



Exotics searches at CMS

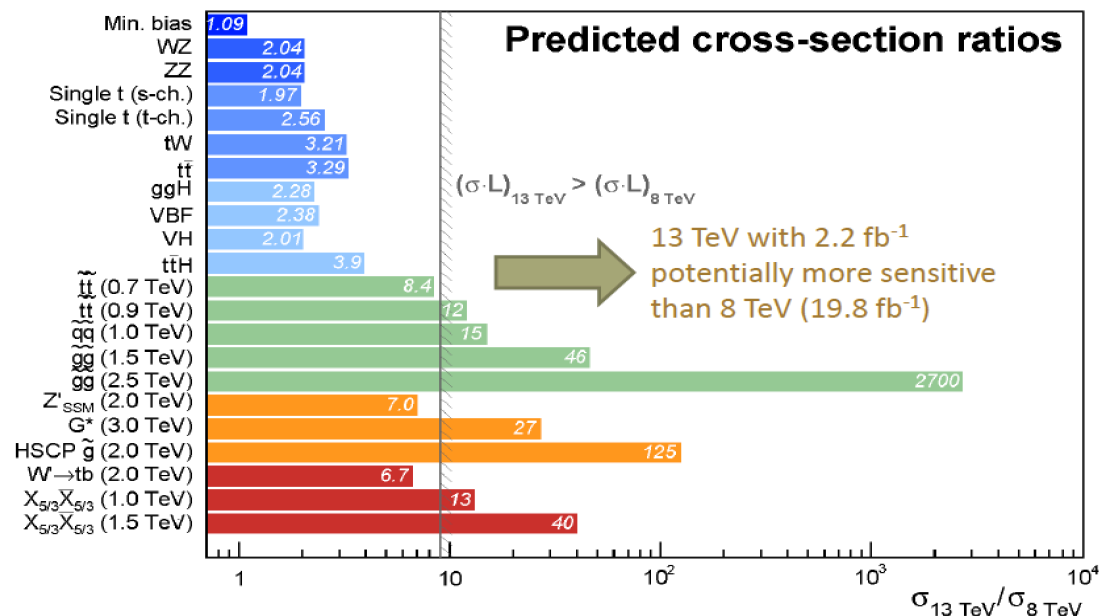
An aerial photograph of a vast valley, likely in the Alps, with a patchwork of green fields and small towns. In the distance, a range of snow-capped mountains is visible under a clear blue sky. A large red circle is drawn over the valley, with several small red circles marking specific locations along its perimeter.

Huaqiao ZHANG (IHEP)
On behalf of CMS collaboration

- Introduction
- Recent search results at CMS
 - Exotics searches with $\gamma/e/\mu/\tau$ /jets/MET
 - Exotics searches with boost objects (W/Z/H/top)
 - Exotics searches with other signature
- Summary

Motivation of exotics searches @ CMS

- SM is very successful but **incomplete**
 - Tells us **how** but not **why**
 - Not cover **gravity**, **dark matter**, **dark energy** etc
- Exotics and SUSY are possible extensions of SM
 - Provide answers to pheno that not explained by SM
 - Only cover exotics in this talk
- LHC is the energy frontier: $E_{cm} = 13$ TeV now



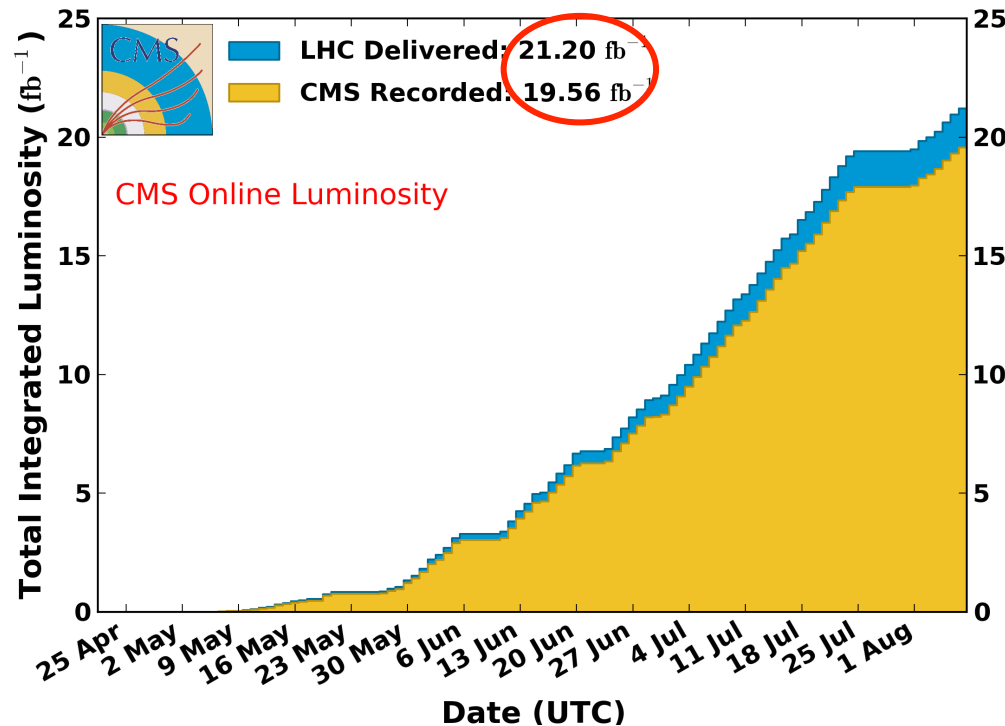


Data collection @ CMS

- An exciting year with 20 fb^{-1} @ 13 TeV data collected to date

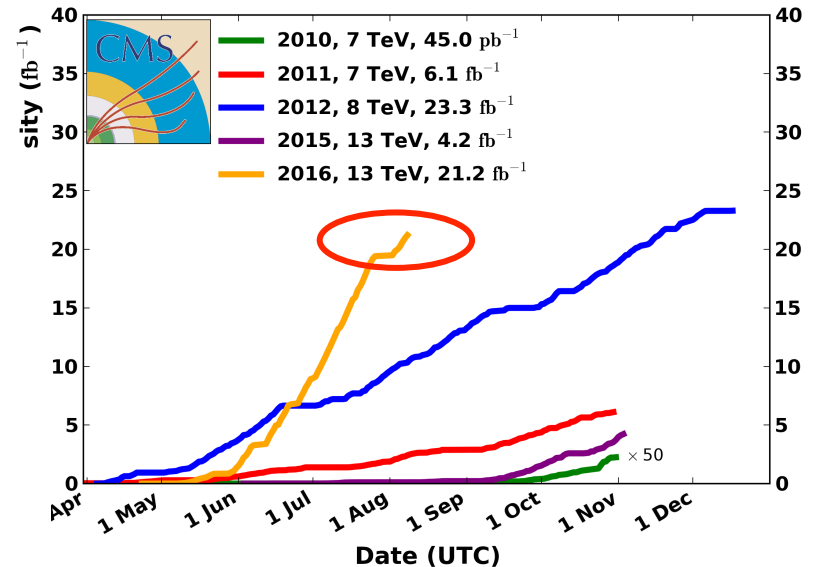
CMS Integrated Luminosity, pp, 2016, $\sqrt{s} = 13 \text{ TeV}$

Data included from 2016-04-22 22:48 to 2016-08-07 15:28 UTC



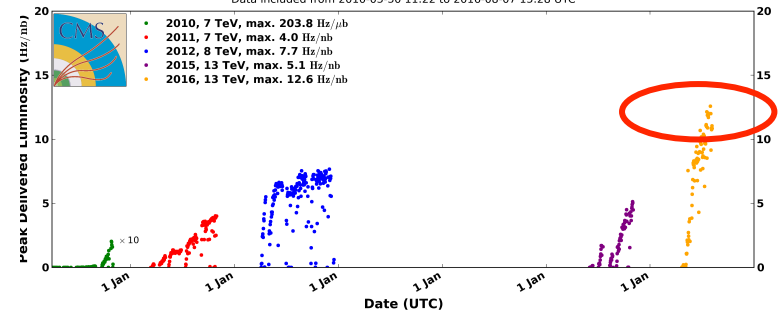
CMS Integrated Luminosity, pp

Data included from 2010-03-30 11:22 to 2016-08-07 15:28 UTC



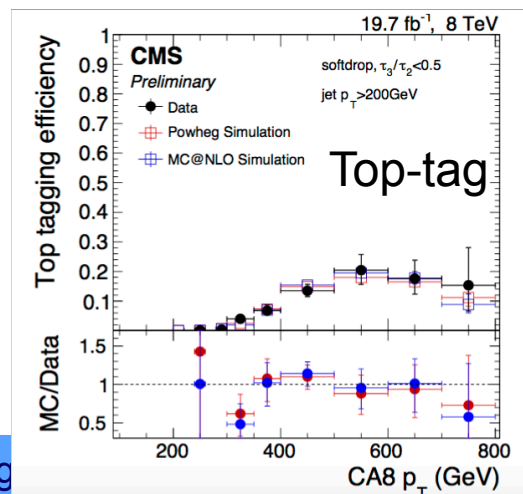
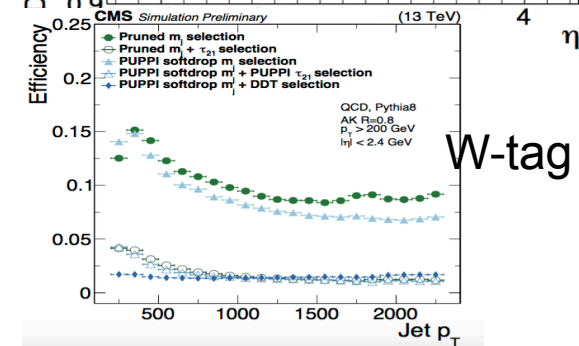
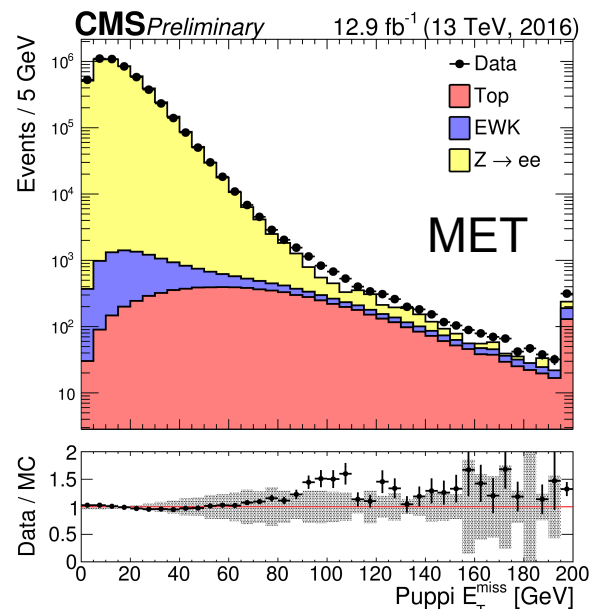
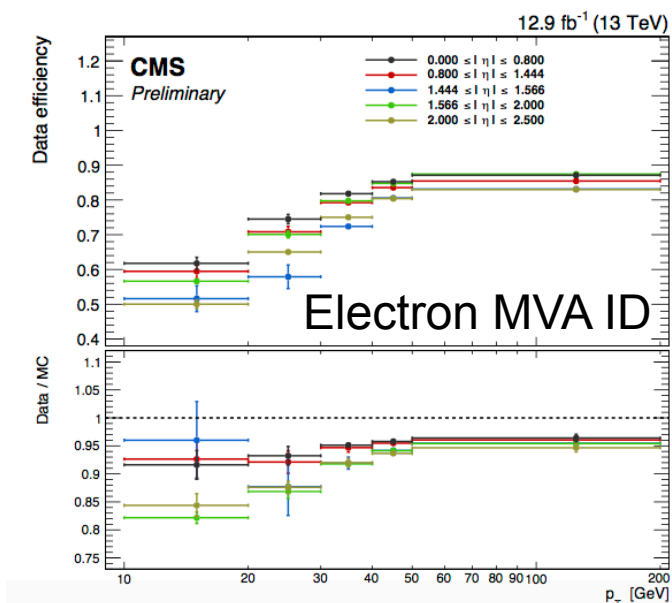
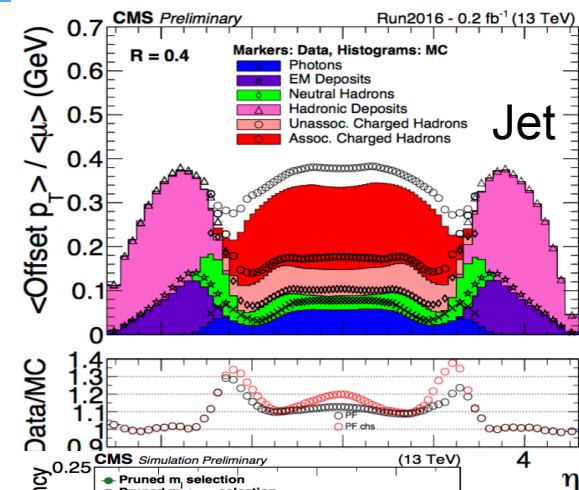
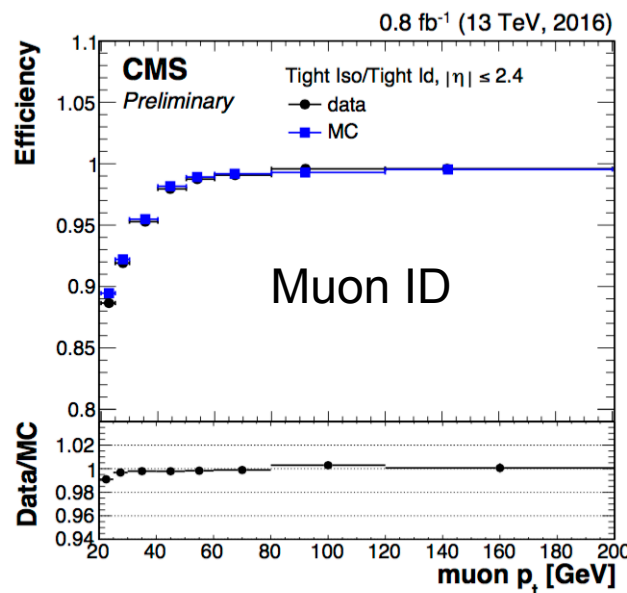
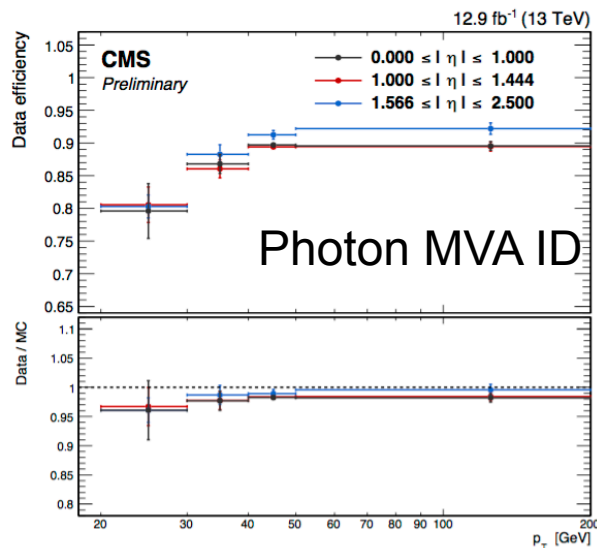
CMS Peak Luminosity Per Day, pp

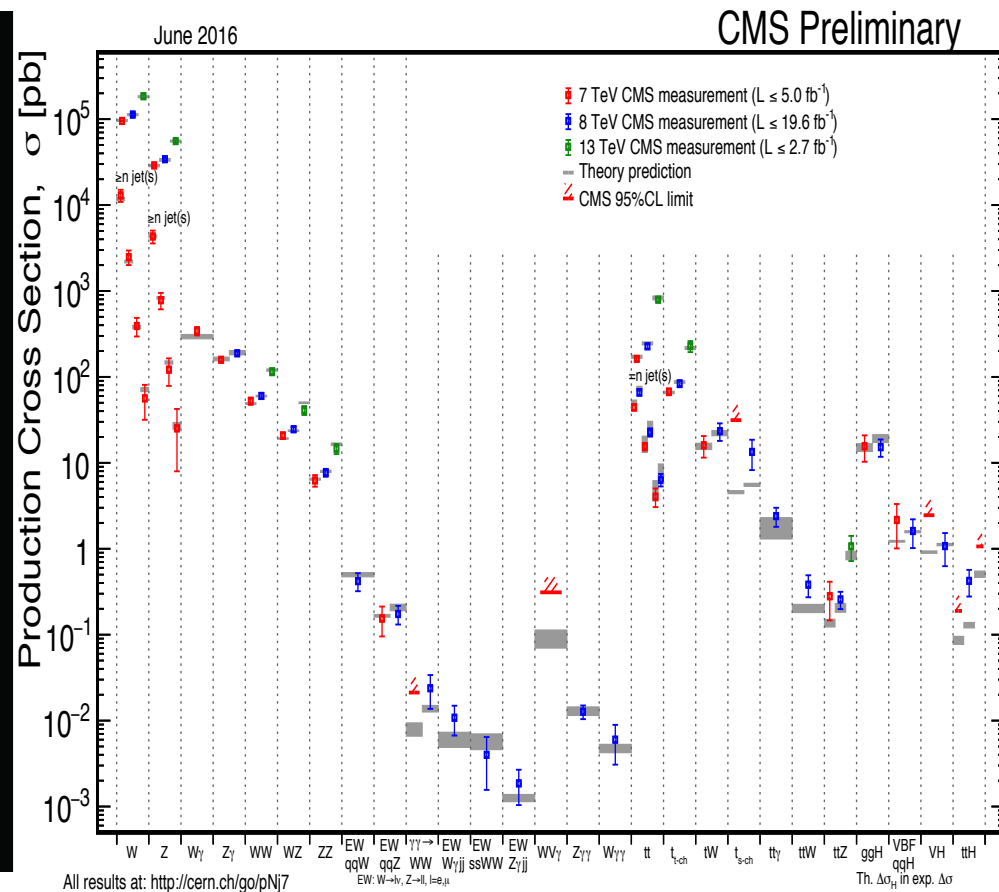
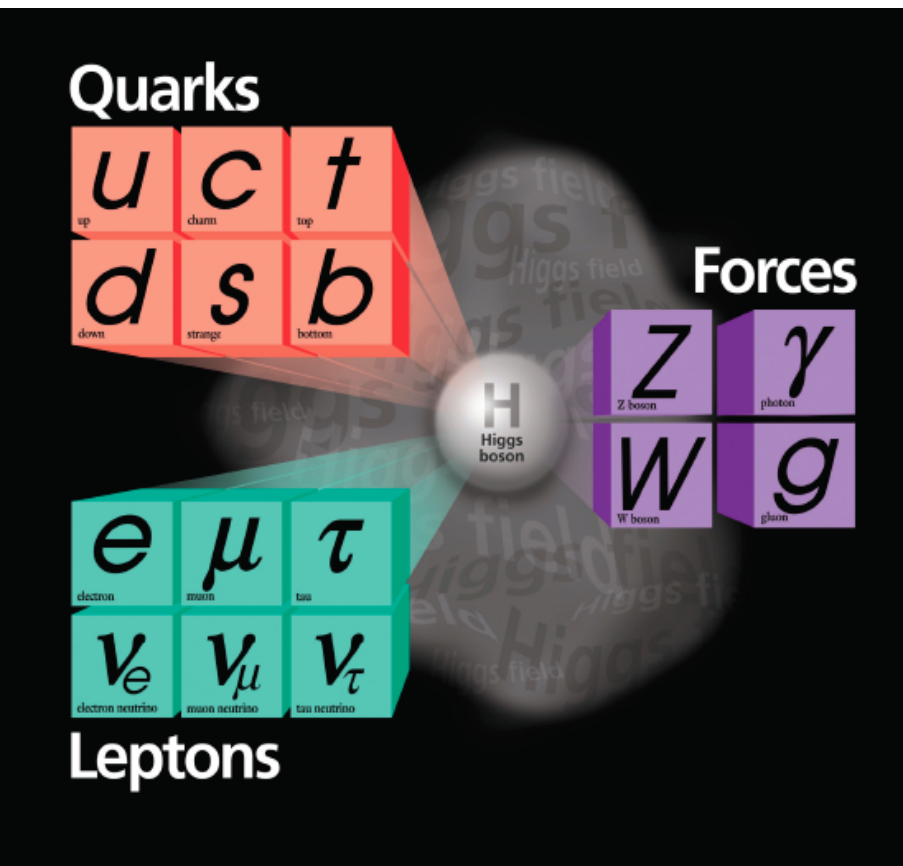
Data included from 2010-03-30 11:22 to 2016-08-07 15:28 UTC





Understanding of physics objects of 2016 data

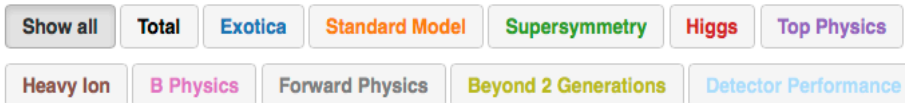




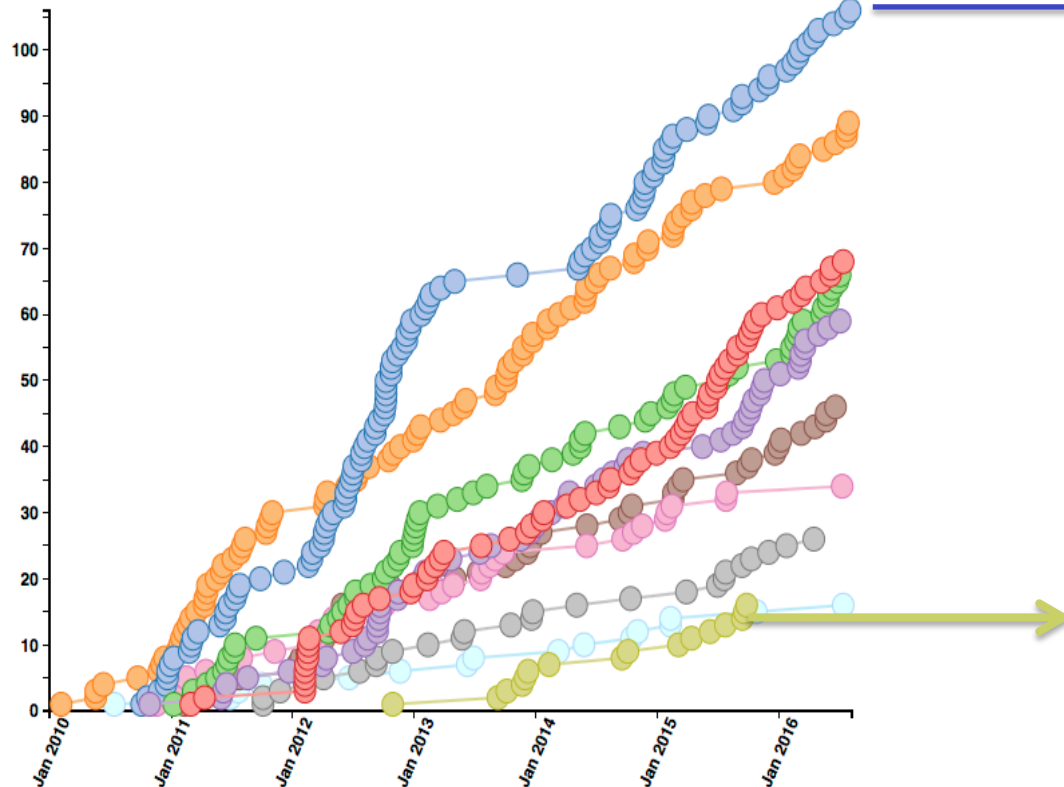
- Well simulated, measured and understood



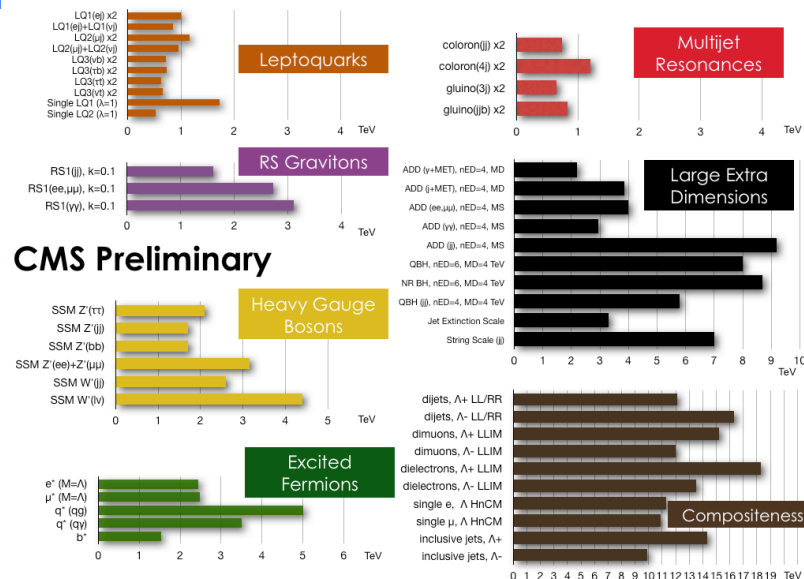
CMS exotic searches overview



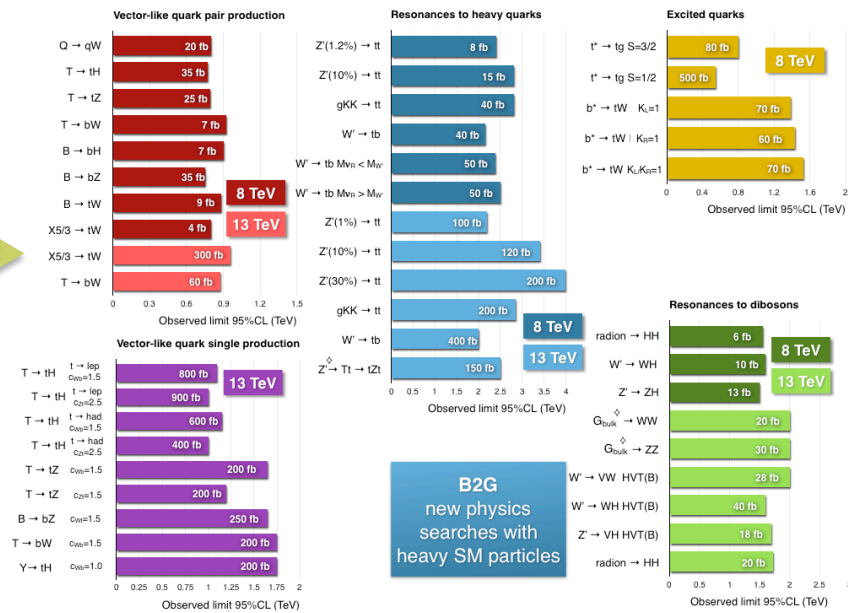
525 collider data papers submitted as of 2016-08-04



- More than 100 publications
- No significant excess observed



CMS Exotica Physics Group Summary – LHCP, 2016



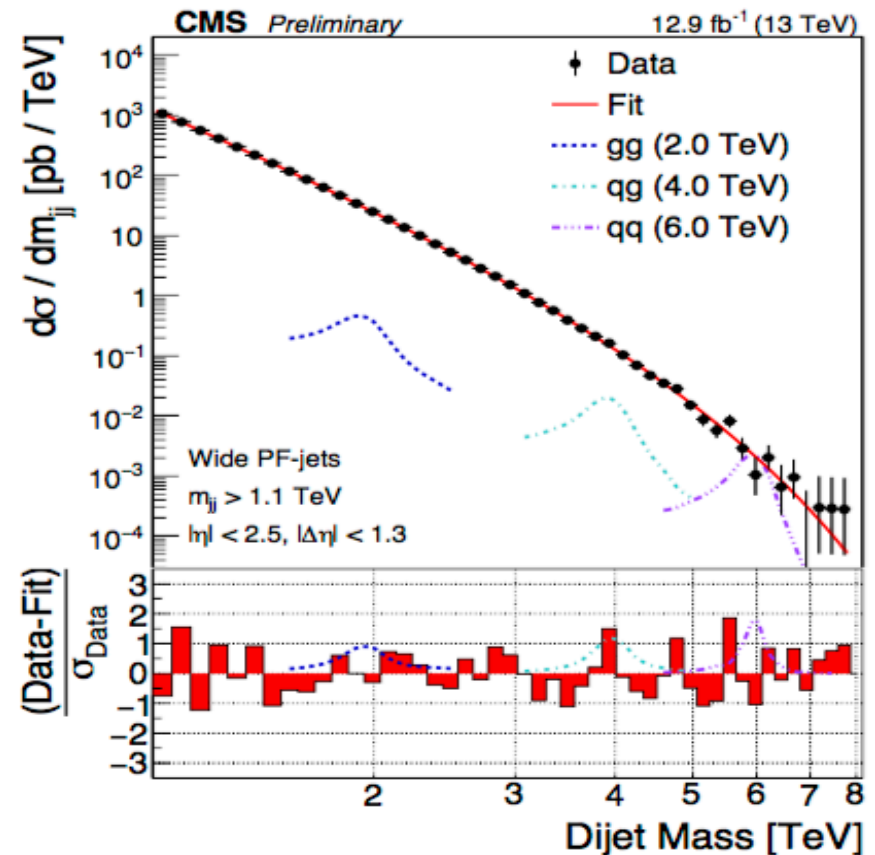
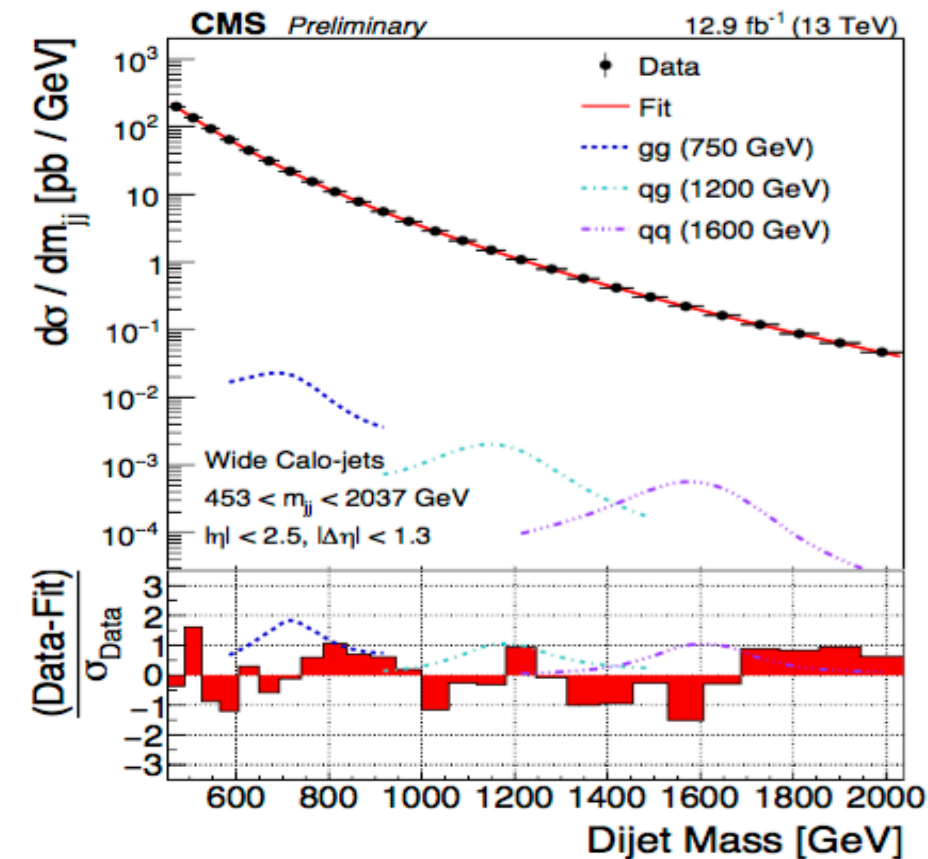
B2G
new physics
searches with
heavy SM particles

Scope of this talk

- Most recent updates of exotics searches from CMS
 - Extra dimensions
 - Compositeness
 - New Gauge Bosons: Z' , W'
 - Quark substructures
 - Long lived particles
 - Displaced e/μ
 - ...
- Will not cover SUSY
 - Dark matter results will be covered by Francesca Ungaro's talk
- Can not cover all recent updated results
 - Selected results by personal preferences
 - Apologize for results not shown here

Exotics Searches with $\gamma/e/\mu/\tau/\text{jets}/\text{MET}$

- Total Luminosity:
 - 12.9 fb⁻¹ @ 13 TeV (2016)
- Final state: J+J
- Background fitted: $\frac{d\sigma}{dm} = \frac{P_0(1 - m/\sqrt{s})^{P_1}}{(m/\sqrt{s})^{P_2+P_3} \ln(m/\sqrt{s})}$
- Narrow width signal checked

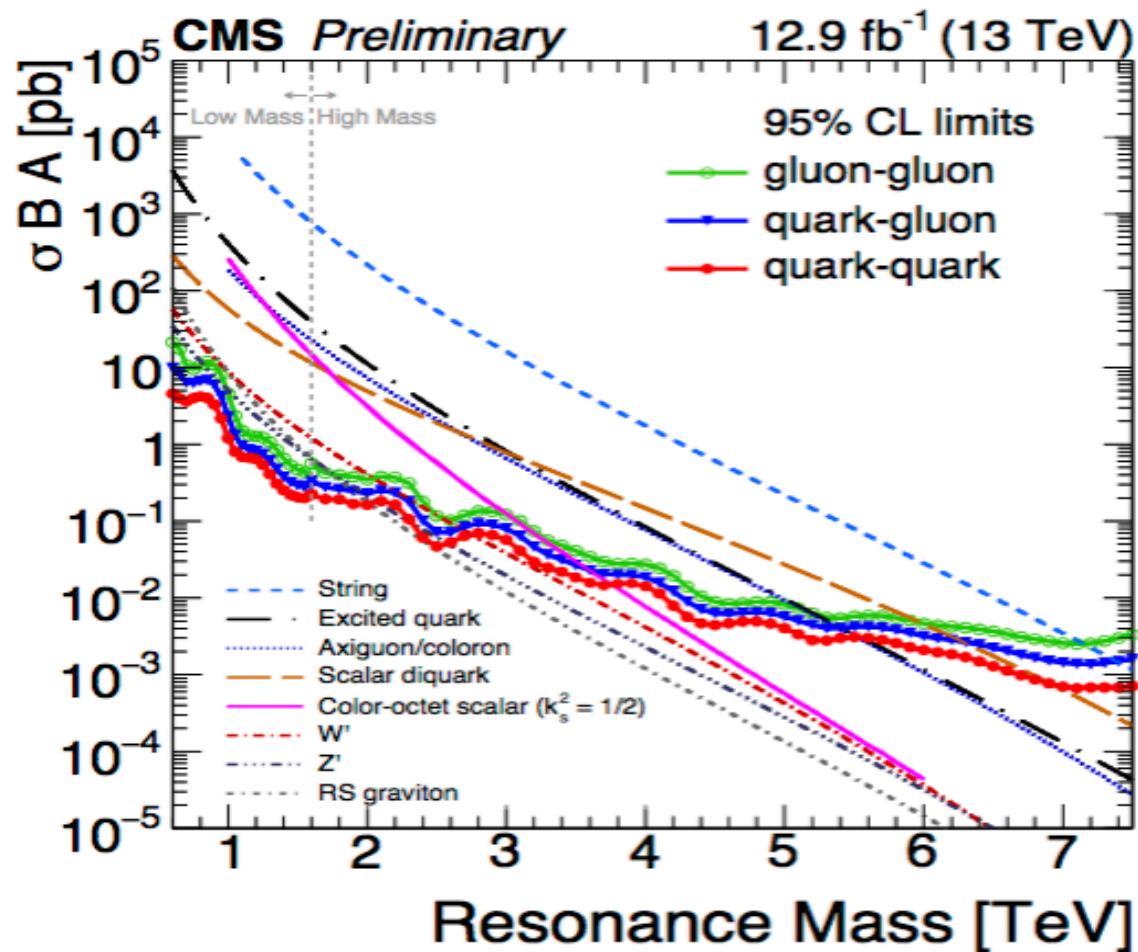


Search dijet resonances of

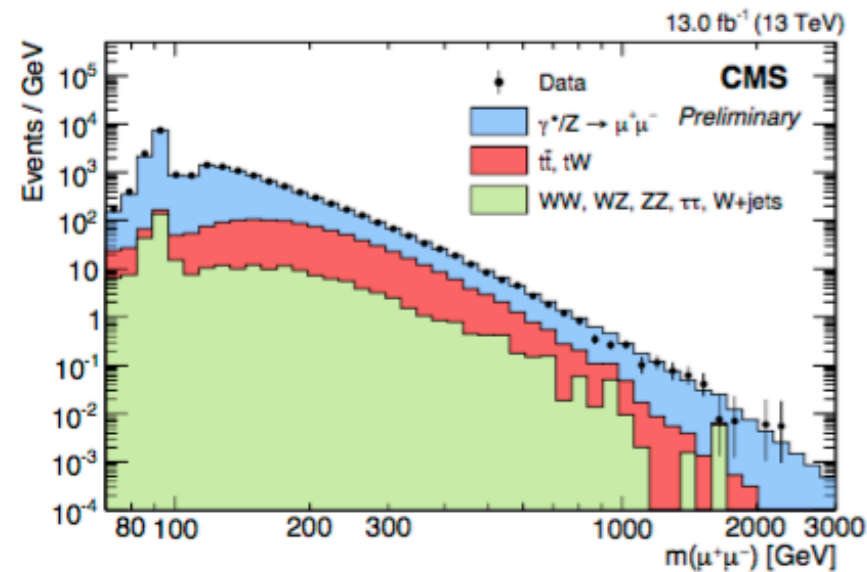
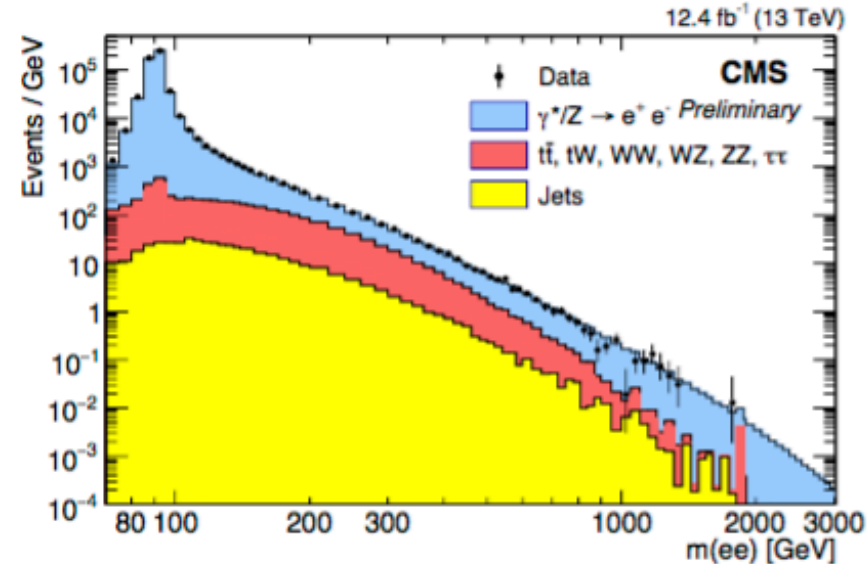
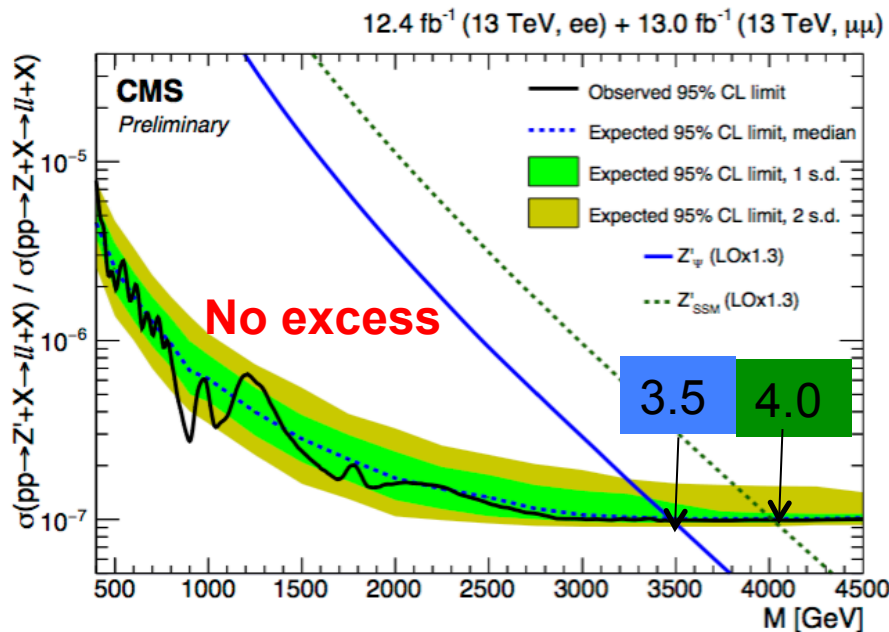
- String (qg)
- Scalar diquark(qq)
- Axigluon/coloron(qqbar)
- Excited quark(qg)
- Color-octet scalar(gg)
- W' (qqbar)
- Z' (qqbar)
- RS Graviton(qqbar,gg)

No sign of excess

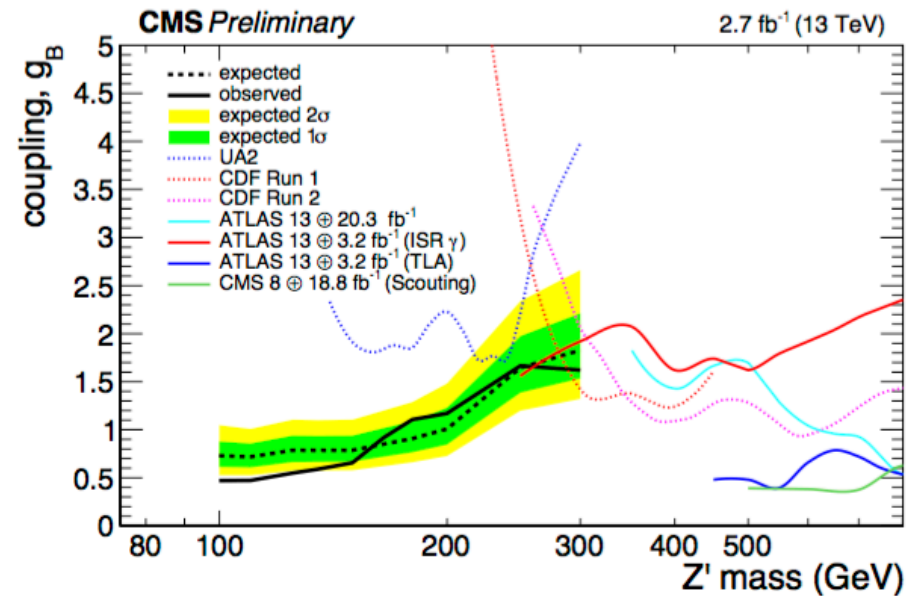
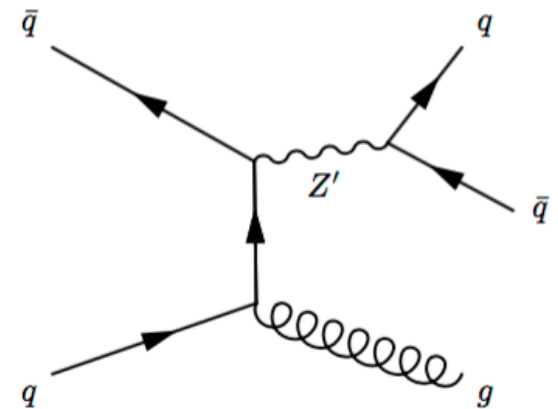
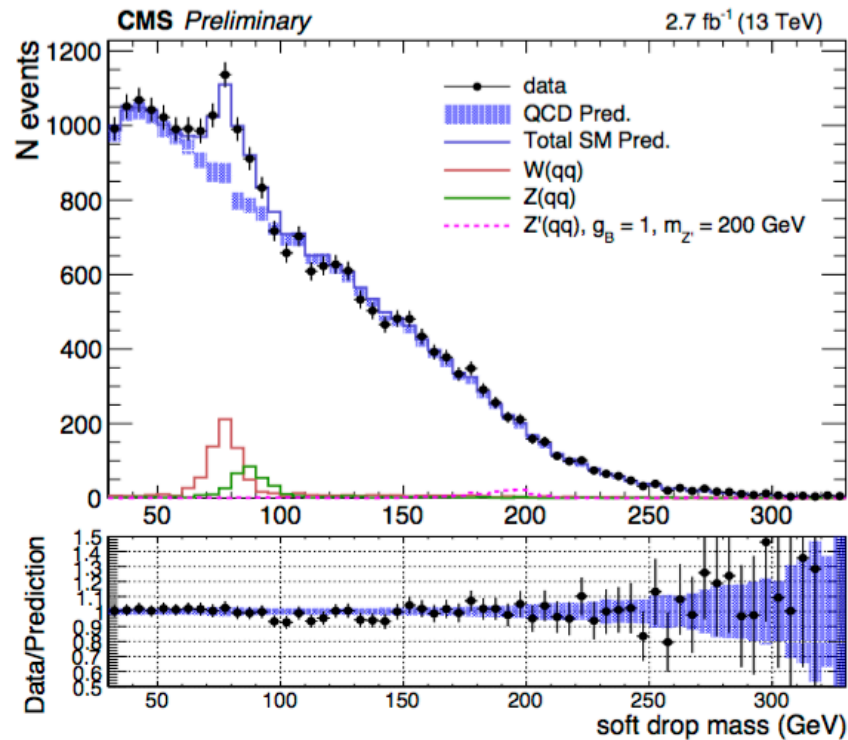
Model	Observed 12.9 fb ⁻¹ 13 TeV
String	7.4 (7.4)
Scalar diquark	6.9 (6.8)
Axigluon/coloron	5.5 (5.6)
Excited quark	5.4 (5.4)
Color-octet scalar	3.0 (3.3)
W'	2.7 (3.1)
Z'	2.1 (2.3)
RS Graviton	1.9 (1.8)



- Total Luminosity:
 - ee: 12.4 fb⁻¹ @ 13 TeV (2016)
 - mm: 13.0 fb⁻¹ @ 13 TeV (2016)
- Final state: l+l
- Background from MC prediction
 - Normalized to 60 < m_{ll} < 120 GeV



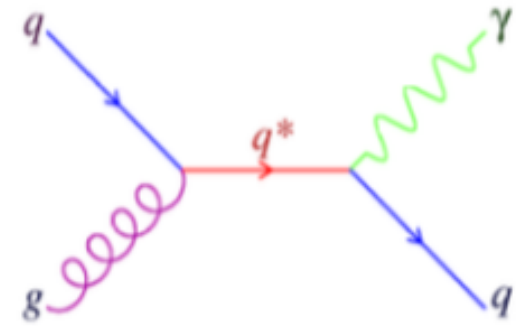
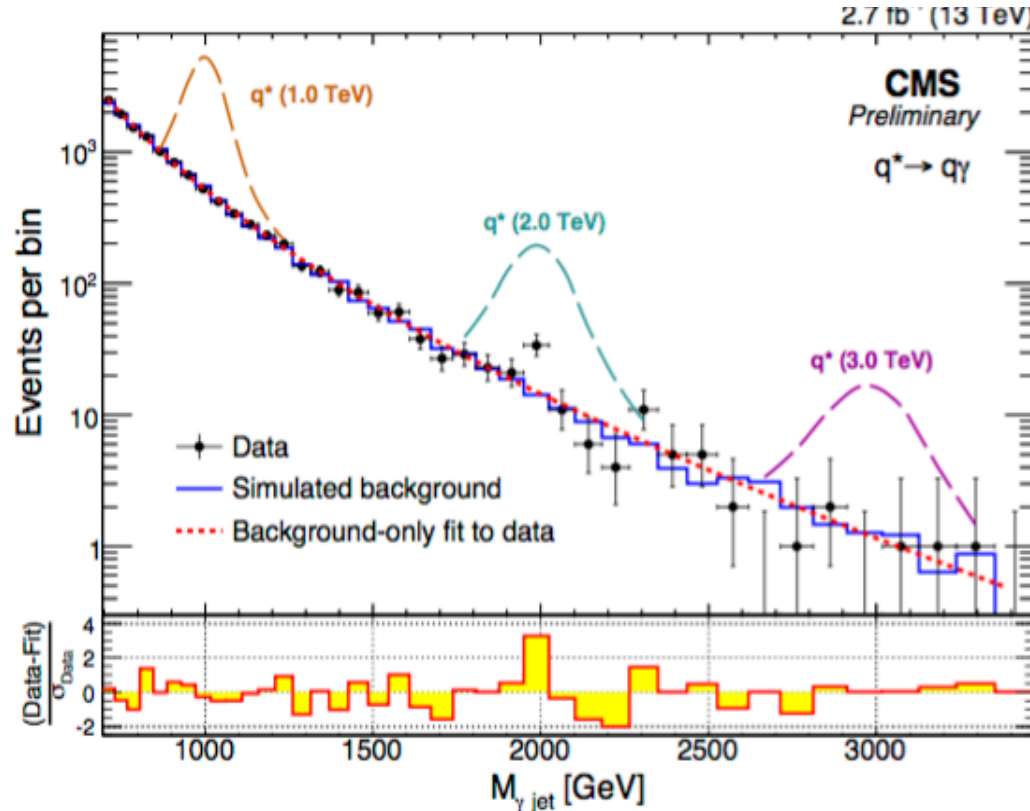
- Total Luminosity:
 - 2.7 fb^{-1} @ 13 TeV (2015)
- Final state: JJ+J
- Search leptophobic vector Z'
 - In the [100,300] GeV range



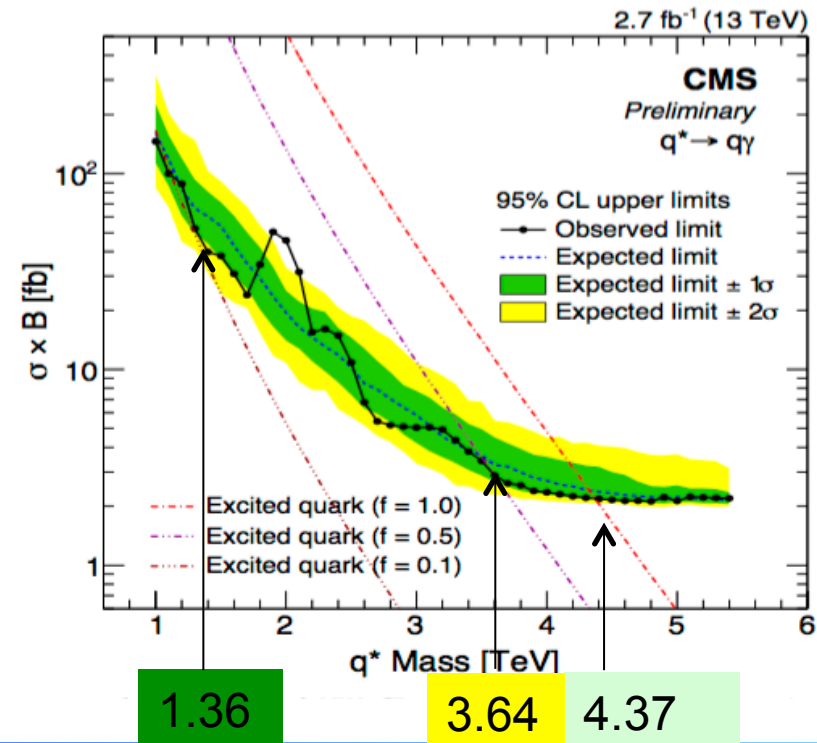
- Total Luminosity:
 - 2.7 fb⁻¹ @ 13 TeV (2015)

- Final state: γ +J

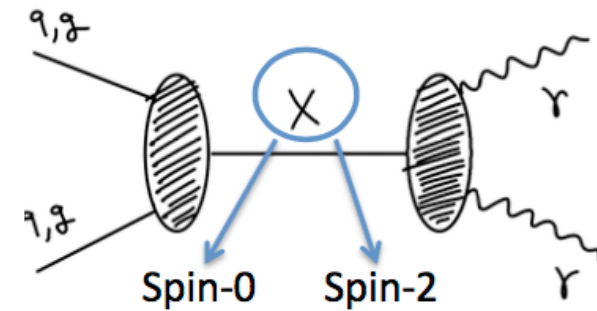
- Background fitted:
$$\frac{d\sigma}{dm} = \frac{P_0(1 - m/\sqrt{s})^{P_1}}{(m/\sqrt{s})^{P_2+P_3} \ln(m/\sqrt{s})}$$



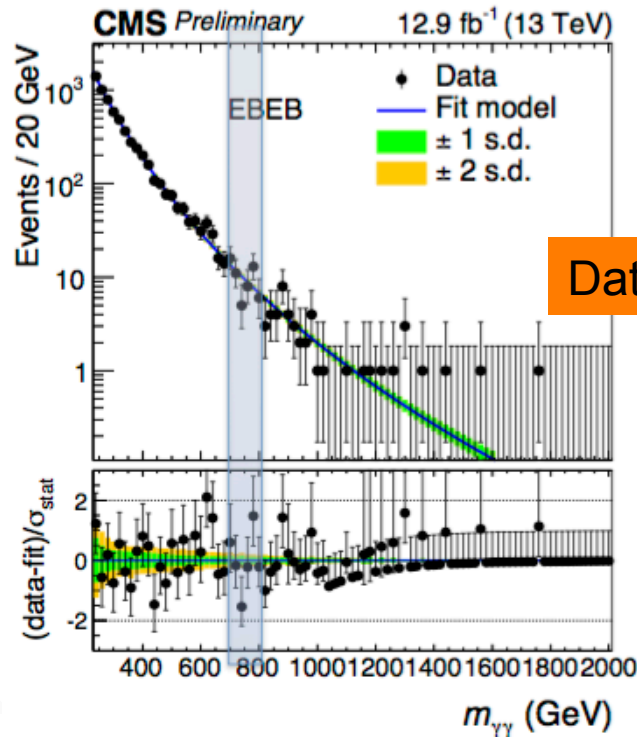
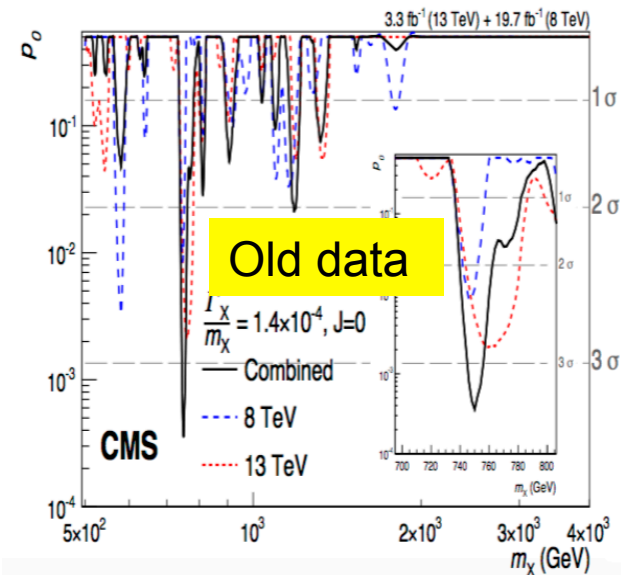
$$\mathcal{L}_{int} = \frac{1}{2\Lambda} \bar{q}_R^* \sigma^{\mu\nu} \left[g_s f_s \frac{\lambda_a}{2} G_{\mu\nu}^a + g f \frac{\tau}{2} W_{\mu\nu} + g' f' \frac{Y}{2} B_{\mu\nu} \right] q_L + h.c.$$



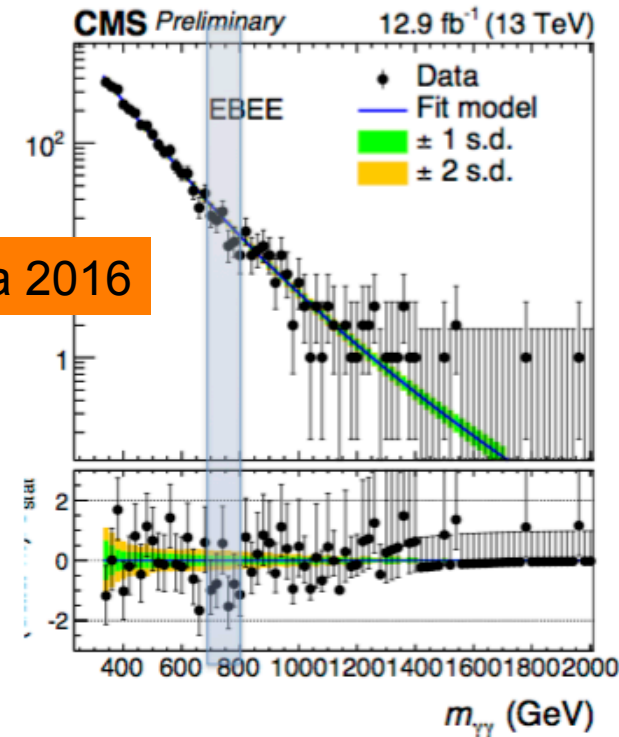
- Total Luminosity:
 - 16.2 fb⁻¹ @ 13 TeV + 19.7 fb⁻¹ @ 8 TeV
- Final state: $\gamma\gamma$
- Background fit: $f(m_{\gamma\gamma}) = m_{\gamma\gamma}^{a+b \cdot \log(m_{\gamma\gamma})}$
- 3.4 σ excess with 2015 and run1 data
 - Need more data



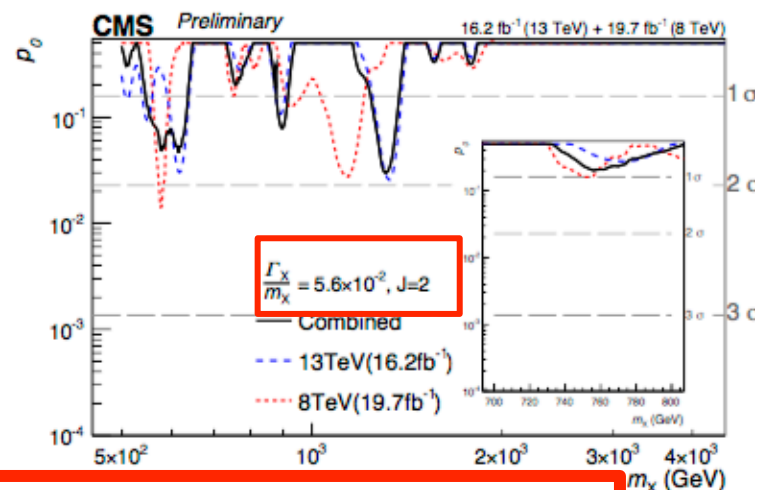
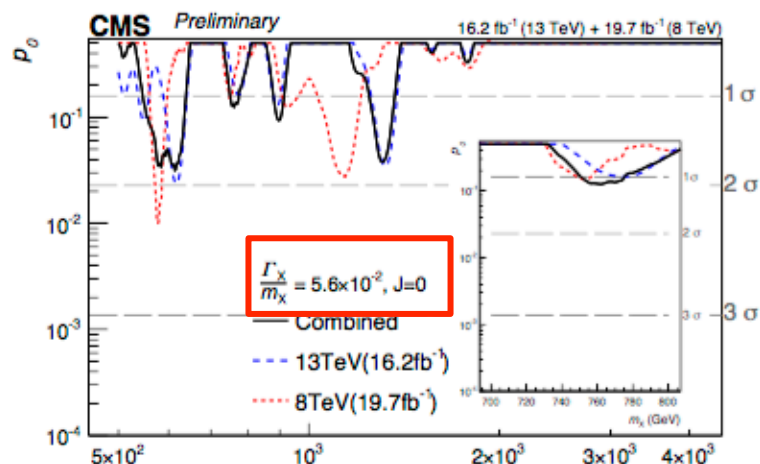
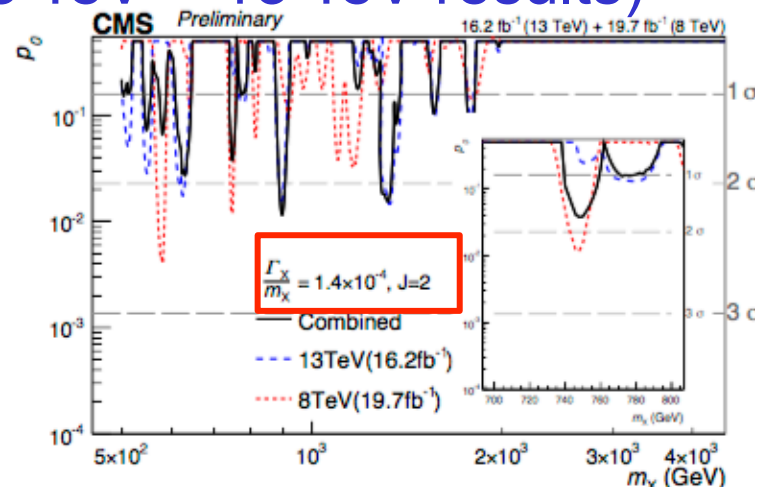
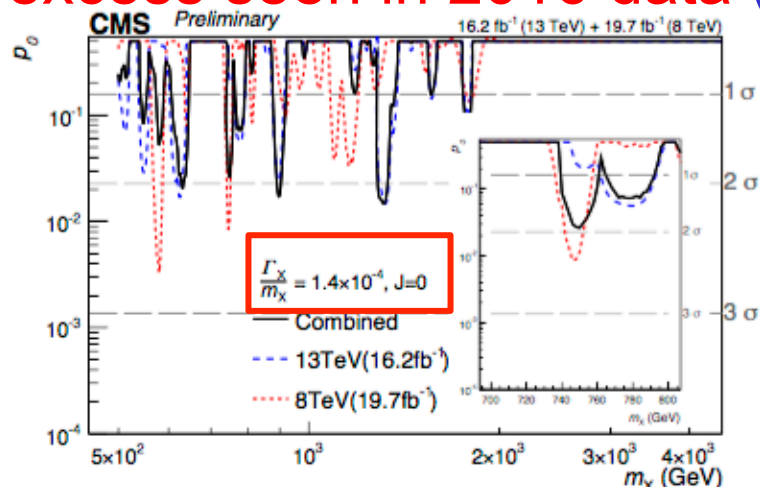
Phys.Rev.Let. 117(2016), no. 5, 051802



Data 2016



- No excess seen in 2016 data (8 TeV + 13 TeV results)



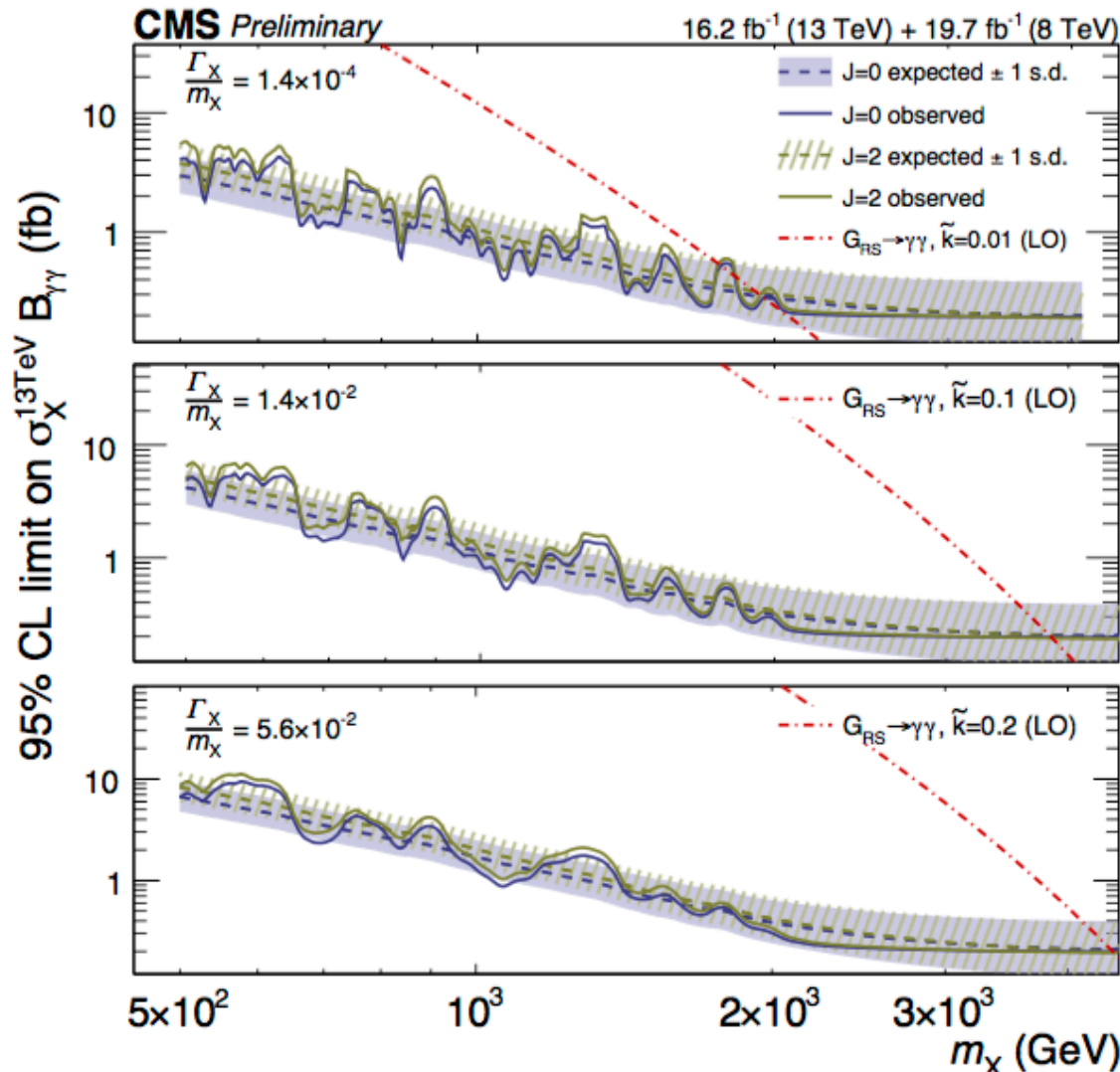
Local excesses around 750GeV:

2015 only: 2.9σ

2015+2016: <1σ

8TeV+2015: 3.4σ

8TeV+2015+2016: <2σ



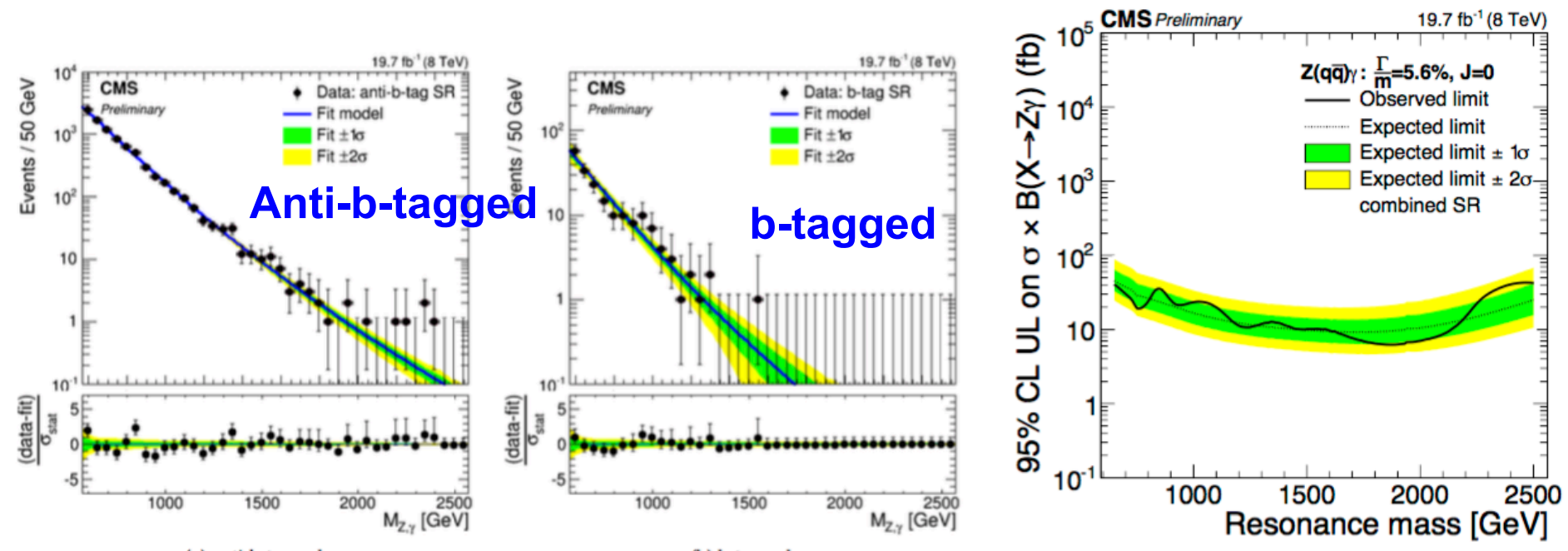
Exclude RS graviton

- < 1.95 TeV, except $[1.75, 1.85]$ (K=0.01)
- < 3.85 TeV (K=0.1)
- < 4.25 TeV (K=0.2)

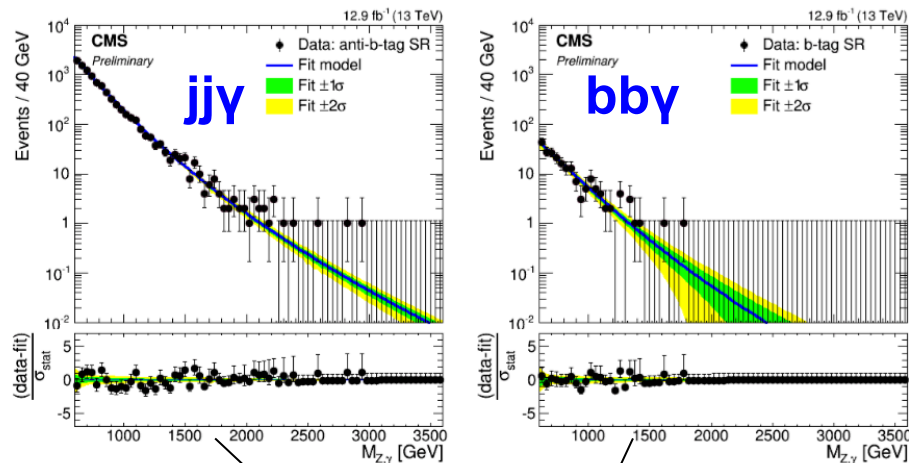
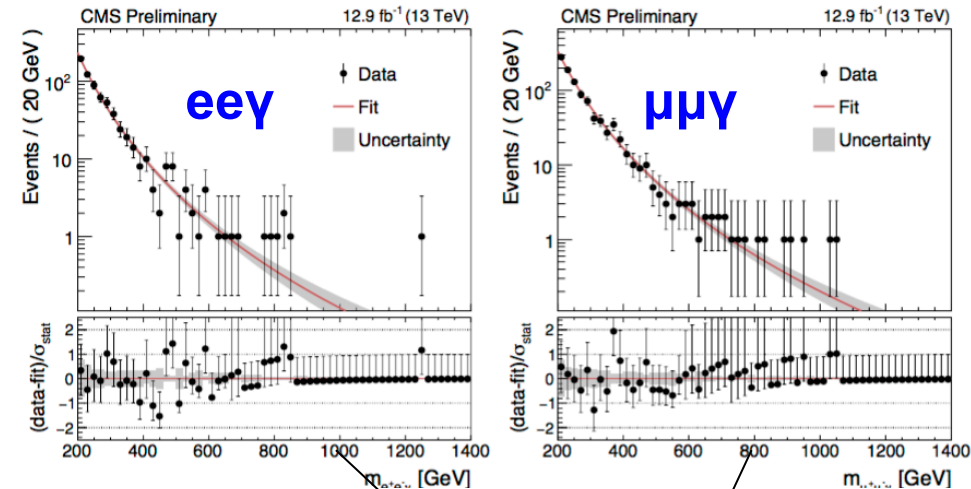
8 TeV contribute $\sim 10\%$ at low mass, negligible at high mass

- Total Luminosity:
 - 12.9 fb⁻¹ @ 13 TeV + 19.7 fb⁻¹ @ 8 TeV
- Final state: Z+ γ , where Z $\rightarrow$ qq/l $\bar{l}$
- If 750 GeV diphoton is real, then Z γ probably see it

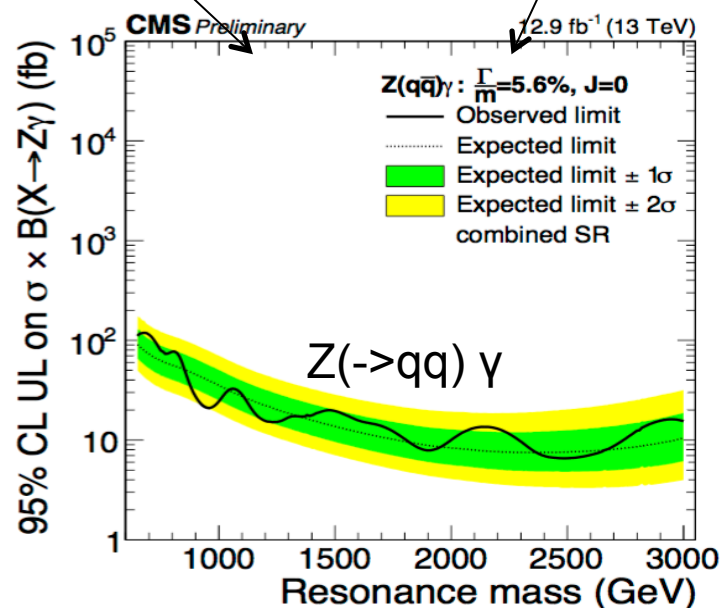
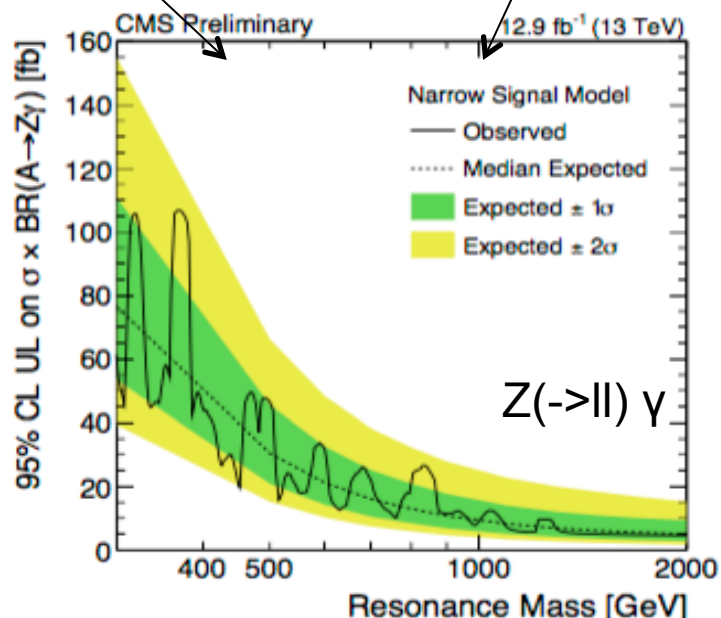
Z($\rightarrow$ qq) γ results with 19.7 fb⁻¹ @ 8 TeV



No excess seen in the b-tagged/anti-btagged and narrow/wide width and spin 0



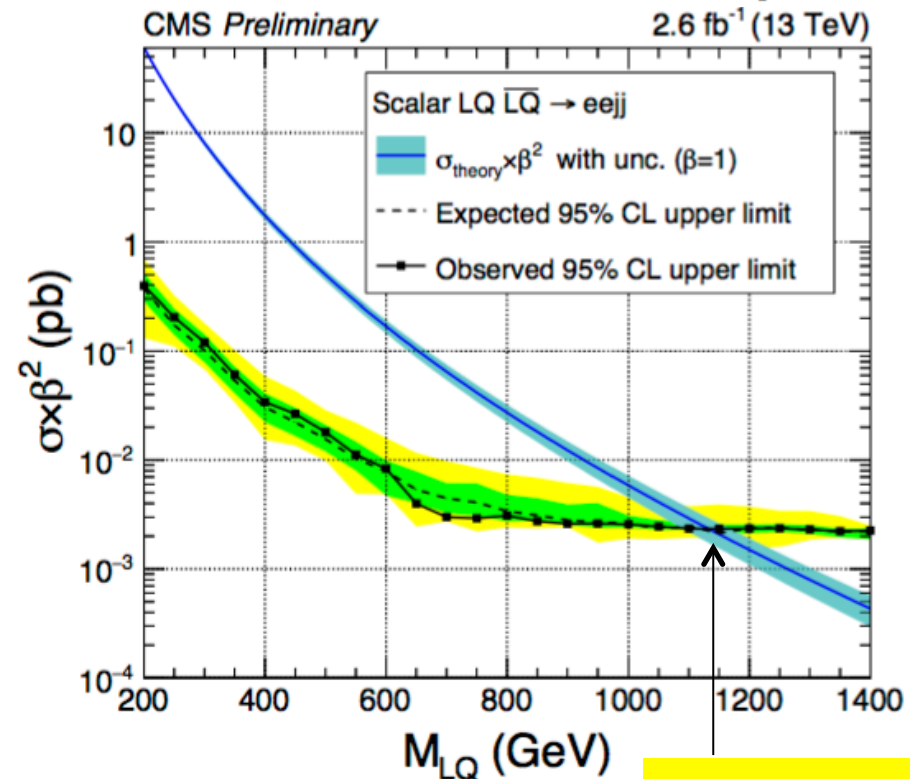
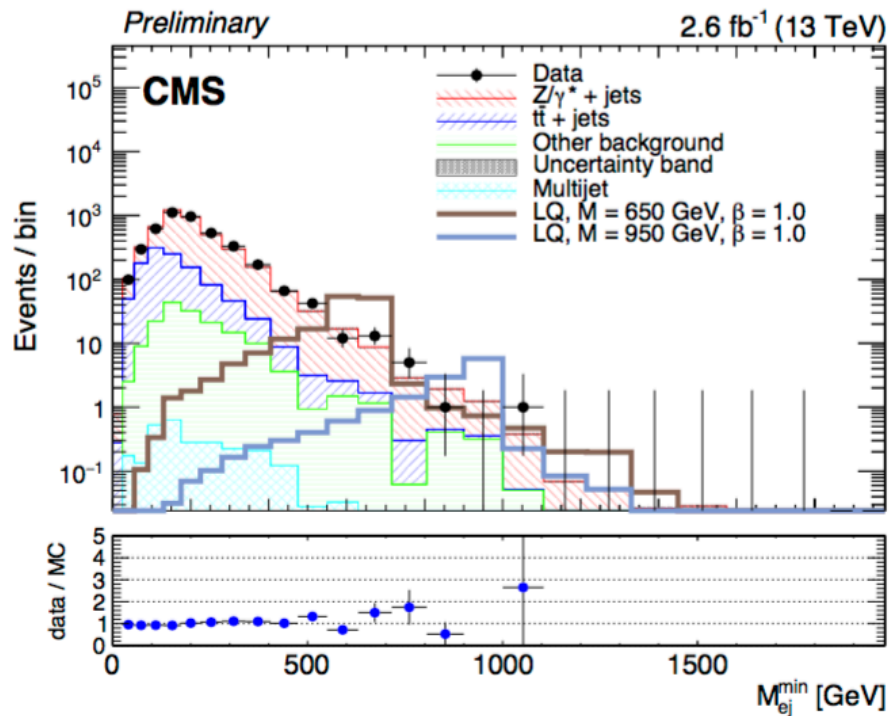
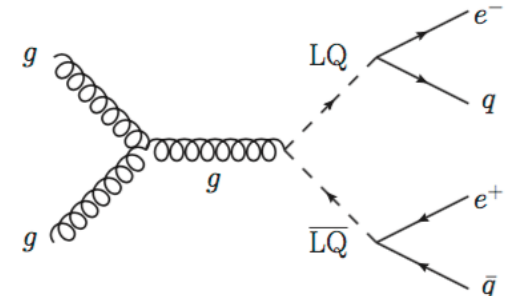
**Data
2016**



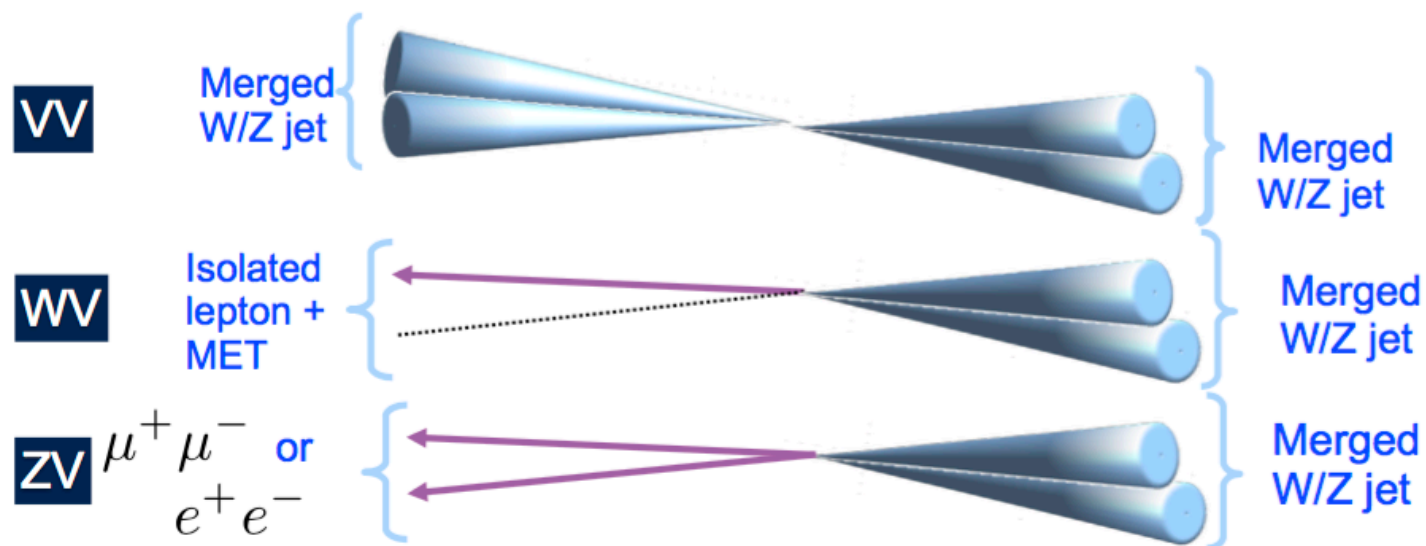
Consistent with diphoton results

- Total Luminosity:
 - 2.6 fb^{-1} @ 13 TeV(2015)
- Final state: $eejj$

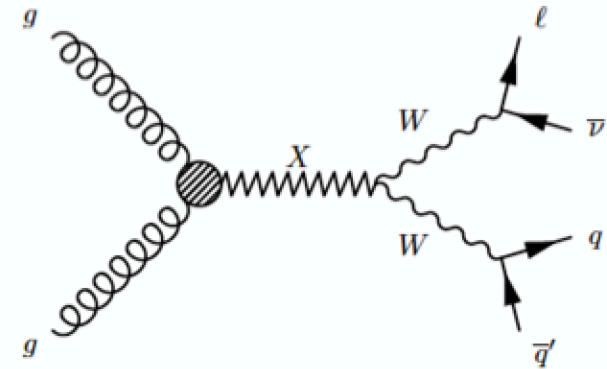
- Scalar



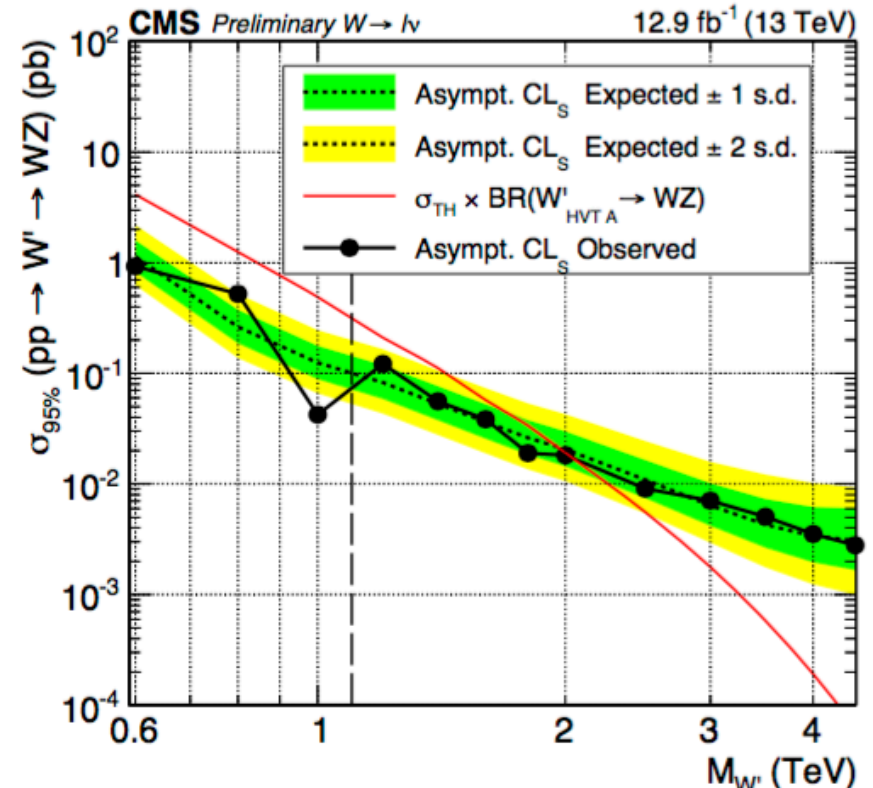
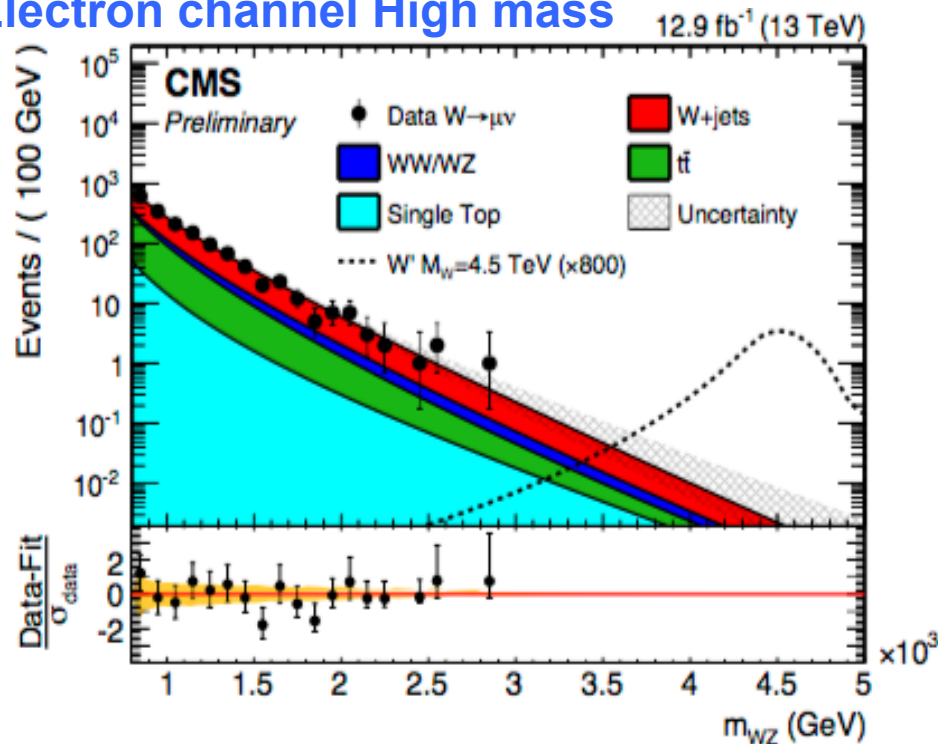
Exotics Searches with boosted objects (W/Z/H/top)



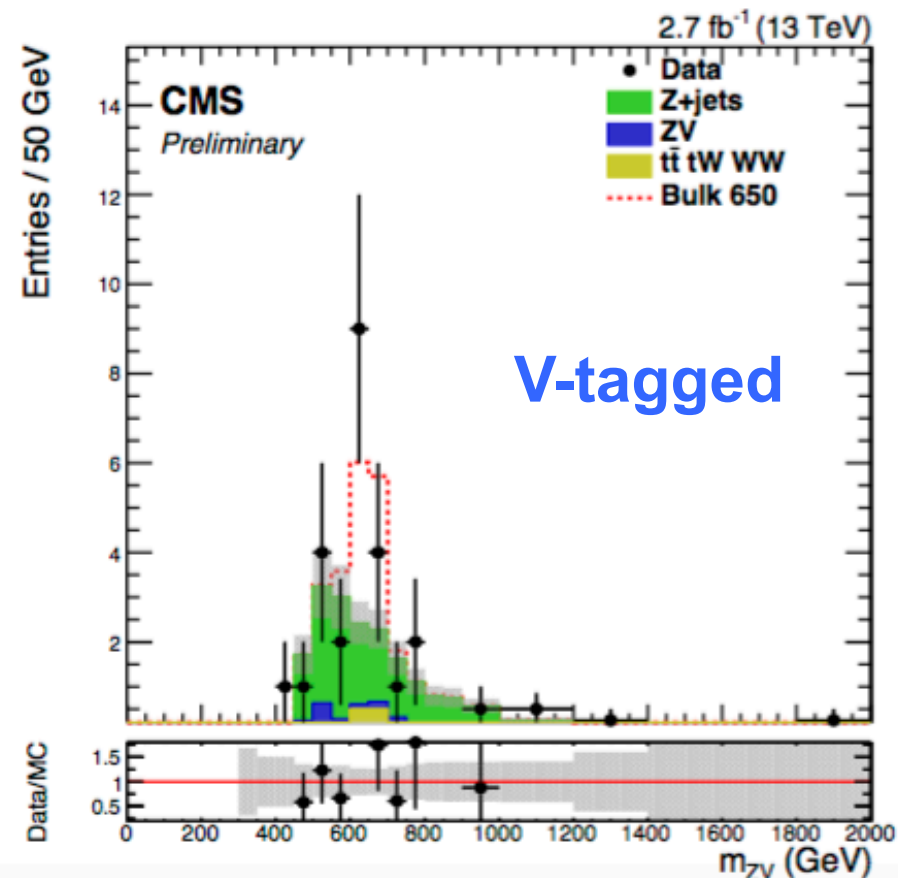
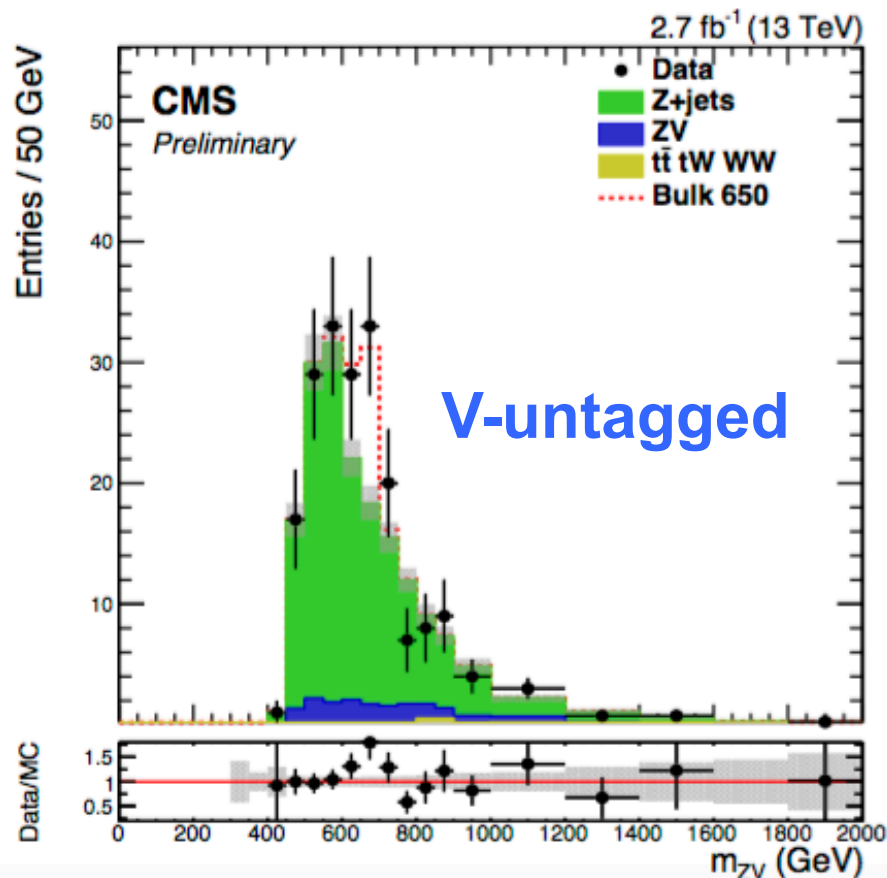
- Total Luminosity:
 - 12.9 fb^{-1} @ 13 TeV(2016)
- Final state:
 - $X \rightarrow WV \rightarrow \ell \nu + \text{boost } W/Z$



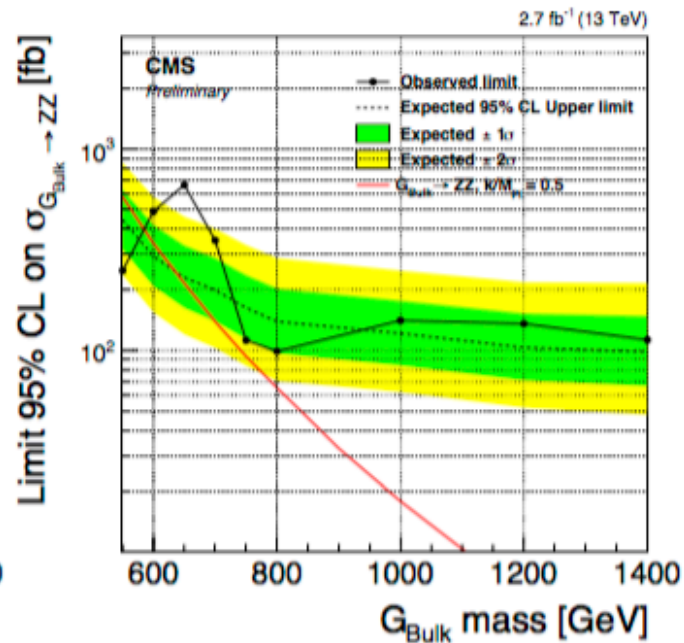
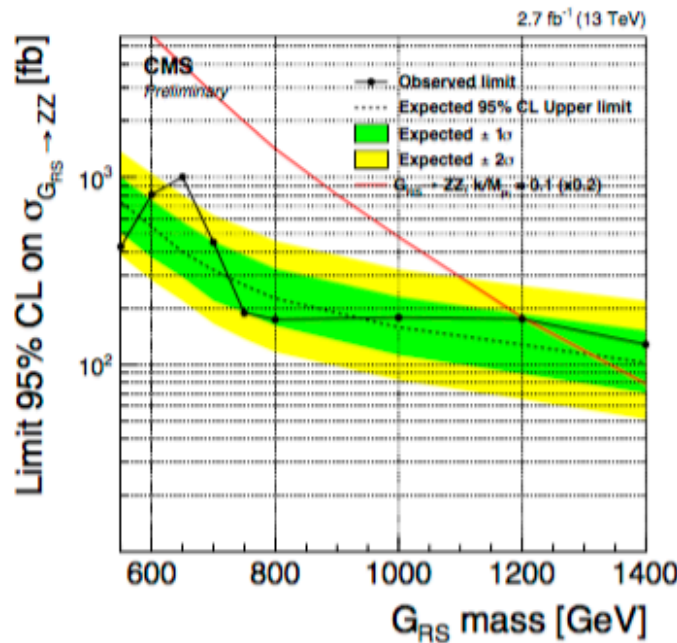
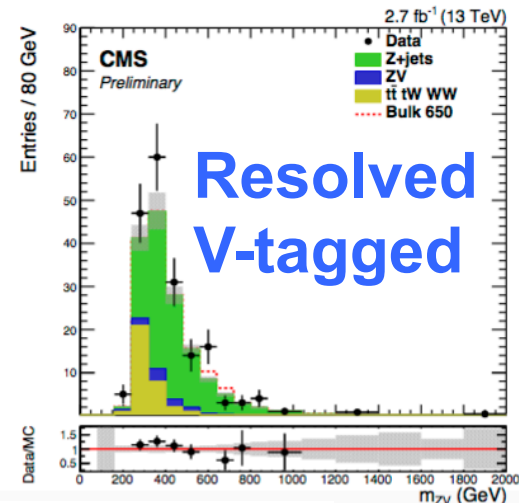
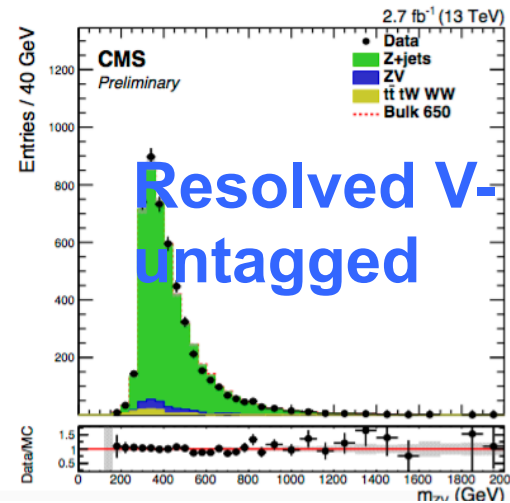
Electron channel High mass



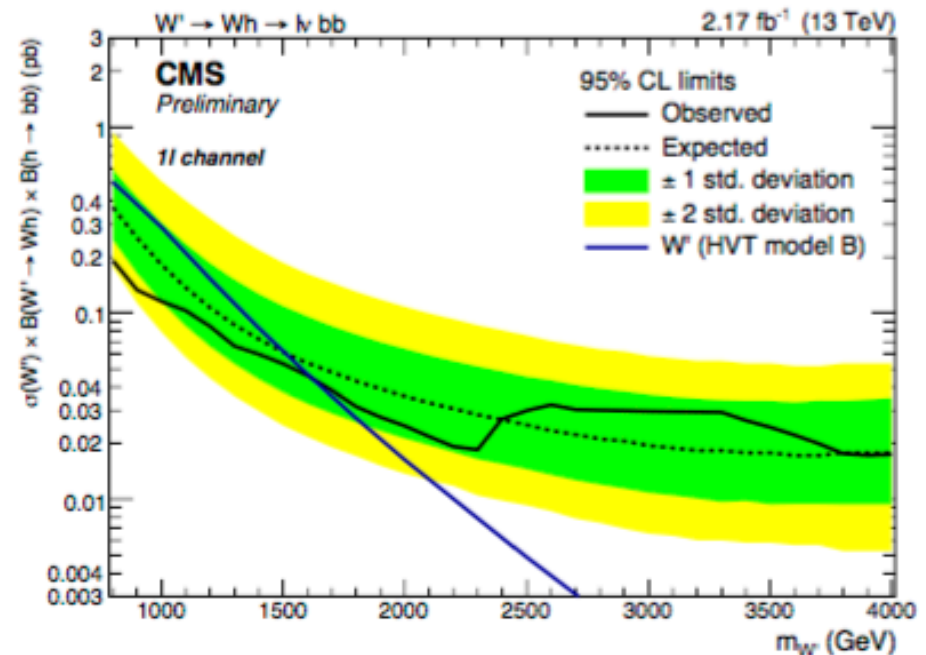
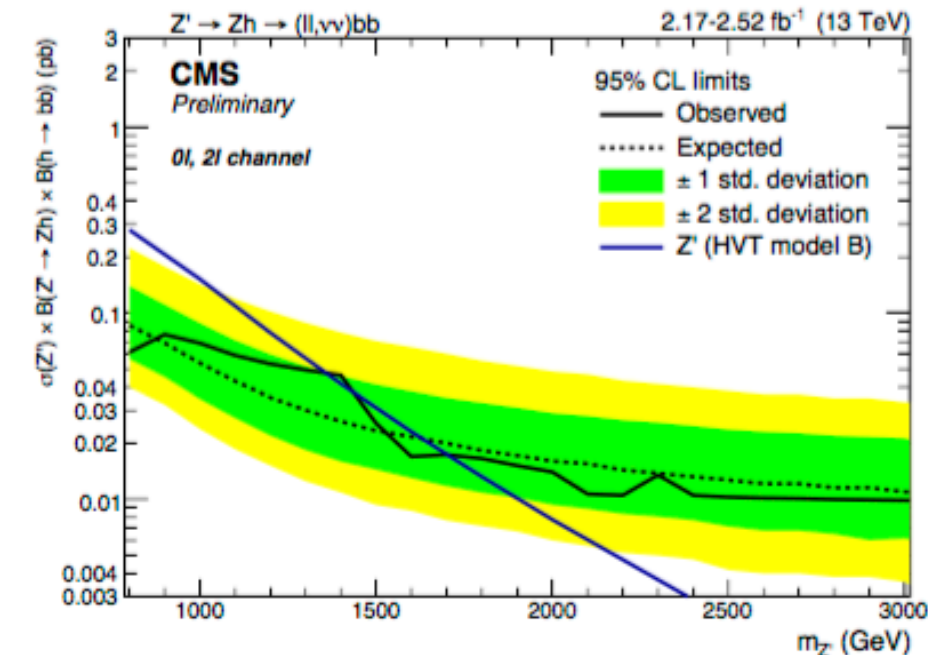
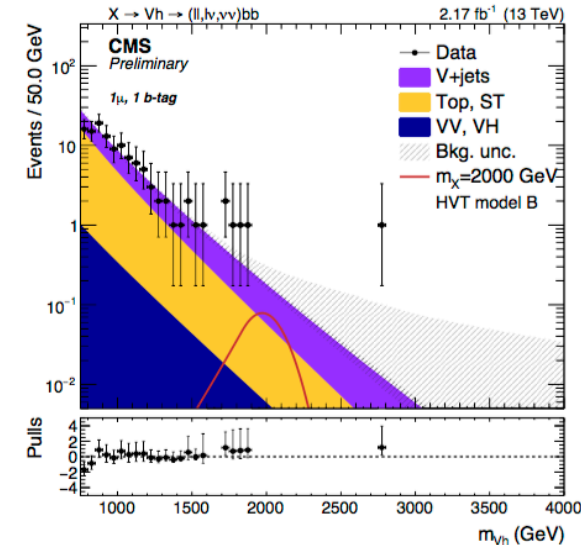
- Total Luminosity:
 - 2.7 fb^{-1} @ 13 TeV(2015)
- Final state:
 - $X \rightarrow ZV \rightarrow \ell\ell + \text{boost } W/Z$



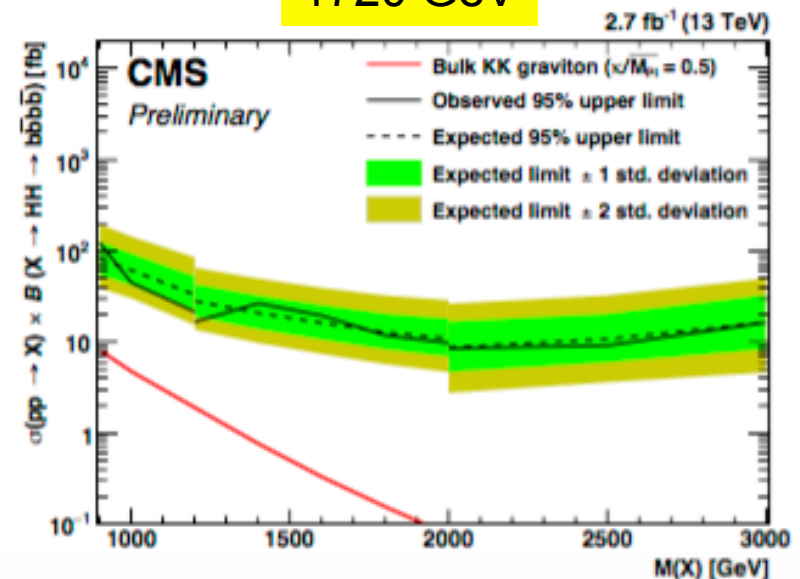
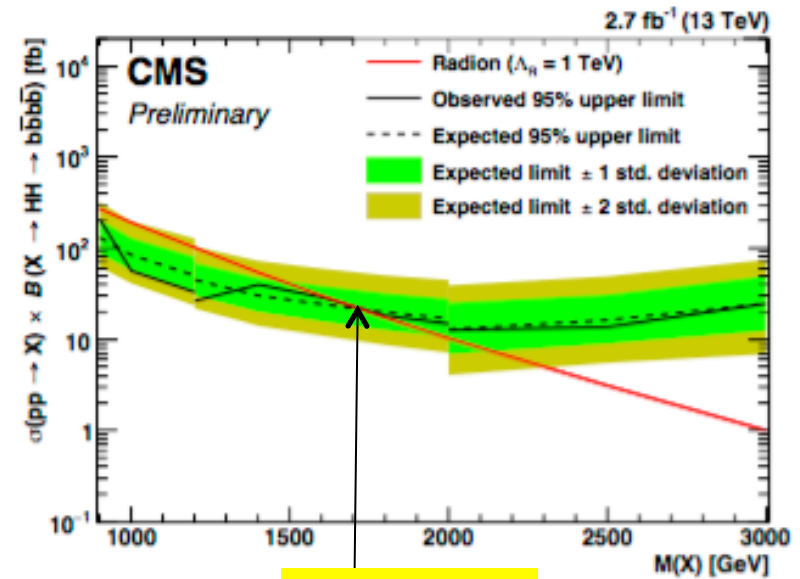
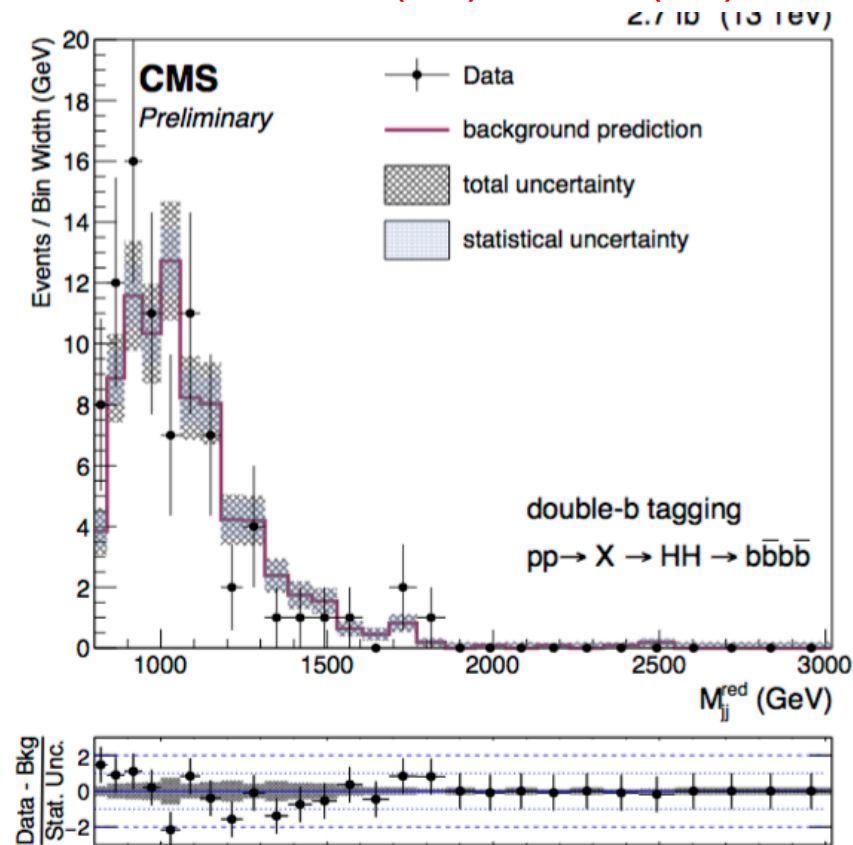
- An excess ~ 650 GeV
 - 3.9/3.5 σ local/global



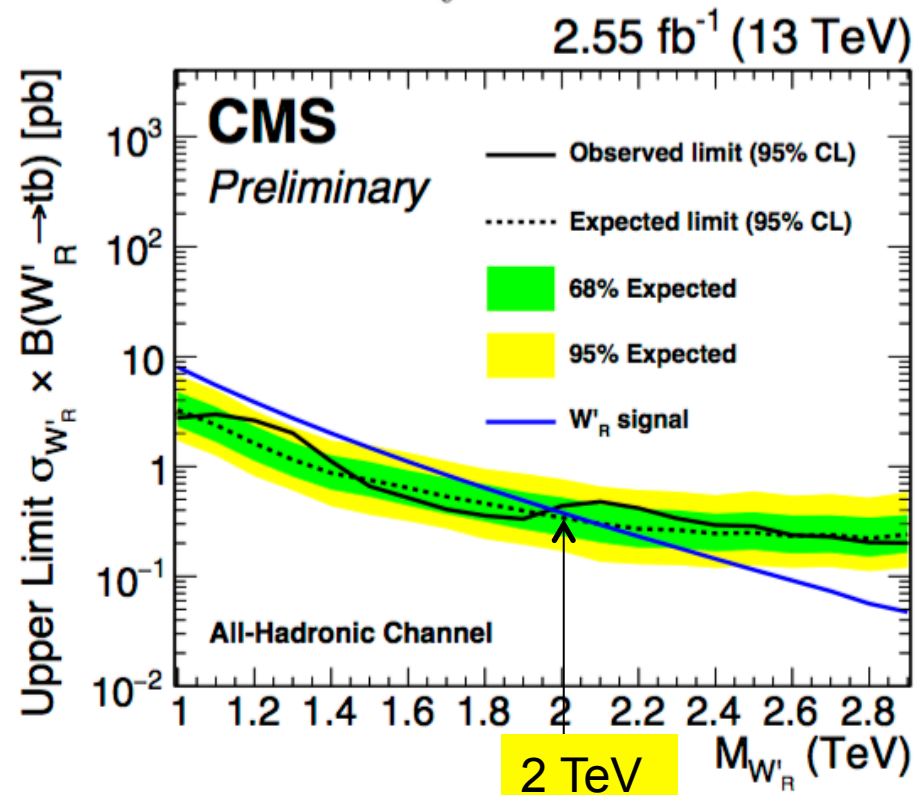
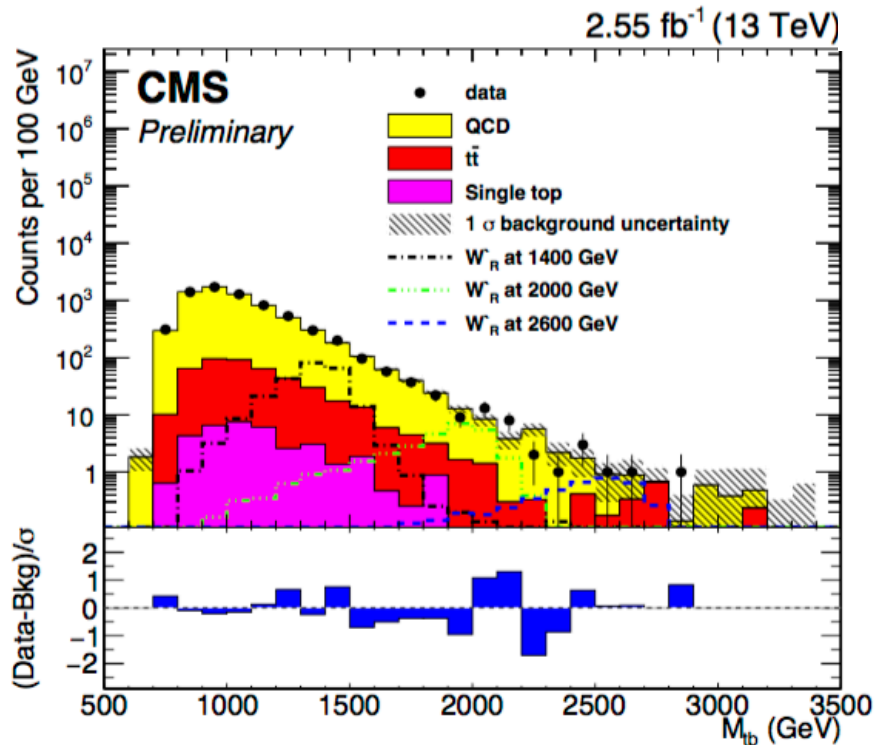
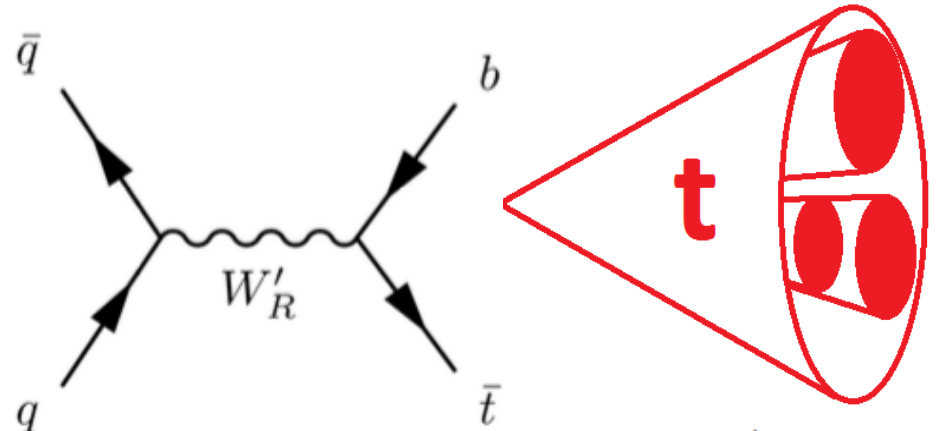
- Total Luminosity:
 - 2.17-2.52 fb⁻¹ @ 13 TeV (2015)
- Final state:
 - $X \rightarrow HV \rightarrow \text{boost}(bb) + lv/l\bar{v}/v\bar{v}$
- Categorize events with
 - Lepton flavor/number and b-tagged sub jets



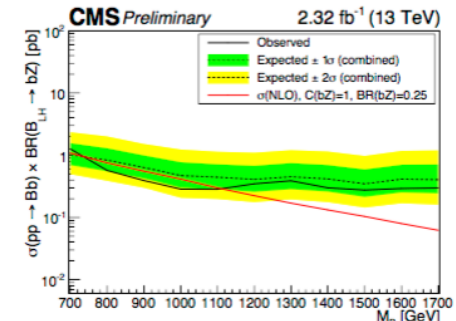
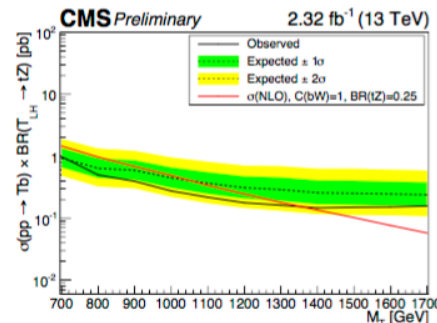
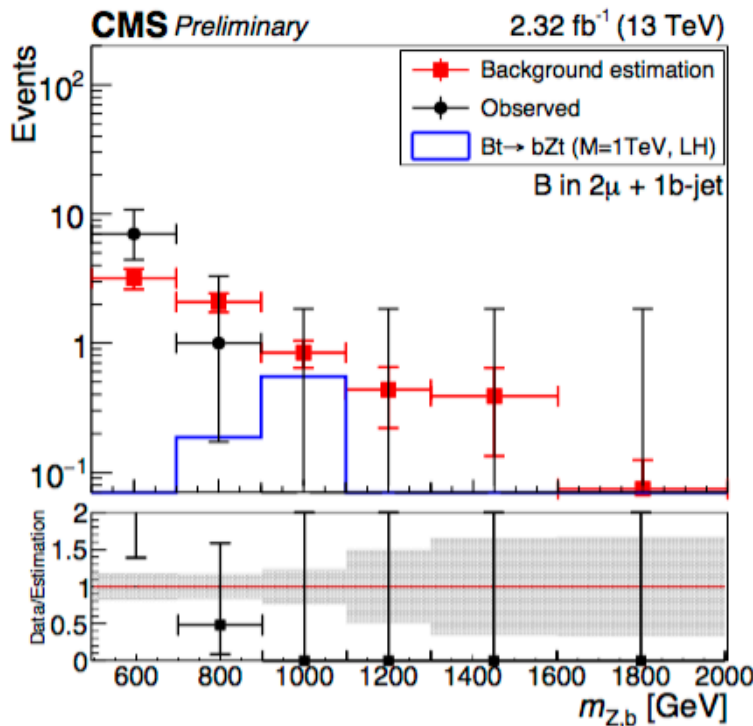
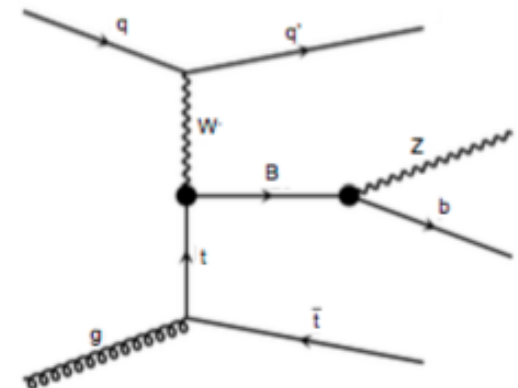
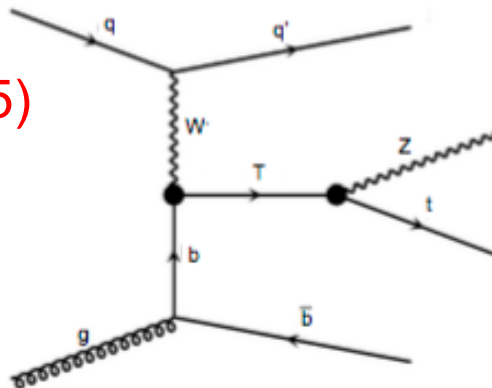
- Total Luminosity:
 - 2.7 fb^{-1} @ 13 TeV (2015)
- Final state:
 - $X \rightarrow HH \rightarrow \text{boost}(bb) + \text{boost}(bb)$



- Total Luminosity:
 - 2.55 fb⁻¹ @ 13 TeV (2015)
- Final state:
 - W' → boost top + b

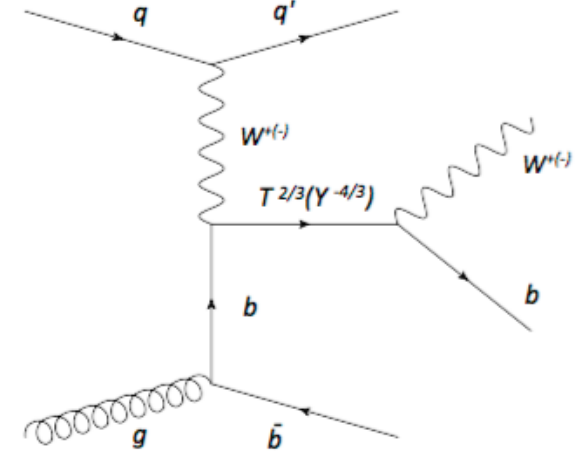


- Total Luminosity:
 - 2.32 fb^{-1} @ 13 TeV (2015)
- Single VLQ production
- Final state:
 - Boost $t + \ell + b + J$

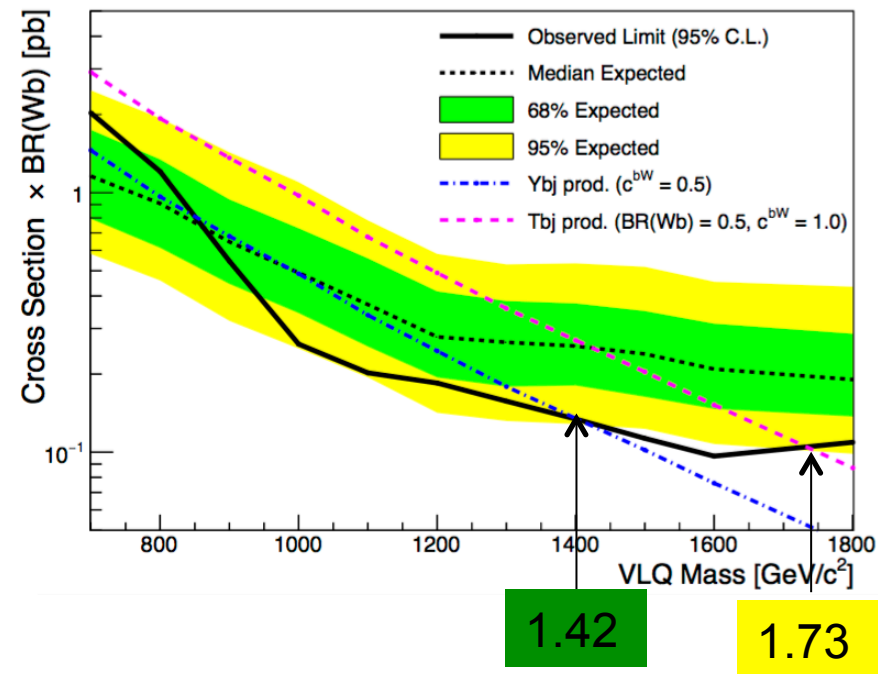
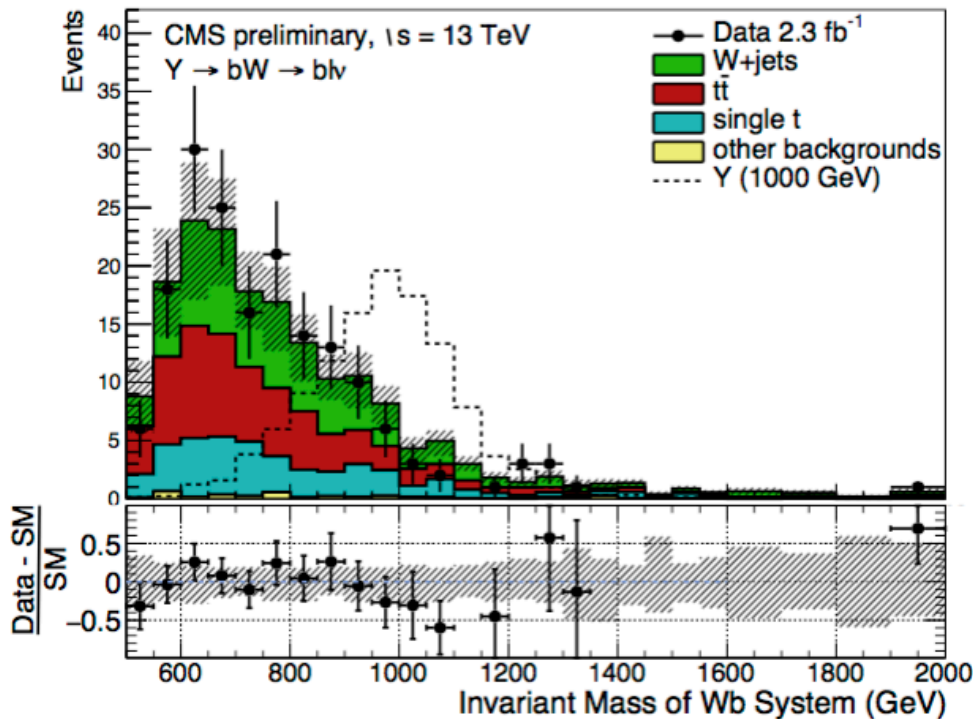


- For unit b-asso. Couplings
 - Exclude $T < 1350 \text{ GeV}$
 - Exclude $B < 1120 \text{ GeV}$
- First $Z' \rightarrow \text{VLQ}$ result @ CMS
 - Probe $1.5 < M_{Z'} < 2.5 \text{ TeV}$

- Total Luminosity:
 - 2.3 fb^{-1} @ 13 TeV (2015)
- Single VLQ production
- Final state:
 - Boost $W + b + 2 J$

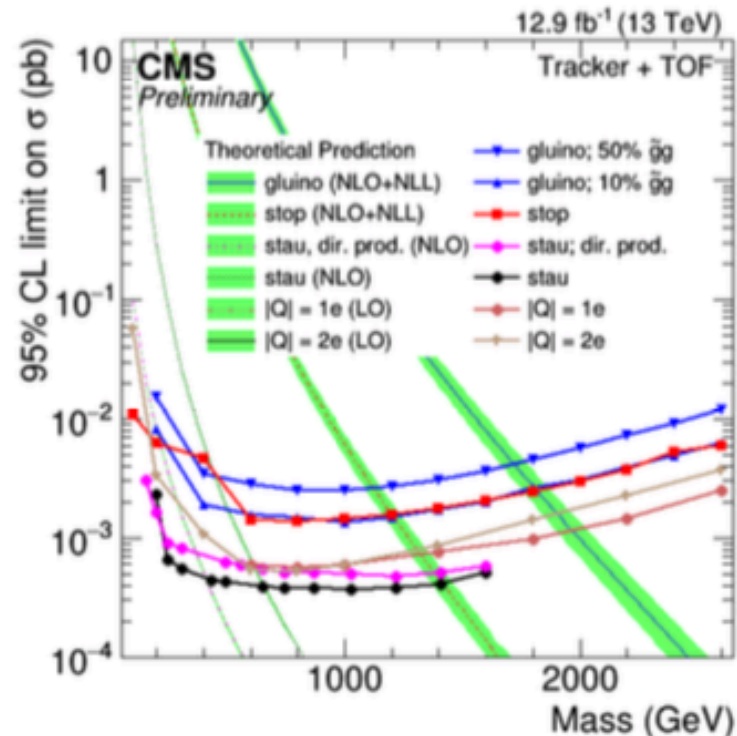
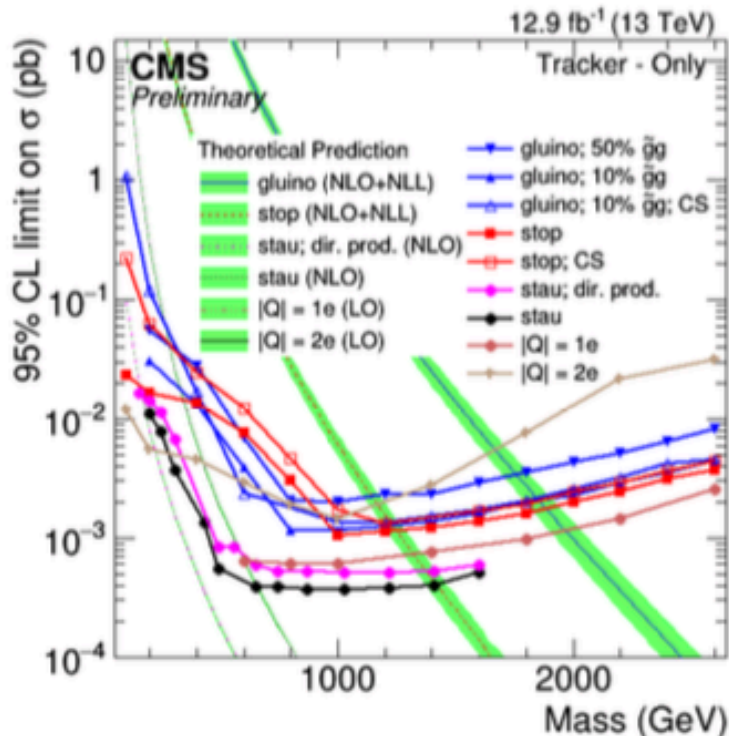
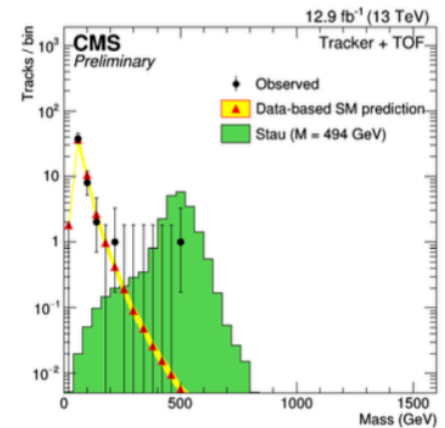
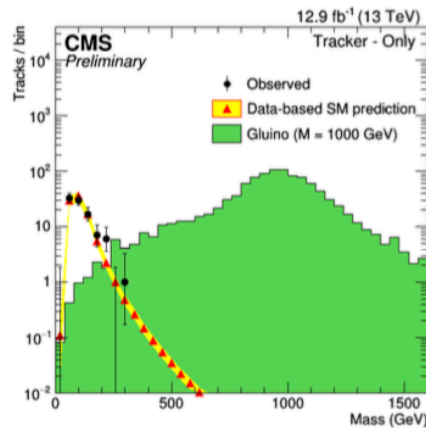


CMS Preliminary, 2.3 fb^{-1} (13 TeV)

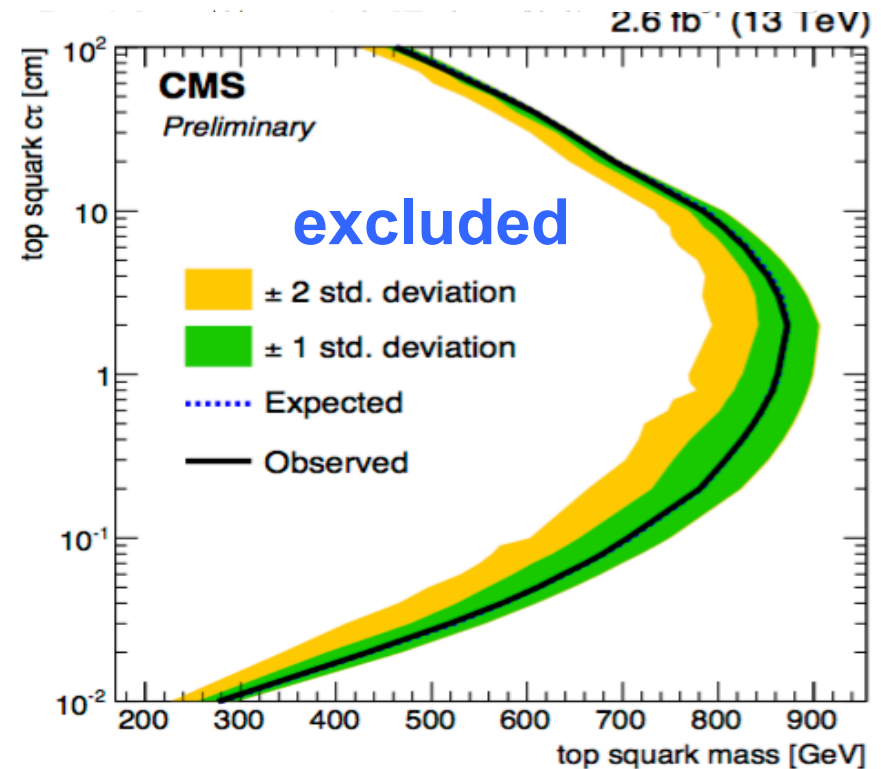
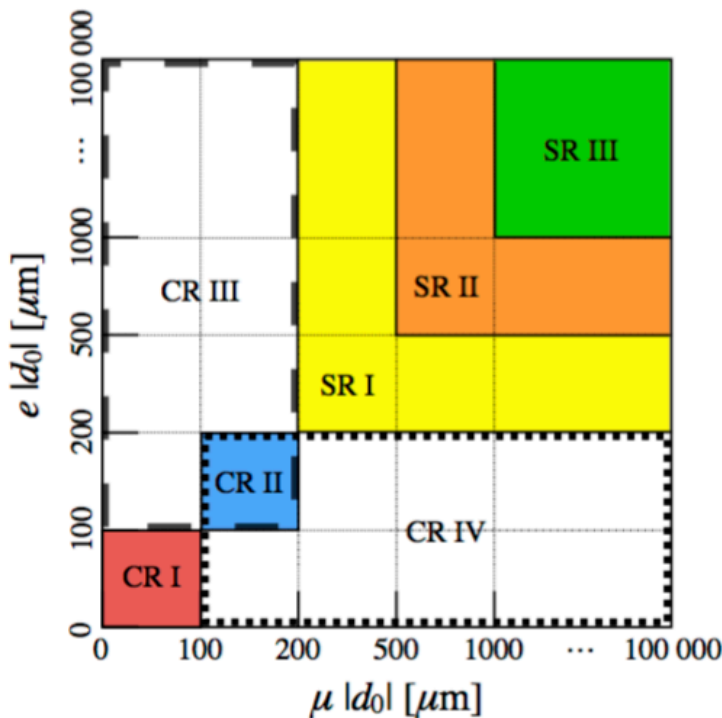
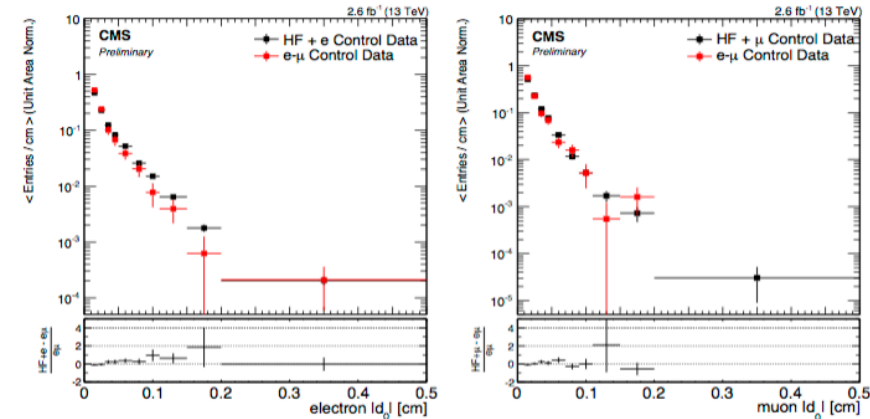


Exotics Searches with other signatures

- Total Luminosity:
 - 12.9 fb^{-1} @ 13 TeV (2016)
- Final state:
 - Heavy stable Charge tracks ($p_t > 55 \text{ GeV}$)
 - Select based on dE/dx and TOF



- Total Luminosity:
 - 2.6 fb^{-1} @ 13 TeV (2016)
- Final state:
 - Opposite charge $e+\mu$ with large impact parameter



- Searching for new physics in lots of final states
 - $\gamma/e/\mu/\tau/\text{jets}/\text{MET}$
 - Boosted W/Z/H/top
 - Displaced signature
 - ...
- **No new physics** found (Yet)
- Sensitivity of new physics searches largely extended with 2016 data @ 13 TeV
 - Thanks to the excellent LHC and CMS operations
- More data coming on the way
 - Stay tuned