hadronic nature of a 4b final state
- Use a combination of jet substructure and b-tagging triggers
  - Utilizes features of heavy resonances while keeping the trigger rate low
  - Fully efficient for $M_{jj}^{red} > 1100$ GeV

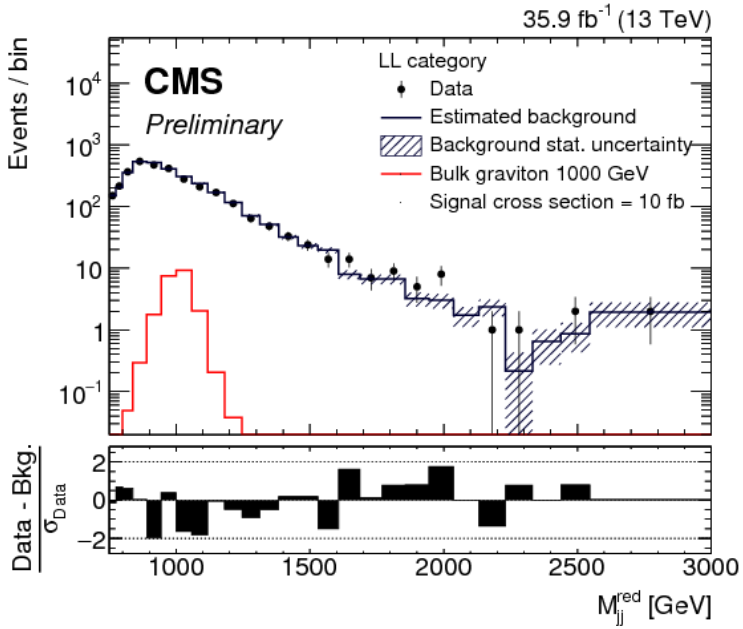
Background Estimation – Alphabet Method

- Alphabet
  - Uses information from sidebands of the (leading) jet mass to predict some conversion factor: $R_{p/f}$
  - $R_{p/f}$ scales Anti-tag region for bin by bin estimate of background
  - Use multiple sidebands to take into account double-b tagger and jet mass correlations



Alphabet Method

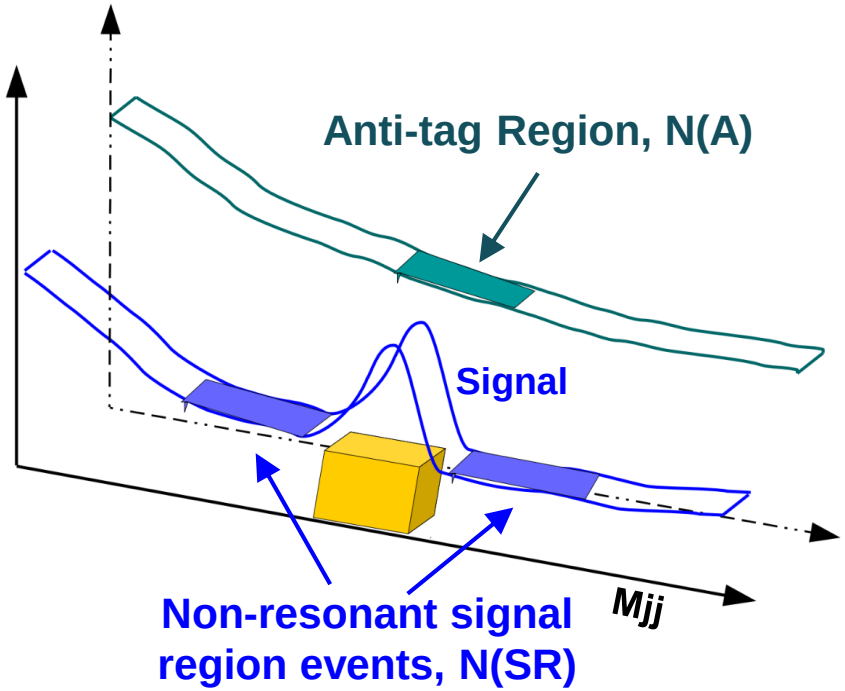




- Alphabet method used to search for $M_X < 1100$ GeV
  - Below the trigger turn-on
- Cross checks showed that the alphabet method can predict the shape and normalization of the reduced mass in data in the signal region

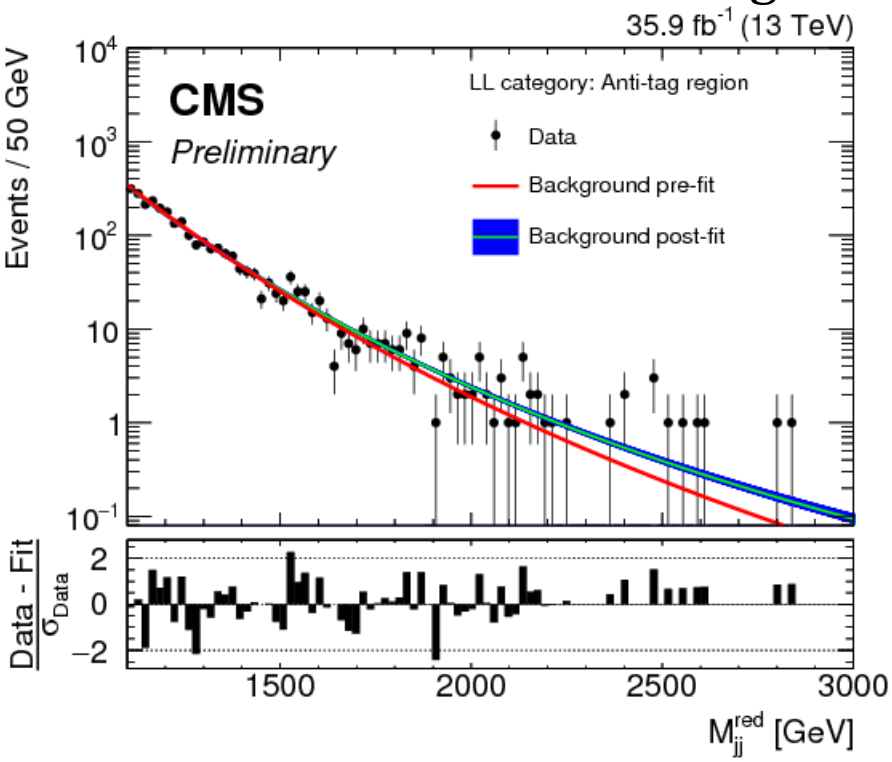
Background Estimation – Alphabet Assisted Bump Hunt

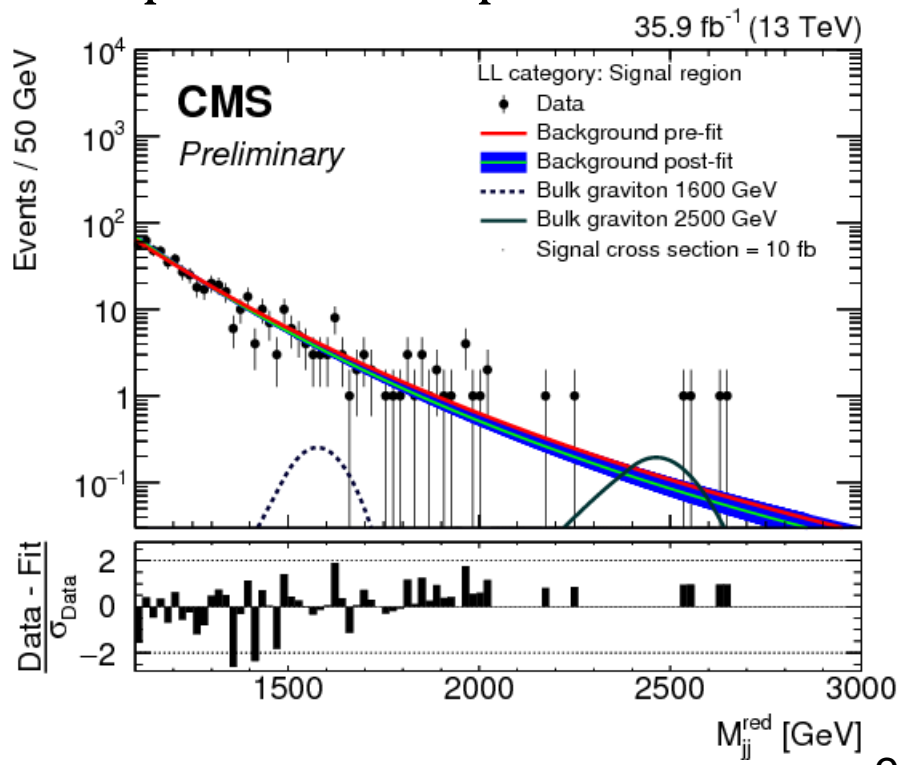
- Classic bump hunt
  - Fit the background shape with a parametric function
  - Bkg. normalization floating
- AABH
  - Simultaneous fit of bkg. in anti-tag and signal region
  - Same parametric shape for both regions
  - Bkg. normalization in signal region constrained by $R_{p/f}$ from Alphabet method
    - $N(SR) = N(A) \times R_{p/f}$
  - Smoothes fluctions from the Alphabet prediction



Alphabet Assisted Bump Hunt

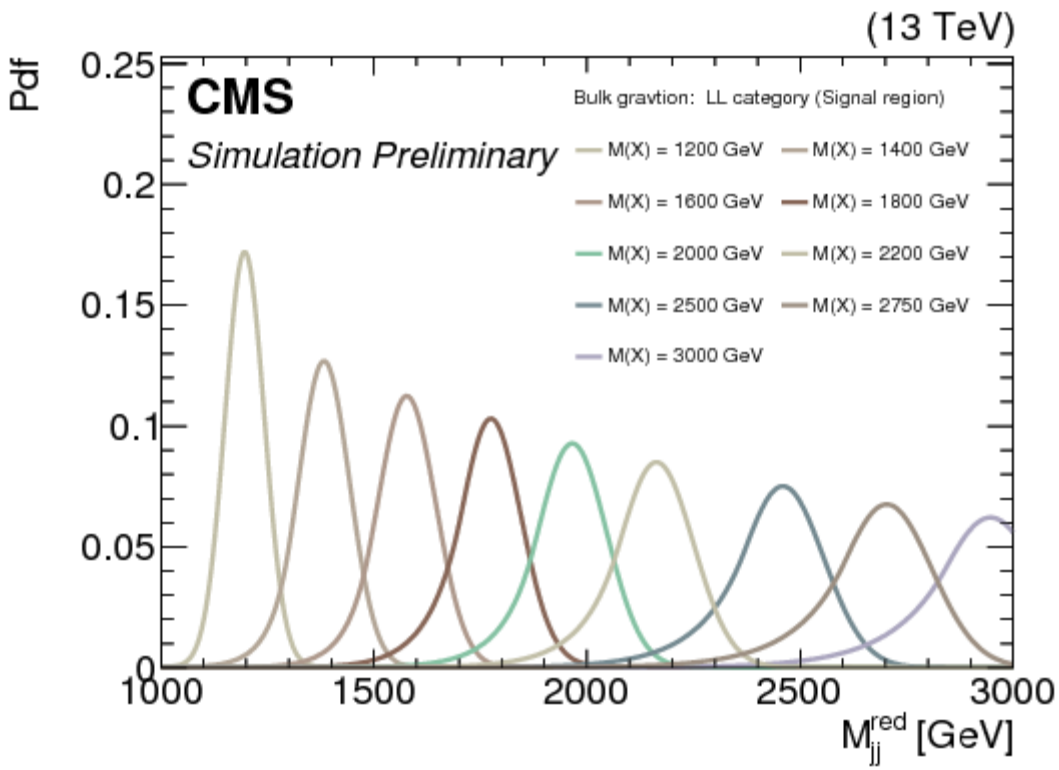
- Fit is performed from $1100 < M_X < 3000$ GeV
  - Above the turn-on
  - 3000 GeV is just beyond the last data point in the anti-tag region
- Leveled exponential: $e^{\left(\frac{-m_{jj}.p_2}{1+(m_{jj}\cdot p_1\cdot p_2)}\right)}$
  - Performed F-tests using 1, 2, and 3 parameter exponentials



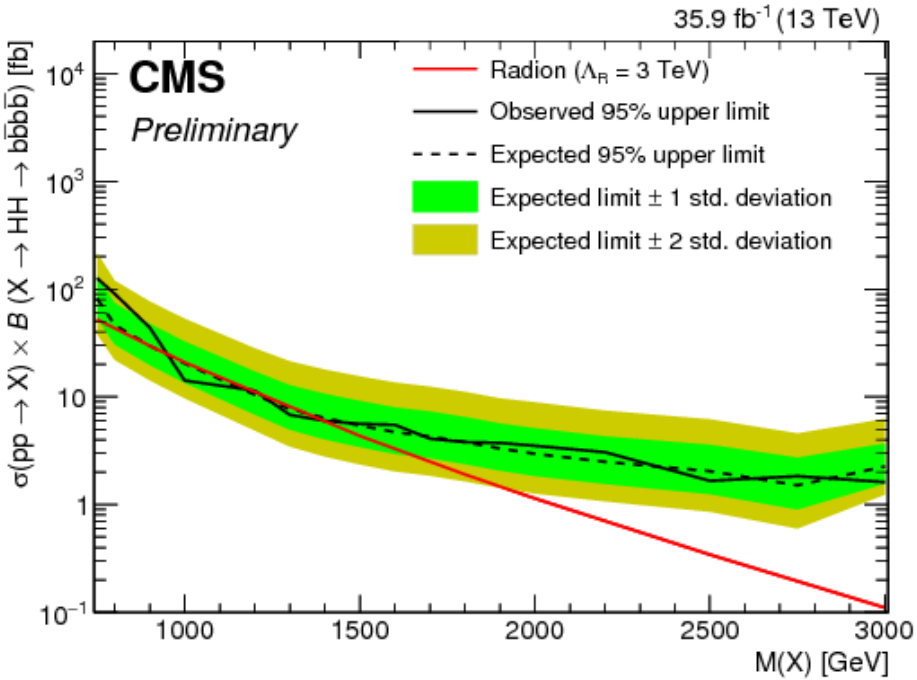


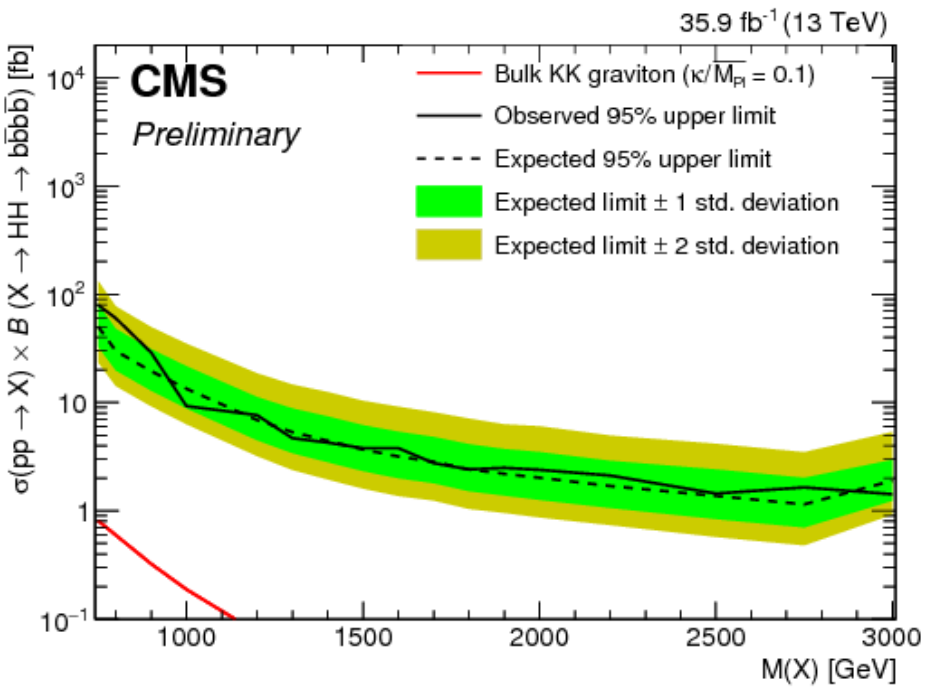
Signal Modeling

- Modeled by the sum of a crystal ball function and a gaussian
  - Used bulk graviton and radion simulated samples
  - Mass points: 750 - 3000 GeV



Limits

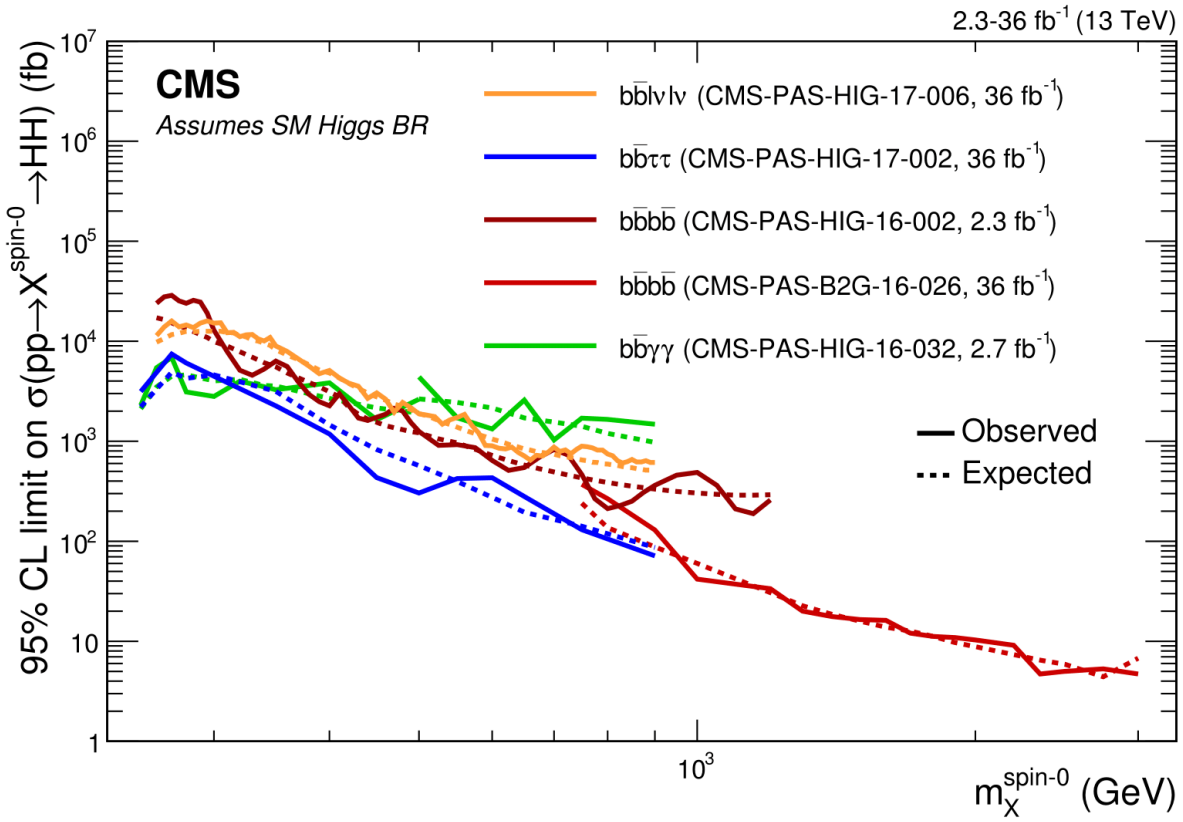




- Limit for $M_X = 3000$ GeV degrades due to signal truncation
- Up to 30% better limit for bulk graviton due to larger acceptance of the $|\Delta\eta|$ selection

Summary

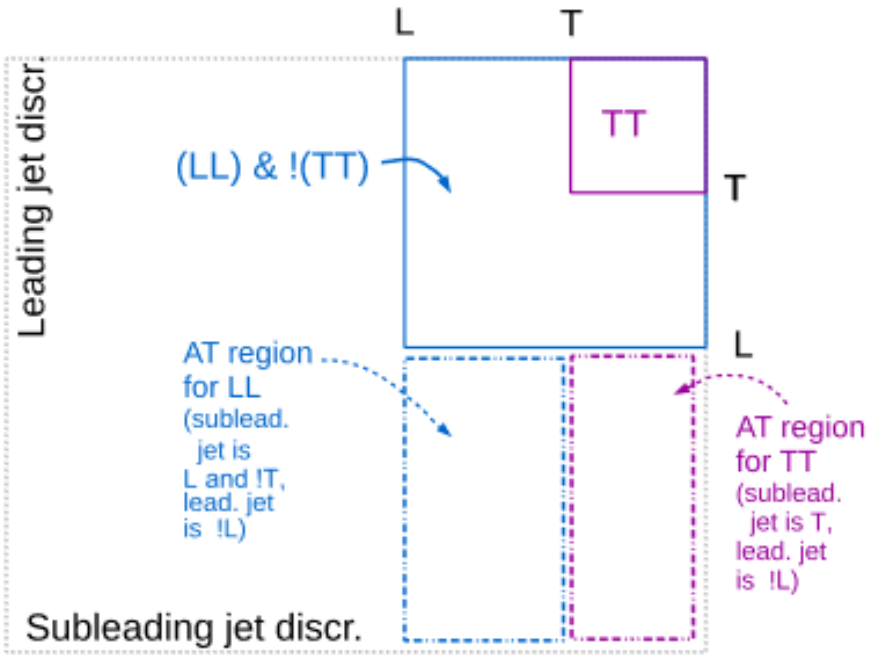
- Extend the HH resonance limits out to 3000 GeV
- Documented in CMS-PAS-B2G-16-026



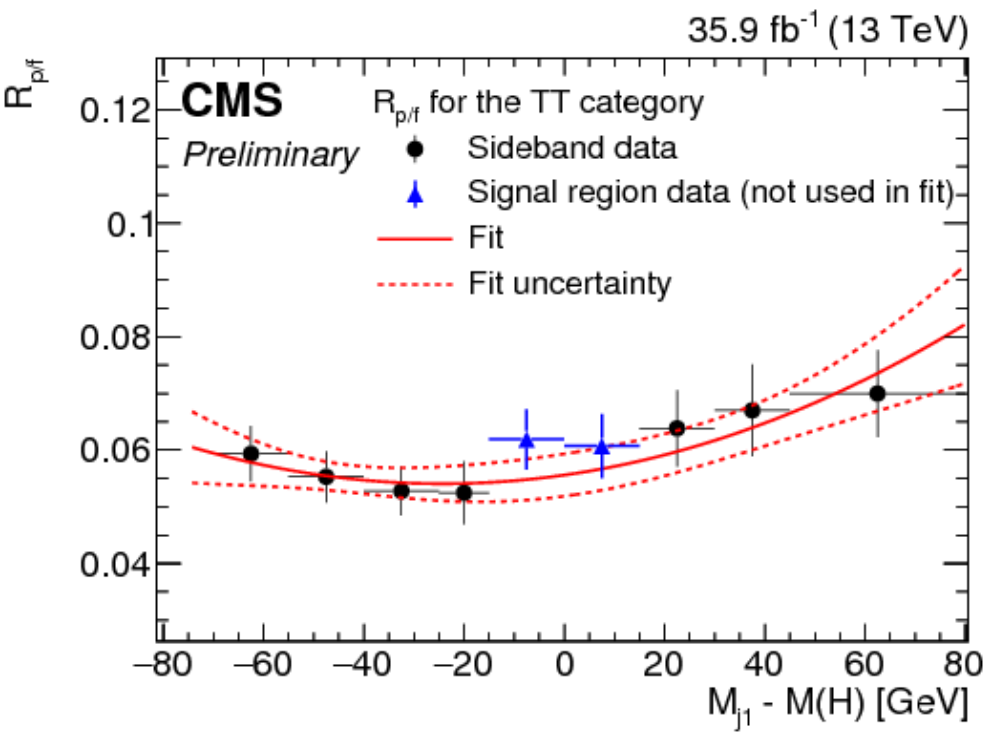
Backup Slides

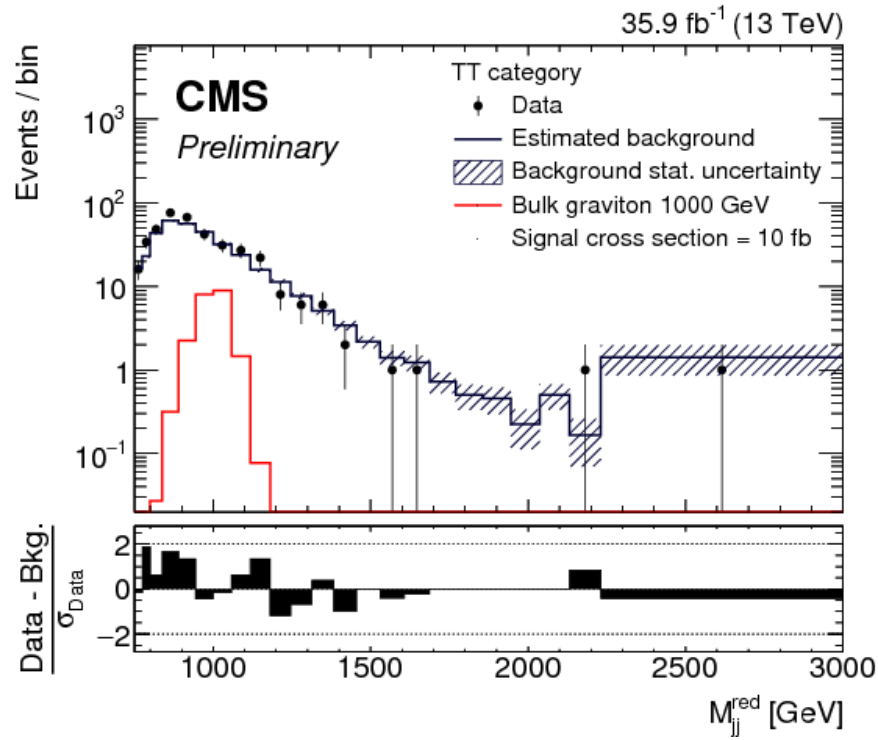
Signal Event Categories

- Categories defined by double b values of both jets
  - Loose: > 0.3, 80% signal efficiency
  - Tight: > 0.8, 30% signal efficiency
- 2 orthogonal categories
  - TT – both jets pass tight working point
    - Better $S/\sqrt{B}$ at lower resonance masses
  - LL – both jets pass loose working point, but fail tight working point
    - Better $S/\sqrt{B}$ at higher resonance masses
- All 4 regions orthogonal

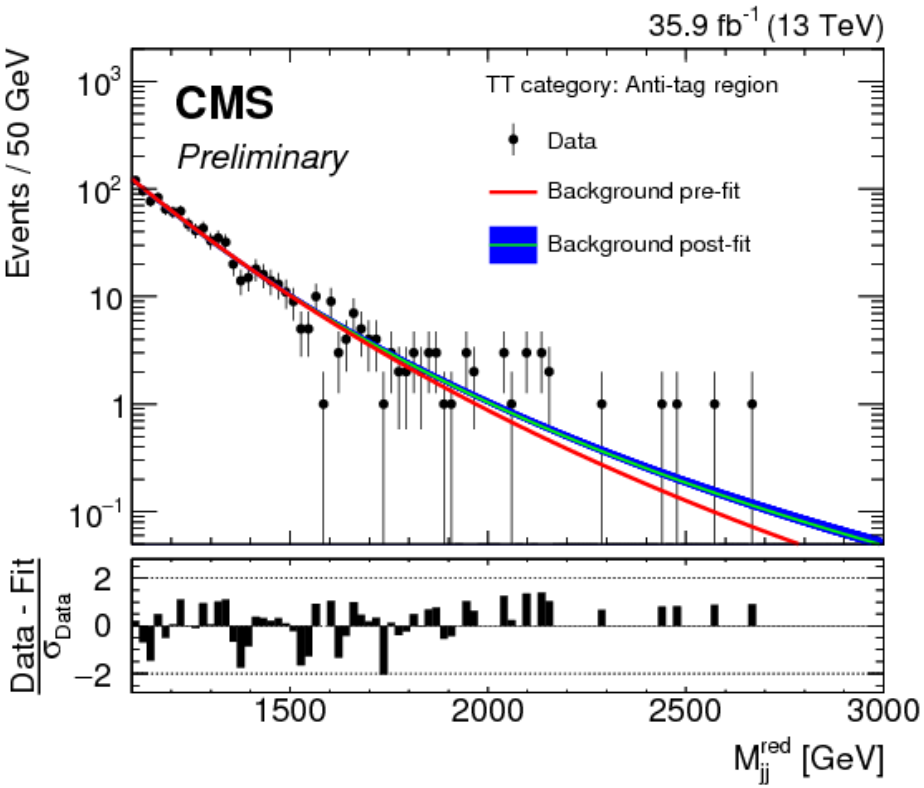


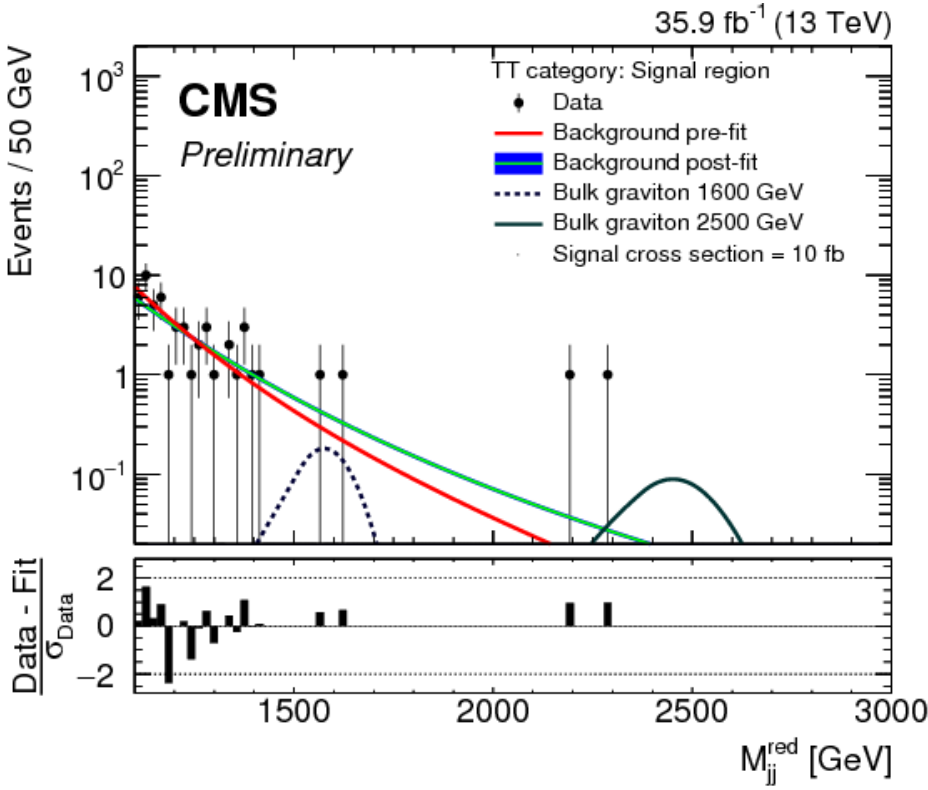
Alphabet – TT Category





AABH – TT Category





Trigger

- OR of HT and substructure triggers:
  - HLT_PFHT650_WideJetMJJ900DEtaJJ1p5
  - HLT_AK8PFJet360_TrimMass30
  - HLT_AK8DiPFJet280_200_TrimMass30_BTagCSV_p20
  - HLT_AK8PFHT650_TrimR0p1PT0p03Mass50
  - HLT_PFHT800/900