Search for the resonant production of two Higgs bosons in the $\gamma\gamma b\bar{b}$ final state

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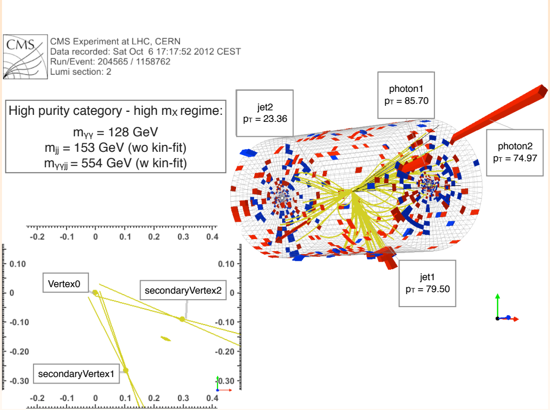
Outline

- Overview of the process:
  1. Motivation from theory
  2. Production and decay

- Analysis
  1. Objects (γ, j)
  2. Signal extraction
  3. Results



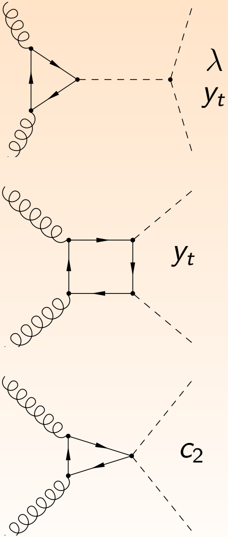
Theoretical motivation

HH production in SM

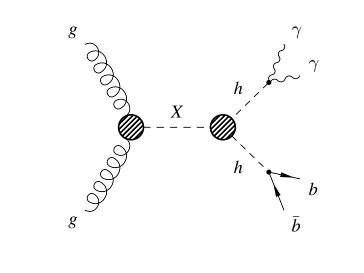
- $\sigma(pp \to HH) \approx 10$ fb at $\sqrt{s} = 8$ TeV.
- Lots of lumi is needed (cf. HL-LHC).

HH production in beyond SM scenarios

- Nonresonant HH can be enhanced by altering the couplings of the Higgs.
  - This models the presence of new particles.
  - There are interference effects.
- λ, y_t, and c_2 can vary in $gg \to HH$.



Theoretical motivation



HH production in beyond SM scenarios

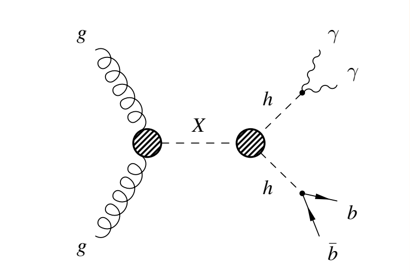
- Resonant HH can be motivated by WED, 2HDM, and (N)MSSM.
  - Radion (spin 0) or Graviton (spin 2) from perturbations of the ED
  - Higgs-like scalar from extended Higgs sector in SUSY
- Resonance can decay to HH if it is kinematically allowed.

Production and decay

Enhanced HH resonance

- We search for a heavy resonance (X) produced through gluon fusion.
- The object decays to a pair of SM Higgs, which decay to a pair of photons (high resolution) and a pair of b quarks (high BR).
- This search concerns the non-boosted regime, m_X from 260 to 1100 GeV.

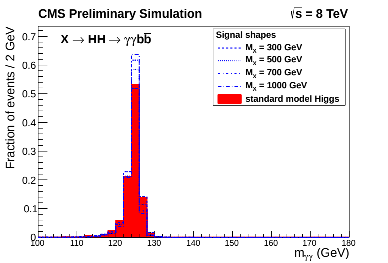
Channel	Freq. (%)
$H(b\bar{b}, c\bar{c}, gg)H(b\bar{b}, c\bar{c}, gg)$	47.86
$H(b\bar{b})H(b\bar{b})$	33.30
$H(b\bar{b}, c\bar{c}, gg)H(VV^*)$	33.40
$H(b\bar{b}, c\bar{c}, gg)H(\tau^+\tau^-)$	8.77
$H(b\bar{b})H(\tau^+\tau^-)$	7.29
$H(VV^*)H(VV^*)$	5.83
$H(l^+l^-)H(VV^*)$	3.06
$H(\tau^+\tau^-)H(\tau^+\tau^-)$	0.40
$H(b\bar{b}, c\bar{c}, gg)H(\gamma\gamma)$	0.32
$H(b\bar{b})H(\gamma\gamma)$	0.26
$H(b\bar{b}, c\bar{c}, gg)H(\mu^+\mu^-)$	0.03
$H(l^+l^-)H(\gamma\gamma)$	0.03



Photons

Starting from SM $H \to \gamma\gamma$ analysis

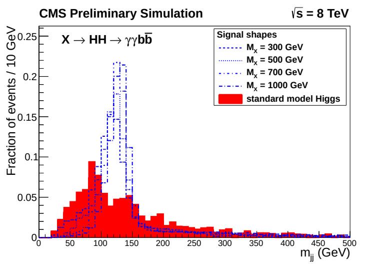
- Diphoton triggers with different thresholds for p_T^{lead}, p_T^{sublead}
- Photon preselection cuts
  - $p_T^{\text{lead}} > \frac{M_{\gamma\gamma}}{3}$
  - $p_T^{\text{sublead}} > \frac{M_{\gamma\gamma}}{4}$
  - $|\eta| < 2.5$
  - $100 \text{ GeV} < M_{\gamma\gamma} < 180 \text{ GeV}$
- Cut-based photon ID using
  - shower shape
  - isolation
  - hadronic leakage
  - electron veto



Jets

Identification

- Anti-k_T jets with R=0.5
- For preselection, require at least two jets with
  - $p_T > 25$ GeV
  - $|\eta| < 2.5$
  - ID for pileup, detector noise
  - A separation of $\Delta R > 0.5$ from each γ candidate
- Each event must have at least one loose b-tagged jet at preselection level.
  - N.B. tighter b-tagging comes after preselection.



Jets

After preselection

b-tagging

- Tighter b-tagging requirement is required for better S/B separation.
- B-tagging is used to categorize events.
  - ≥ 2 b-tagged jets gives the **high purity** category.
  - $= 1$ b-tagged jet gives the **medium purity** category and recovers signal efficiency

Combinatorics

- The dijet is chosen from the pair that gives the highest p_T^{jj}.
  - Choose among all tagged jets in the high-purity category
  - Choose among all untagged jets in the medium-purity category

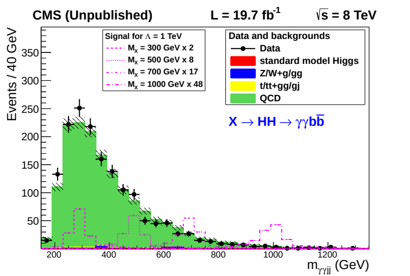
Analysis strategy

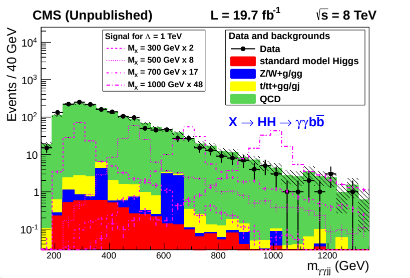
Three mass spectra

- A signal will appear as an excess in $M_{\gamma\gamma}$, M_{jj}, and $M_{\gamma\gamma jj}$ spectra.
- Analysis was blinded during design.

High-mass regime

- $M_{\gamma\gamma jj}$ gives a direct handle on m_X. Due to the background peaking around 300 GeV, this spectrum is only used for high mass hypotheses.
- The **high-mass regime** examines the shape of $M_{\gamma\gamma jj}$ to test $m_X \geq 400$ GeV.
- Mass windows are applied to $M_{\gamma\gamma}$ and M_{jj}.





Data/MC comparison after preselection,

event-normalized

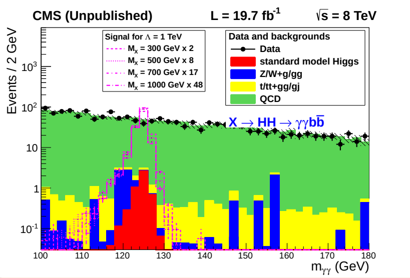
Analysis strategy

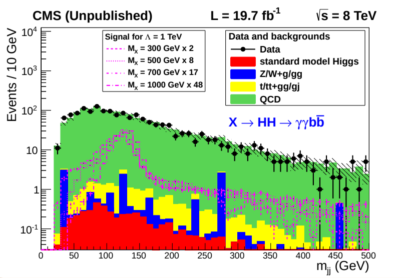
Three mass spectra

- A signal will appear as an excess in $M_{\gamma\gamma}$, M_{jj}, and $M_{\gamma\gamma jj}$ spectra.
- Analysis was blinded during design.

Low-mass regime

- To avoid fitting a signal peak on the background peak, $M_{\gamma\gamma jj}$ is not used for fitting m_X hypotheses close to 300 GeV.
- The **low-mass regime** examines the shape of $M_{\gamma\gamma}$ to test $m_X \leq 400$ GeV.
- Mass windows are applied to $M_{\gamma\gamma jj}$ and M_{jj}.





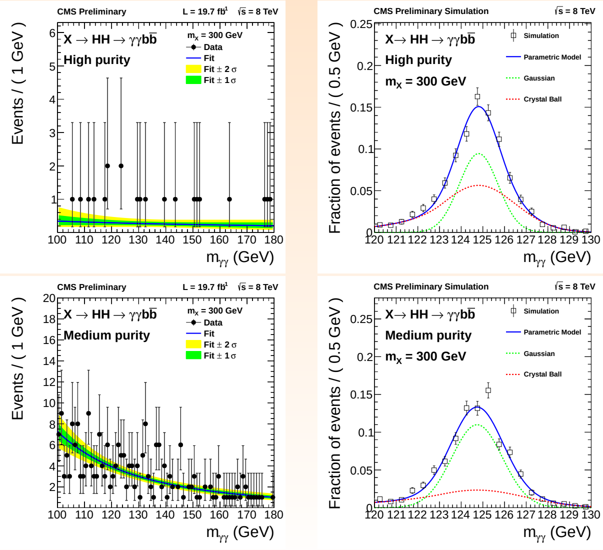
Data/MC comparison after preselection,

event-normalized

Signal extraction

Low mass ($m_X \leq 400$ GeV) modeling

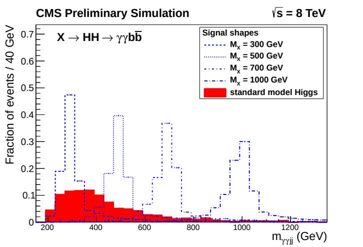
- Fit to $M_{\gamma\gamma}$
- Cut on $M_{\gamma\gamma jj}$
- Cut on M_{jj}

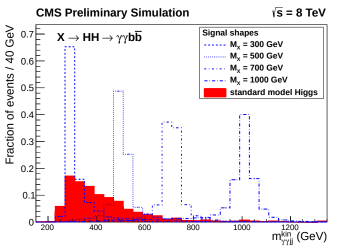


Kinematic fit

Kinematic fit

- After all cuts, an additional constraint used in the high mass regime is $M_{jj} = 125$ GeV.
  - The four-momentum of each jet in the dijet candidate is varied over its energy and position resolutions so that $M_{jj} = 125$ GeV.
  - In the $M_{\gamma\gamma jj}$ spectrum, the resonant and nonresonant backgrounds are shuffled around while the resolution of the signal is improved.
- Effect on signal and resonant background, top (before) and bottom (after)

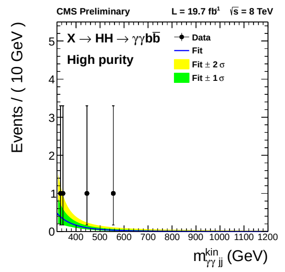


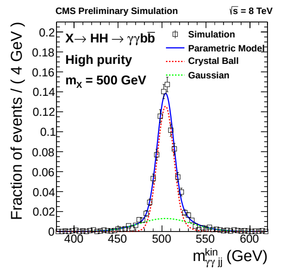


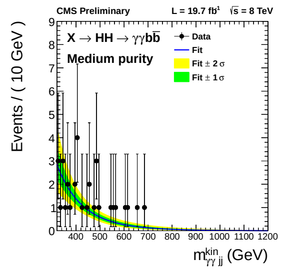
Signal extraction

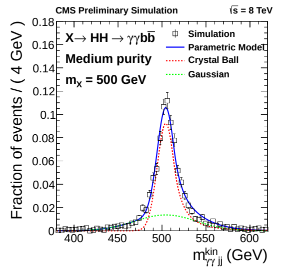
High mass ($m_X \geq 400$ GeV) modeling

- Fit to $M_{\gamma\gamma jj}$
- Cut on $M_{\gamma\gamma}$
- Cut on M_{jj}







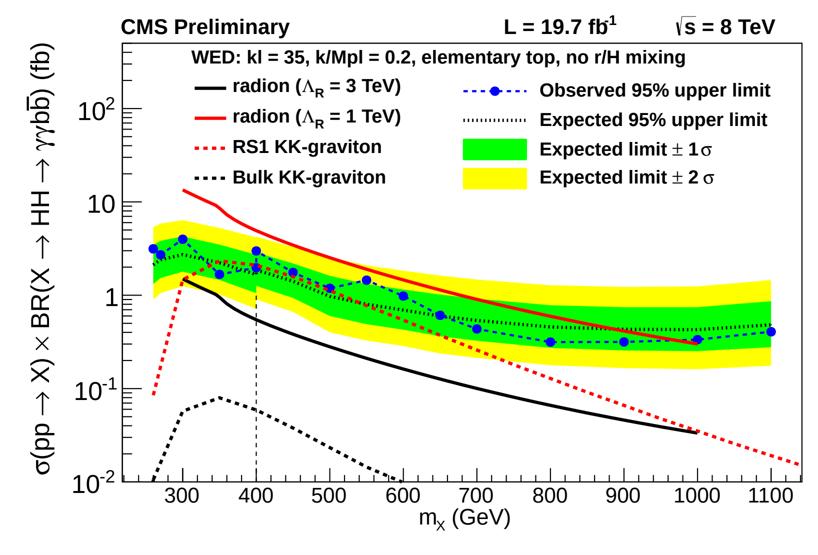


Notes on limits

- Statistically limited (systematics have 2% effect)
- Resonant background contribution is very small.

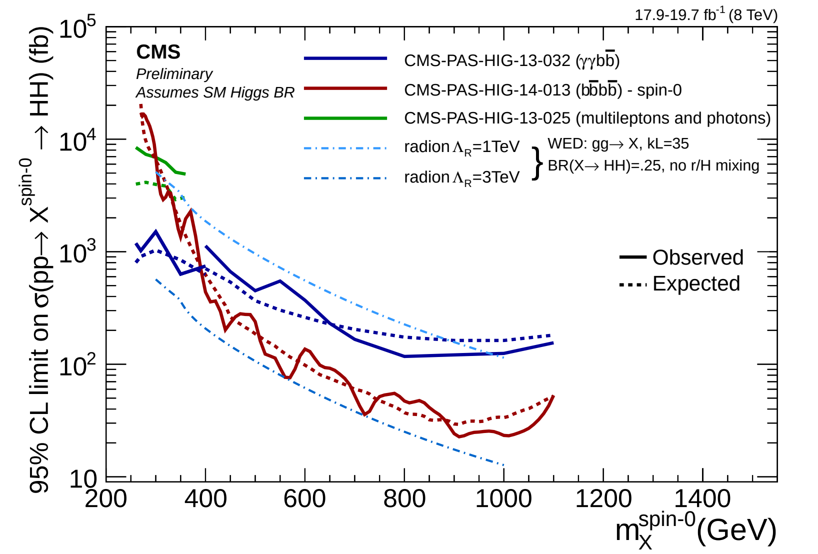
Sample	High-purity	Medium-purity
di-Higgs resonance (300 GeV, Λ_R=1 TeV)	18.73	21.66
$ggH(\rightarrow \gamma\gamma)$	0.02	0.19
VBF $(H \rightarrow \gamma\gamma)$	0.00	0.04
$VH(\rightarrow \gamma\gamma)$	0.01	0.08
$t\bar{t}H \rightarrow \gamma\gamma$	0.10	0.15
data	21	230

Exclusions



CMS Preliminary
L = 19.7 fb^{-1}
$\sqrt{s}$ = 8 TeV
WED: kl = 35, k/Mpl = 0.2, elementary top, no r/H mixing
radion (Λ_R = 3 TeV)
radion (Λ_R = 1 TeV)
RS1 KK-graviton
Bulk KK-graviton
Observed 95% upper limit
Expected 95% upper limit
Expected limit $\pm 1\sigma$
Expected limit $\pm 2\sigma$
$\sigma(pp \to X) \times BR(X \to HH \to \gamma\gamma b\bar{b})$ (fb)
10^{2}
10
1
10^{-1}
10^{-2}
300
400
500
600
700
800
900
1000
1100
m_X (GeV)

Comparison with other CMS HH results



Conclusions

Results

- $X \to HH \to \gamma\gamma b\bar{b}$ for 260 GeV $< m_X <$ 1100 GeV

Outlook

- Look for SM HH analysis to come out soon!
  - Similar to low mass resonant search around 400 GeV with much wider $M_{\gamma\gamma jj}$ peak.
- This will include interpretation for nonresonant models with anomalous couplings (λ, y_t, c_2).

Run II

- We are looking to target the first 5 /fb at $\sqrt{s} = 13$ TeV.
- Improved low-mass sensitivity probes low $tan(\beta)$ in NMSSM.
- Nonresonant search will come from anomalous couplings as in Run I.

Backup

Signal efficiency