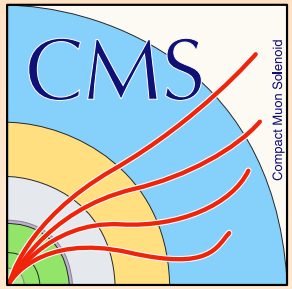



# Search for the resonant production of two Higgs bosons in the $\gamma\gamma b\bar{b}$ final state

CMS-PAS-HIG-13-032

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Princeton University

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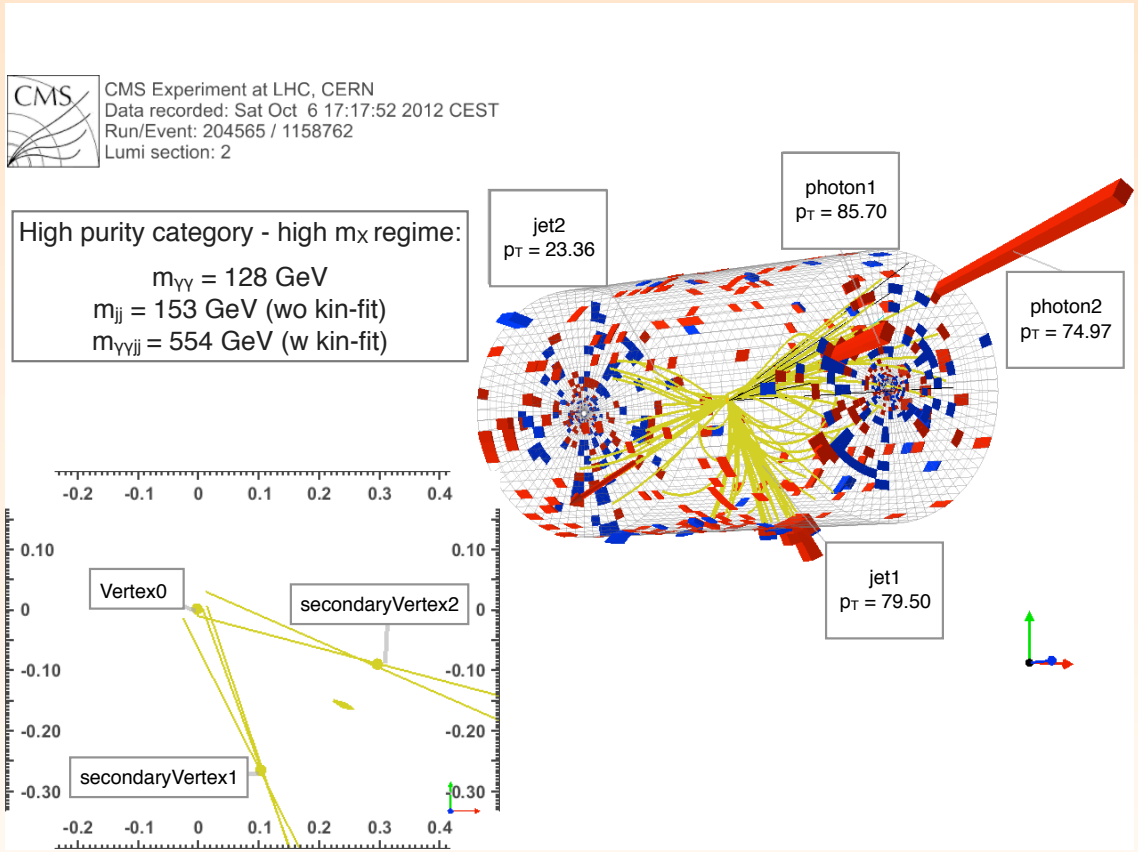
# Outline

- Overview of the process:
  1. Motivation from theory
  2. Production and decay
- Analysis
  1. Signal extraction
  2. Results



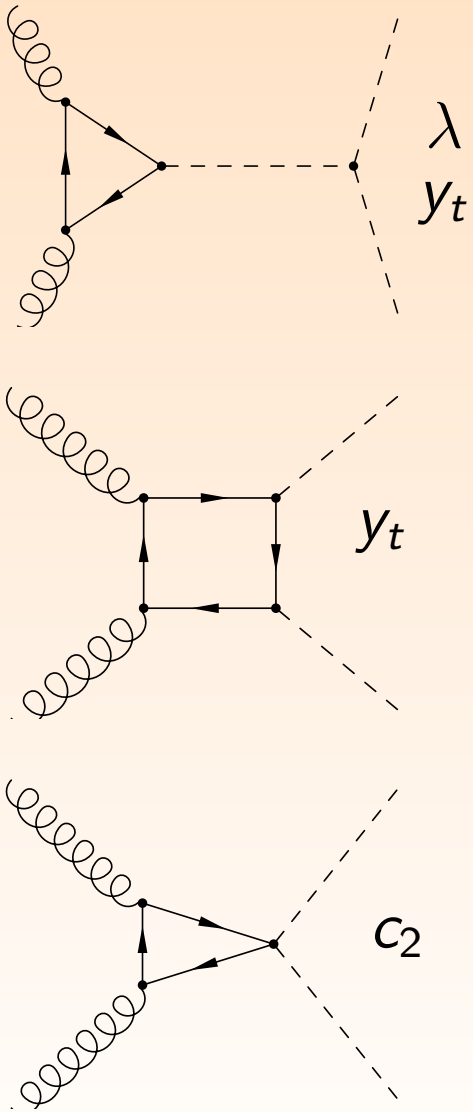
# Theoretical motivation

## HH production in SM

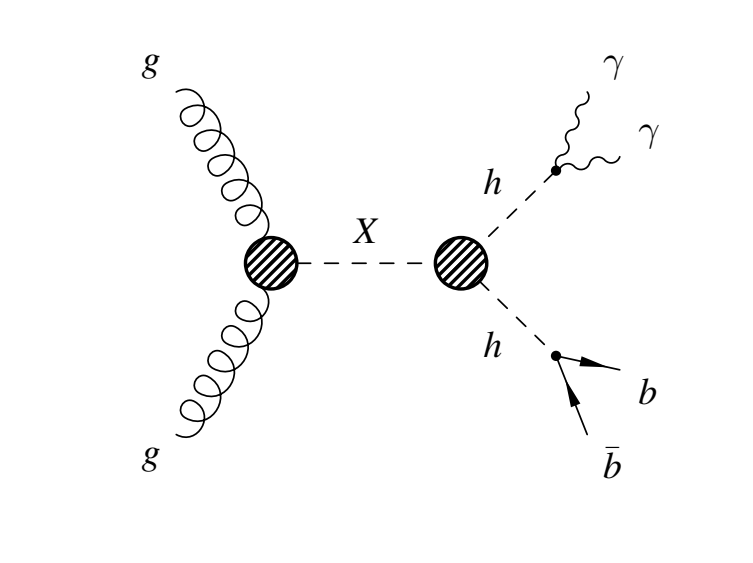
- $\sigma(pp \to HH) \approx 10$ fb at $\sqrt{s} = 8$ TeV.
- Lots of lumi is needed (cf. HL-LHC).

## 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.
- $\lambda$, $y_t$, and $c_2$ can vary in $gg \to HH$.



# Theoretical motivation




## HH production in beyond SM scenarios

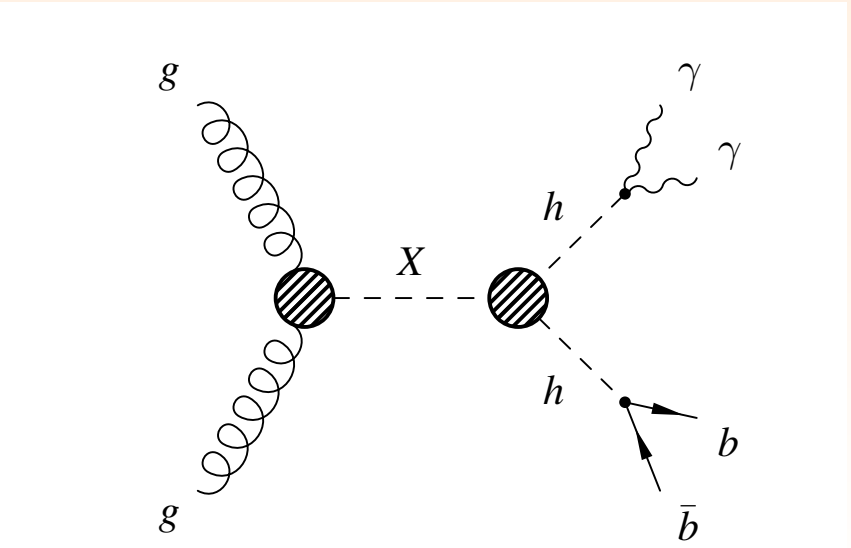
- Resonant HH can be motivated by WED, 2HDM, and (N)MSSM.
  - Radion (spin 0) or Graviton (spin 2) from perturbations of the ED
  - Higgs-like scalar from extended Higgs sector in SUSY
- Resonance can decay to HH if it is kinematically allowed.

# 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 |



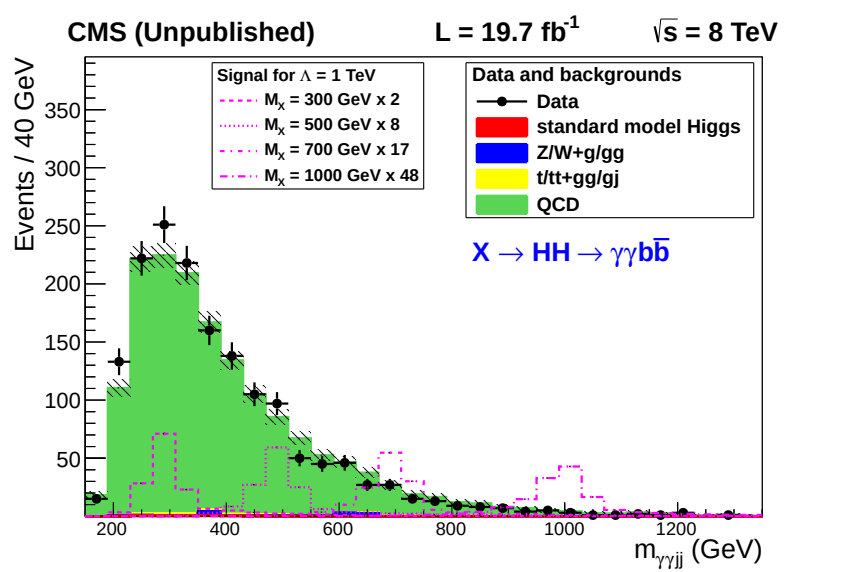
# Analysis strategy

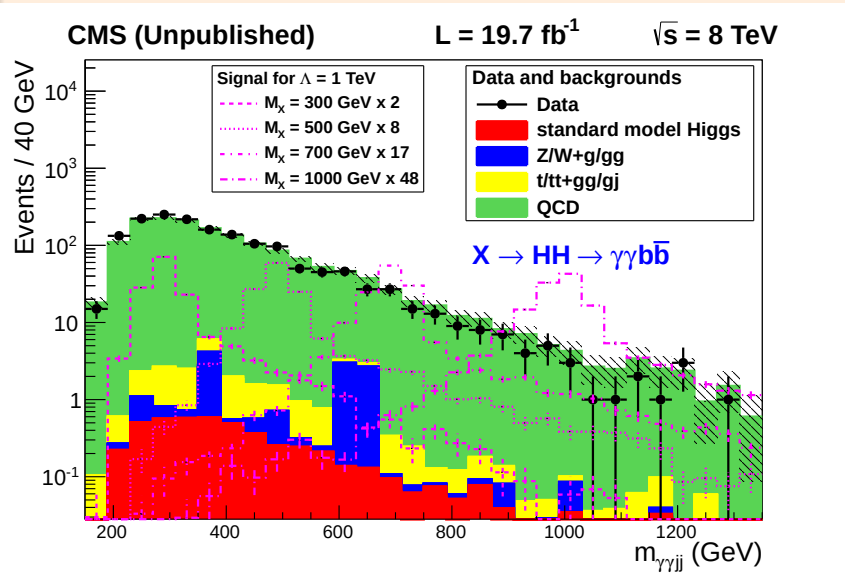
## Three mass spectra

- 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**

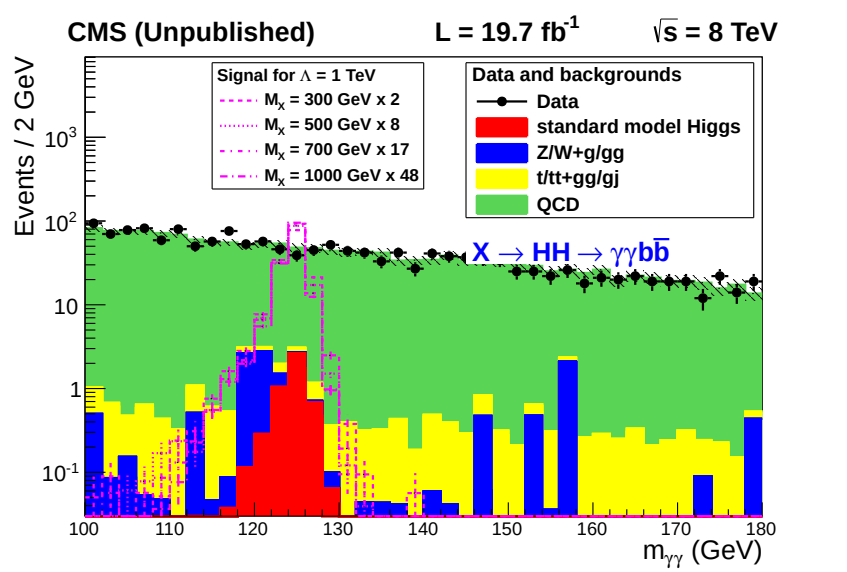
# Analysis strategy

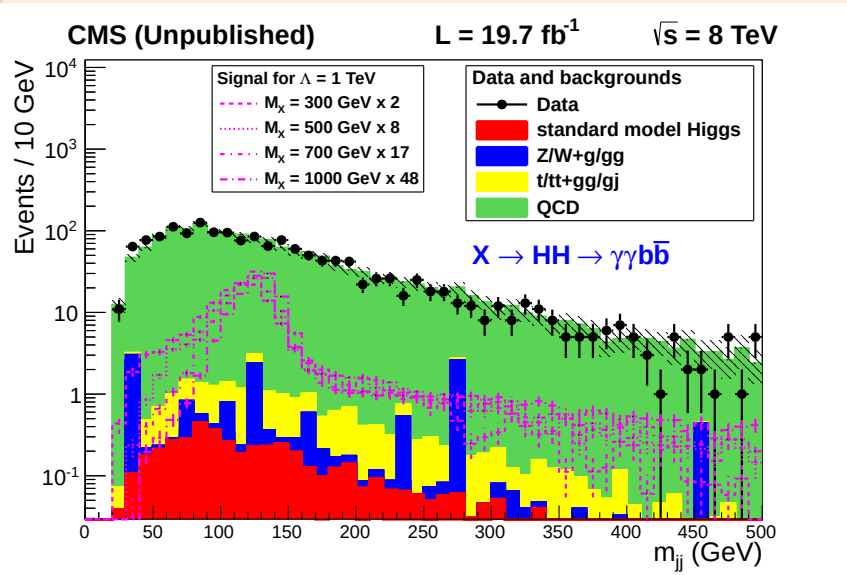
## Three mass spectra

- 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 $M_{jj}$.



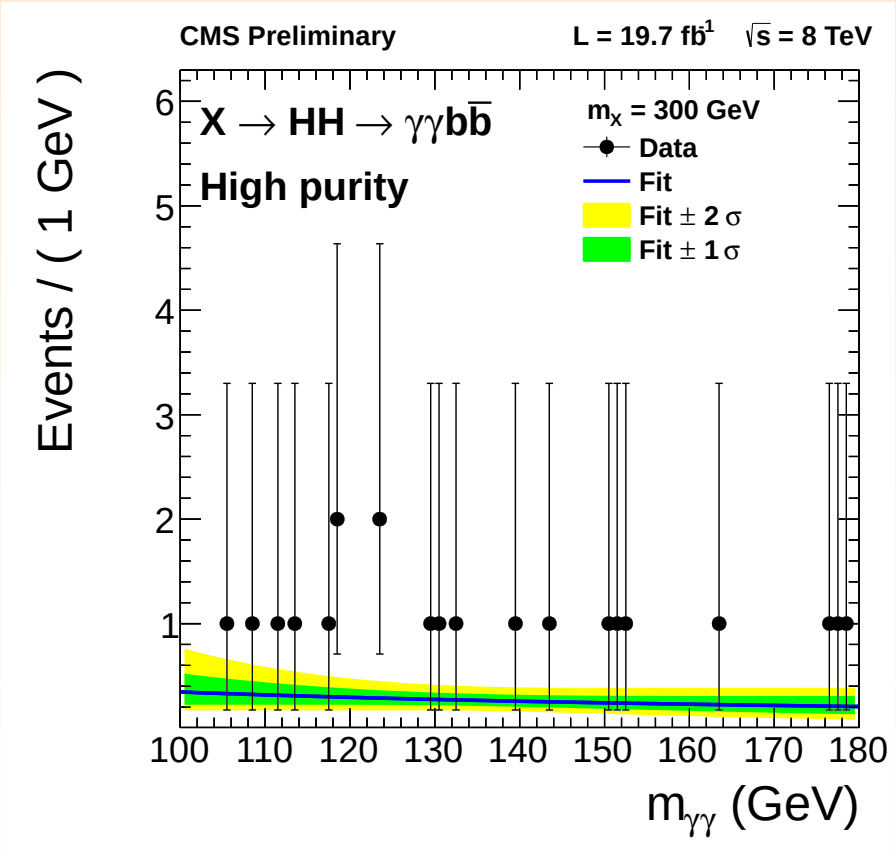

Data/MC comparison after preselection,

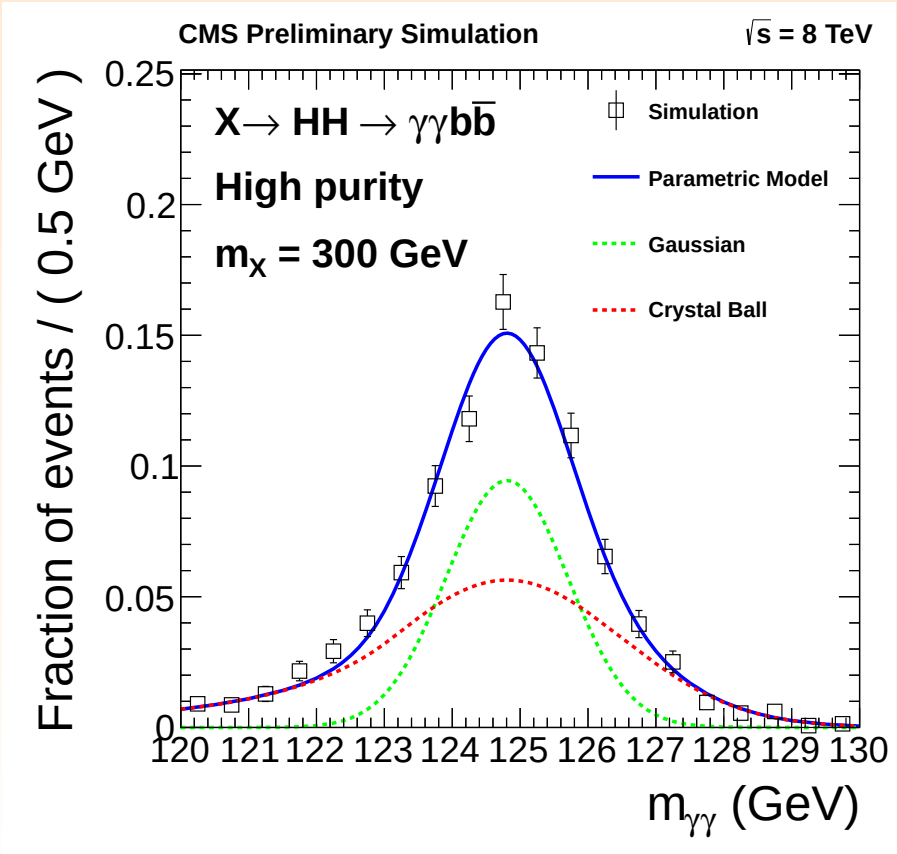
**event-normalized**

# Signal extraction

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

Fit to $M_{\gamma\gamma}$, cut on $M_{\gamma\gamma jj}$ and $M_{jj}$

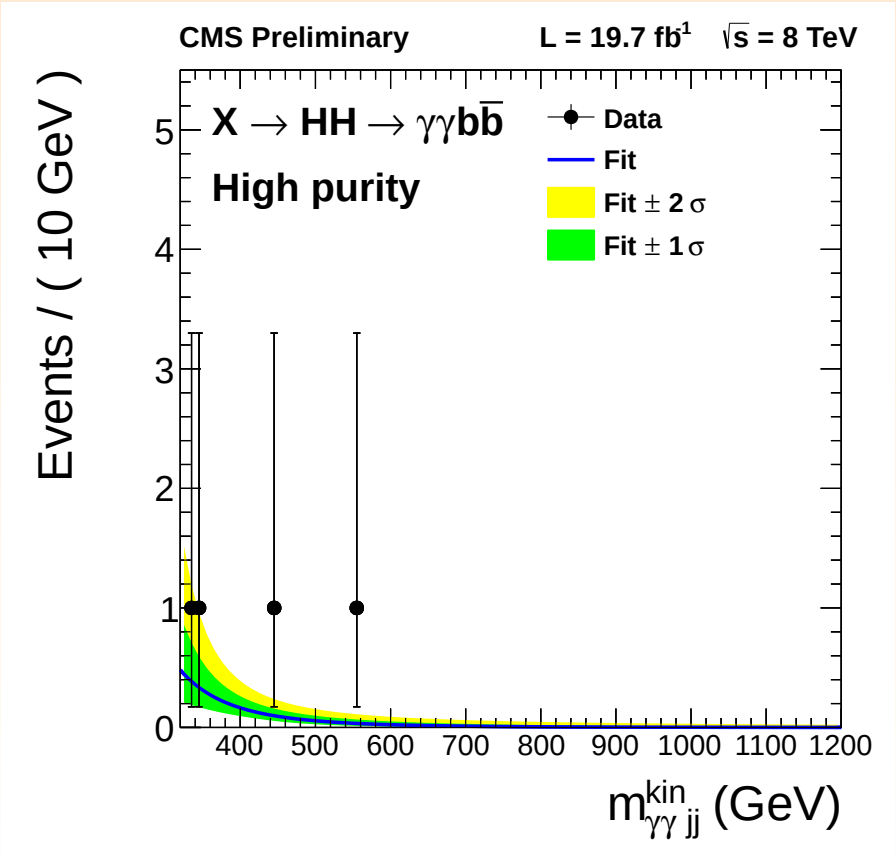


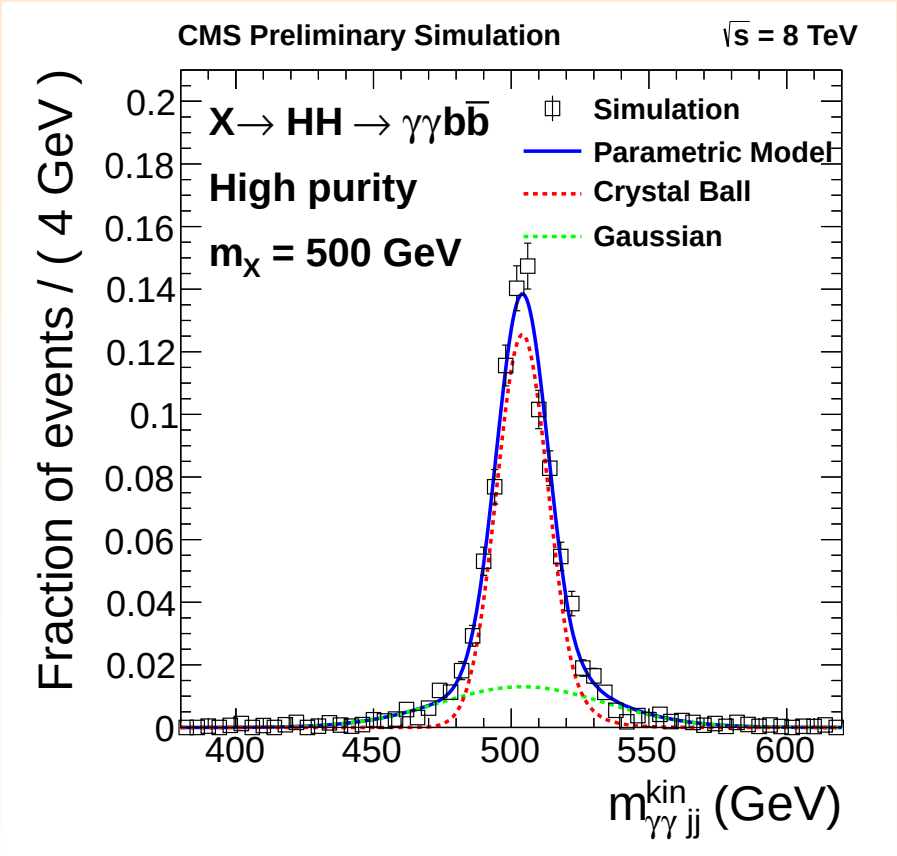



# Signal extraction

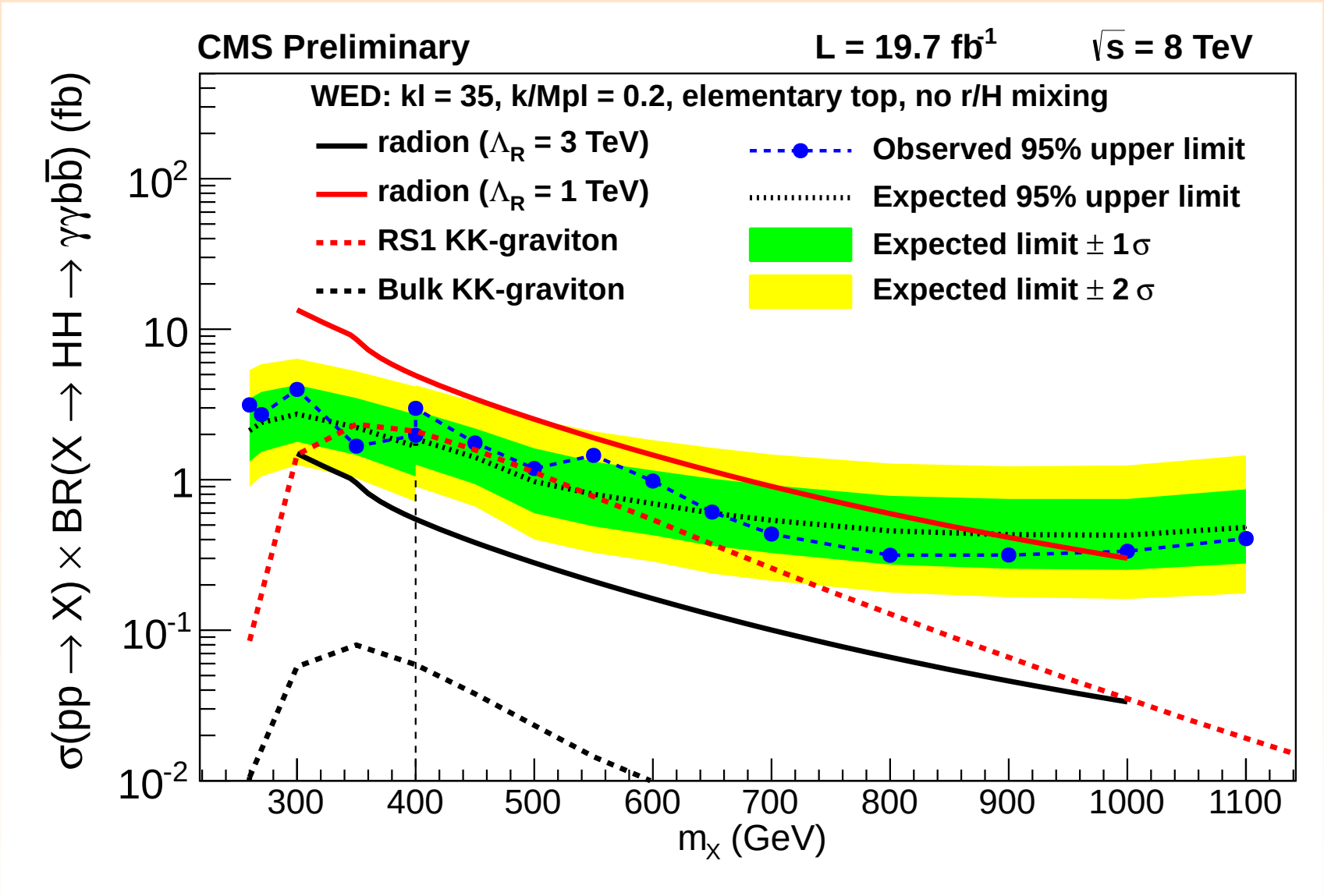
## High mass ($m_X \geq 400$ GeV) modeling

Fit to $M_{\gamma\gamma jj}$, cut on $M_{\gamma\gamma}$ and $M_{jj}$

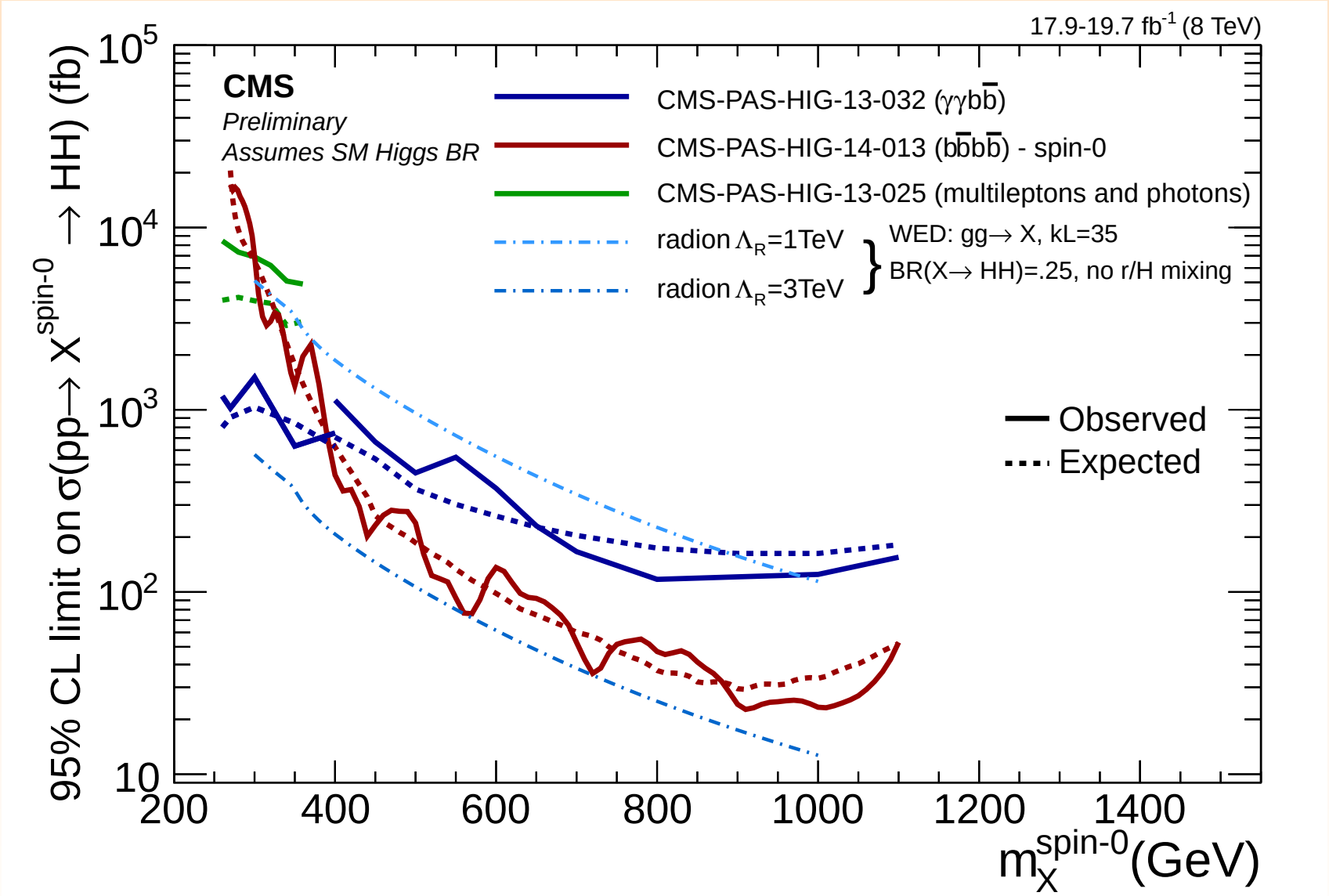


# Exclusions


CMS Preliminary
L = 19.7 fb-1
√s = 8 TeV
WED: kl = 35, k/Mpl = 0.2, elementary top, no r/H mixing
radion (ΛR = 3 TeV)
radion (ΛR = 1 TeV)
RS1 KK-graviton
Bulk KK-graviton
Observed 95% upper limit
Expected 95% upper limit
Expected limit ± 1σ
Expected limit ± 2 σ
σ(pp → X) × BR(X → HH → γγbb̄) (fb)
10²
10
1
10⁻¹
10⁻²
300
400
500
600
700
800
900
1000
1100
mX (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
- Analysis is statistically-limited.
- SM Higgs contribution is negligible.
- Analysis is spin-independent.

## Outlook

- Look for SM HH analysis to come out soon!
- This will include interpretation for nonresonant models with anomalous couplings ($\lambda$, $y_t$, $c_2$).

# Backup

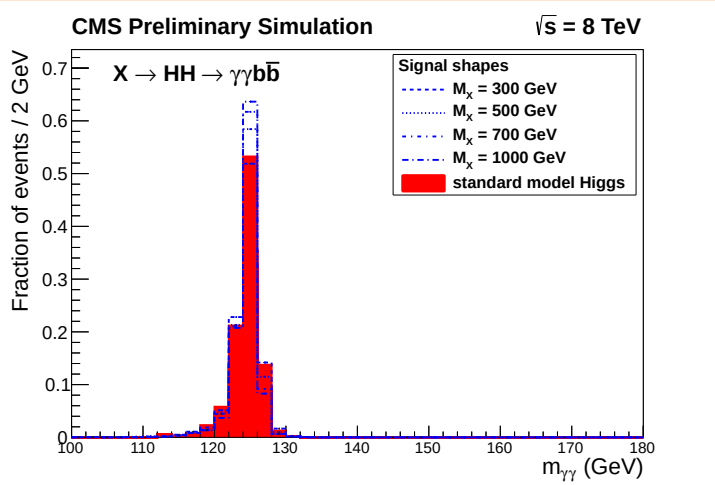
# Objects

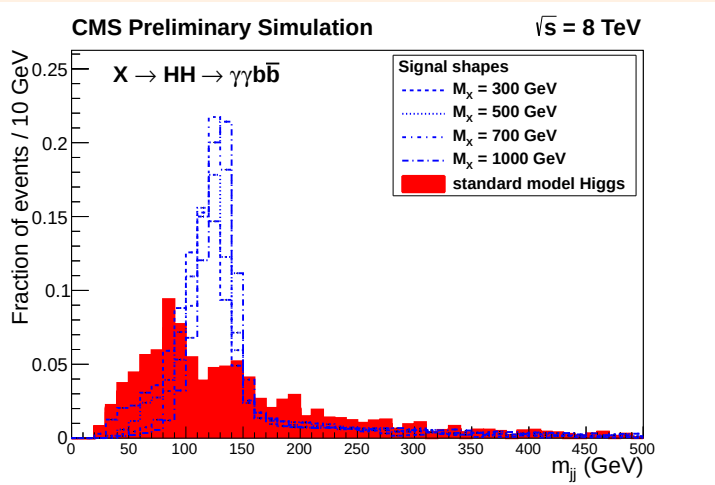
## Starting from SM $H \to \gamma\gamma$ analysis

- Double photon triggers
- 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 based on shower shape and isolation

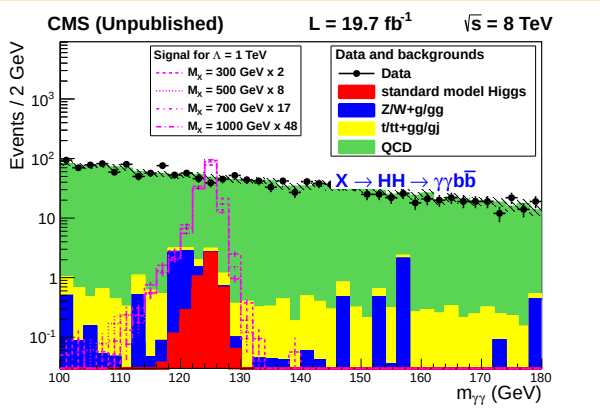
## And adding jets

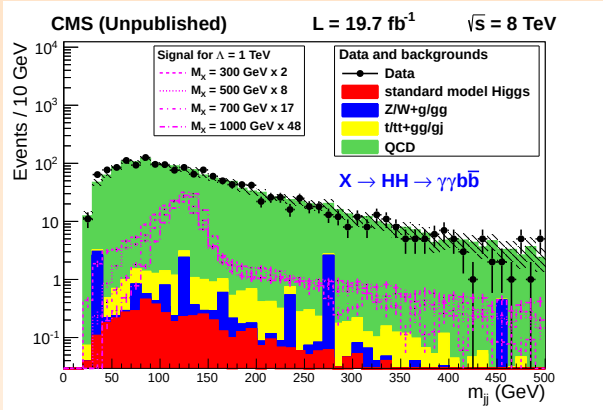
- Anti-$k_T$ jets with R=0.5
- Jet preselection cuts
  - $p_T > 25$ GeV
  - $|\eta| < 2.5$
  - Loose/pileup jet ID

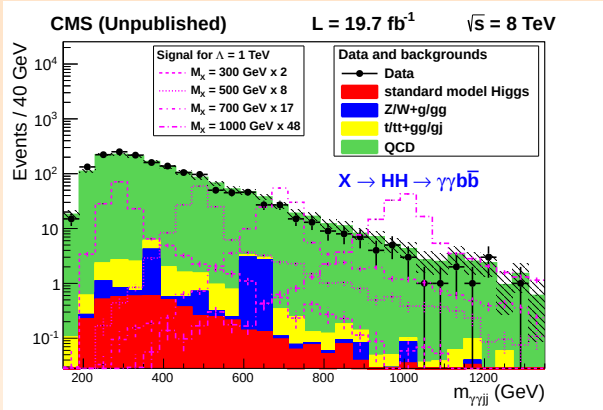


# To the signal region




## b-tagging and mass windows

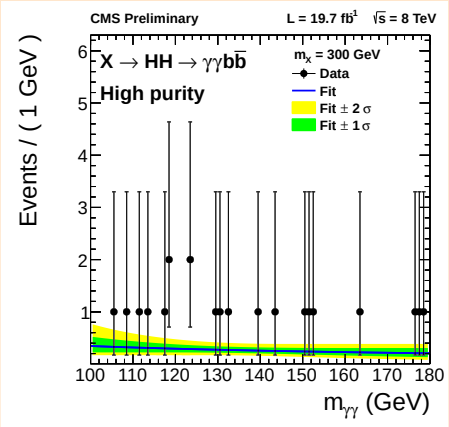
- Displaced tracks allow for identification of jets coming from b quarks.
- The tagger used has 70% signal efficiency and 10% background acceptance.
  - $\geq 2$ b-tagged jets is **high purity**
  - $= 1$ b-tagged jet is **medium purity** and recovers signal efficiency
- Finally, mass windows are applied to the two spectra not being fit.

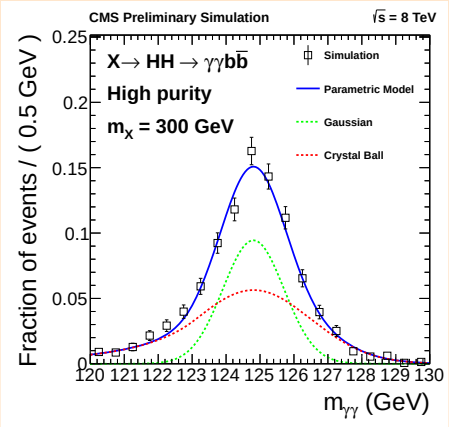
# Signal extraction

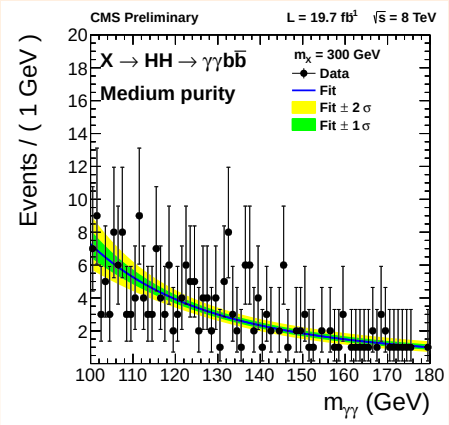
## Low mass ($m_X \leq 400$ GeV) modeling

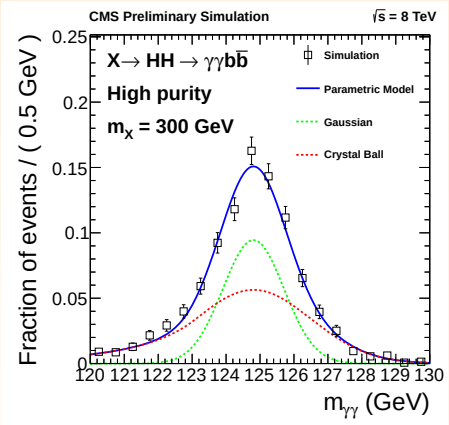
### Modeling choice

- Background is modeled by a power law in both categories.
  - Mass windows are placed on $M_{jj}$ and $M_{\gamma\gamma jj}$, changing background shape for different mass hypotheses.
- Signal is modeled by a sum of Crystal Ball and Gaussian.



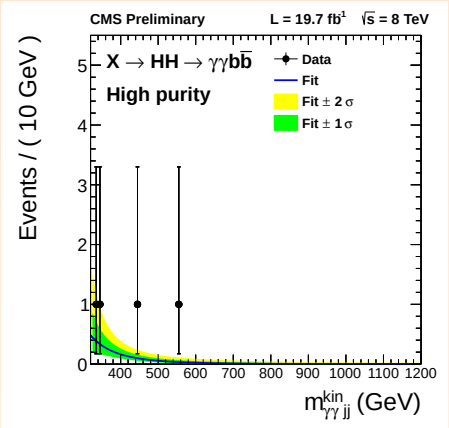



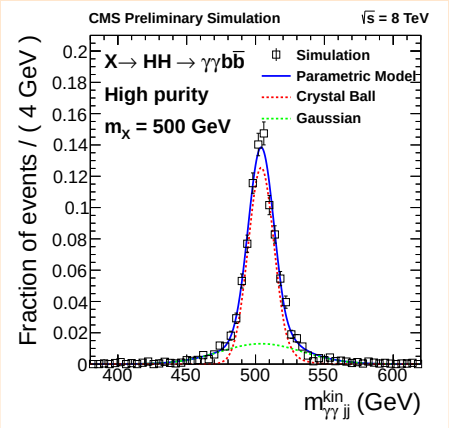
# Signal extraction

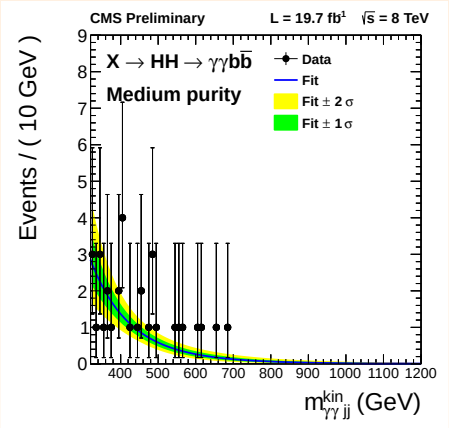
## High mass ($m_X \geq 400$ GeV) modeling

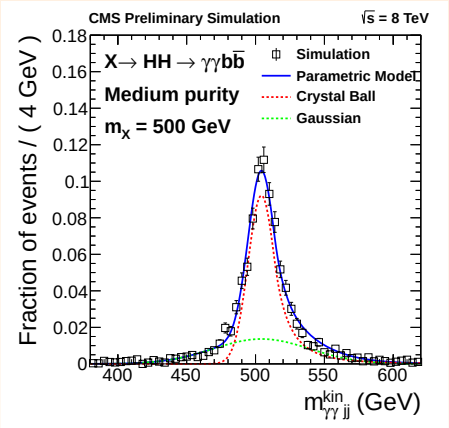
### Modeling choice

- Background model depends on category.
  - For high-purity category: $\frac{1}{(M_{\gamma\gamma jj})^{2a}}$
  - For medium-purity category: $\frac{1}{\left(M^2_{\gamma\gamma jj}+b\right)^a}$
- Signal is modeled by a sum of Crystal Ball and Gaussian.



# Signal efficiency