

# CMS Run 2 Results

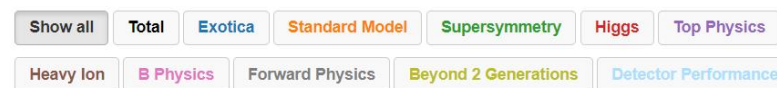
Joe Pastika on behalf of the CMS Collaboration



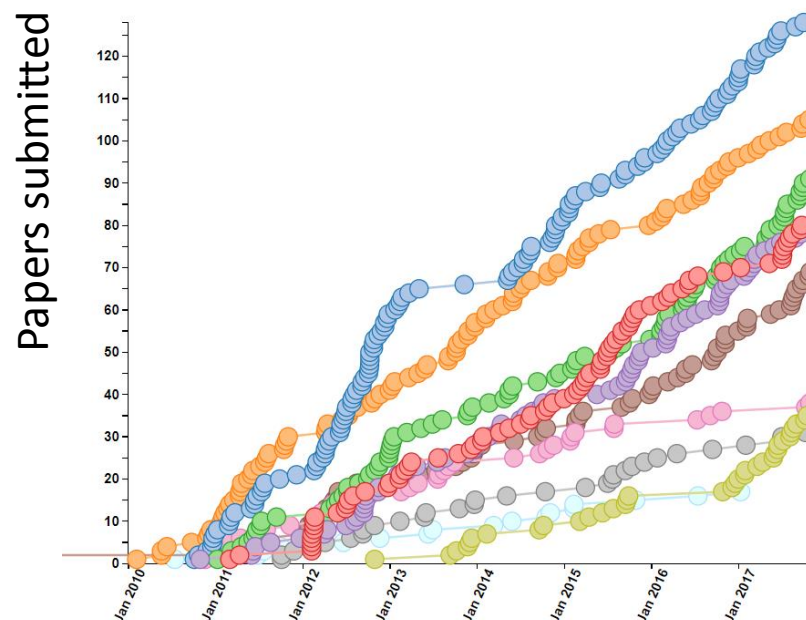
BAYLOR  
UNIVERSITY

- Introduction to CMS
- Higgs results
- SUSY results
- Dark matter searches
- Heavy resonance searches
- Standard model measurements
- Top results
- Heavy ion results
- Summary

671 collider data papers submitted as of 2017-10-28



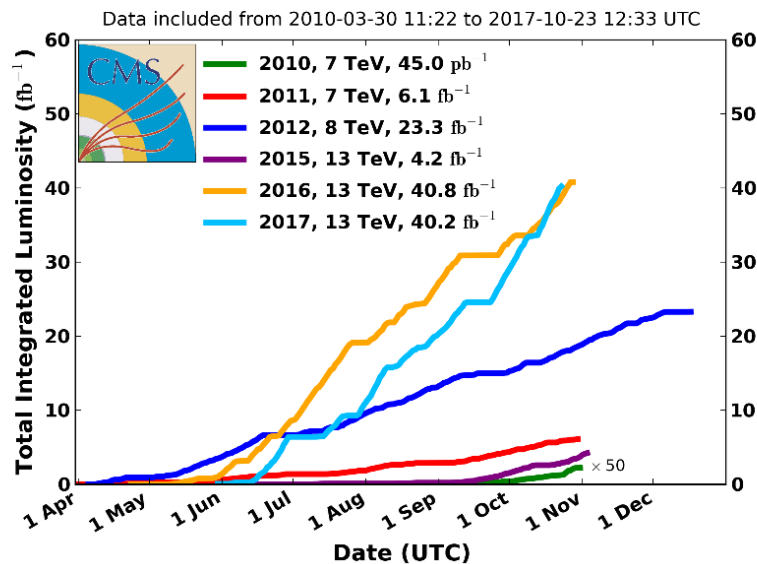
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<http://cms-results.web.cern.ch/cms-results/public-results/publications/>

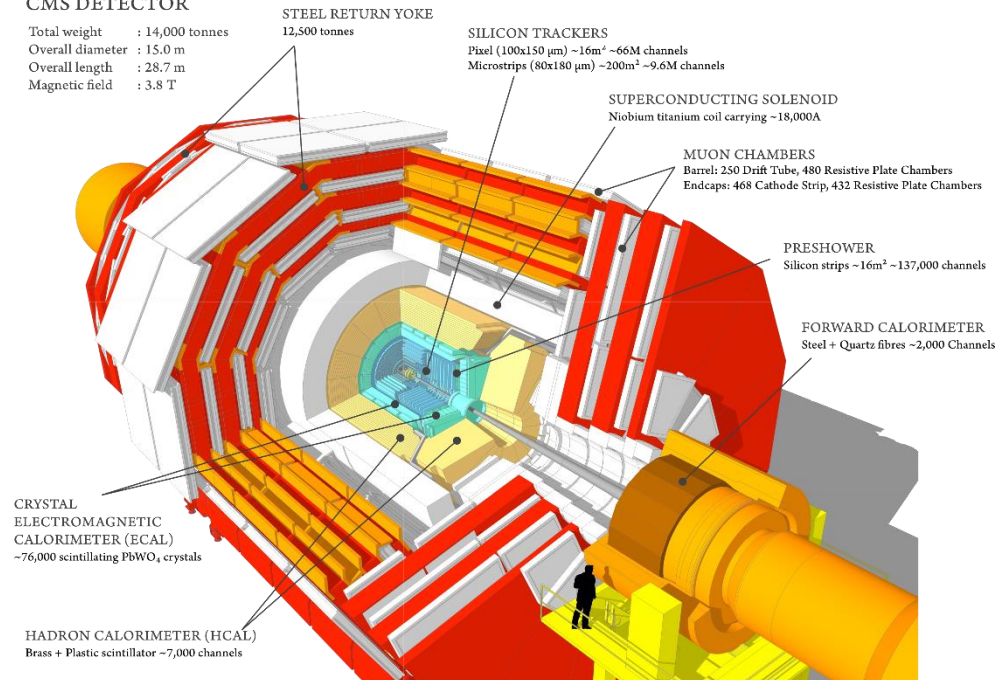
# Intro to CMS & Performance

**CMS Integrated Luminosity, pp**



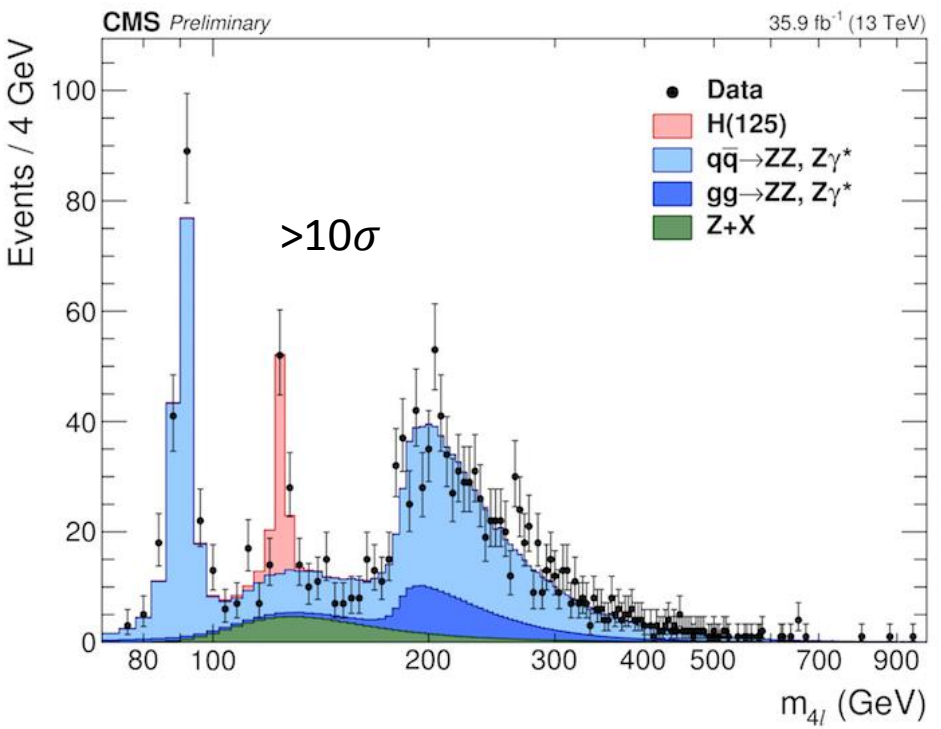
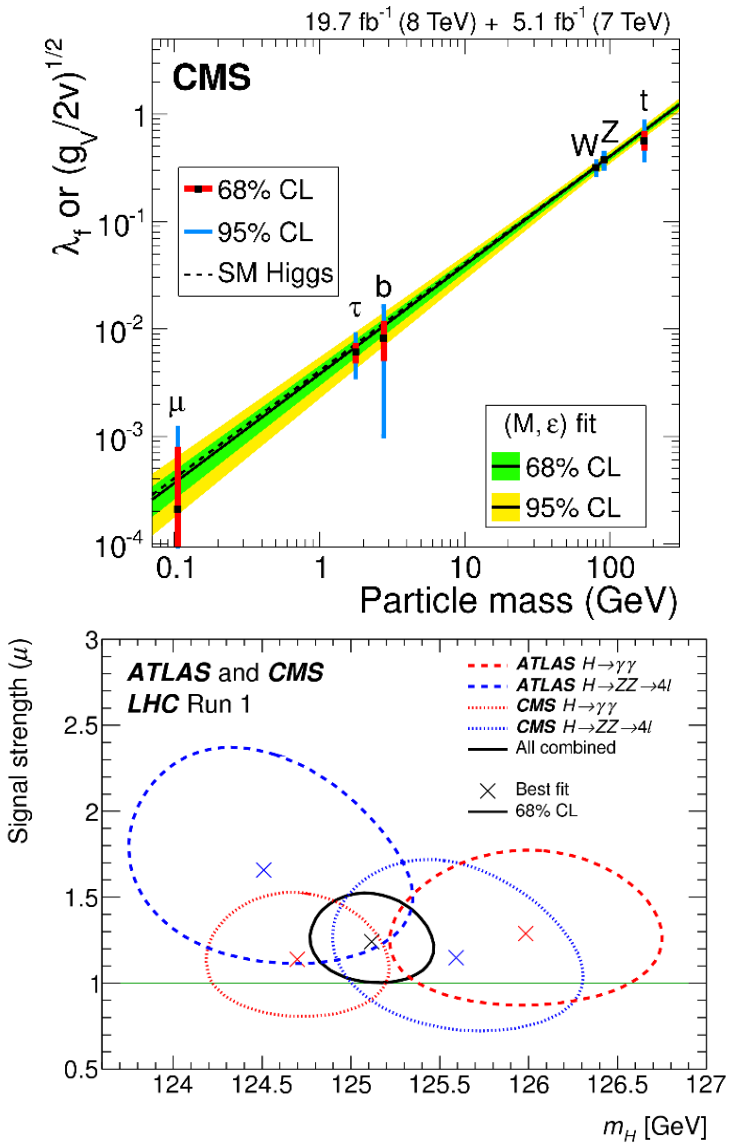
**CMS DETECTOR**

Total weight : 14,000 tonnes  
Overall diameter : 15.0 m  
Overall length : 28.7 m  
Magnetic field : 3.8 T



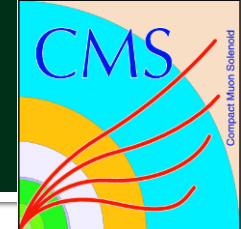
Excellent data taking performance from CMS to match the excellent performance of the LHC!

<http://arxiv.org/abs/1706.09936>



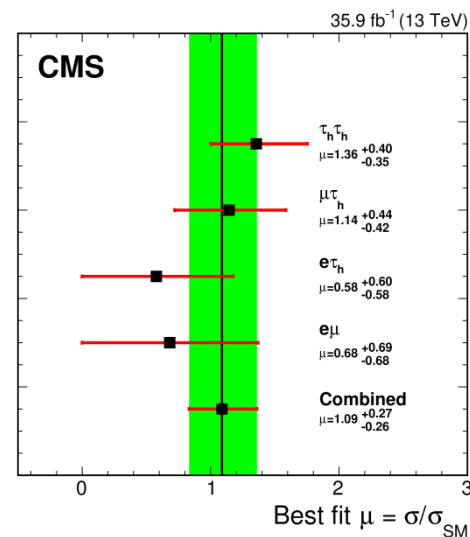
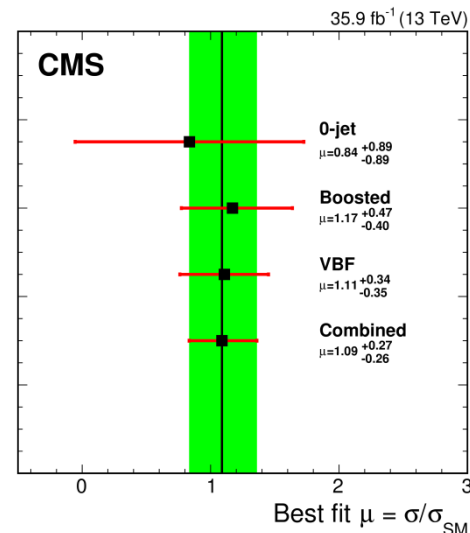
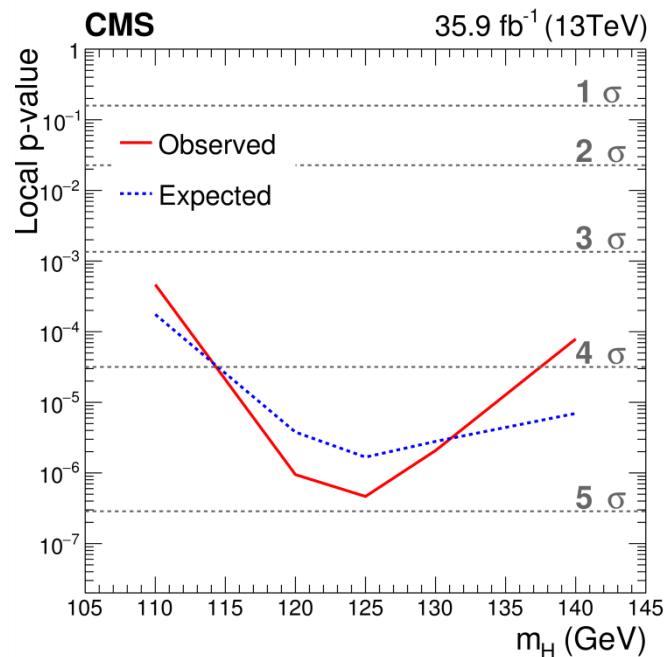
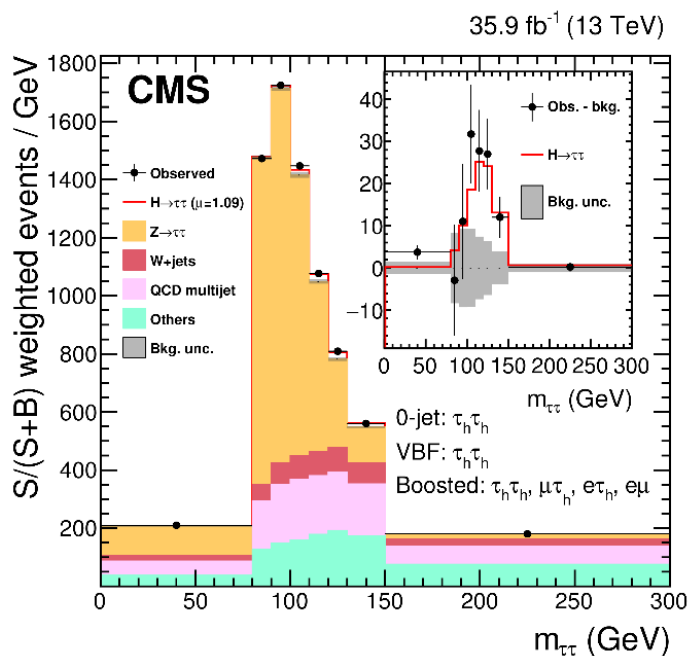
- Run 1 brought the discovery of the Higgs boson with 125 GeV mass
- Run 2 is bringing about more understanding
- (Above) 4-lepton mass distribution for the  $H$  to  $4l$  search.

# B Higgs to $\tau\tau$

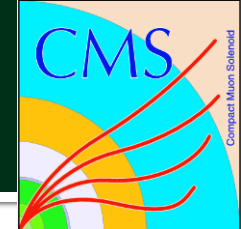


<http://arxiv.org/abs/1708.00373>

- Search for  $H \rightarrow \tau\tau$  using leptonic and hadronic decays
- The di-tau mass is reconstructed using a dedicated algorithm which takes into account the visible energy and  $\vec{p}_T^{miss}$
- Split by lepton flavor and vector boson fusion tags
- First single experiment observation of  $H \rightarrow \tau\tau$  decay with  $5.9\sigma$  (Run 1 + Run 2) significance



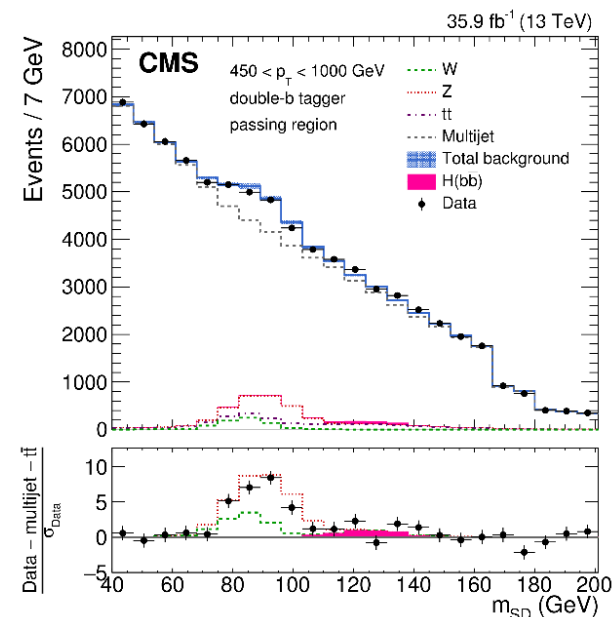
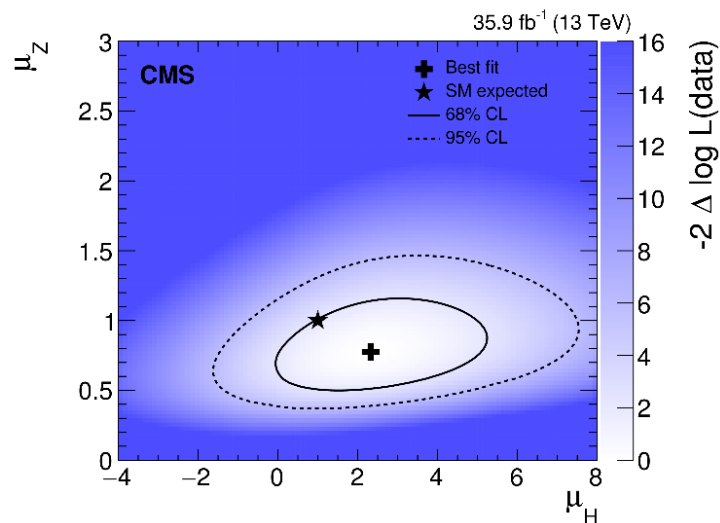
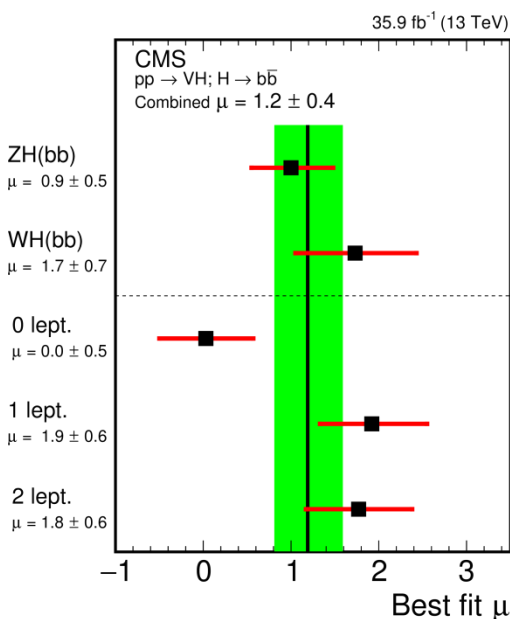
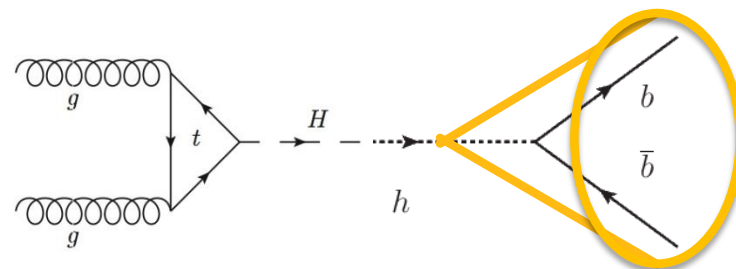
# Boosted Higgs to bb



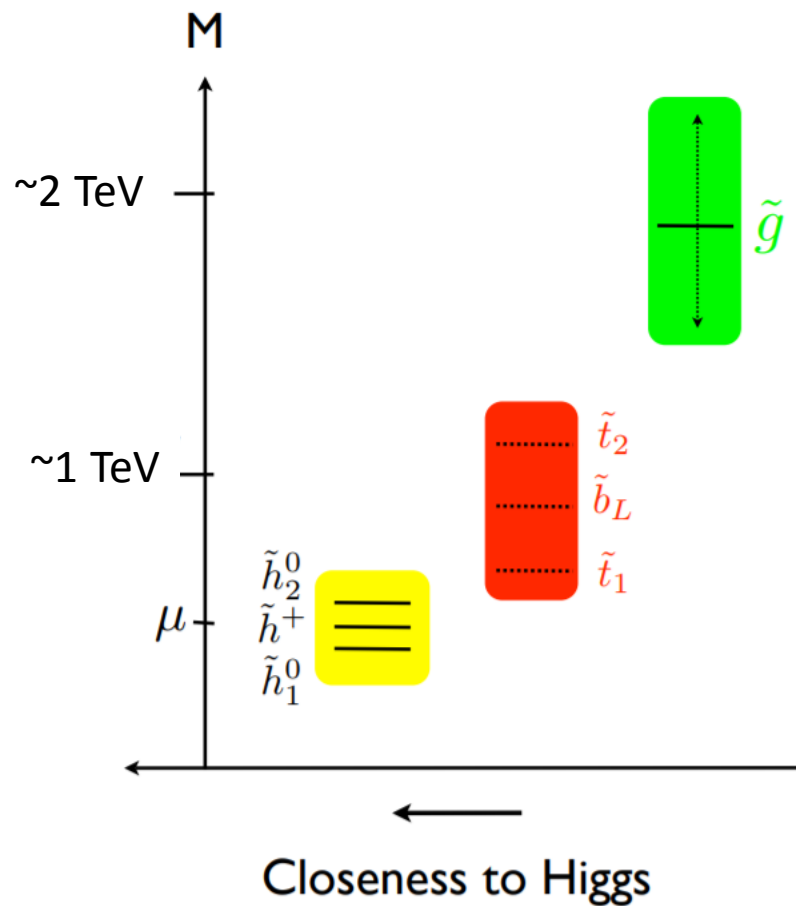
- Traditional  $H \rightarrow bb$  search shows good agreement between SM and observations ( $3.3\sigma$ ) at 13 TeV
- Dedicated search for events where boosted Higgs decay products end up in a single fat-jet
- Boosted channel significance of  $1.5\sigma$

<http://arxiv.org/abs/1709.07497>

<http://arxiv.org/abs/1709.05543>



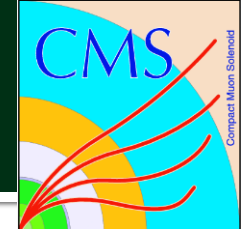
- Higgs discovery raises questions about  $m_H \simeq 125$  GeV
- $m_H^2 = m_{H,0}^2 + \delta m_H^2$ 
  - SM predicts  $\delta m_H^2$  will be driven up to the UV cutoff of the theory
  - SUSY allows small  $\delta m_H^2$
- Natural SUSY models
  - Choose sparticle masses (namely  $\tilde{h}/\tilde{t}/\tilde{g}$ ) to keep fine-tuning small
  - Motivates “light” higgsino/stop/gluino searches at LHC



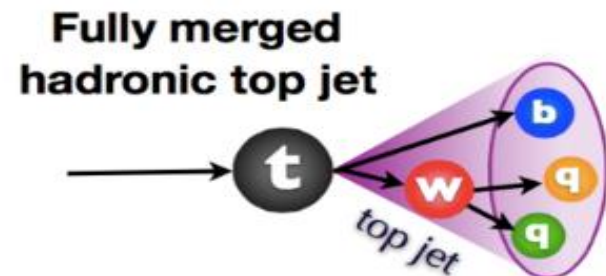
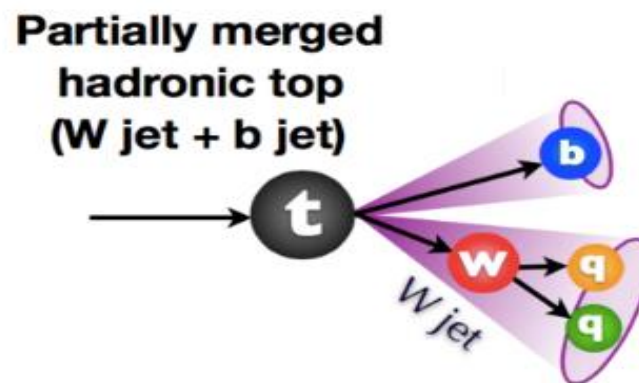
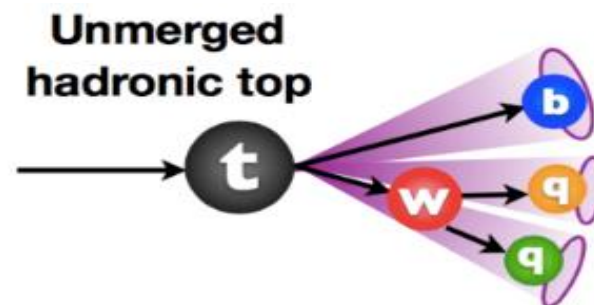
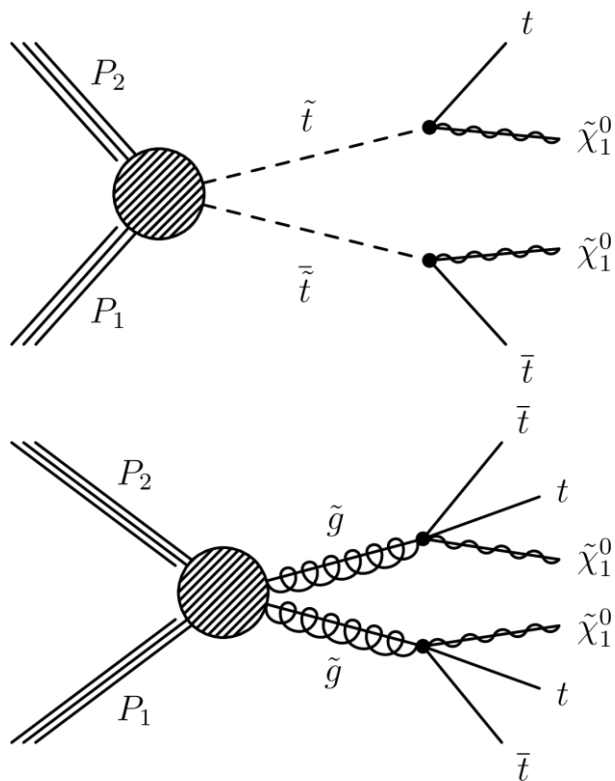
L. Hall. Searches for SUSY at the LHC, LBL Workshop, 19-21 Oct 2011



# Stop searches

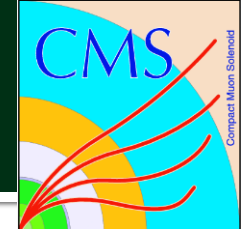


- Dedicated searches using top tagging
- Custom SUSY-specific top tagging algorithms



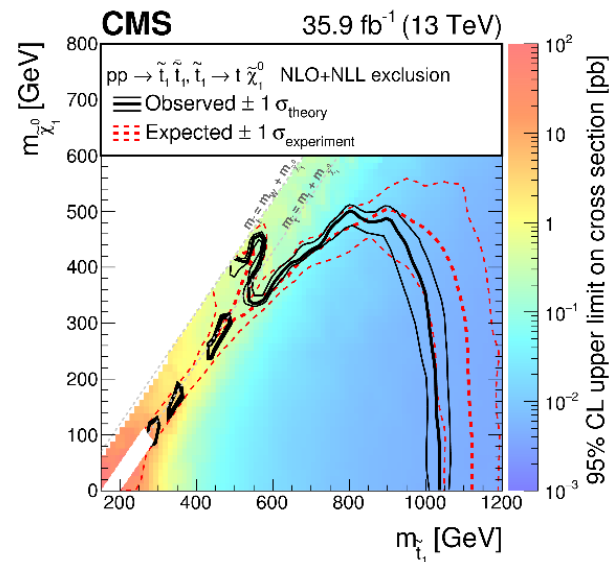
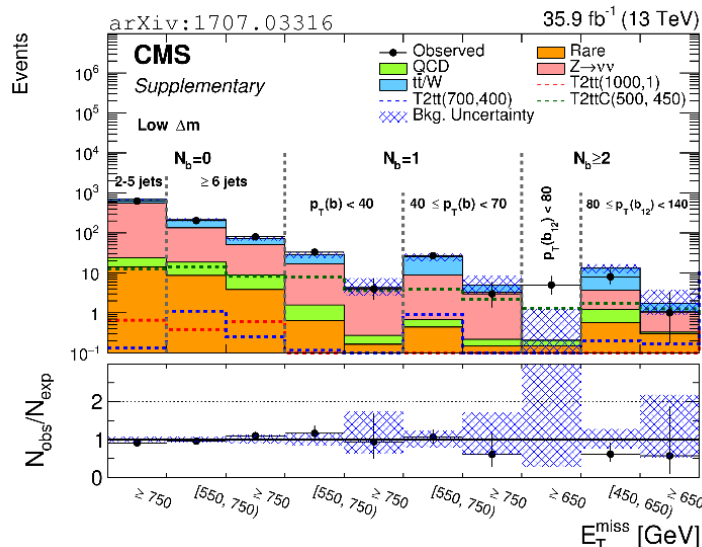


# Stop search results



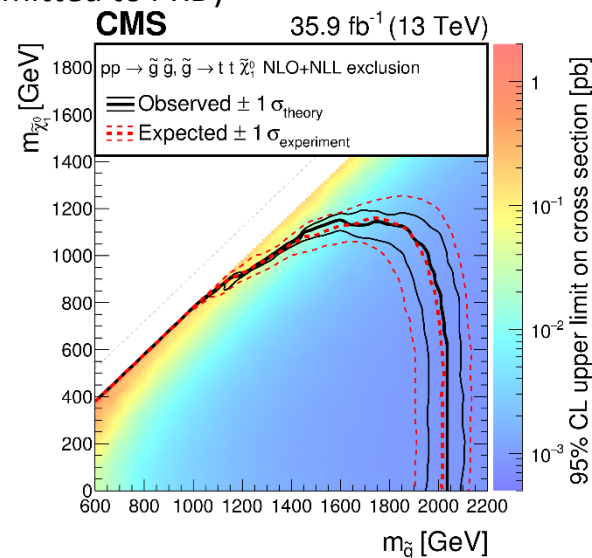
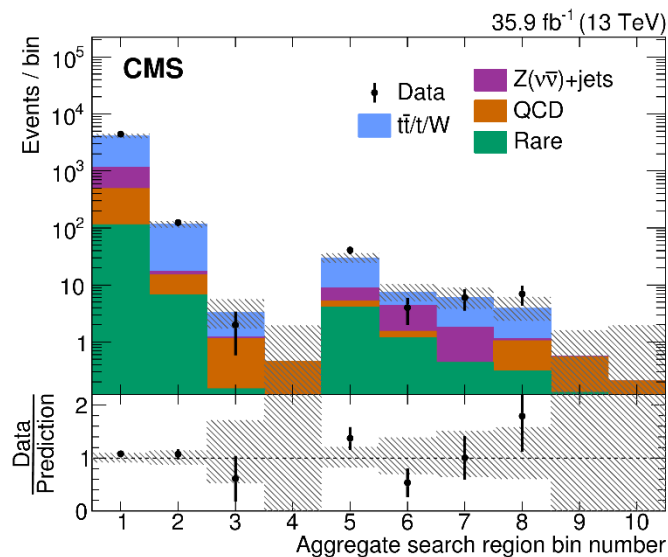
<http://arxiv.org/abs/1707.03316>

Direct stop production



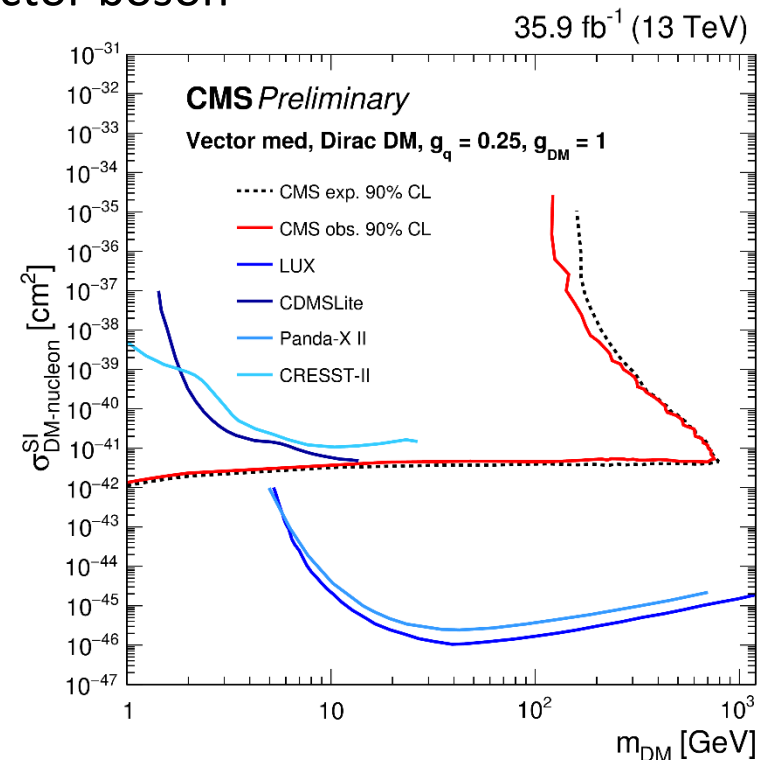
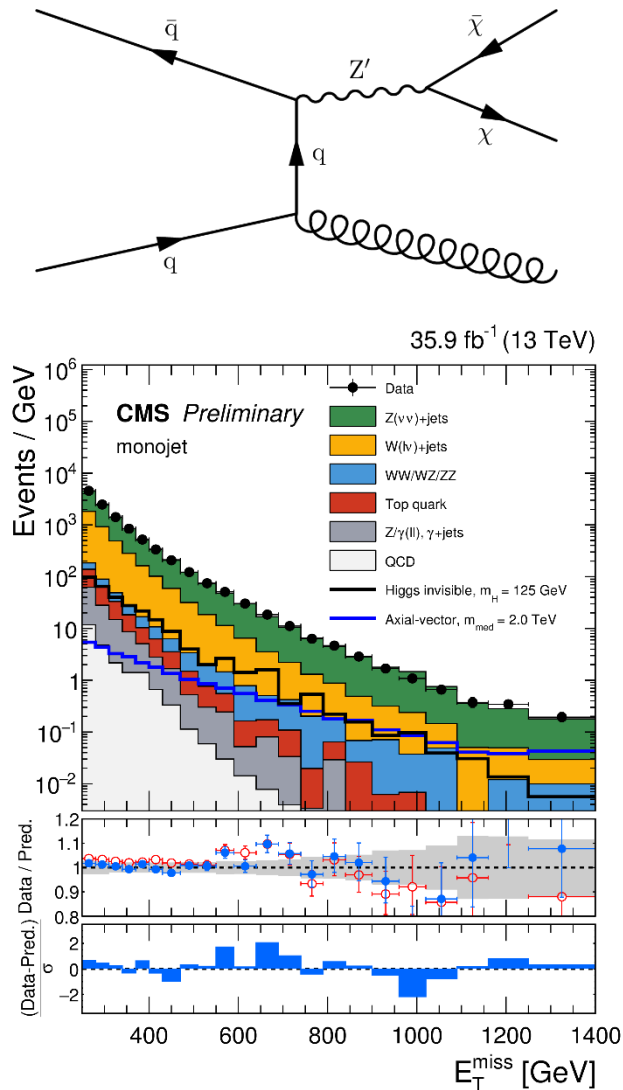
<https://cds.cern.ch/record/2291019> (submitted to PRD)

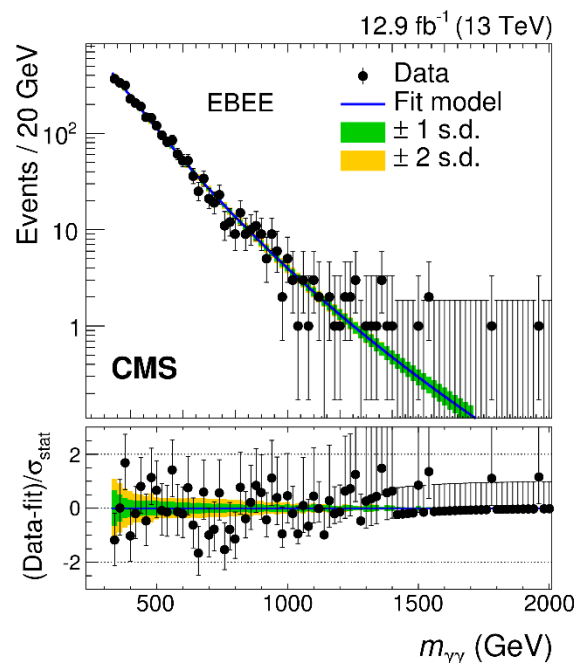
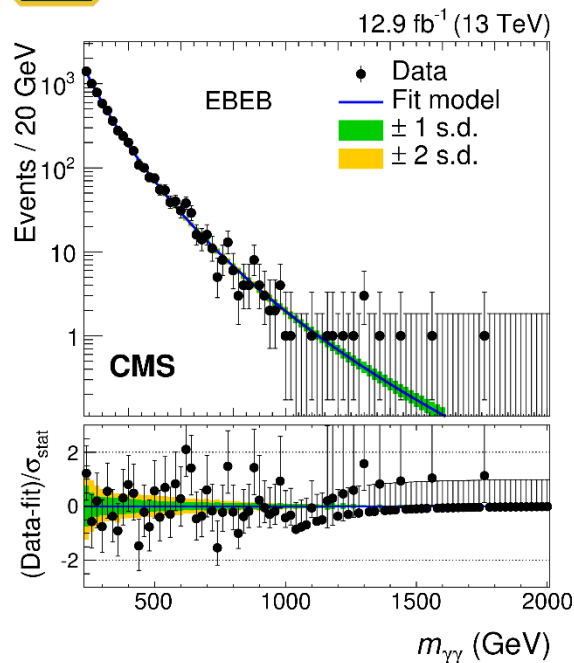
Indirect stop production  
 through gluinos



<https://cds.cern.ch/record/2264698>

- Dark matter well motivated without SUSY
- Simplest search is  $p_T^{miss} + X$
- Monojet search looks at  $p_T^{miss}$  spectrum in association with a single high  $p_T$  jets or a highly boosted hadronically decaying vector boson

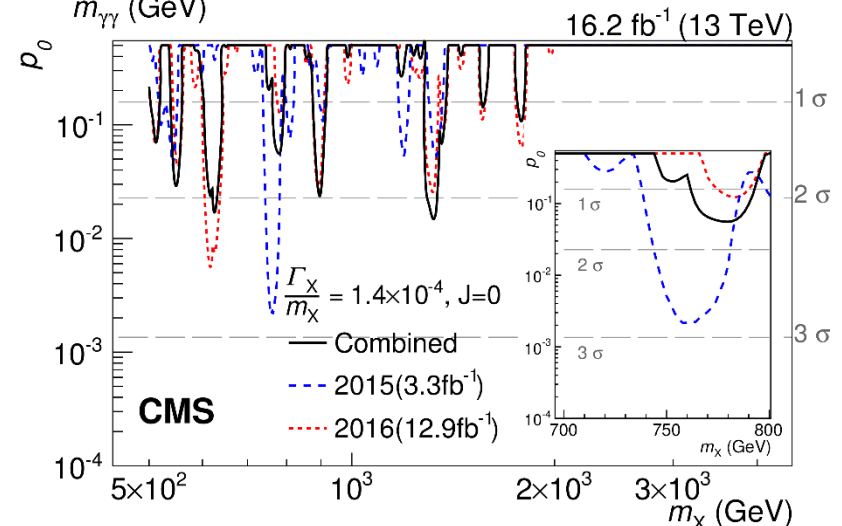


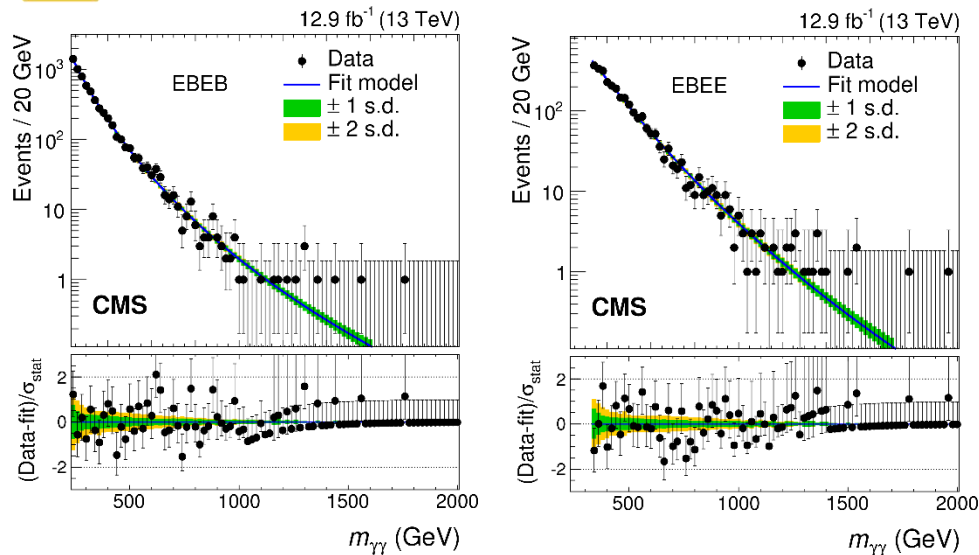


<http://arxiv.org/abs/1609.02507>

- Search for diphoton events
- “Bump-hunt” in diphoton invariant mass
- Sensitive to scalar resonances and RS gravitons

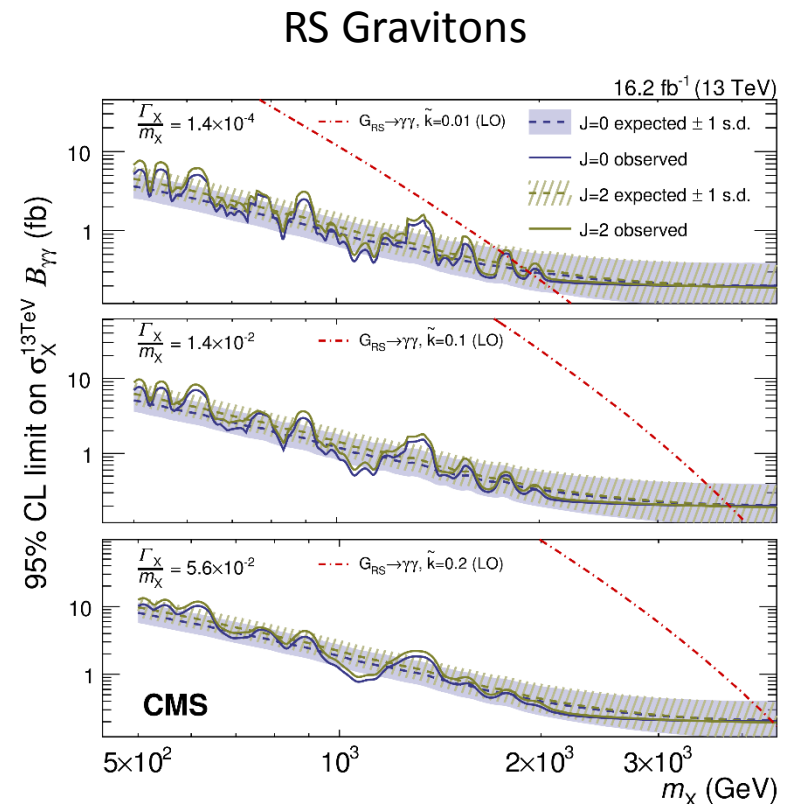
- Caused some excitement in early Run 2 when a  $\sim 750$  GeV excess was seen in both CMS and Atlas
- CMS saw a local significance of  $\sim 3.4\sigma$  in 2012+2015 data
- Reduced  $< 2\sigma$  in 16.2 fb<sup>-1</sup> (2015 + partial 2016 data)





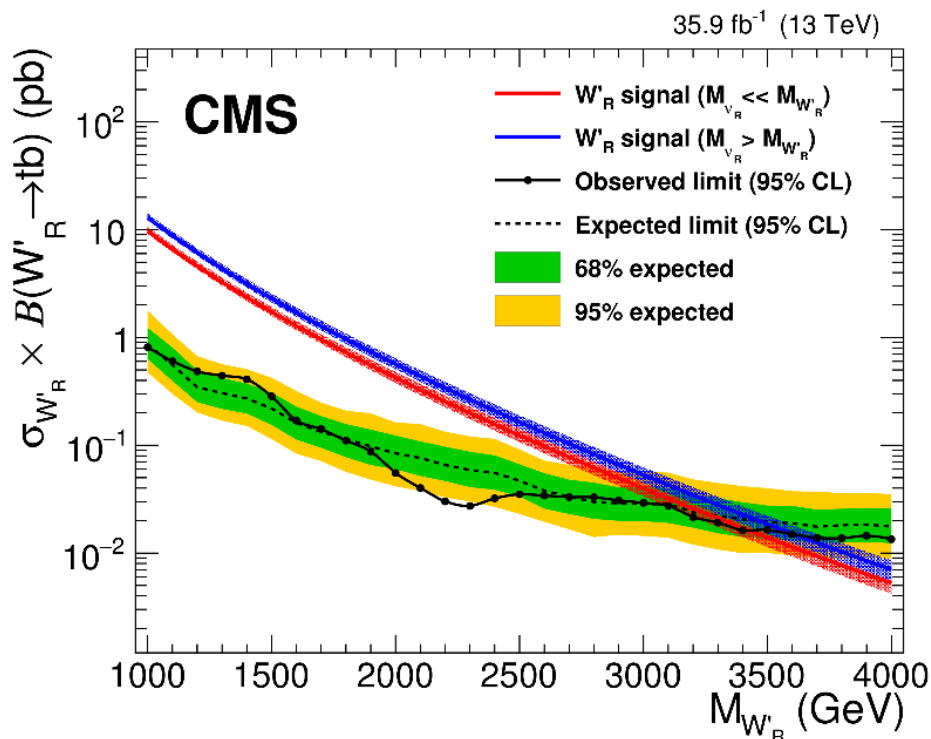
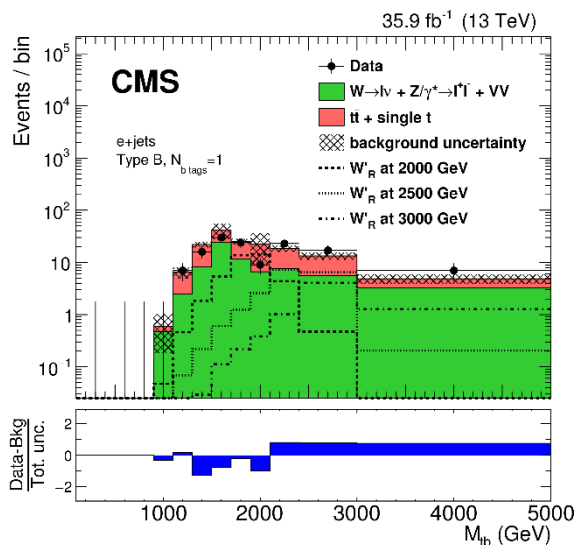
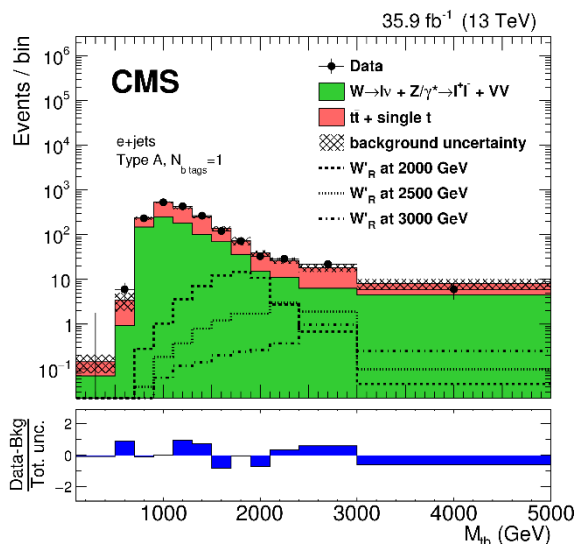
<http://arxiv.org/abs/1609.02507>

- Limits are set on the presence of RS Gravitons between  $\sim 2$  to 4.5 TeV depending on coupling parameters



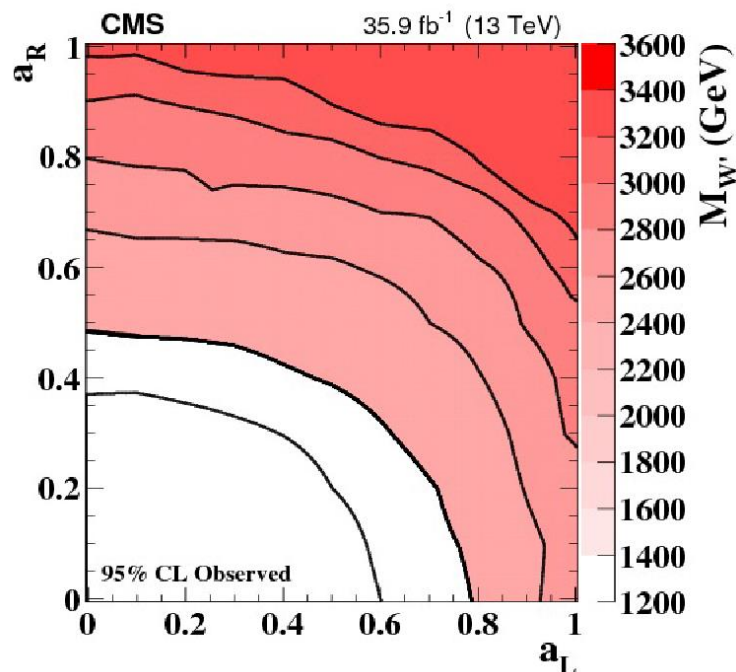
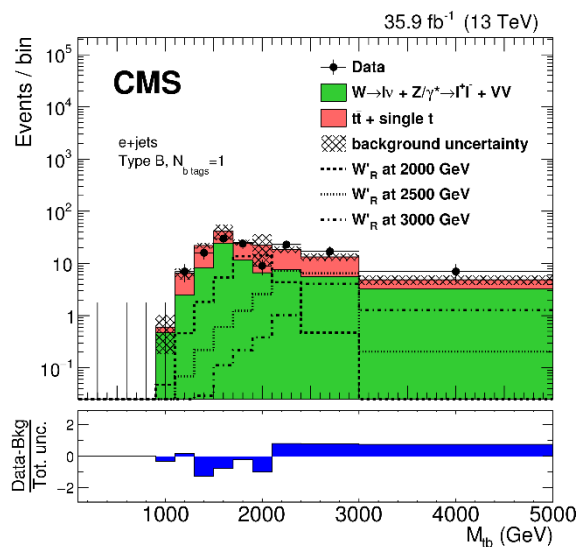
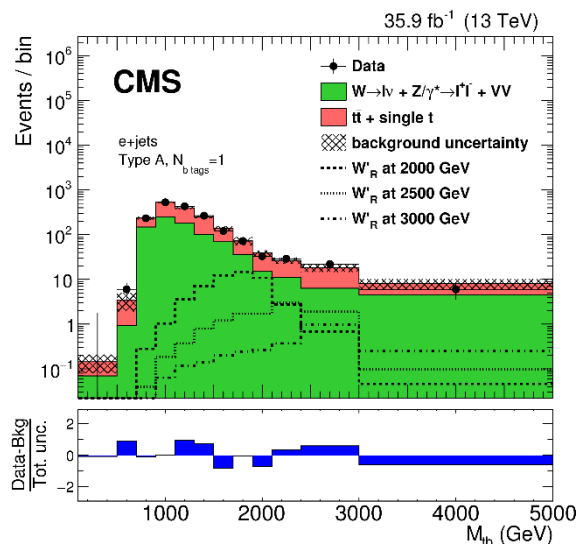
<http://arxiv.org/abs/1708.08539>

- Search for  $W' \rightarrow tb$  where  $t \rightarrow bl\nu$
- Reconstruct  $M_{tb}$  from  $ljj + \vec{p}_T^{miss}$
- Split by  $e/\mu$  channel and by number of b-tagged jets used in  $M_{tb}$  calculation
- Set limits on left and right-handed  $W'$  models



<http://arxiv.org/abs/1708.08539>

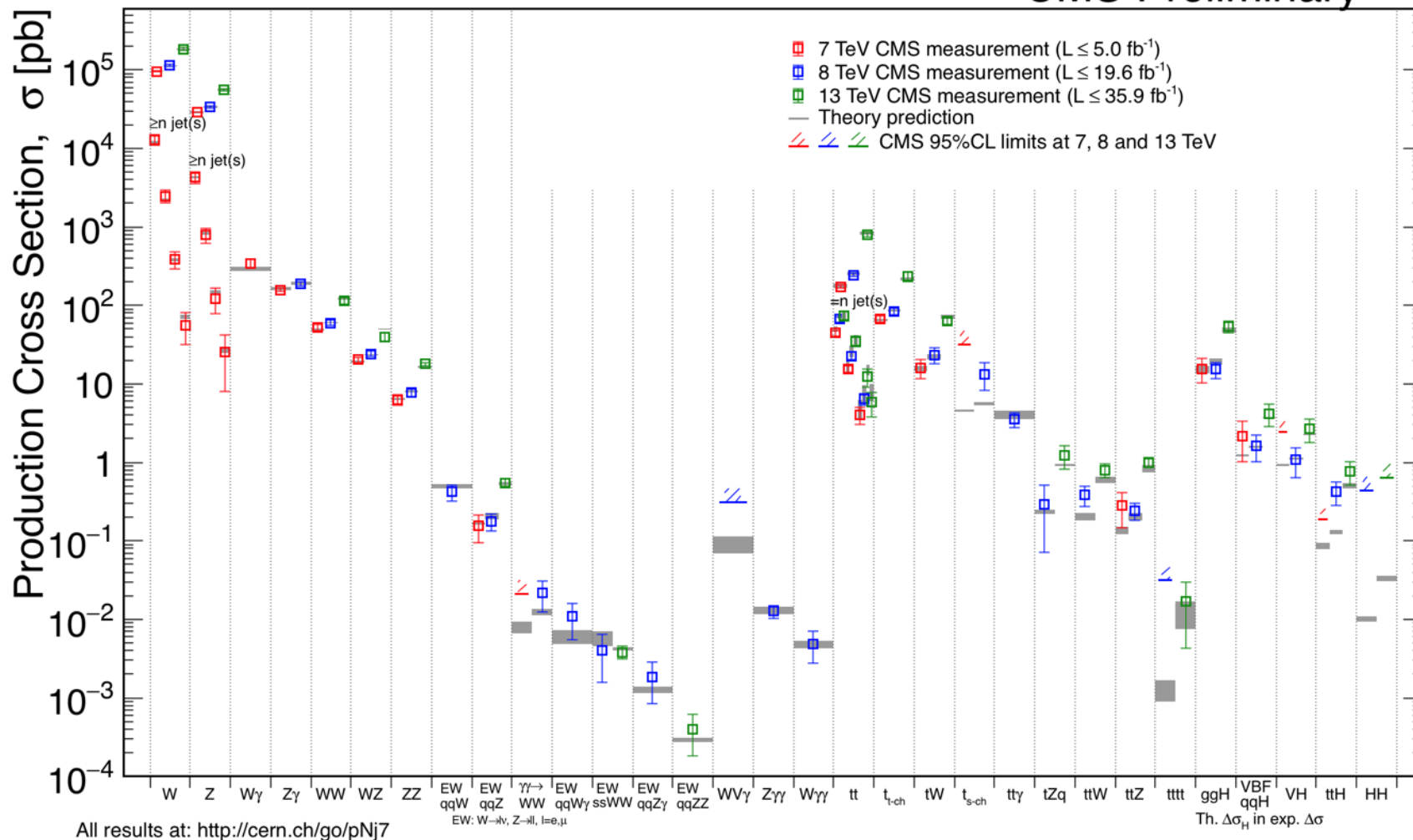
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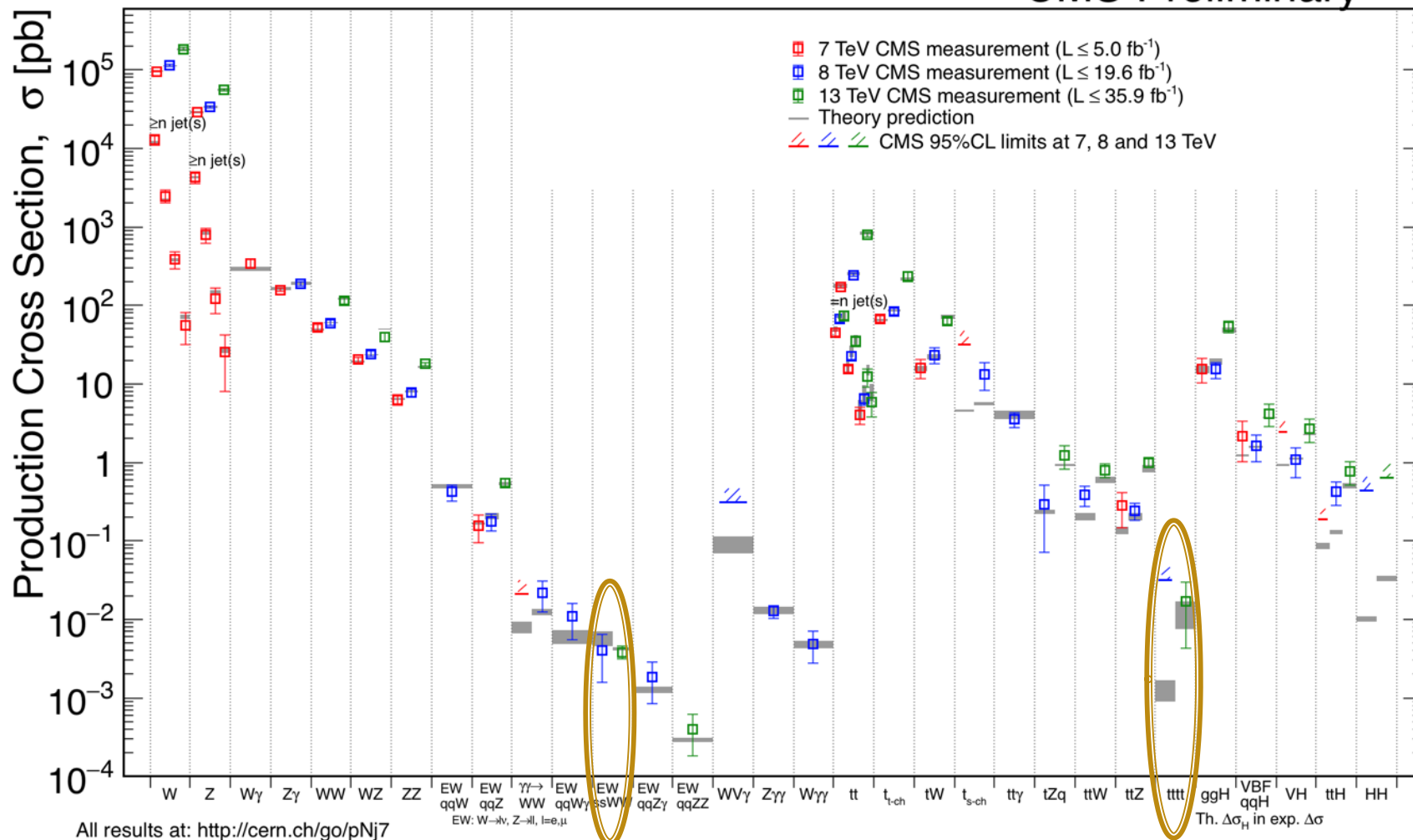
September 2017

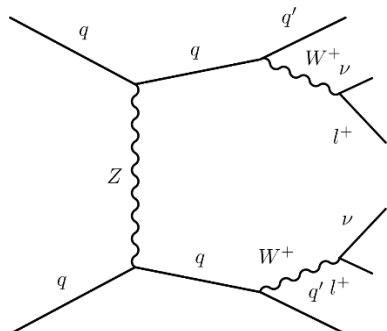
CMS Preliminary



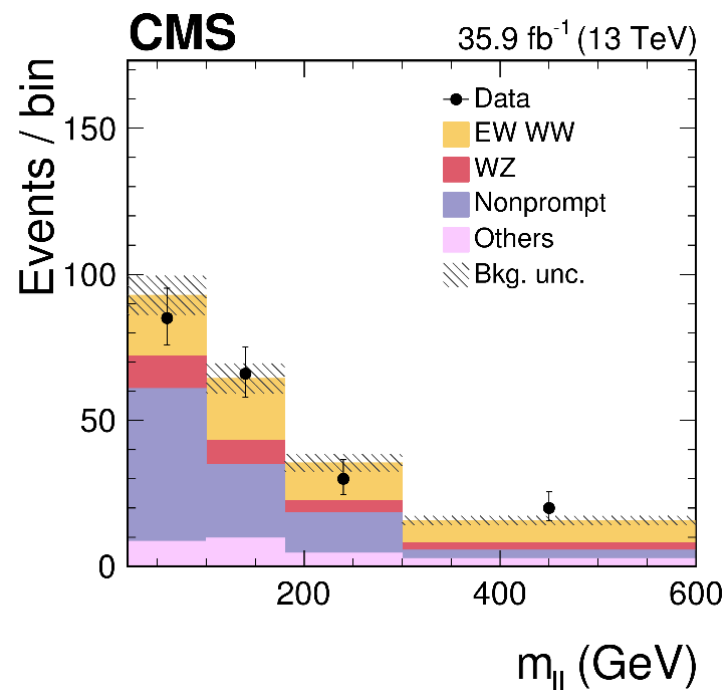
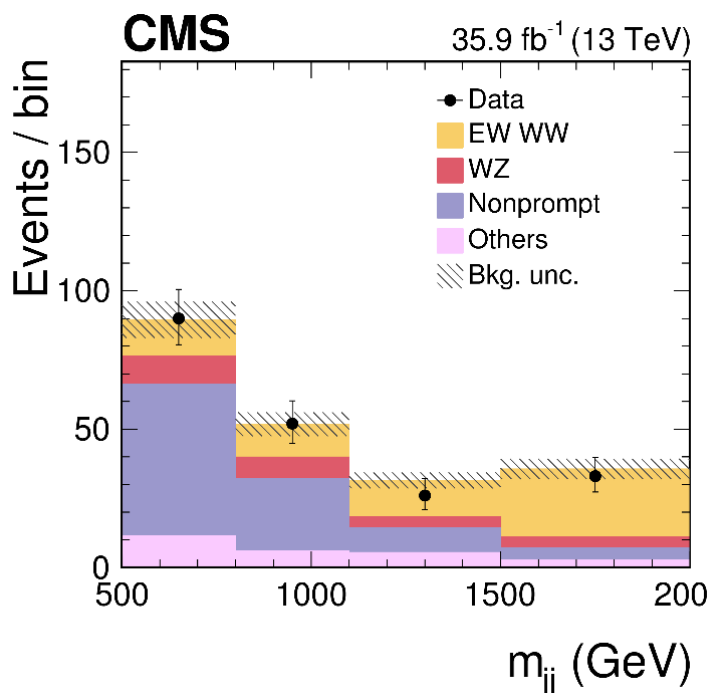
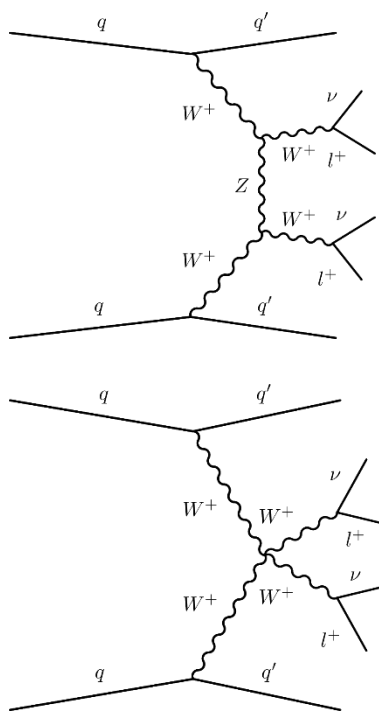
September 2017

CMS Preliminary





- First observation of EW production of same-sign  $WW$  production
- Low background channel, probes for new physics
- 2 same-sign lepton 2 jet final state
- $W^\pm W^\pm$  Signal found with  $5.5\sigma$  significance
- Signal consistent with SM expectations

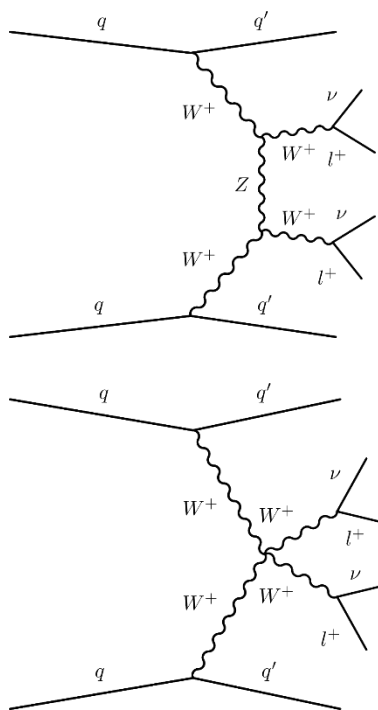
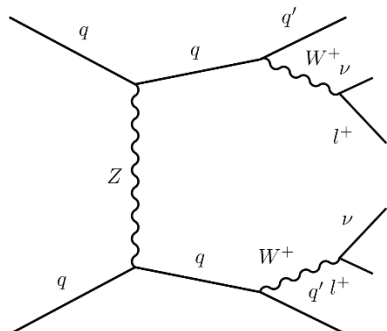


# Vector boson scattering

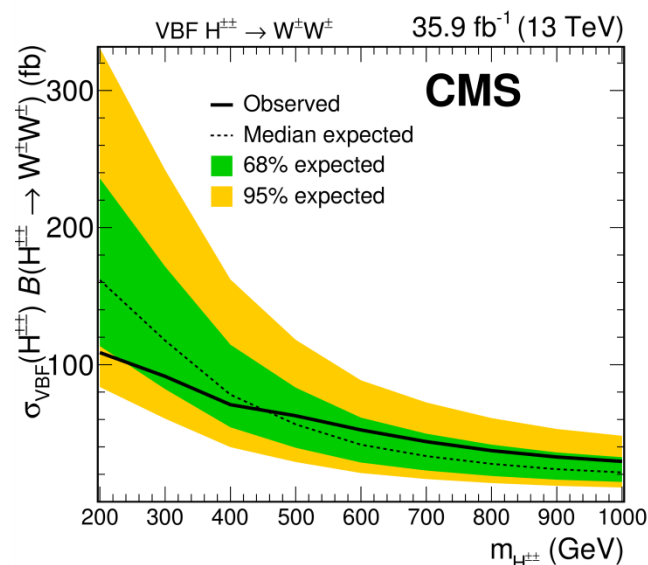


<http://arxiv.org/abs/1609.02507>

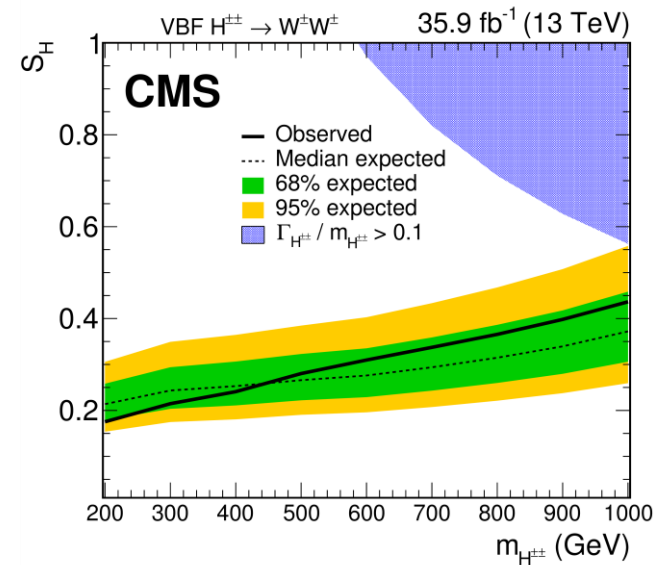
- First observation of EW production of same-sign  $WW$  production
- 2 same-sign lepton 2 jet final state
- Results interpreted as  $H^\pm H^\pm \rightarrow W^\pm W^\pm$  search

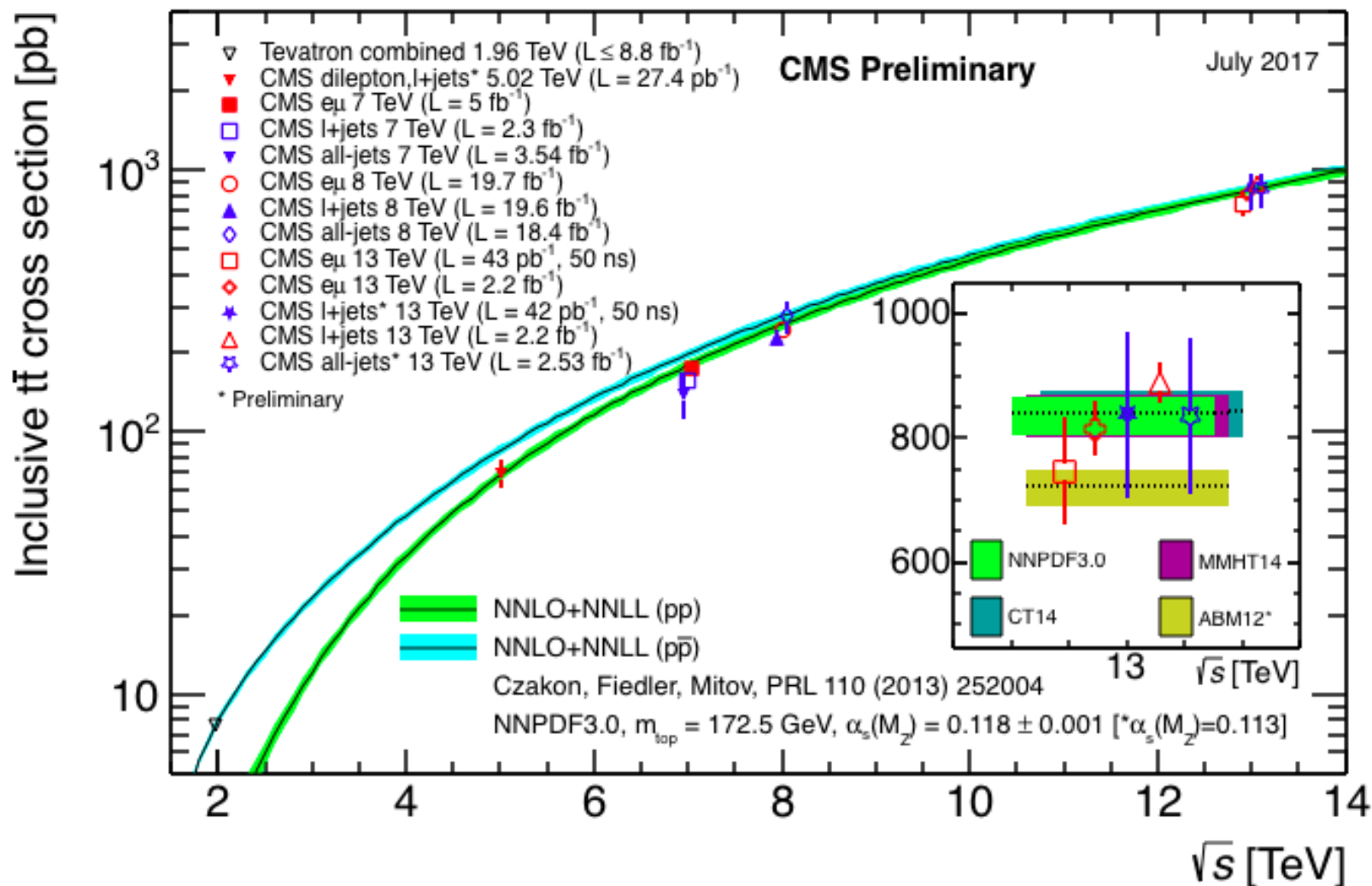


Vector boson fusion



Georgi-Machacek model

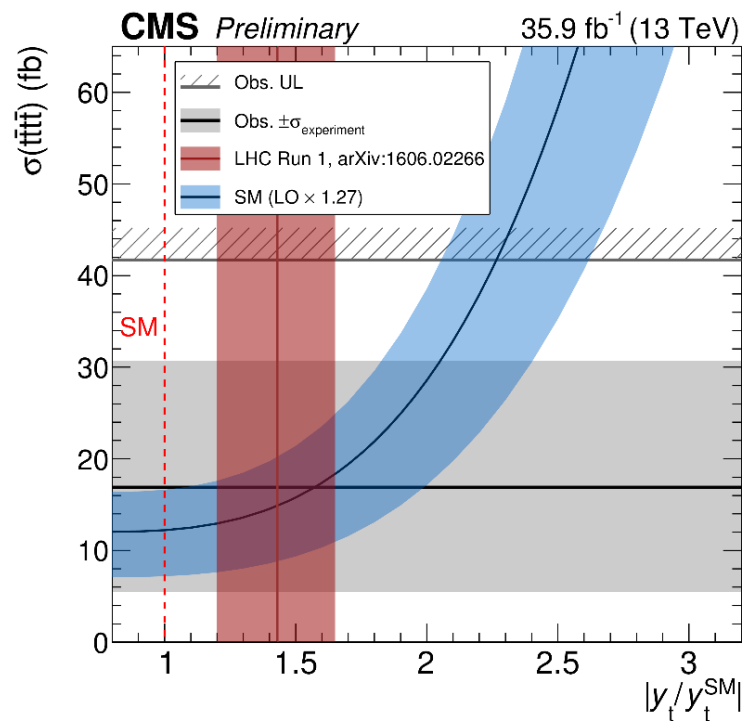
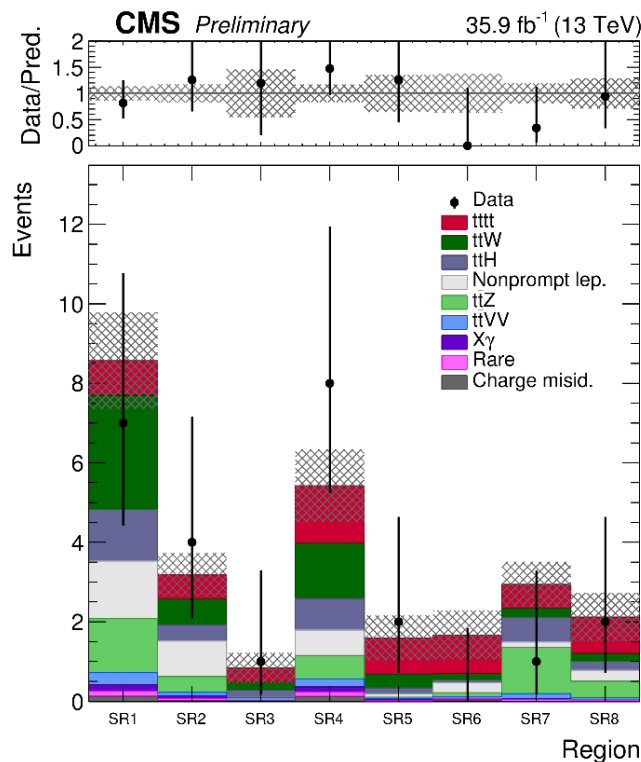
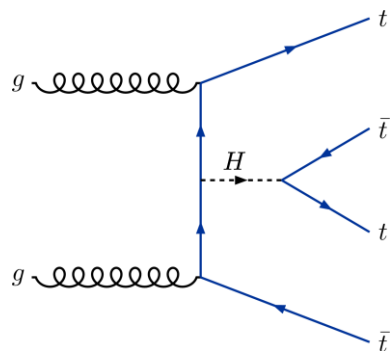
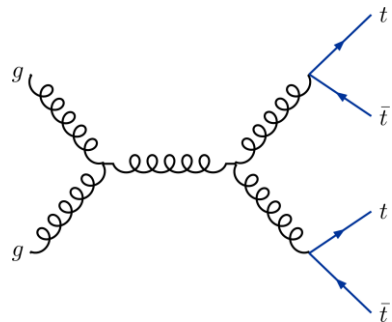
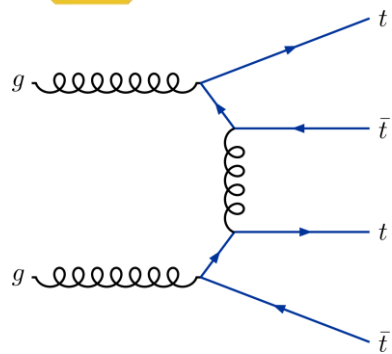




# Evidence for SM $t\bar{t}t\bar{t}$ production

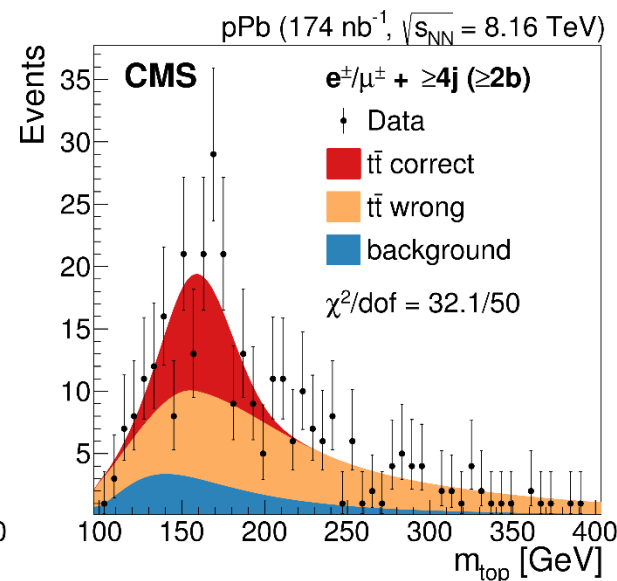
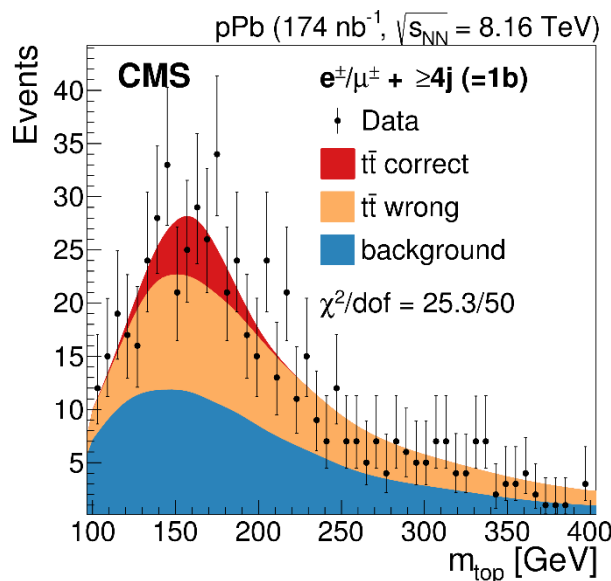
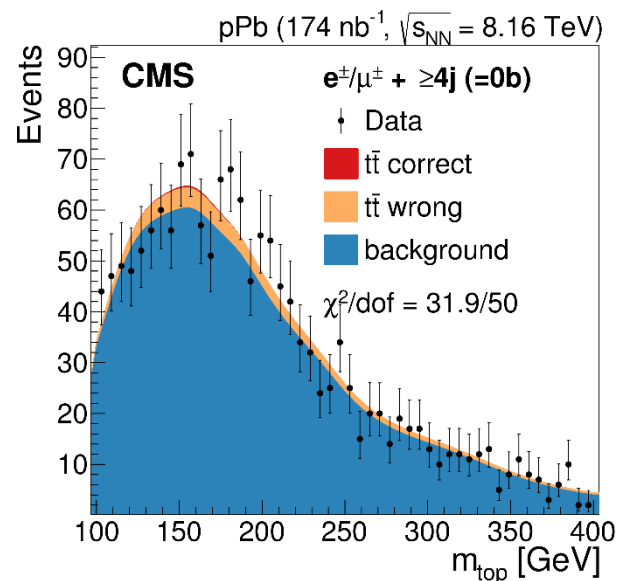
<https://cds.cern.ch/record/2284599> (submitted to EPJC)

- Search conducted in same-sign di-lepton ( $e/\mu$ ) and  $\geq 3$  lepton final states
- Cross-section measured to be 16.9 fb with a  $1.6\sigma$  significance
- This is consistent with SM prediction of  $\sim 12$  fb

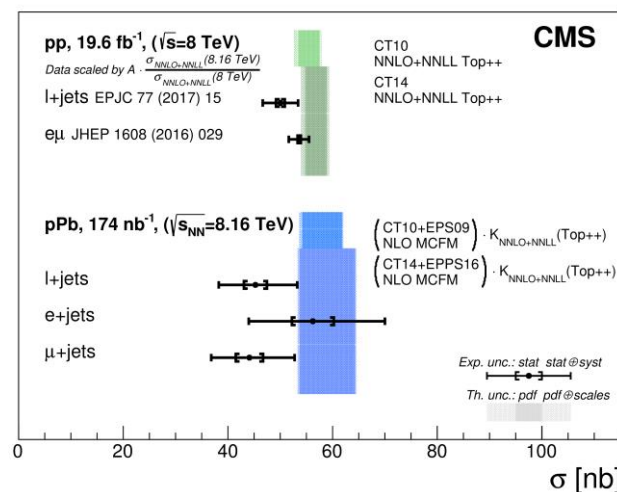




<http://arxiv.org/abs/1709.07411>



- First observation of  $t\bar{t}$  in p-Pb collisions
- Single lepton ( $e/\mu$ ) channel, top mas reconstructed adding 4 additional jets
- Measured cross-section of  $45 \pm 8 \text{ nb}$  is consistent with predictions from perterbative QCD
- Excellent probe of high x region of nuclear gluon density



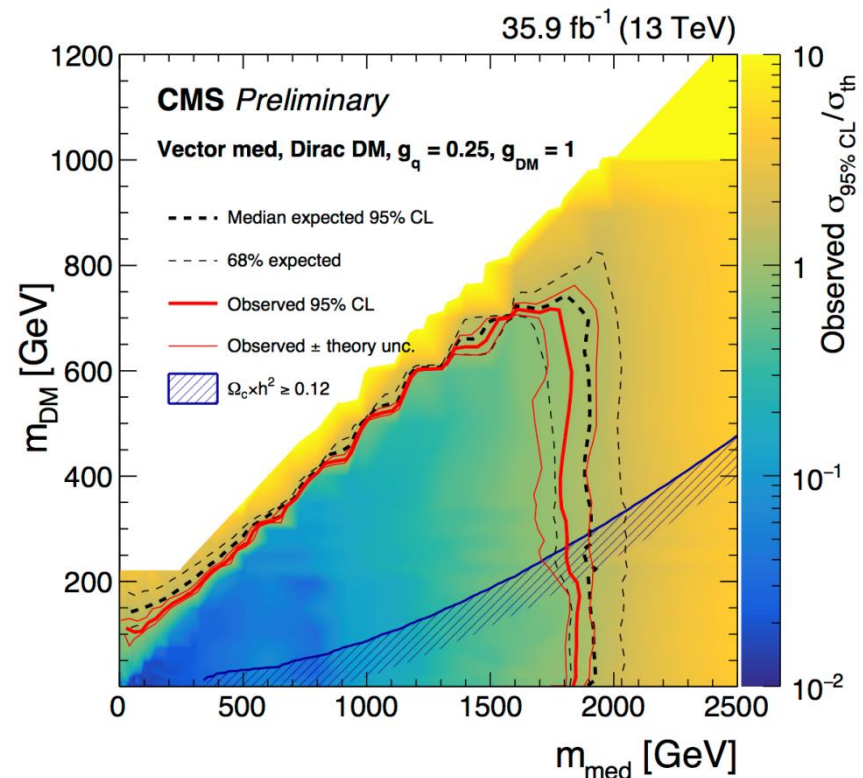
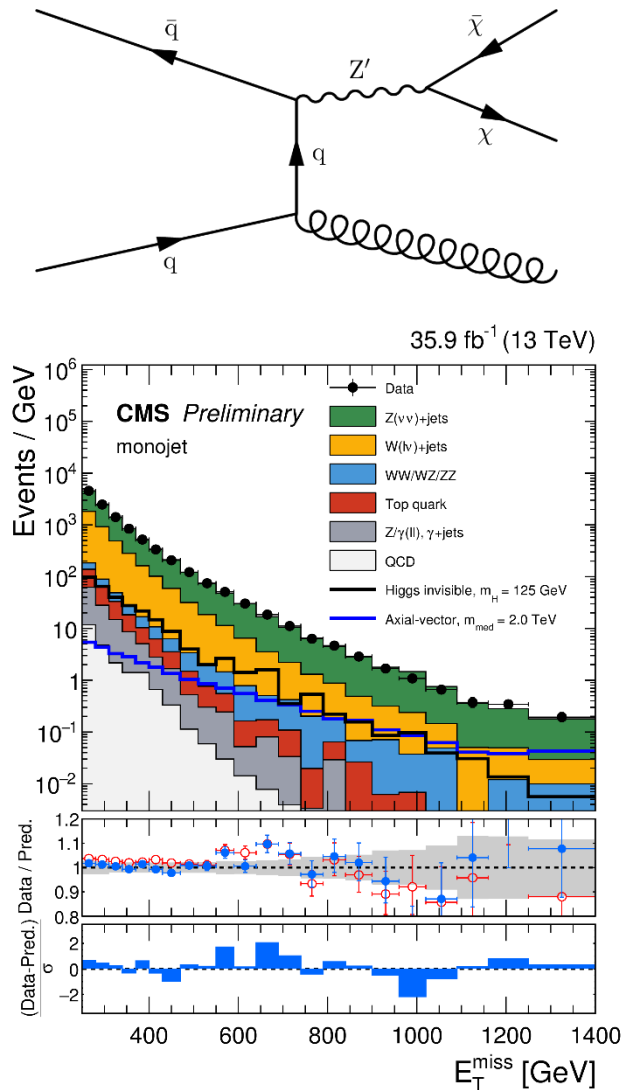
- CMS has produced a wide array of high quality physics results across many sub-fields
- The large dataset provided by the LHC has provided the data for many precision measurements, discovery of rare processes and expanded mass limits of exotic searches
- With the dataset already doubled between 2016 and 2017 and more data on the way in 2018 stay tuned for more exciting physics!



# Backups

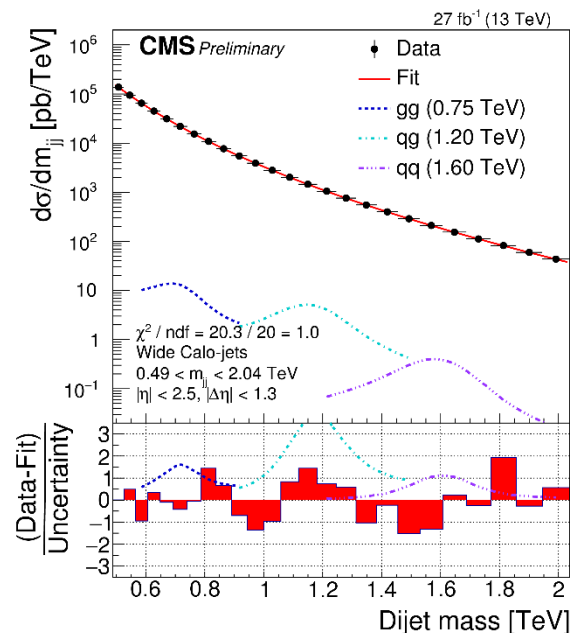
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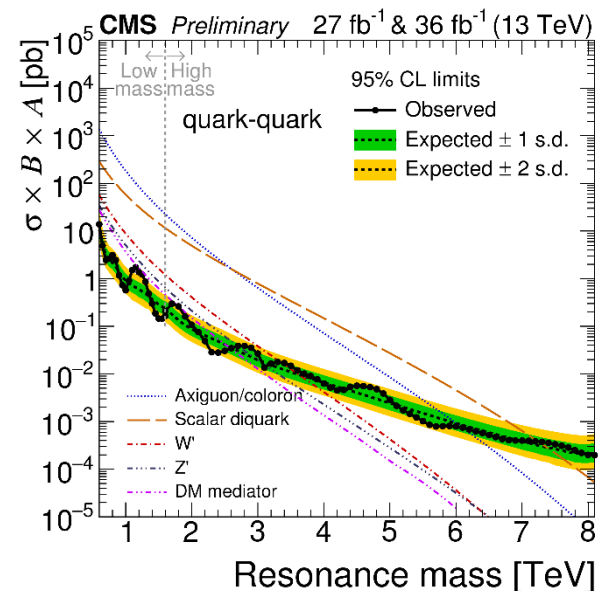
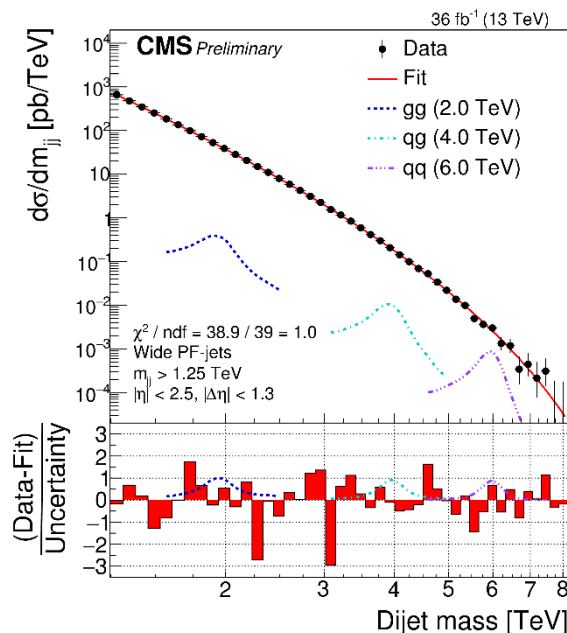


<https://cds.cern.ch/record/2256873>

## Low-mass search



## High-mass search



- Search for dijet resonances
- Low-mass search performed within high-level trigger
- Traditional high-mass search performed with off-line objects