Search for vector boson fusion production of a massive resonance decaying to a pair of Higgs bosons in the four b quark final state at the HL-LHC using the CMS Phase-2 detector

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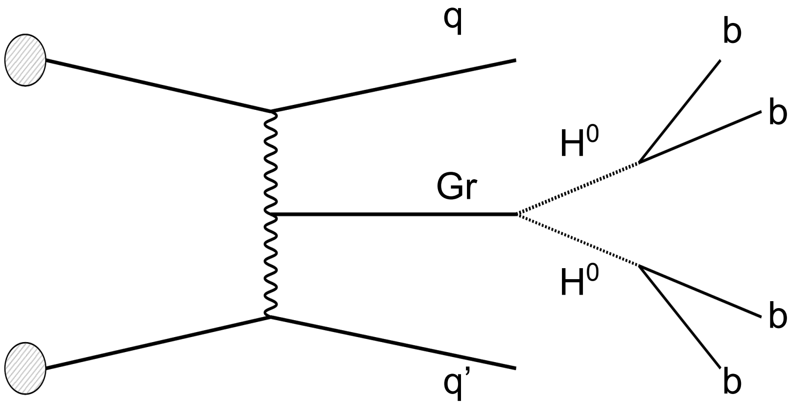
3. University of Kansas, US

Introduction

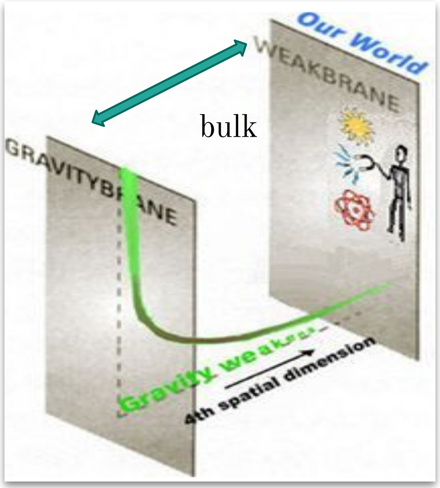
1. It is a projection analysis in which:
   - Work on warped extra dimension BSM model
   - Study resonant production of HH in 4b final state
     - High BR but QCD contribution is huge
     - Need proper background modeling
   - Project the signal sensitivity with CMS phase-2 detector, assuming the signal cross-section 1 fb with $\sqrt{s}$ = 14 TeV



2. Analysis has been approved by UPSG group and PAS is public now.
3. Reference:
   - [arXiv 1404.0102]
4. Documentation
   - [FTR-18-003]

About BSM Model

- Warped Extra Dimension model which predicts new state spin-2 (Graviton)
  - Two Scenarios: RS1 and RS_bulk.
  - Working with RS_Bulk scenario.
  - Solves hierarchy problem of the SM



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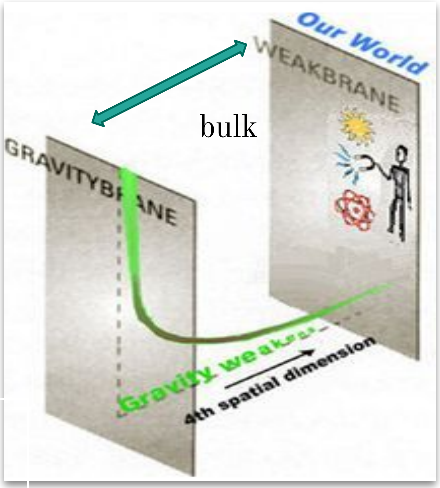
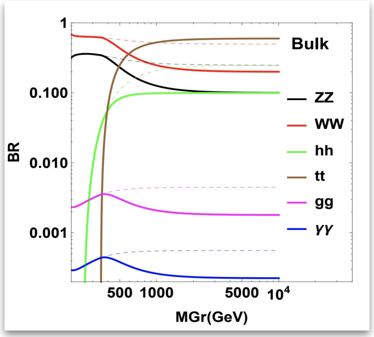
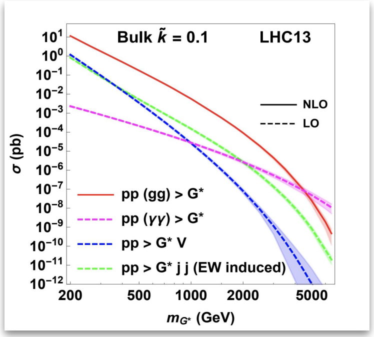
  - Negligible s-channel production rate.
  - VBF production might dominate.







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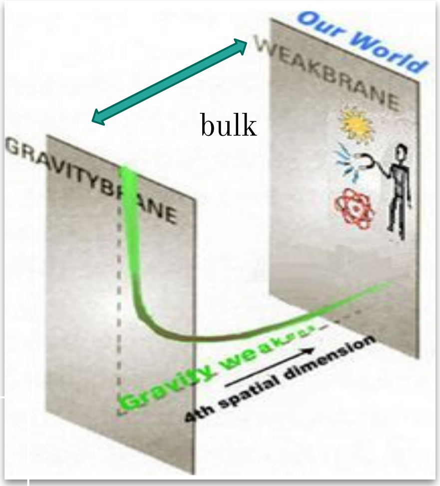

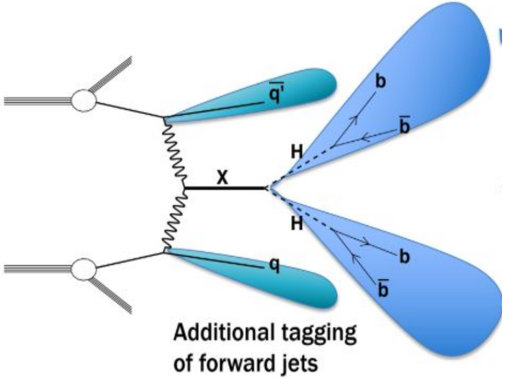

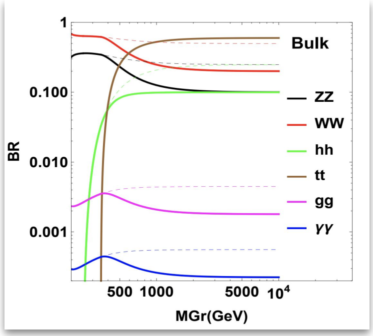

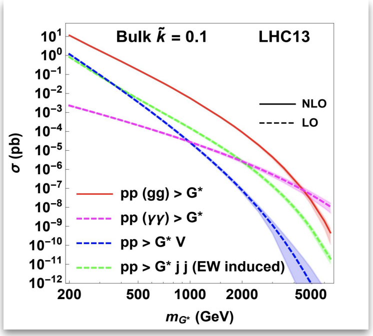

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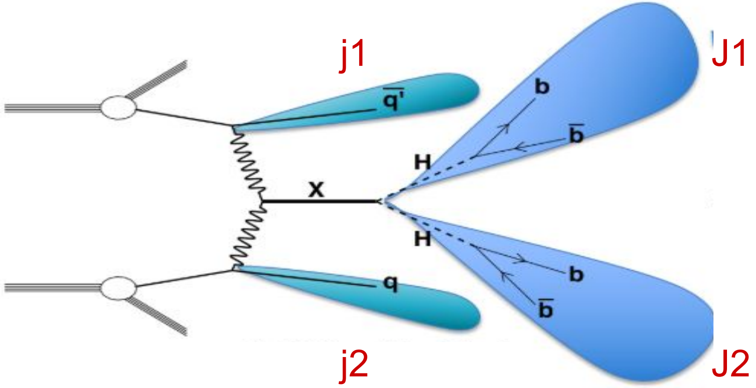
Motivation for searches at HL-LHC

- VBF production accessible at HL-LHC with 3 ab^{-1} data.
- This is the first look at VBF X→ HH production at CMS
- With CMS Phase-2 detector it will get benefit with
  - Extended tracker coverage⇒ for boosted H→ bb using subjet b-tagging
  - HGCAL ⇒ For VBF Jet identification

Event Selections

Final state objects: J1, J2, j1, j2



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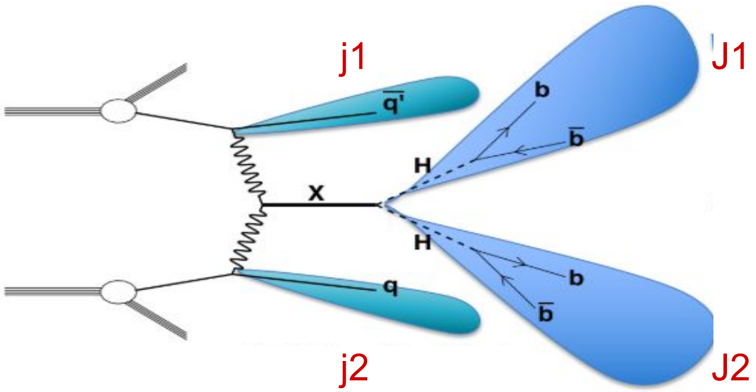

1. Two fatjets J1, J2 coming from boosted Higgs.
    - AK8 PUPPI Jets (anti-k_T, R=0.8)
    - p_T > 300 GeV and |η| < 3
    - Soft-drop mass window:
        - 90-140 GeV for first two leading
        - Optimized by looking at the S/√B
    - N-subjettiness for Higgs-tagging: $\tau_2/\tau_1 < 0.6$
    - Subjet b-tagging:
        - DeepCSV medium working points (mistag 1%)
        - Optimized by looking at signal significance

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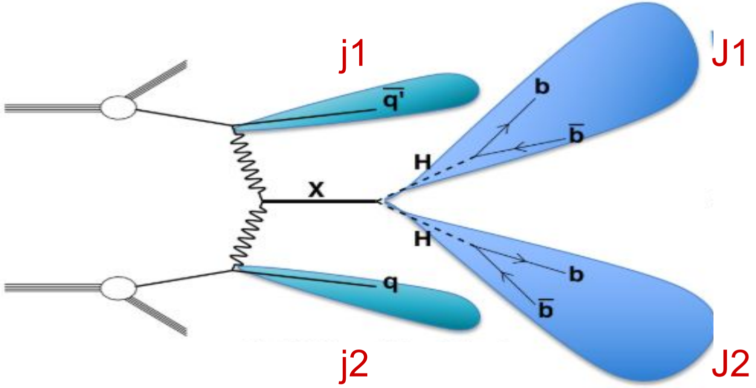

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2. VBF jets j1 and j2
   - p_T > 50 GeV and |η| < 5
   - Δη > 5 (large η-separation)
   - $\eta_{ji} * \eta_{j2} < 0$ (opposite direction)
   - M_{j1j2} > 300 GeV (large reconstructed mass)
   - dR (Higgs jet, AK4 jet) > 1.2
     - To not count Higgs jets as VBF jets.

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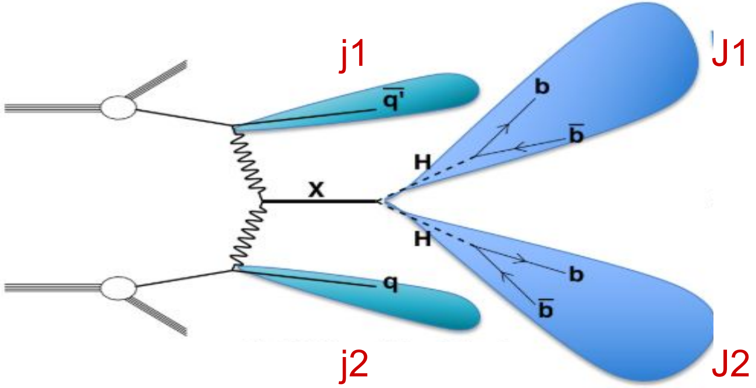

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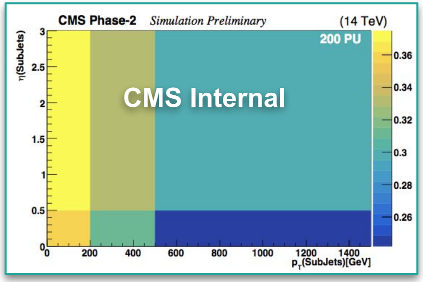
3. Events categorized based on number of b-tagged subjets:
   - 3b and 4b

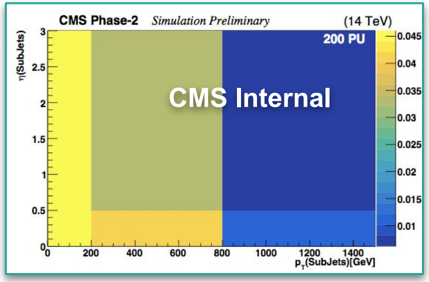
Background estimation

- subjet b-tagging selection kills almost all the background events.
- Model the background by reweighting M_{JJ}-distribution with the subject b-tagging efficiencies.
- Reweight QCD events which pass the H-jet selection excluding subjet b-tagging cut.

b_eff. DeepCSV medium



light_eff. DeepCSV medium



Note:

- DeepCSV loose mappings are in backup
- Eff = events passing b-tag selection/ events before b-tag cuts (within particular p_T and eta range)

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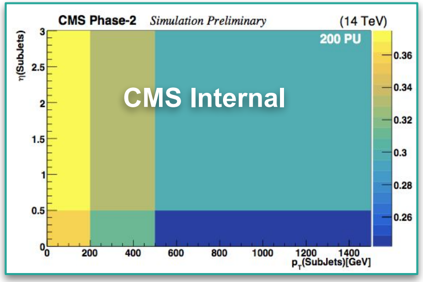

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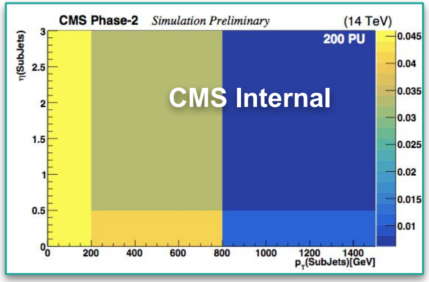

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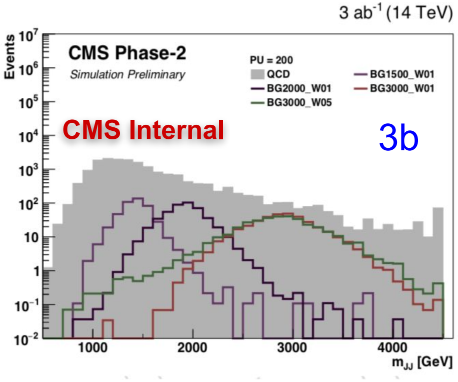
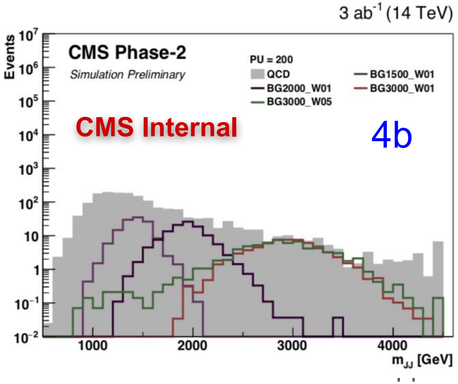
M_{JJ}-distribution

- Signal events:
  - passing all the event selection cuts.
- Background events:
  - All event selection cuts excluding subjet b-tagging cut,
  - For full M_{J1J2}-distribution, events are reweighted as explained
- QCD is scaled by factor 0.7 (from Run-2 Data/MC comparison)





Mass window optimization

Soft-drop mass [GeV]		$S/\sqrt{B}$
Leading-p_T AK8 jet	2nd-p_T AK8 jet	
80–160	60–140	2.06
80–160	80–160	3.12
60–140	60–140	2.73
90–140	90–140	3.34
90–130	90–130	3.25

- Compare, the S/√B with different mass cuts for boosted H-jet
- Get high significance with 90-140 GeV mass window.

Note: systematics are in the backup

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- We study two scenarios:
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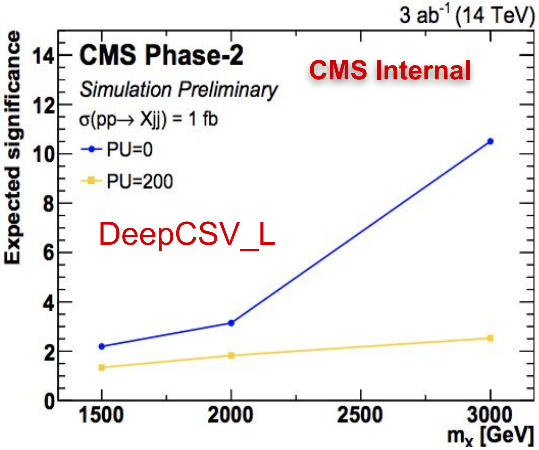

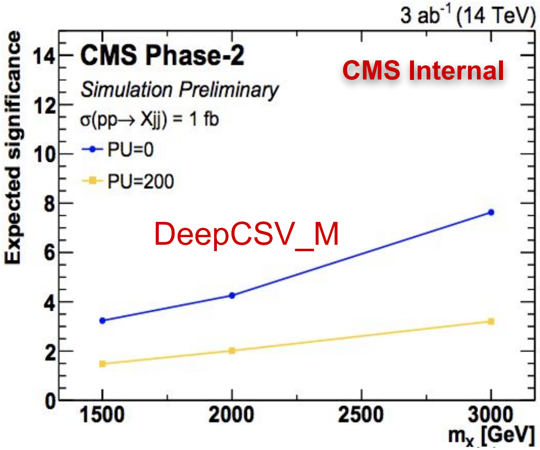

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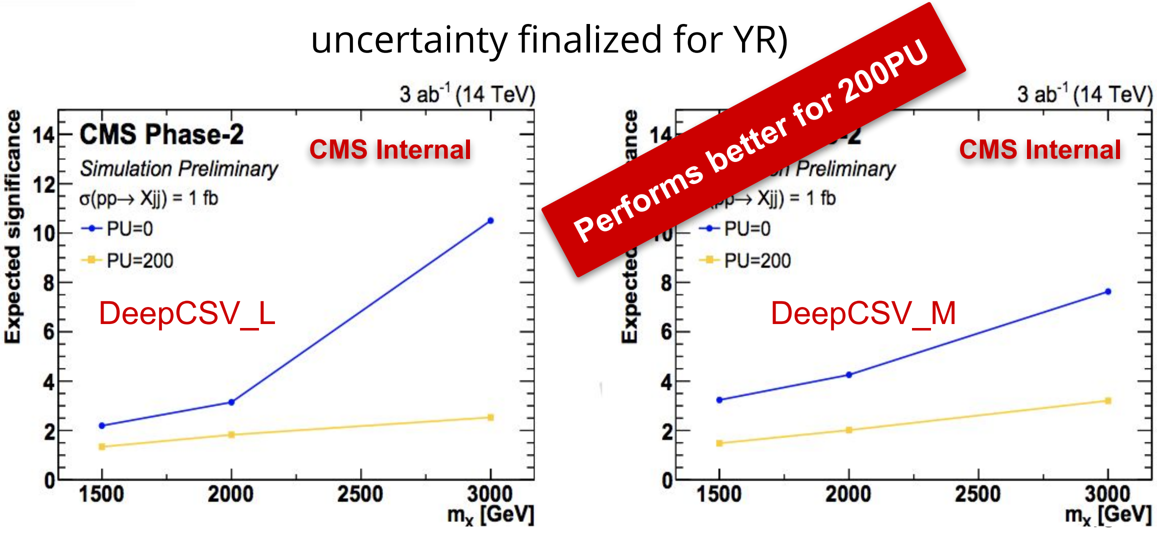

Results: Efficiencies and significance

- Results are public only for 200PU case since 0PU is not a realistic scenario.
- Yields are from M_{JJ} distribution. (only for 200 PU)

Process	3b category		4b category	
	Events	Efficiency (%)	Events	Efficiency (%)
Multijets	4755	1.6×10^{-3}	438	1.5×10^{-4}
BG (m_X =1500 GeV)	326	11	95.2	3.2
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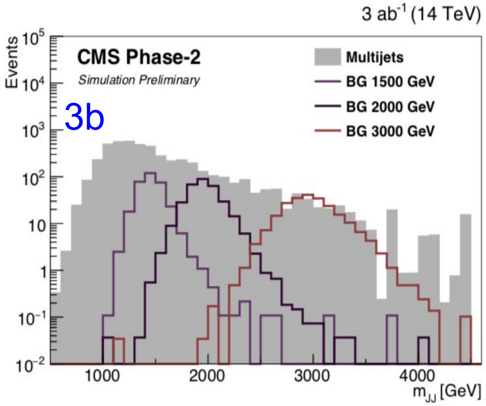

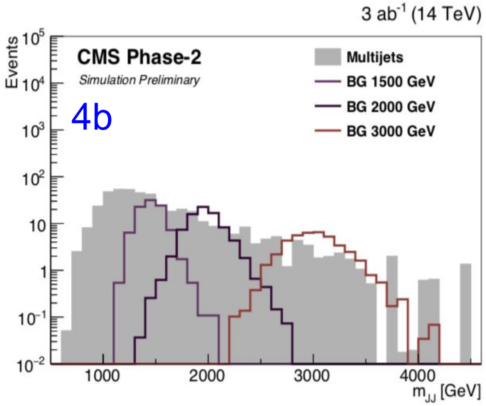

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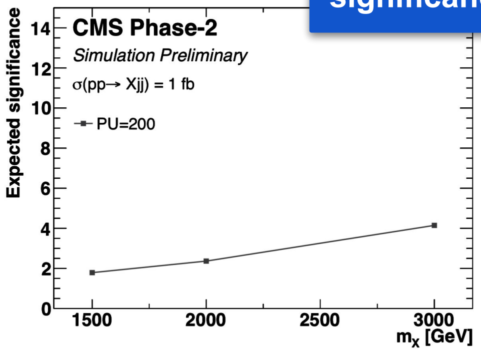

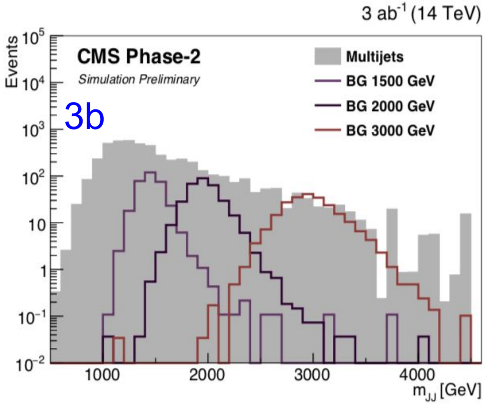

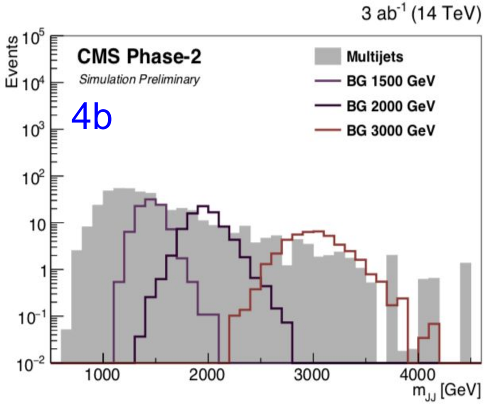

- we get high expected significance for higher masses with this analysis strategy.
- Indicates that these searches are good to study with HL-LHC data to probe the new physics as it answers the questions where SM fails.

Summary and plans

- The complete projection study for the searches of heavy resonances in VBF production mode is presented.
- These searches also get benefit from new CMS detector design.
- Also, it is expected that future advances in the event reconstruction and physics object identification techniques, with the Phase-2 CMS detector design, will help to further improve these projections.
- We plan to extend these searches for wide resonances (couldn’t study because of production issue of wide samples).

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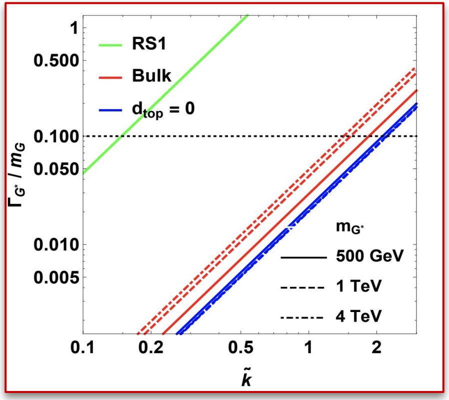

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  - A 30% width for k~ 2 is quite feasible for a bulk graviton.

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Also working on the non-resonant HH→ 4b boosted for YR. Summary on the next slides. PAS = FTR-18-019 (Approved)

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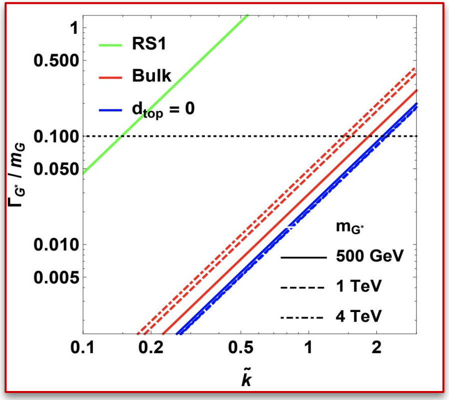

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Analysis strategy for boosted non-res HH→ 4b

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- Analysis strategy is as same as FTR-18-003 (public) analysis:
  - For public analysis, background samples were used to model the background for heavy (> 1 TeV) resonances.
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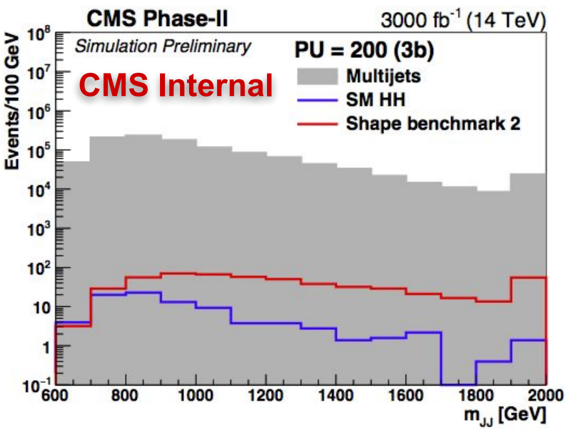
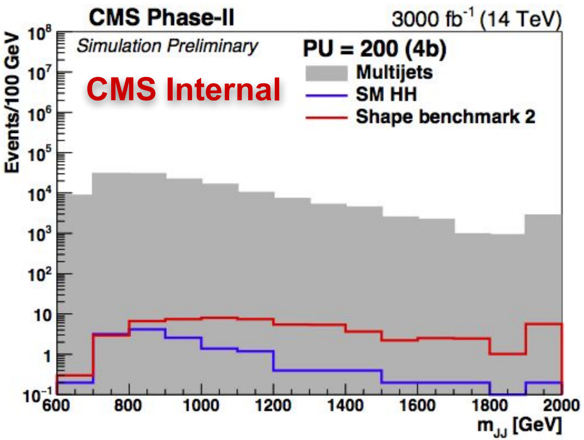
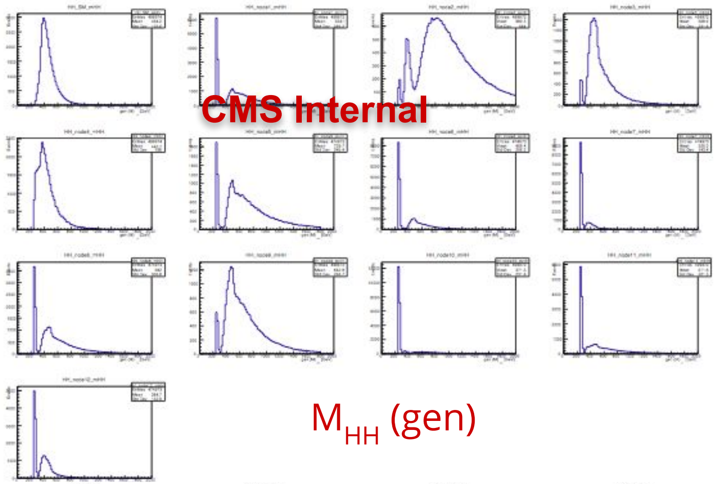


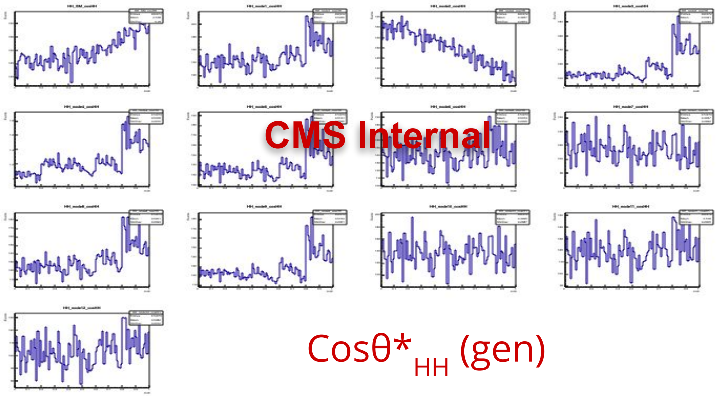


13 BSM+SM benchmarks and upper limits

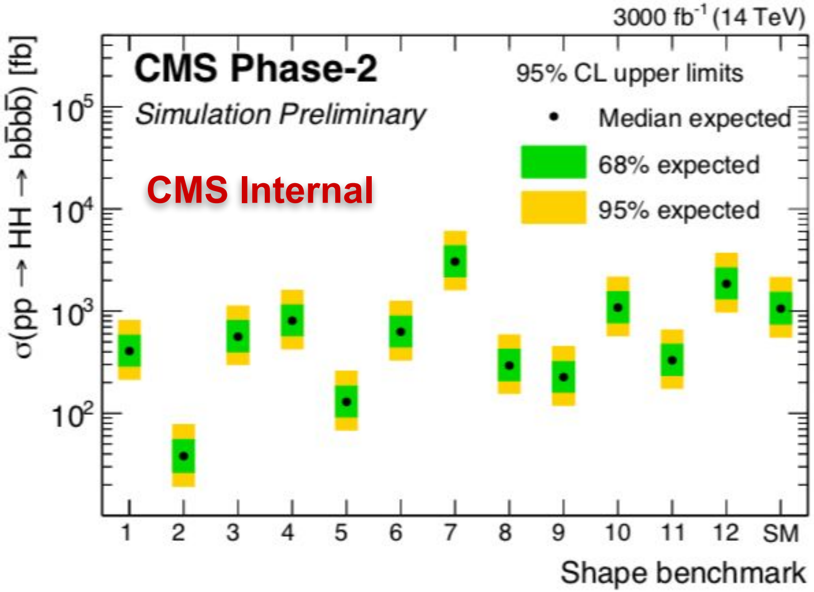
- We use reweighting method for BSM node -2 shape to mimic like other benchmark shapes.



M_{HH} (gen)



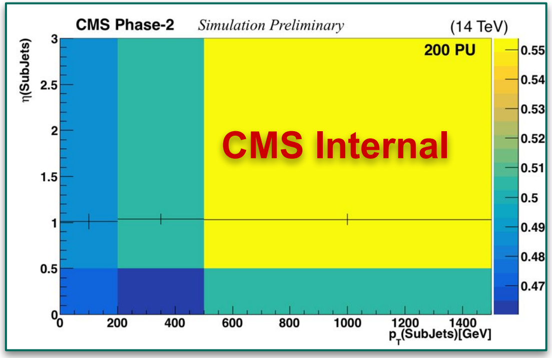
$Cos\theta^*_{HH}$ (gen)



Backup

DeepCSV loose mappings and systematic uncertainties

b_eff. DeepCSV loose



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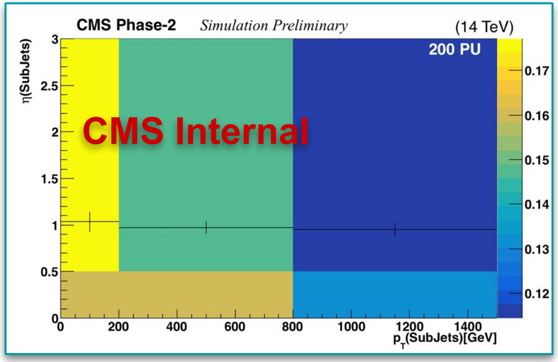
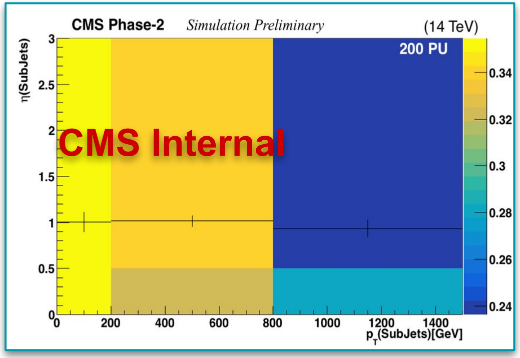


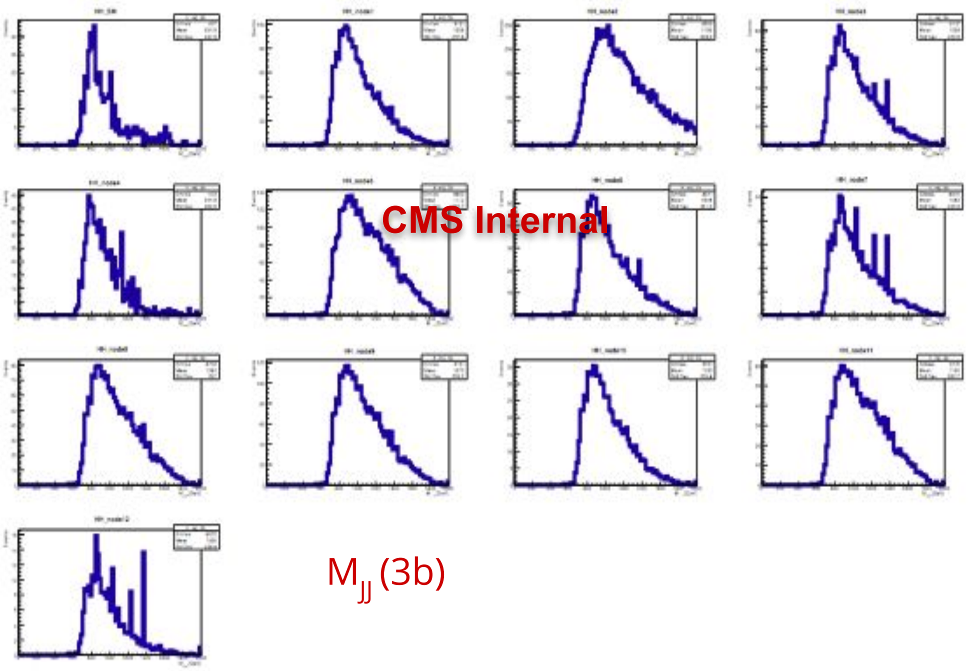
c_eff. DeepCSV loose



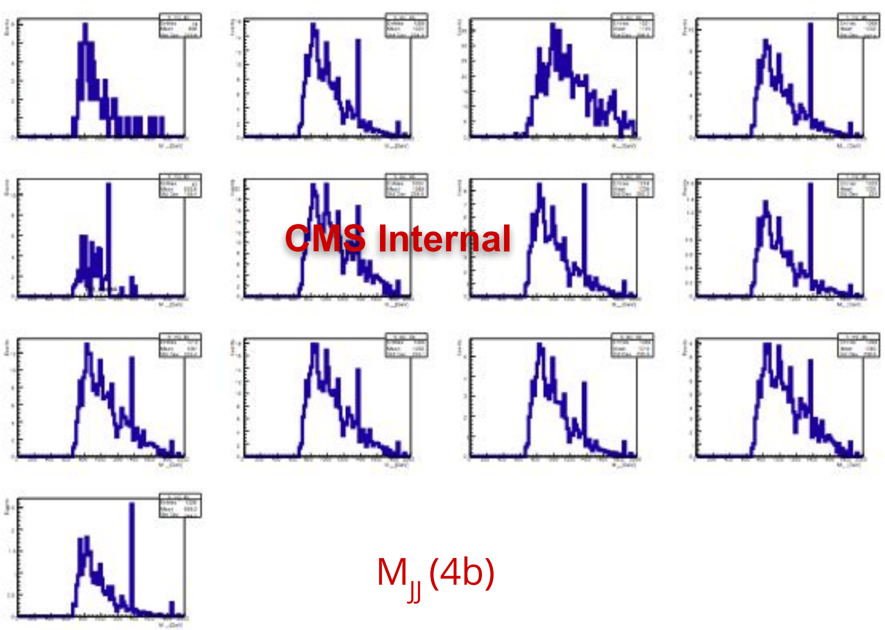
Source	Value	Obtained from
H jet mass scale and resolution	1	B2G-16-026, scaled by 0.5
H jet τ_{21} selection	13%	B2G-16-026, scaled by 0.5
H-tagging correction factor	3.5%	B2G-16-026, scaled by 0.5
Pileup modelling	1	B2G-16-026, scaled by 0.5
PDF and scales	1	B2G-16-026, scaled by 0.5
Luminosity	1.5%	UPGAnalysisSystematics
Jet energy scale	1%	UPGAnalysisSystematics
b tagging	1%	UPGAnalysisSystematics

13 BSM+SM benchmarks and upper limits

- We use reweighting method for BSM node -2 shape to mimic like other benchmark shapes.



M_{JJ} (3b)



M_{JJ} (4b)