Search for vector-like B pairs

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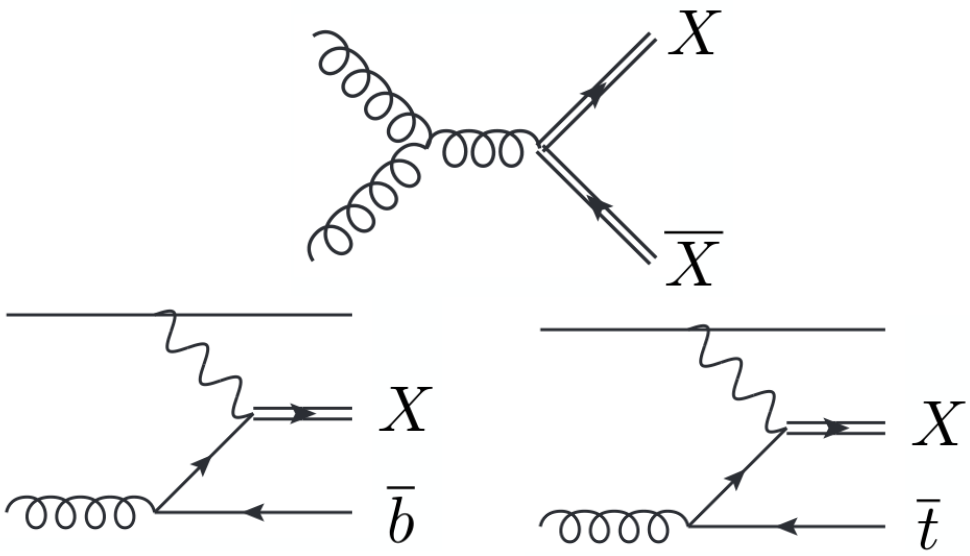
Vector-like quarks

- Many SM extensions feature **new fermions**
- Non-chiral **vector-like quarks** in models such as Little/Composite Higgs
- Could help stabilize Higgs mass – no Yukawa coupling required for mass term
- **Strong** production of pairs, **electroweak** single production
- Various multiplets possible with corresponding T or B decay modes (preferential mixing with 3rd generation SM)

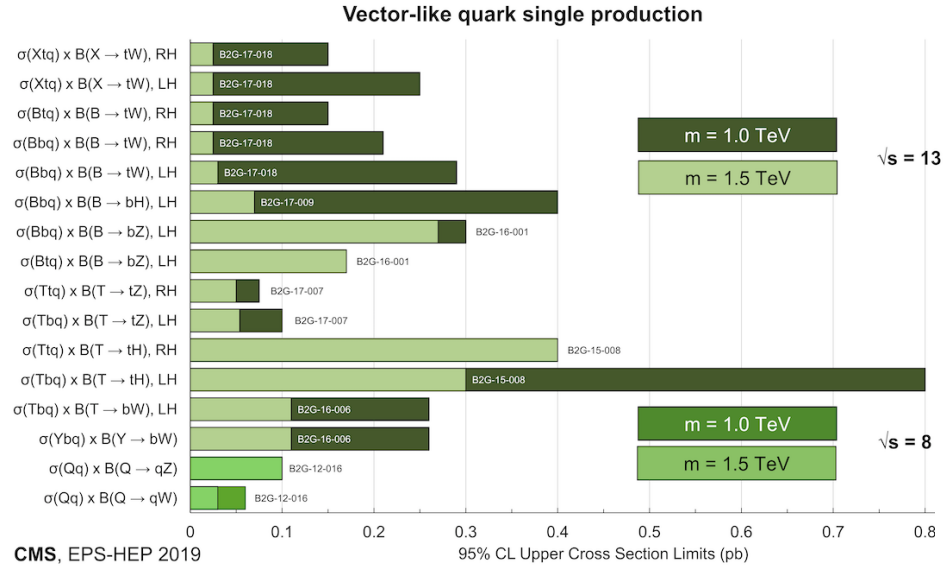
Weak multiplets ($\text{isospin}_{\text{hypercharge}}$)

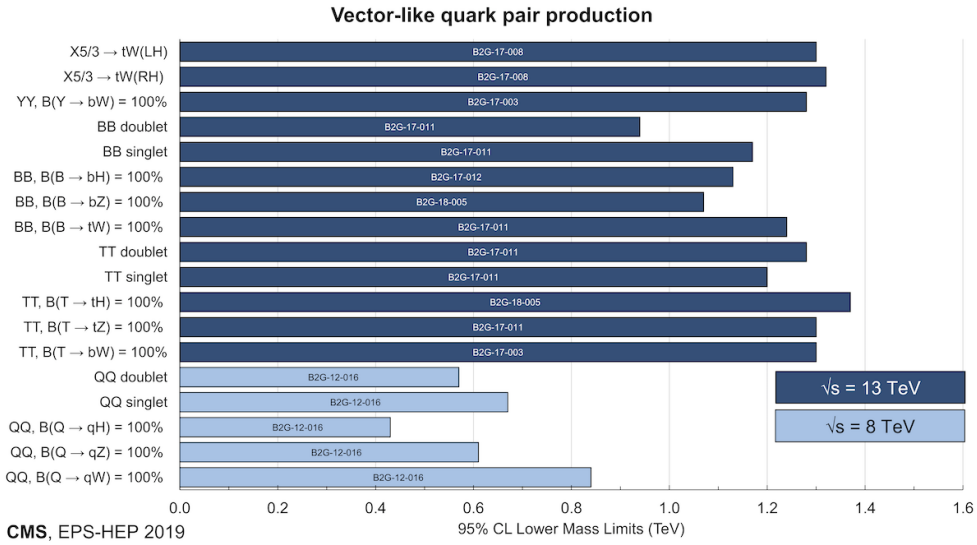
Singlets	Doublets	Triplets
$\mathbf{1}_{2/3} = T$	$\mathbf{2}_{1/6} = \begin{pmatrix} T \\ B \end{pmatrix}$	$\mathbf{3}_{2/3} = \begin{pmatrix} X \\ T \\ B \end{pmatrix}$
	$\mathbf{2}_{7/6} = \begin{pmatrix} X \\ T \end{pmatrix}$	
$\mathbf{1}_{-1/3} = B$	$\mathbf{2}_{-5/6} = \begin{pmatrix} B \\ Y \end{pmatrix}$	$\mathbf{3}_{-1/3} = \begin{pmatrix} T \\ B \\ Y \end{pmatrix}$



Current program

- Robust search program in ATLAS and CMS in many final states – pair sensitivity pushing past 1.2 TeV for many decay modes
- **Unique signature** with many high-momentum, massive SM particles
- 137 fb^{-1} searches are underway – **first one public this week!**



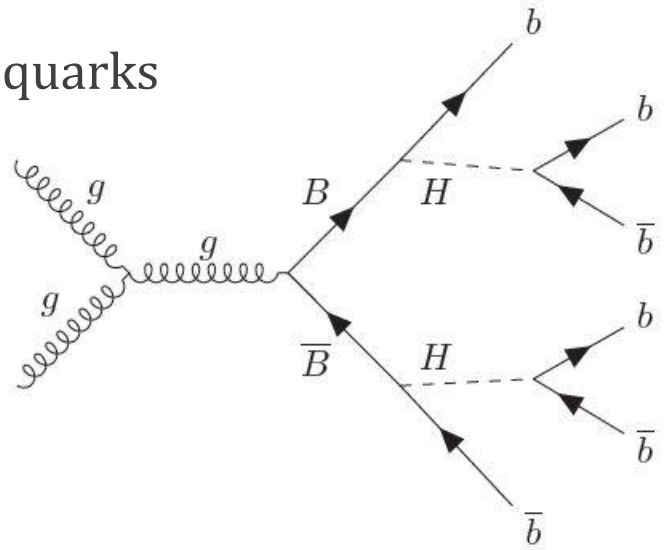


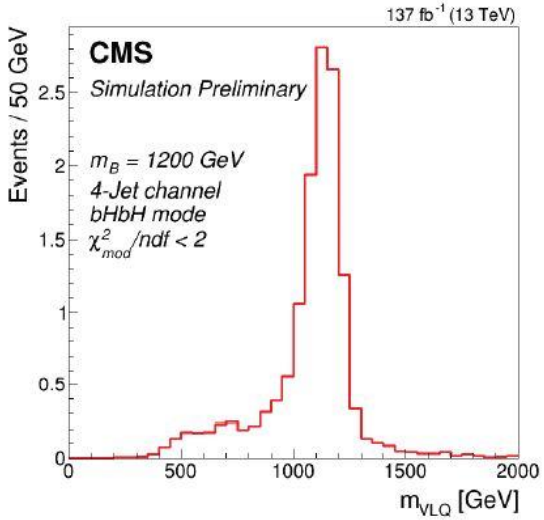
PhysicsResultsB2G

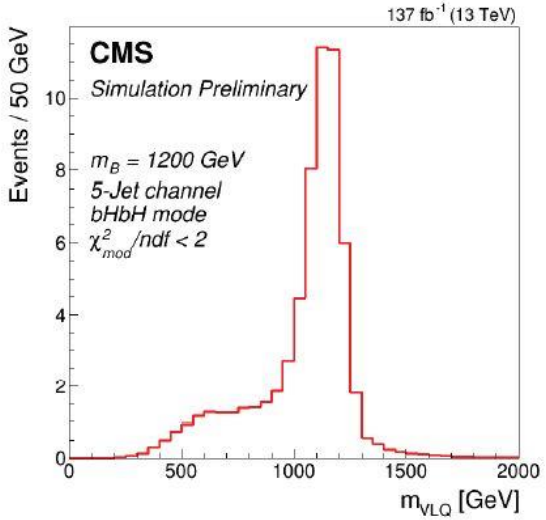
$B\bar{B}$ with hadronic decays

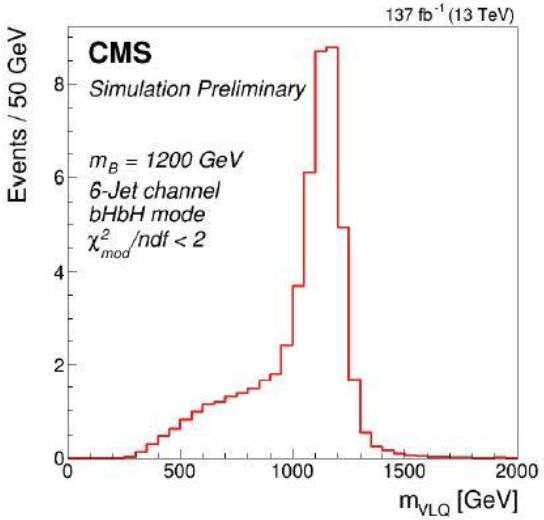
CMS-B2G-19-005

- Search targeting **$B\bar{B}$ production** with decays to bH or bZ
- Strategy based on mass reconstruction from 6 quarks
- 3 independent analyses:
  - 6-jet events: all 6 quarks are resolvable
  - 5-jet events: one H or Z boson was boosted
  - 4-jet events: both H or Z bosons were boosted
- Signal mass peak reconstructed clearly:









VLQ reconstruction

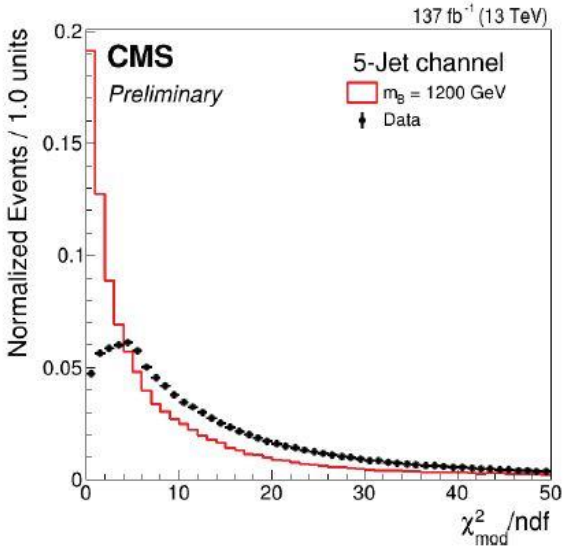
- Jets must be consistent with a **pair of bosons** (H or Z)
- VLQ candidates must have equal masses
- Some jets are identified as arising from b quarks
- χ^2-like metric (example for 5 jets):

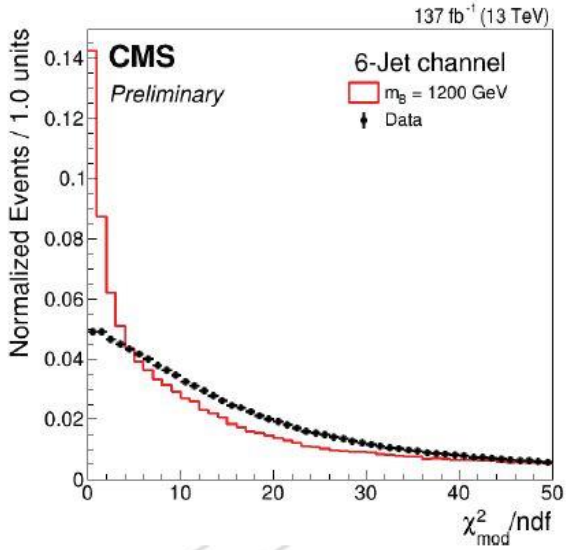
Softdrop mass

$$\chi^2_{\text{mod}} = \frac{(m_{\text{dijet}} - \bar{m}_{\text{dijet}})^2}{\sigma^2_{m_{\text{dijet}}}} + \frac{(m_{\text{merged}} - \bar{m}_{\text{merged}})^2}{\sigma^2_{m_{\text{merged}}}} + \frac{(\Delta m_{\text{VLQ}} - \overline{\Delta m}_{\text{VLQ}})^2}{\sigma^2_{\Delta m_{\text{VLQ}}}}$$

MC Gaussian width

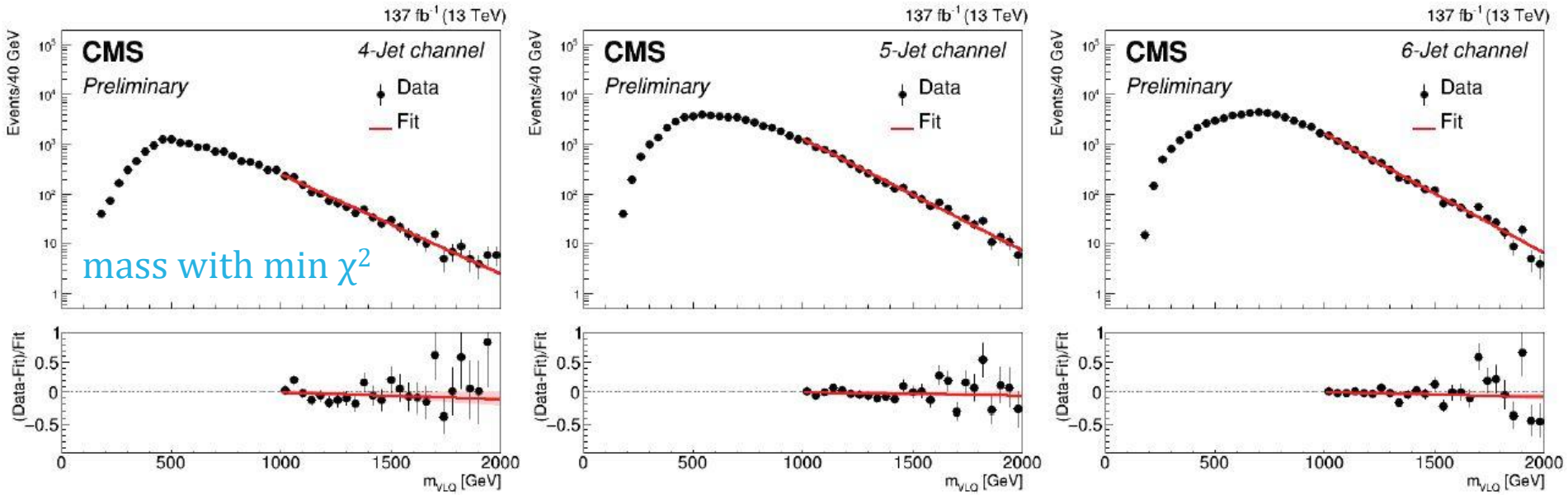
MC Gaussian mean





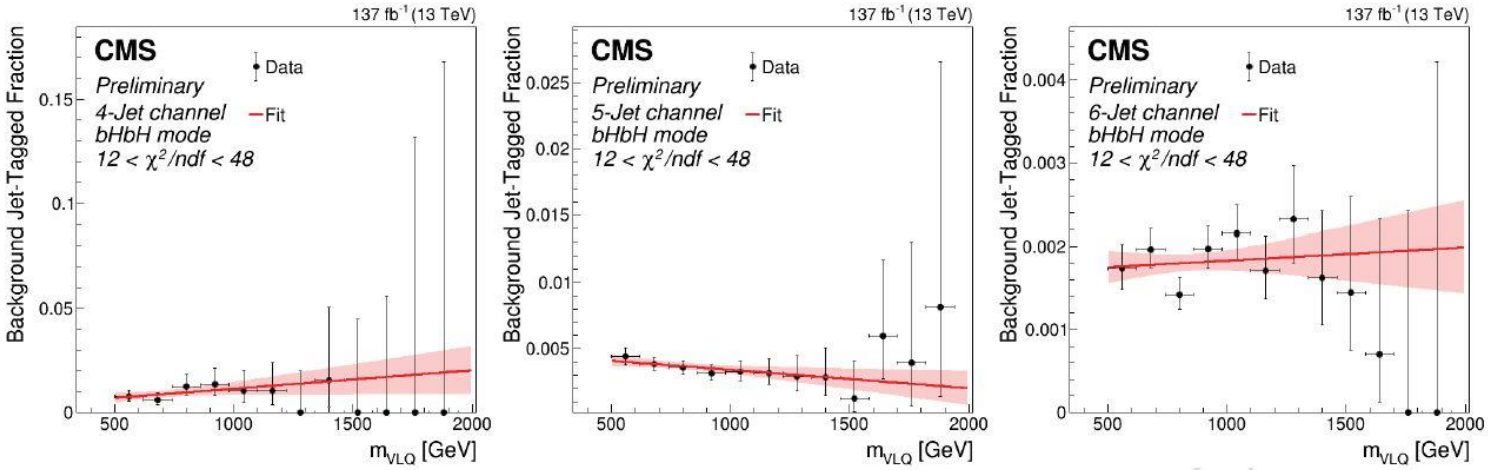
Background estimation

- **Determine shape in data** without tagging b quarks – all background!
  - Baseline requirement of $\chi^2/\text{ndf} < 4$
  - Exponential fit to mass distribution for masses > 1000 GeV
- Apply **b/$b\bar{b}$ identification rate** to estimate background in signal region
  - 6 jets: 4 b-tagged jets (3 if bZbZ)
  - 5 jets: 3 b-tagged jets (not from boosted H/Z)
  - 4 jets: 2 b-tagged jets + 1 boosted bb tag (unless bZbZ)



Background estimation

- b/$b\bar{b}$ tag rate is determined in ranges with low VLQ mass: 0.2 – 0.5%
- Rate is propagated to higher masses via a high-χ^2 control region
  - Choice of χ^2 validated by evaluating variation across many χ^2 ranges – flat!



- Number of background events as a function of mass becomes:

Low mass tagging rate

Mass variation

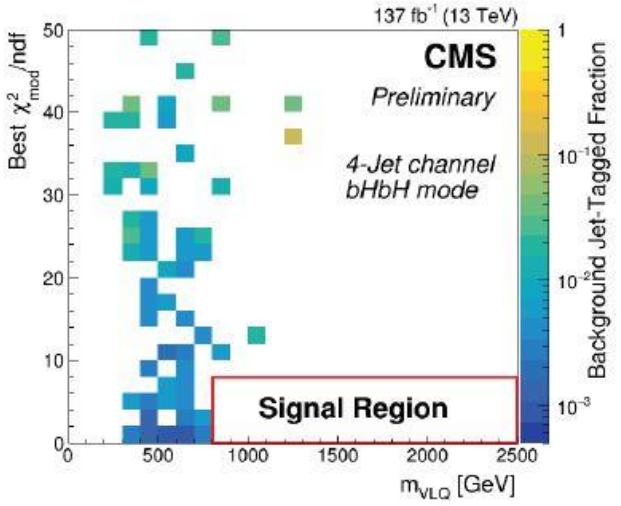
$$n_b(m) = n(m) e_0 \frac{e(m)}{\left(\int_{500}^{800} e(m')dm'\right) / (300\,\text{GeV})}$$

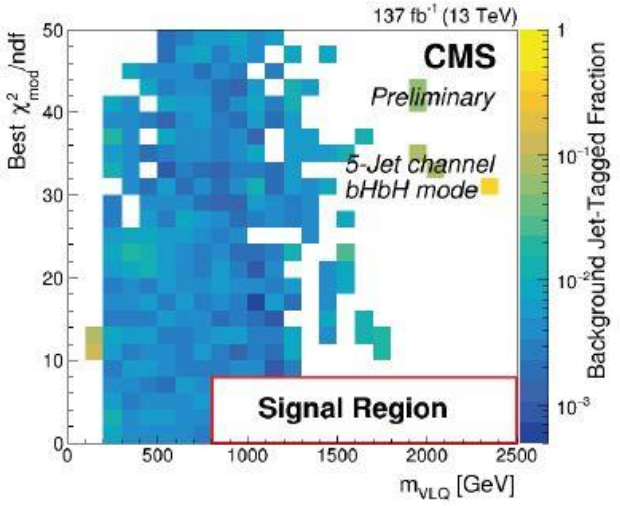
Exponential from data

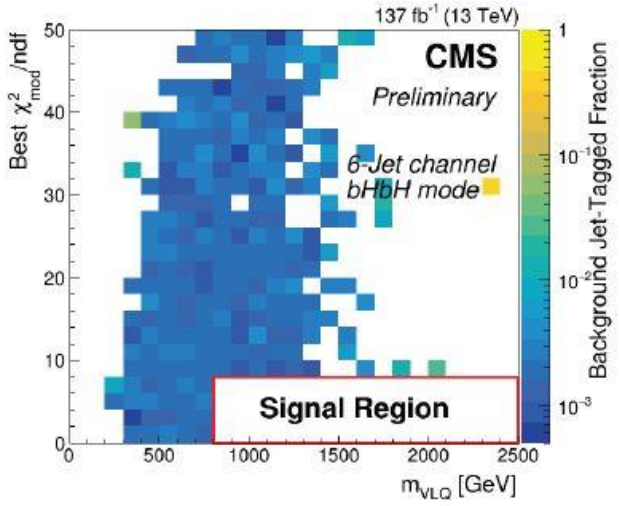
normalization

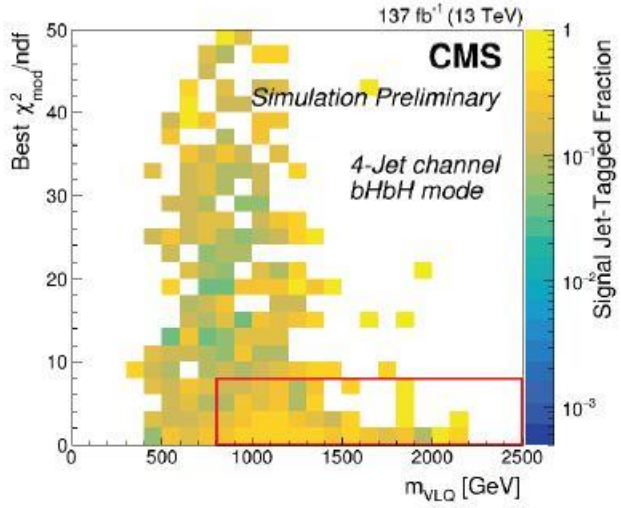
Background estimation

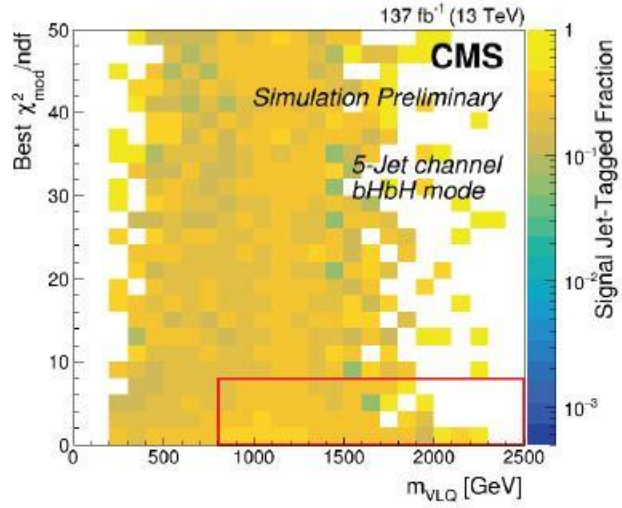
- Tagging b/$b\bar{b}$ quark jets gives powerful background reduction!

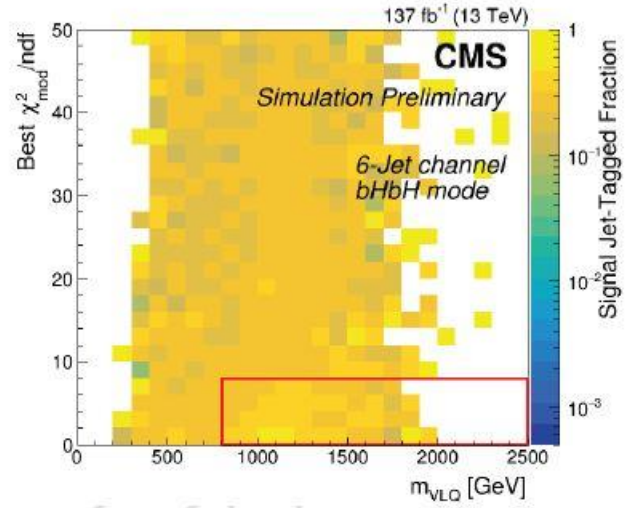






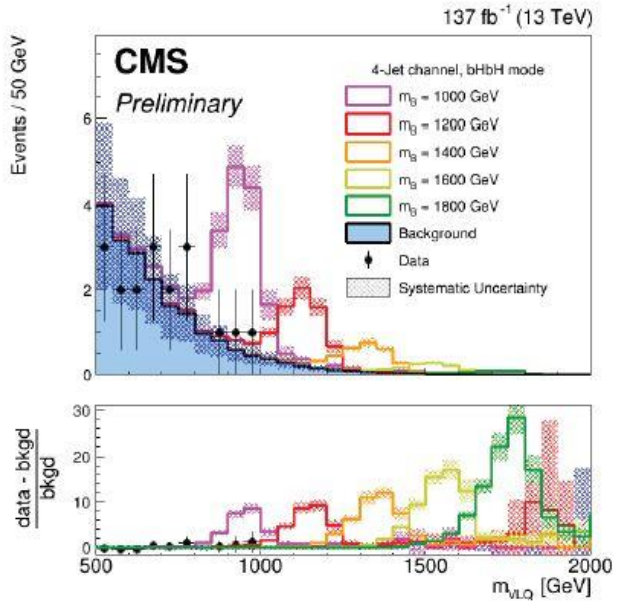


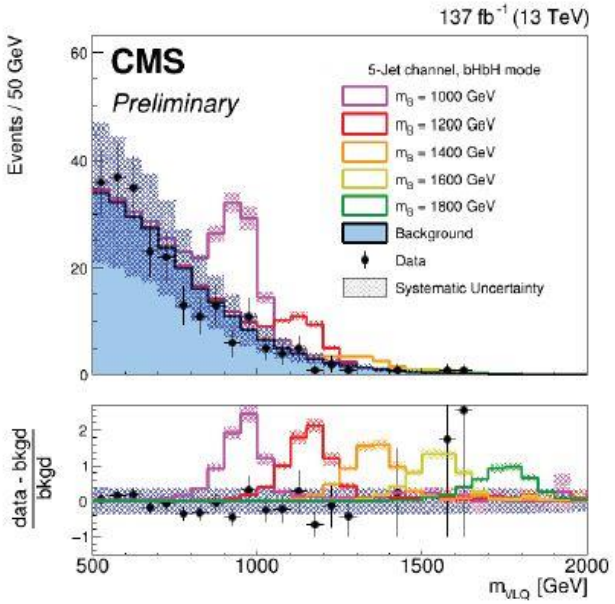


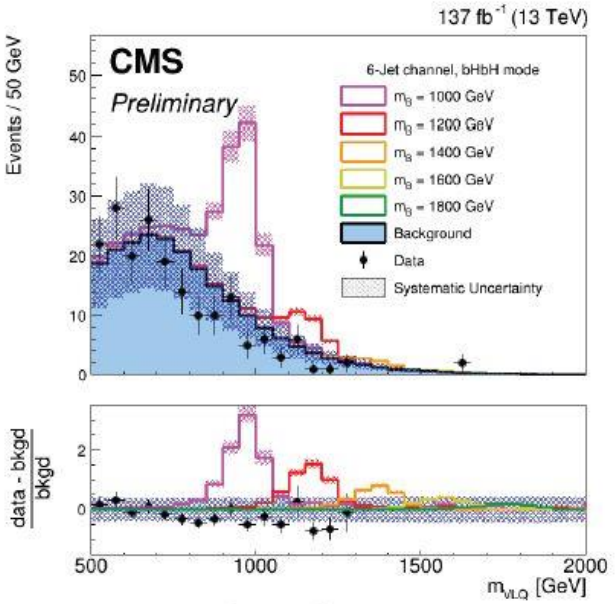


Signal region

- Background falls quickly as VLQ mass increases, peaking signal
- Simultaneous optimization of b quark tagging and maximum χ^2 (2 – 5.5)
- Signal uncertainty dominated by pileup and b quark tagging
- Background uncertainty dominated by uncertainty in slope of exponential fit
- **No significant excess of data observed**







Results

- Strongest CMS sensitivity to date for BB production in bH/bZ-dominated decay scenarios – **300 to 500 GeV more powerful!**
- To be joined by other final states before a "Run 2 legacy" combination