Search for pair production of vector-like partners of the top quark (T) with T→ tH, H→$\gamma\gamma$

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on behalf of the CMS collaboration
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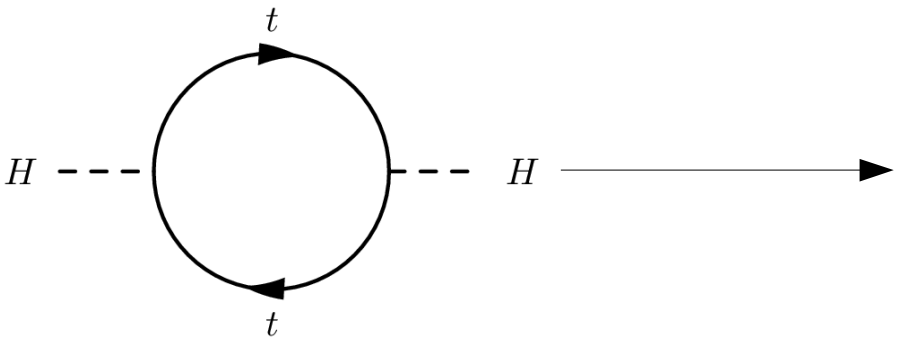
Introduction and motivation

- The Standard Model (**SM**) is a very well established theory, whose predictions have been experimentally tested with high precision
- The Higgs (BEH) boson has been discovered with a M_H~125 GeV
- Now the question is: **'Why is the mass of the Higgs boson so small ?'**



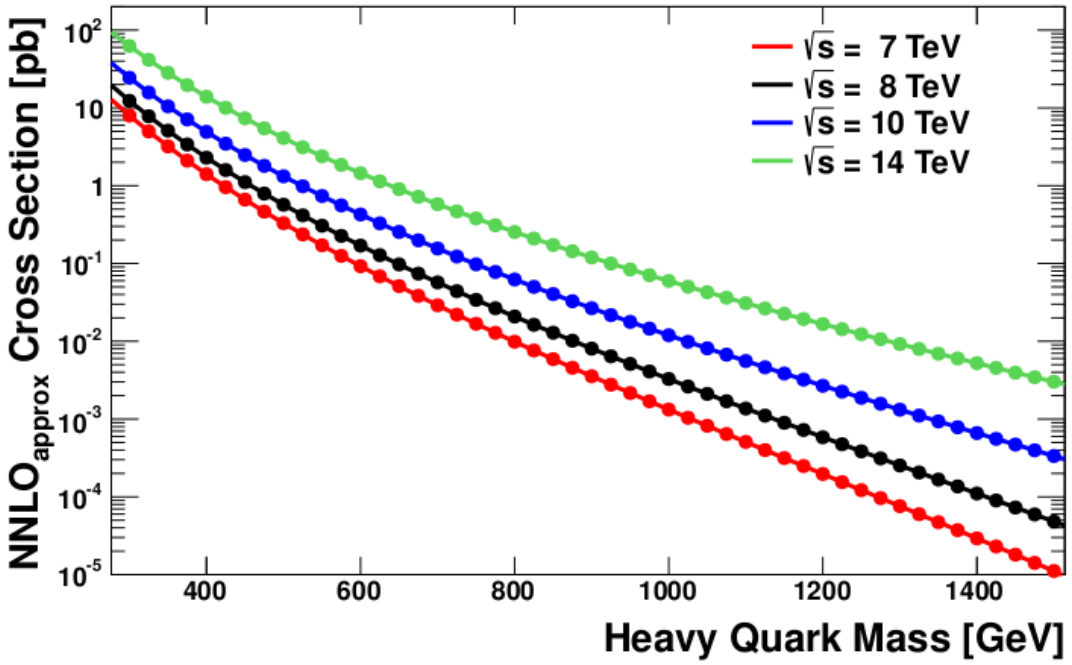
Correction to $M_H \sim \Lambda^2$,
with Λ validity scale of SM

Need to cancel out the divergent contribution → **Heavy replicas of the t quark (T)**

Existence of T quark : needed in several BSM theories
(*little Higgs, composite Higgs*)

T pair production

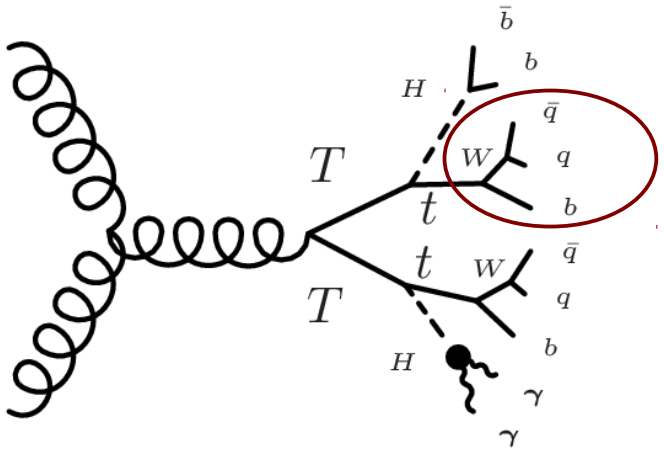
- Within several theories BSM : extra "up-type" (T) quarks with vector-like couplings
- Possible decay modes: T → tH, tZ , Wb
- TT production has large cross-section (~pb) in a wide range of m_T (strong production) and independent on the weak isospin quantum numbers



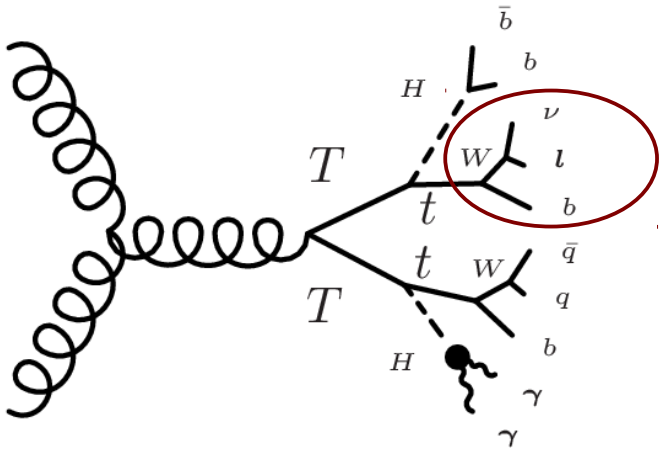
- Decay mode considered: **T → tH** , where the presence of a well-identified H in the final state would be **crucial** in order **to characterize the signal**

Search for T: strategy

B2G-14-003



Hadronic Channel (Example)

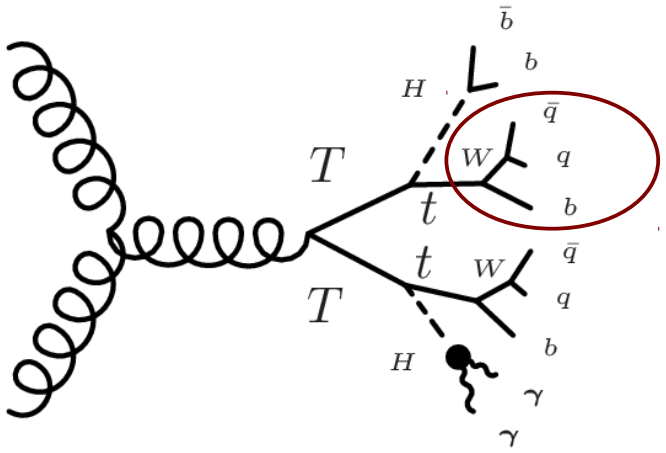


Leptonic Channel (Example)

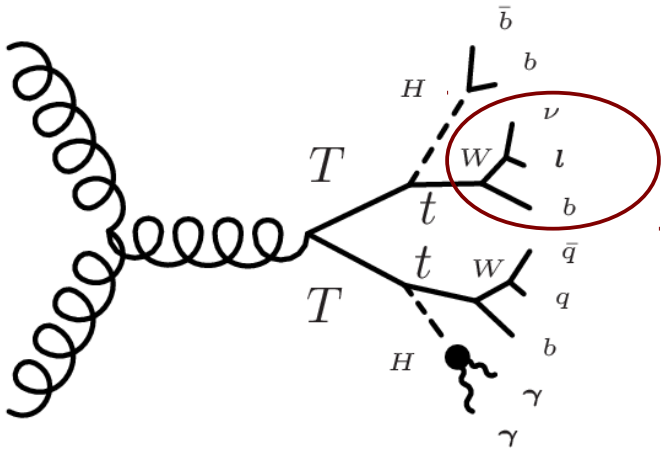
- **Search technique**: **exploit the narrow resonance of** $H\rightarrow\gamma\gamma$, fitting a peak in $M\gamma\gamma$ distribution (as done in Hgg analysis)
- **Main advantage** wrt other decay channels: estimate the **background** directly **from data**
- **Hadronic/Leptonic** channel to improve sensitivity
  (Leptonic channel has better S/B, the hadronic one has higher xsec)

Search for T: strategy

B2G-14-003



Hadronic Channel (Example)



Leptonic Channel (Example)

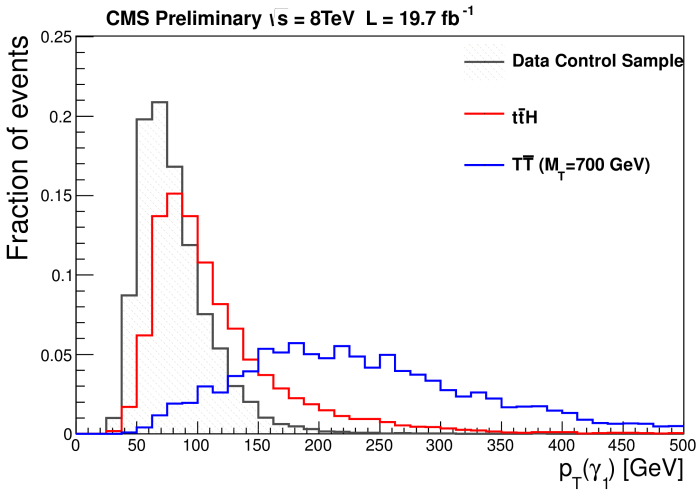
Main aspects of the analysis:

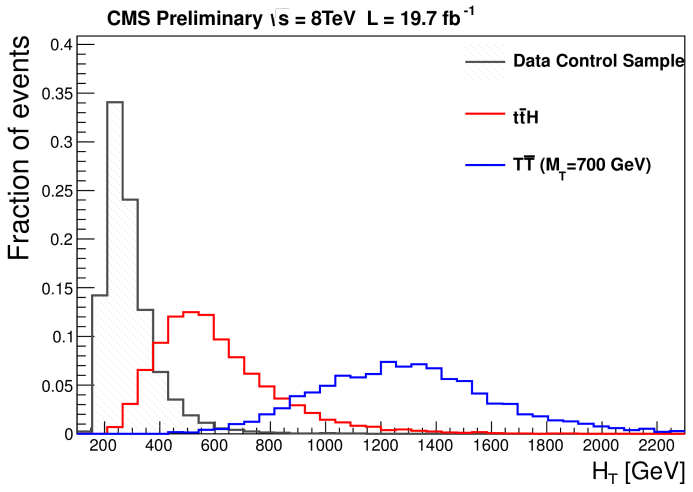
- **Optimization** using TT signal @ 700 GeV in the scenario BR(T→ tH)=1
- **Background** obtained with **data-driven methods** both for signal extraction and limit derivation
- **Searching for signal** in the scenario BR(T→ tH)=1 , then reinterpreted in all other possible sets of different BRs

Optimization Strategy

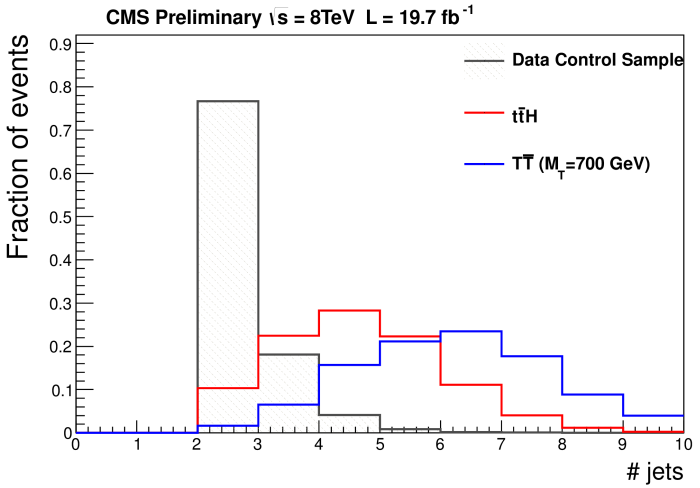
- **Data Control Sample** (for non-resonant bkgs)
- **ttH(→γγ)** (resonant background)
- **TT** (m_T=700 GeV) for signal

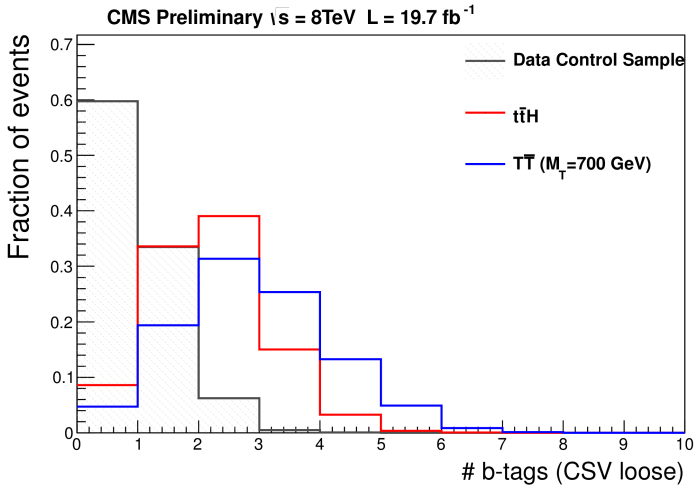
Event selection defined optimizing cuts on the most discriminant variables: $p_T(\gamma_1)$, $p_T(\gamma_2)$, H_T/ # jets, # b-tags





$$H_T = p^T_{jets} + p^T_{photons} + p^T_{leptons}$$



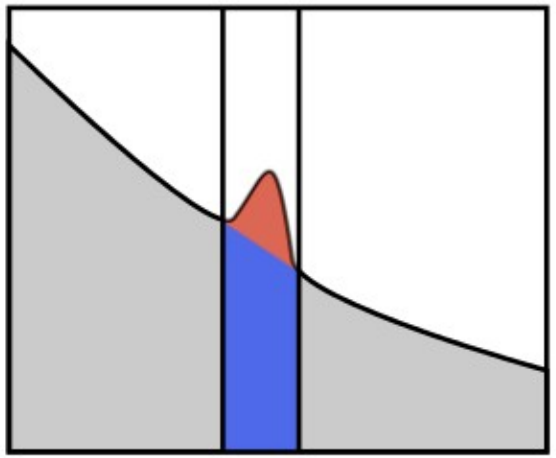


→ Photons and jets with higher p_T wrt bkg

→ Higher jet multiplicity for signal

Signal and Bkg estraction

- **Diphoton channel advantage**:
  - Presence of a **narrow mass peak**
  - Possibility to use **Mγγ spectrum to evaluate bkg** under signal peak
- **Signal region**: window around nominal mass
- **Sidebands**: the rest of the Mγγ spectrum, from 100 to 180 GeV



Mγγ

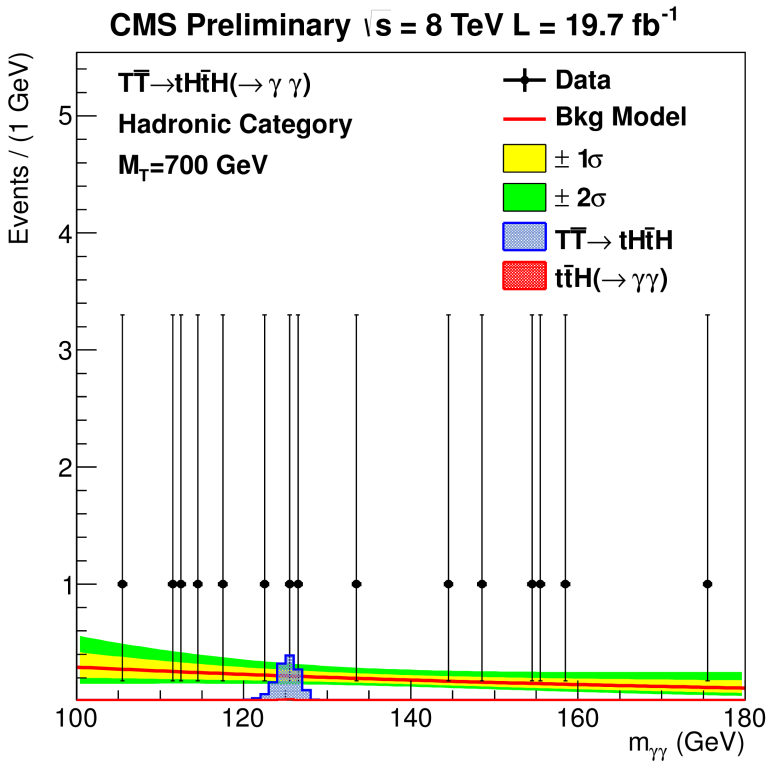
- Main issues:
  - **Width** of the signal region: 3 GeV around 125 GeV (1 FWHM region)
  - **Shape of the background: exponential**

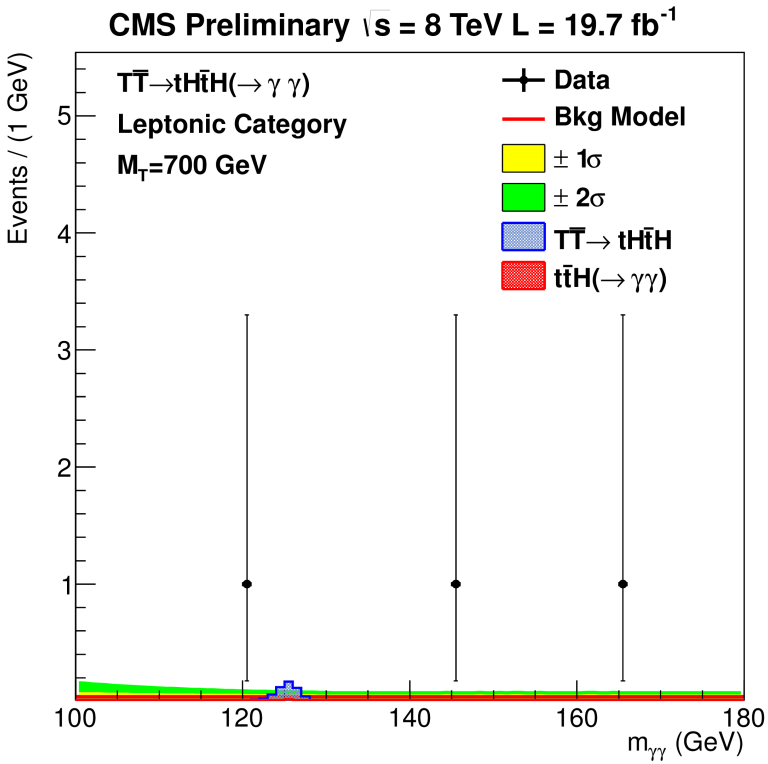
Systematic uncertainties

	$T\bar{T}$	$t\bar{t}H$
Luminosity	$\pm 2.4\%$	$\pm 2.4\%$
PDF	-	$\pm 8.1\%$
QCD scale	-	+4/-9 %
Photon Energy Resolution	+4/-2 %	+4/-2 %
Photon Energy Scale	+1/-4 %	+1/-4 %
Photon ID Efficiency	$\pm 2\%$	$\pm 2\%$
Trigger	$< 0.1\%$	$< 0.1\%$
JEC	$\pm 2\%$ (had) $\pm 1\%$ (lep)	$\pm 7\%$ (had) $\pm 5\%$ (lep)
JER	$\pm 1\%$	$< 0.5\%$
b-tagging	$< 0.5\%$ (had)	$< 0.5\%$ (had)
Pile-up identification	$\pm 2\%$	$\pm 2\%$
Lepton Reconstruction	$\pm 1\%$ (lep)	$\pm 1\%$

- Photons' systematics are **shape systematics**
- All the others are just systematics on **normalization**
- Systematics on photons, leptons, jets:
  same approach as for Hgg exclusive categories

Mass plots after full selection





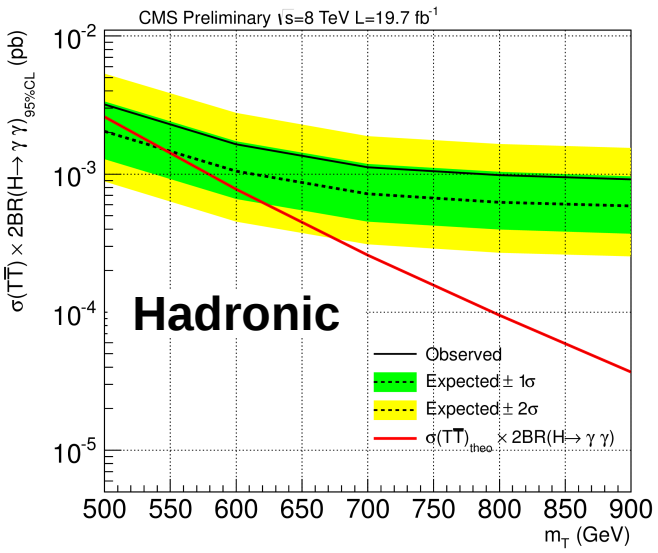
Unbinned maximum-likelihood fit between 100-180 GeV

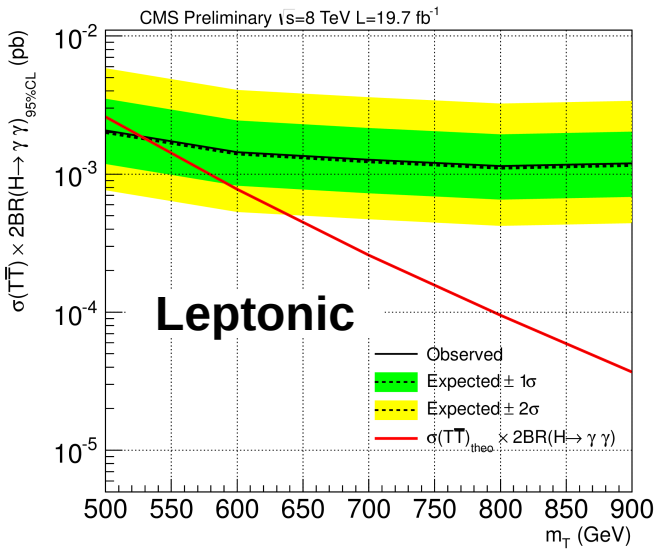
Window:
3 GeV around 125 GeV

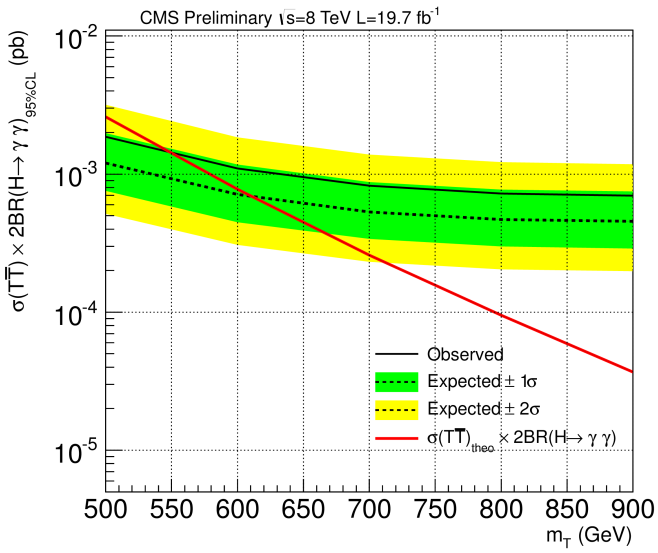
Process	Hadronic	Leptonic
$T\bar{T}(m_T = 700\ \text{GeV})$	1.05	0.43
$t\bar{t}H$	0.042	0.039
Background	$0.65^{+0.16}_{-0.13}$	$0.11^{+0.07}_{-0.03}$
Observed Data	2	0

No excess found in data wrt background-only hypothesis

Interpretation: cross section limits







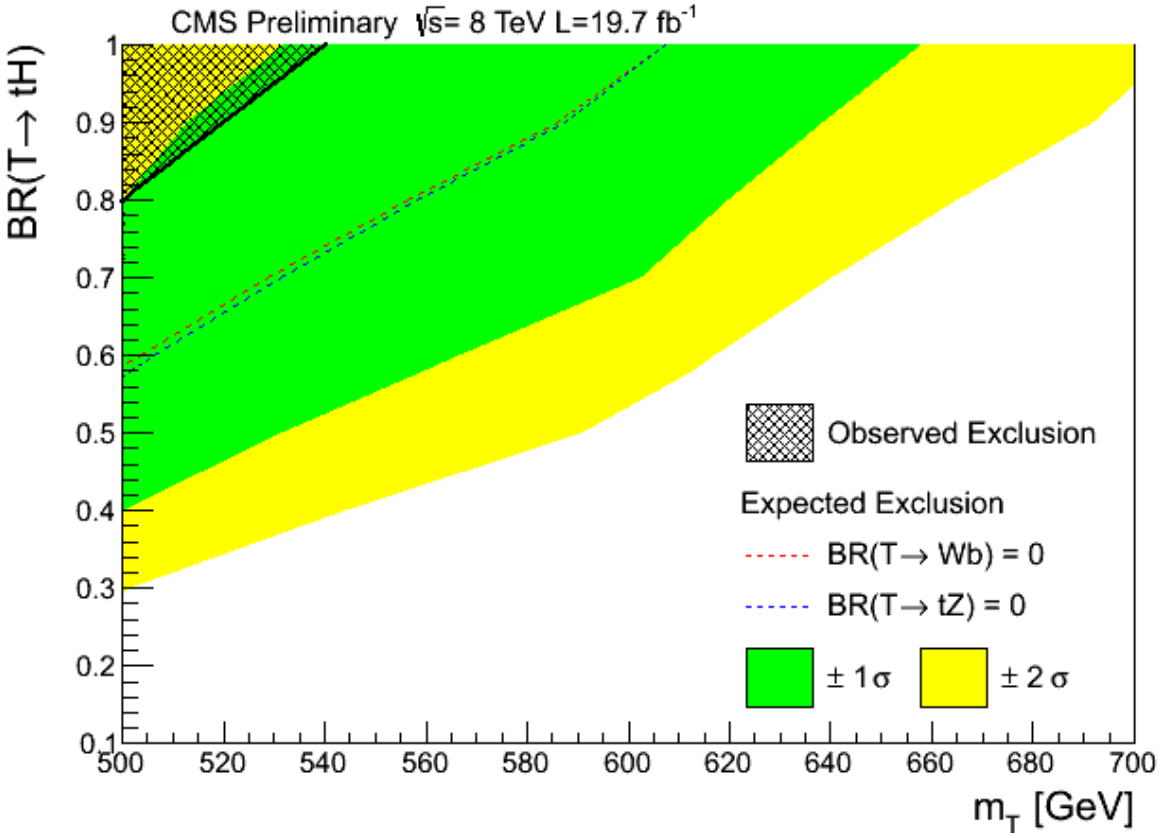
	Observed UL	Expected UL for $m_T = 700$ GeV
Hadronic Channel	0.25 pb	0.16 pb
Leptonic Channel	0.29 pb	0.27 pb
Combined	0.19 pb	0.12 pb

95% CL exclusion, In the hypothesis **BR(T→tH)=1**:

- Expected excluded mass for hadronic channel is up to m_T=538 GeV
- Expected excluded mass for leptonic channel is up to m_T=522 GeV
- **Observed** combined exclusion up to m_T=**540 GeV (exp. 607 GeV)**

2D interpretation of results

- Interpretation for other values of BRs in the 2D plane **BR(T→ tH) vs m_T**

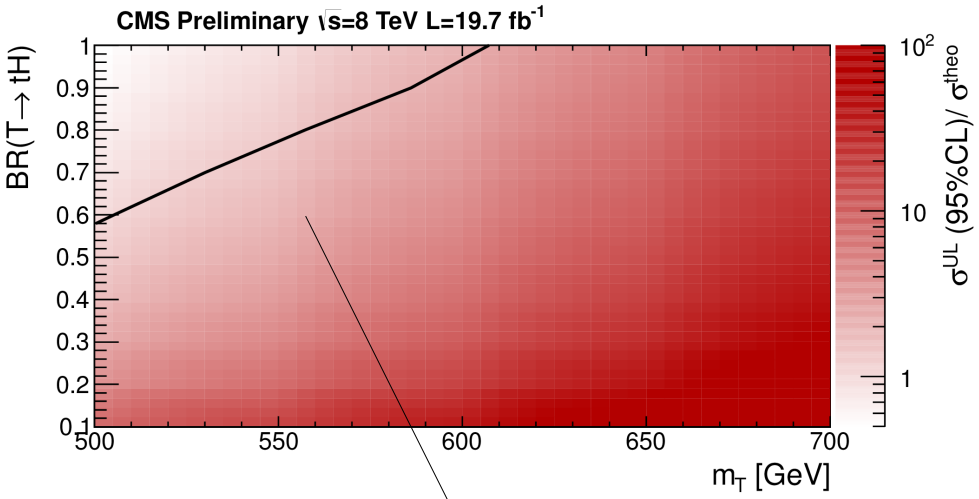


- **Different scenarios** for BR(T→Wb) and BR(T→tZ)
- Results **only sensitive to BR(T→tH)**
- **Excluded region:** upper left corner

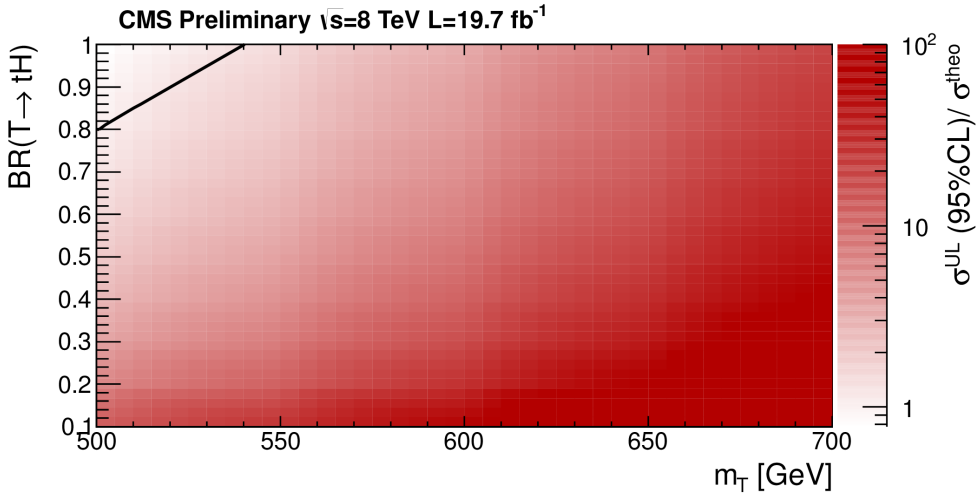
2D interpretation of results

- Interpretation for other values of BRs in the 2D plane **BR(T→ tH) vs m_T**

Expected



Observed



Solid black line corresponds to $\sigma/\sigma_{theo} = 1$

Excluded region: upper left corner

Conclusions

- **Search** for top partner in events **with the Higgs boson fully reconstructed in the gamma gamma decay** mode
- **Two optimized categories**: full-hadronic / leptonic
- **Observed exclusion** for Top partner **at 540 GeV (Expected 607 GeV)**, in the case BR(T→tH)=1
- Interpretation of results **extended to other scenarios**
- Analysis under **combination with other channels** (different Higgs' decay channels, and T decay channels)

Back-up

Documentation

PAS: B2G-14-003

CMS Draft Analysis Note

The content of this note is intended for CMS internal use and distribution only

2014/05/29
Head Id: 244099
Archive Id: 244247M
Archive Date: 2014/05/28
Archive Tag: trunk

Search for pair production of vector-like partners of the top quark (T), with $T \to tH(\to\gamma\gamma)$

https://twiki.cern.ch/twiki/bin/view/CMSPublic/B2G14003TWiki

http://cds.cern.ch/record/1709129?ln=en

Datasets and technicalities

- Analysis fully developed within the **official Hgg framework** (CMSSW_6_1_1)

Data

- Full 8 TeV dataset: 19.7 fb^{-1} Jan22 ReReco
- Standard diphoton Trigger used for Hγγ (~100% efficiency for our signal) :

  HLT_Photon26_*_Photon18 seeded by L1 DoublePhoton OR

  HLT_Photon36_*_Photon22 seeded by L1 SinglePhoton

MC

- ttH (Pythia)
- TT: T→tH, T→tZ, T→Wb official Madgraph samples

  Samples cover m_T: 500, 600, 700, 800, 900 GeV

Physics Objects

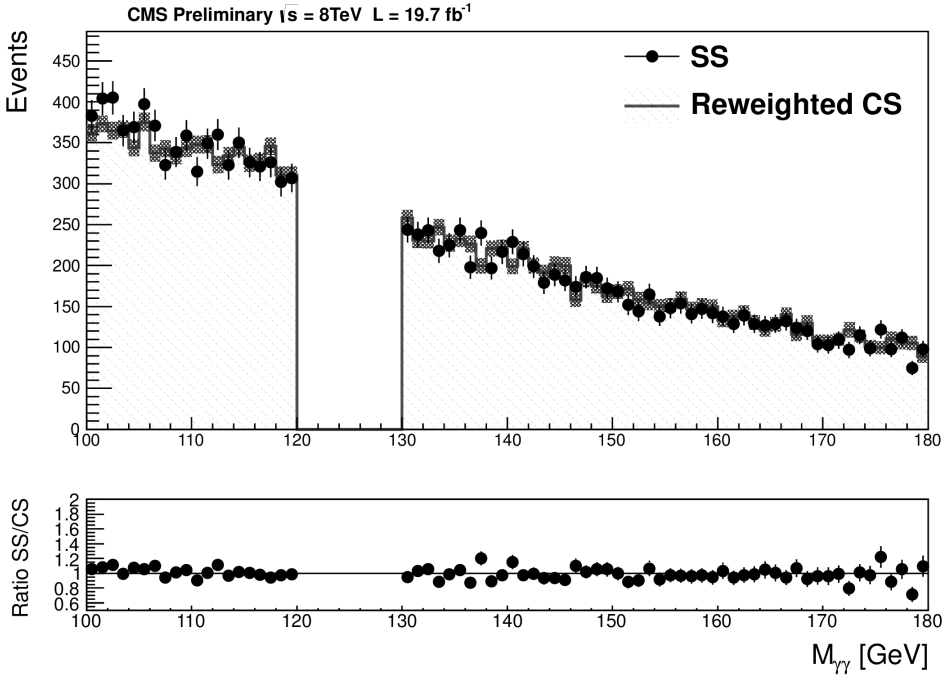
- **Photons** use all the latest Hgg energy corrections and selections (Jan22 ReReco):
  - Cut in categories (CiC) Super Tight working point, same as H→gg (other working points tried, no significant improvement to the analysis sensitivity)
- **Leptons** (e/μ) (p_T > 20 GeV):
  - **electrons**: MVA EGM ID, loose WP, pfISO
  - **muons**: cut-based MUO ID, tight WP, pfISO
- **Jets** are AK5PF:
  - p_T > 25 GeV, up to $|\eta|$=2.4
  - Jet ID and loose cut-based PU ID
- **CSV** (combined secondary vertex) **b-tagging** (loose WP)

Analysis Optimization

- **CS** definition: **inverted photon ID** for leading or subleading photon (standard procedure used for Hgg exclusive categories)

→necessity to reweight photon kinematics in order to mimic standard sample (SS) kinematics with control sample's one (match p_T and η spectra for the photons)

$$\text{Weight}(p_T(\gamma_1), p_T(\gamma_2), \eta_1, \eta_2) = \text{Weight}(p_T(\gamma_1), \eta_1) \times \text{Weight}(p_T(\gamma_2), \eta_2)$$



Analysis Optimization

TT→tHtH(→γγ)

- Resonant background: ttH(→γγ)
- The main non-resonant backgrounds are:
  - Diphoton + jets; tt+γγ, t+γγ, tt+jets
  - MC of these backgrounds is not reliable (difficult for the presence of many legs in the final state)

For **Optimization**:
Data driven bkg (Control Sample)

For **Limit Extraction**:
Mγγ from **sidebands**

- Optimization performed with:

  → **TT signal @ 700 GeV**

  → data-driven **background**

Event Selection

- Optimize **background rejection**

- **Select the working point which optimizes exclusion limit** (including both resonant and non resonant background)

- **Limit performed as a simple cut & count** analysis in a window of 3 GeV around 125 GeV (**1 FWHM** region)

- Non resonant background extrapolated from **Data control sample** (using scale factor derived at preselection level)

Variable	Hadronic channel	Leptonic channel
$p_T(\gamma_1)$	$> \frac{3}{4} m_{\gamma\gamma}$ GeV	$> \frac{1}{2} m_{\gamma\gamma}$ GeV
$p_T(\gamma_2)$	35 GeV	25 GeV
n_{jets}	≥ 2	≥ 2
H_T	≥ 1000 GeV	≥ 770 GeV
leptons	0	≥ 1
b tags	≥ 1	-

Bkg estimation: bias study

Non-resonant bkg estimated through a fit to Myy:
→ To extract signal we **need to choose the background fit function**

Standard Hgg procedure: **bias study** on data sidebands

- **Truth models** derived **from bkg** only fit
- **Different fit models tested** generating bkg only toys according to the truth models
- Fit function: **bias < 20%** for every mass point (with fewest degrees of freedom)

$$\text{Bias} = \frac{N_{bkg}(\text{fit}) - N_{truth}(\text{fit})}{\sigma_{fit}}$$

Leptonic Channel				
Fit function	Truth models			
	exp1	lau1	pol1	pow1
exp1	0.01	-0.06	0.18	0.06

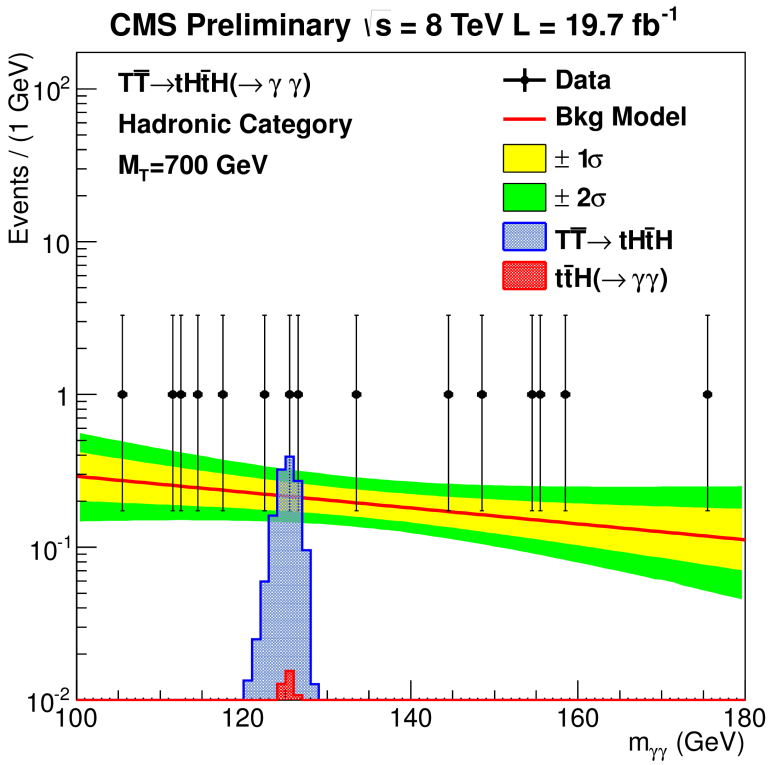
Hadronic Channel				
Fit function	Truth models			
	exp1	lau1	pol1	pow1
exp1	-0.05	0.03	-0.17	-0.00

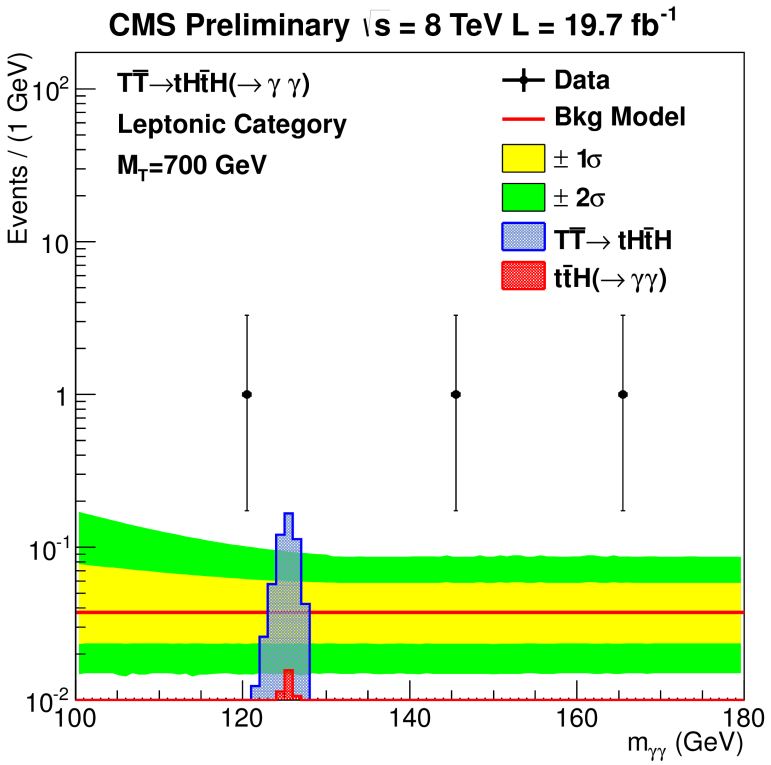
- **Bias < 20% means:**

statistical uncertainty of the fit covers the systematic uncertainty on the knowledge of the truth function

For **both the hadronic and leptonic** channel, the **simple exponential** is chosen

Mass plots after full selection





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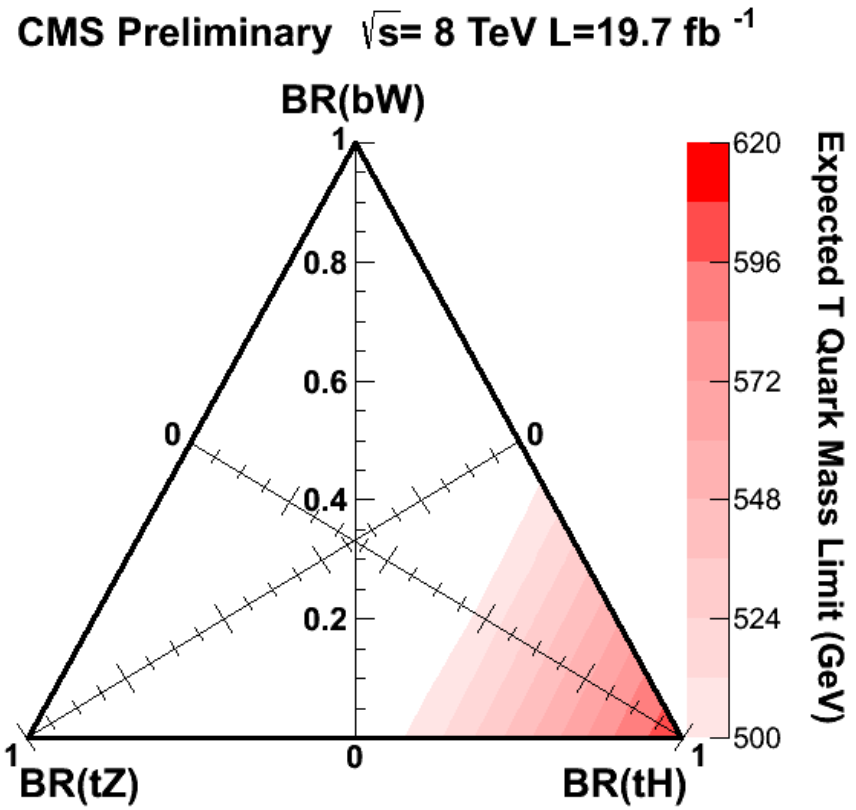
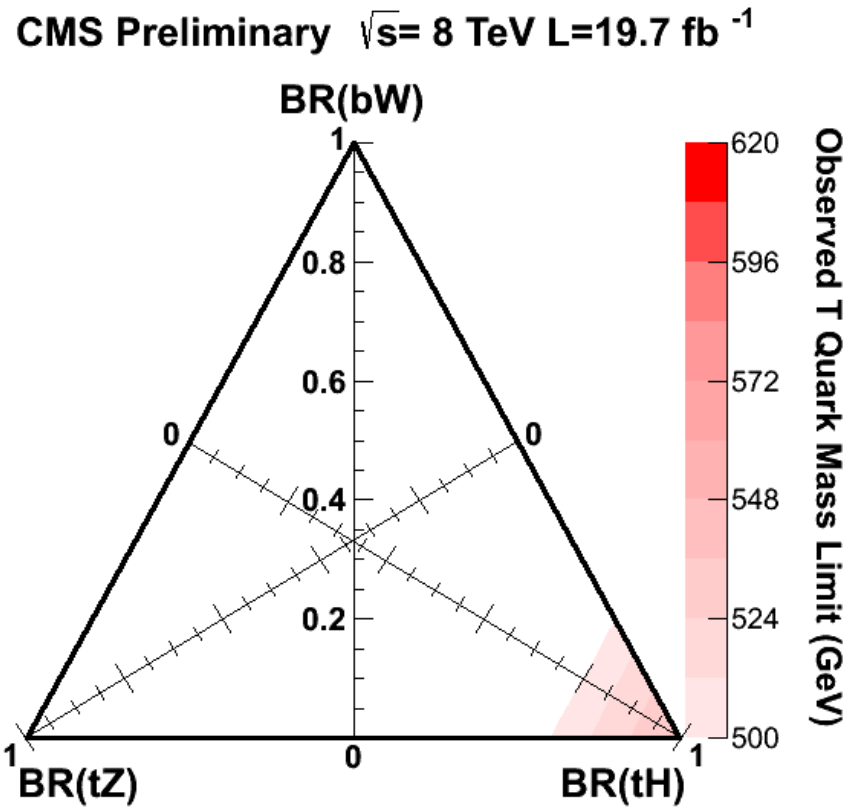
Triangle Plots



Expected



Observed

As expected we are most sensitive to the region corresponding to BR(tH)=1