Searches for New Physics (non-SUSY) with CMS

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On behalf of the CMS collaboration

LHC Ski 2016
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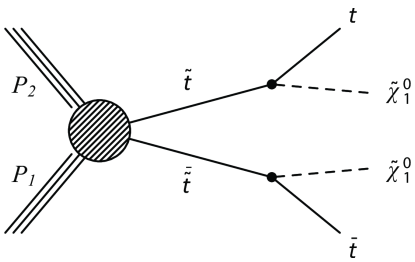
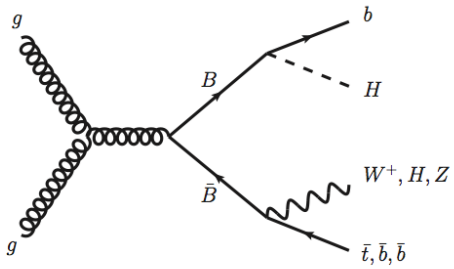
Towards new physics searches

A variety of BSM analyses are conducted at the LHC, targeting various viable models

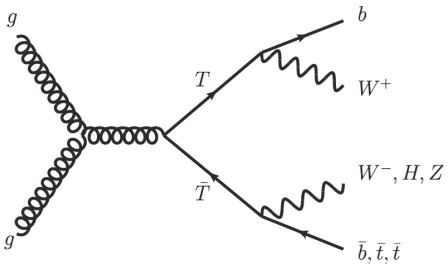
SUSY, Little Higgs, Composite Higgs, Extra-Dimension, Heavy Vector Triplet…



SUSY production



Heavy fermion production



Heavy fermion production

Different assumptions and kinematics of these models make them fully orthogonal or partially overlapped but there is a "somewhat" common interest to preserve "naturalness"

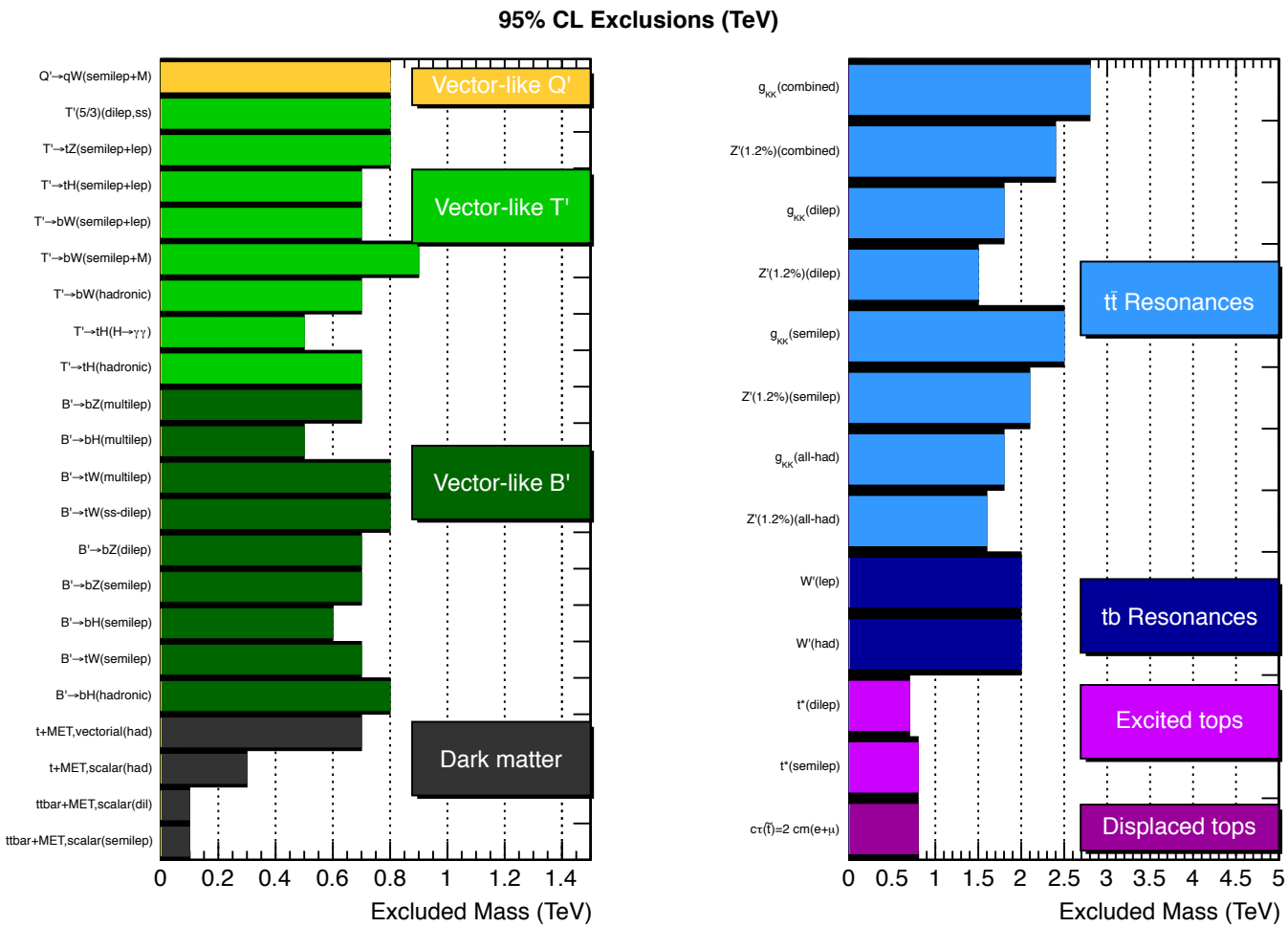
Light Higgs (~125 GeV) plus **Low Tuning** requires **Light (ish) BSM particle(s)**

SUSY searches in Vinc Welke's talk

LHC 13 TeV data is critical to probe these models, discover or constrain

Glance at Run I

Valuable experience was gained from the 8 TeV and 20 fb^{-1} Run I data

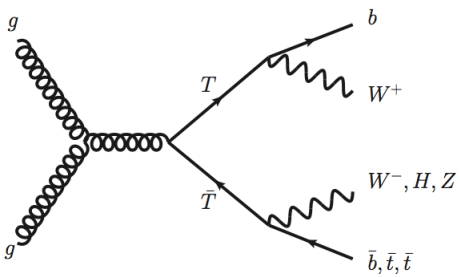


This is not a full list!

Run I sensitivity probed various models around 1 TeV and above, depending on the final states and hypotheses

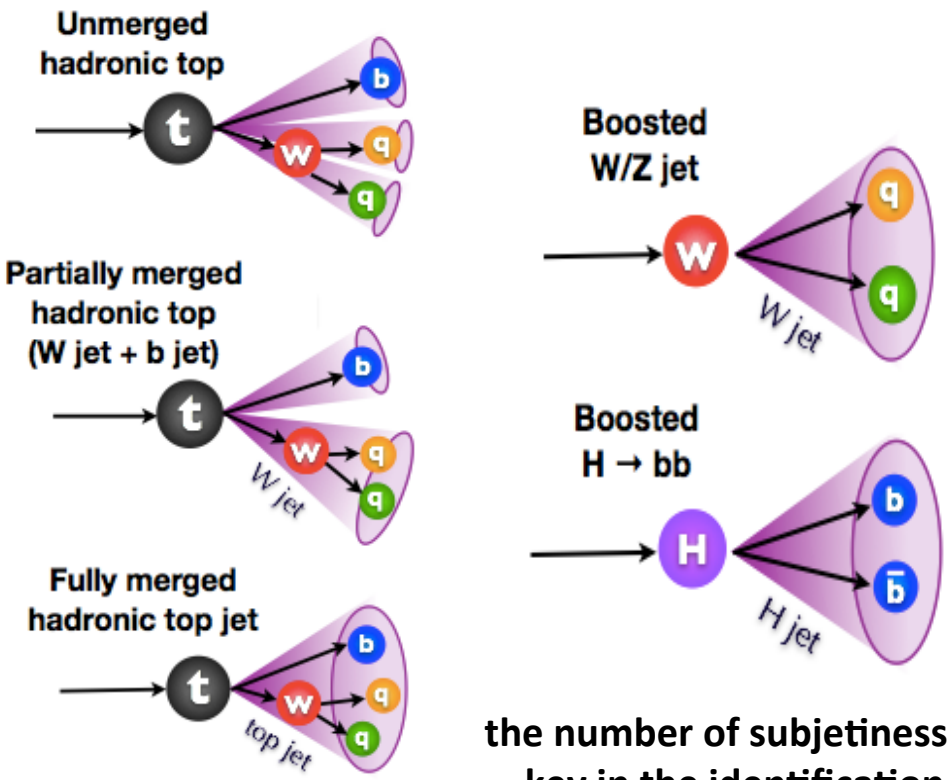
Boosted techniques in non-SUSY searches

- Boosted topologies become critical for high mass searches
- Essential to retain high efficiency for the signal acceptance
- Various algorithms for **W±/Z/H/top** (decaying hadronically)

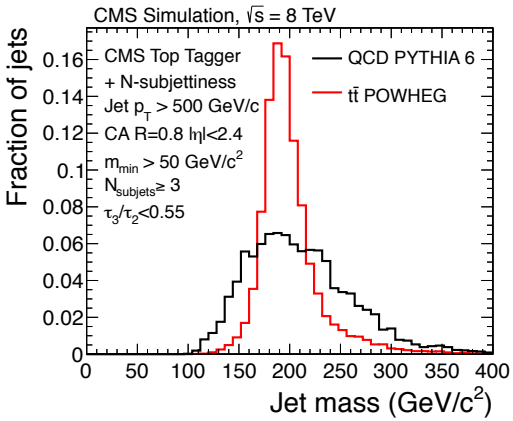


Direct decay into SM particles leads to a significant boost

Illustration of the boosted scenarios



the number of subjetiness is key in the identification



Top/W/Z/H taggers work for a large range of jet P_T

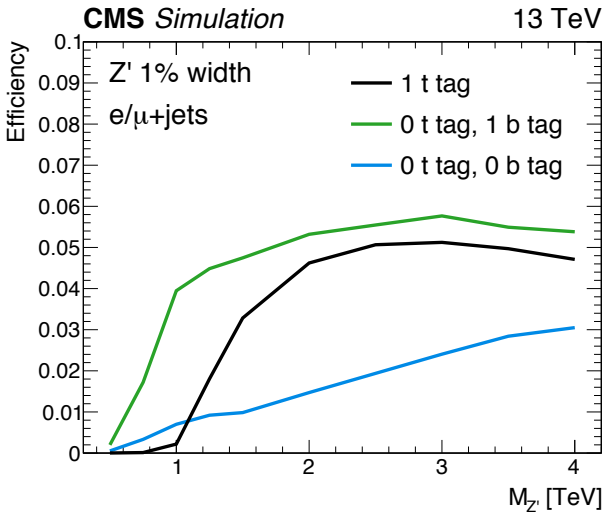
Resonant top pair production

B2G-15-002

- Model independent search for heavy resonance -> ttbar
  (This topology appears in a various models, Z' and KK gluon for example)

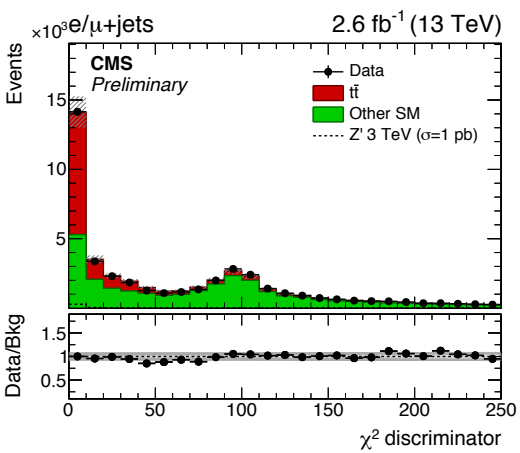
- Analysis targets the semi-leptonic final state
  - single lepton (e/μ)
  - E_T^{miss} signature
  - a number of jets

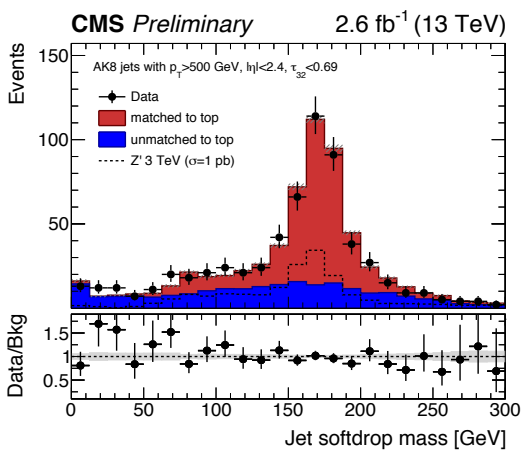
  + top- and b-tagging exclusive selections



- Utilize X^2 discriminator for leptonic and hadronic top pairs

$$\chi^2 = \left(\frac{M_{lep} - \overline{M}_{lep}}{\sigma_{M_{lep}}}\right)^2 + \left(\frac{M_{had} - \overline{M}_{had}}{\sigma_{M_{had}}}\right)^2,$$

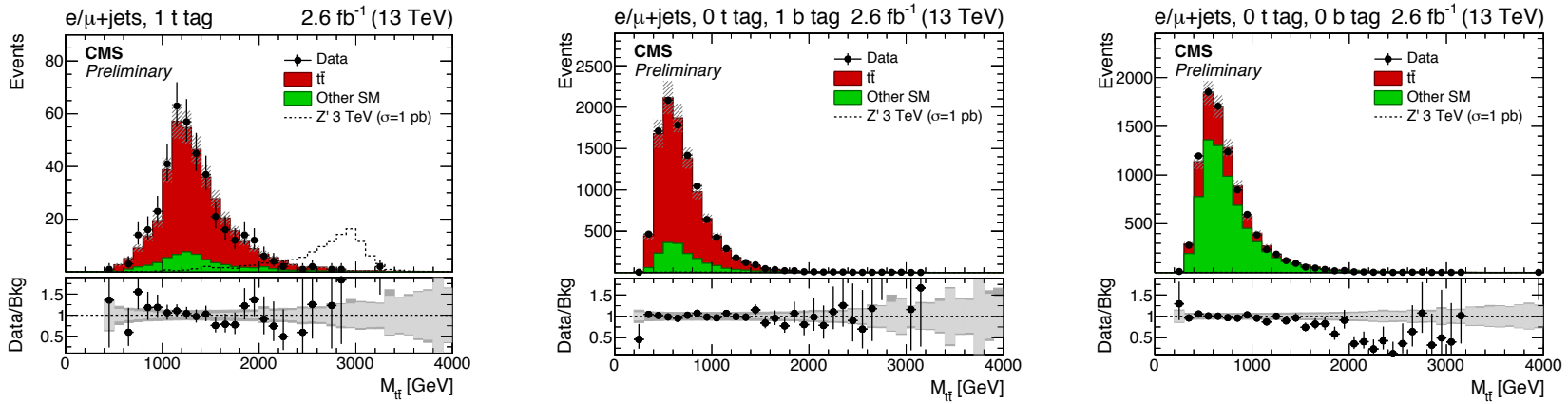


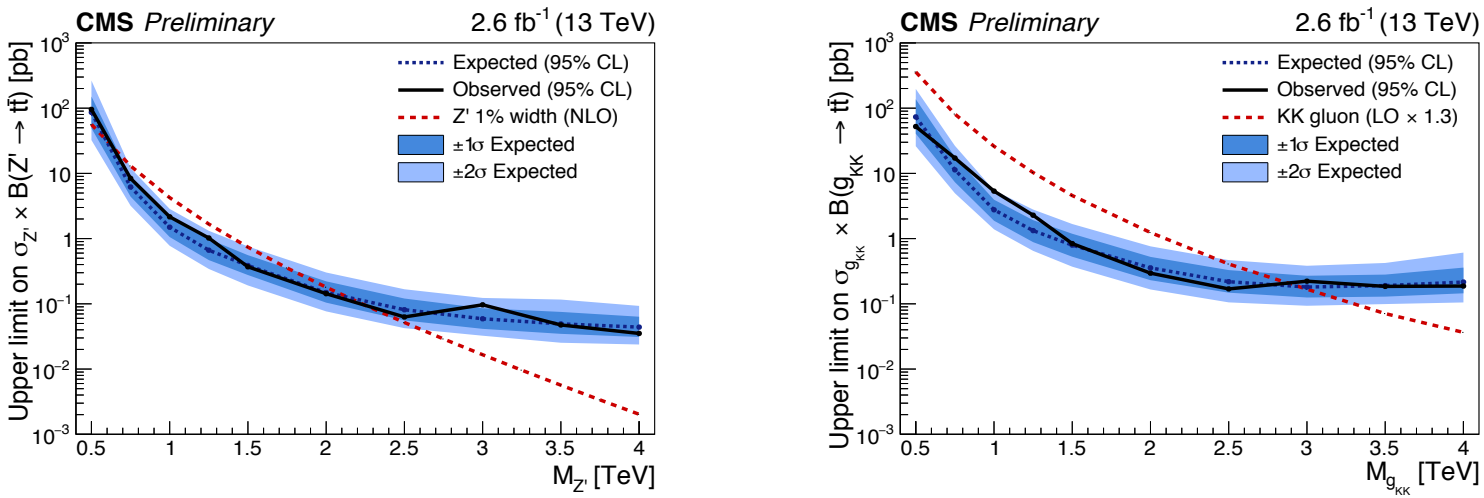


Resonant top pair production

B2G-15-002

- The final result is obtained using the maximum-likelihood fit to the data, the shapes derived from various control regions





Z' width matters

Results are interpreted for KK and Z' scenarios

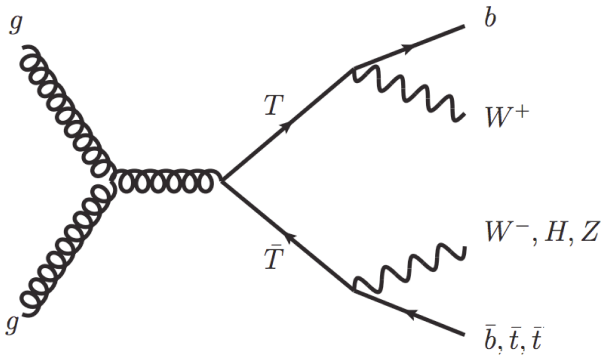
Very similar sensitivity as in Run I

VLQ $T_{2/3}$ pair production

B2G-16-002

- Generic search for the pair production of $T_{2/3}$
  - $T_{2/3}$ can decay in three modes

    T -> Wb, tH or tZ

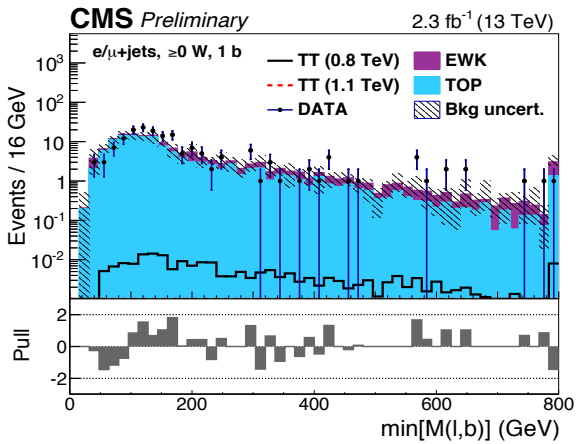


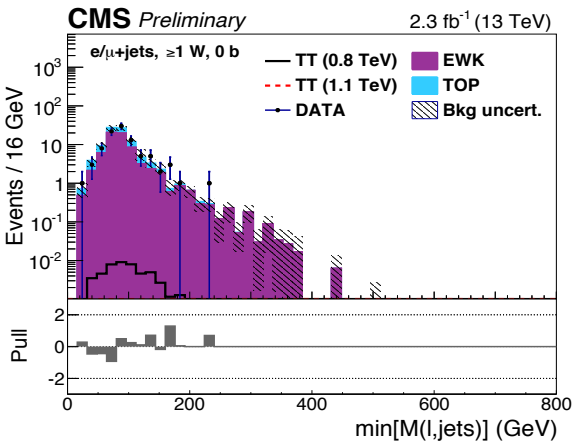
- Analysis utilizes the single lepton (e/μ) + a number of jets + E_T^{miss} signature

- Sensitivity is enhanced by splitting the sample into
  - b-tag jet multiplicity requirement (0, 1, 2,3)
  - W-tag requirement (0 or above)

Baseline BRs
Wb(50%):tH(25%):tZ(25%)

- Background estimated from the simulation, checked in dedicated control regions



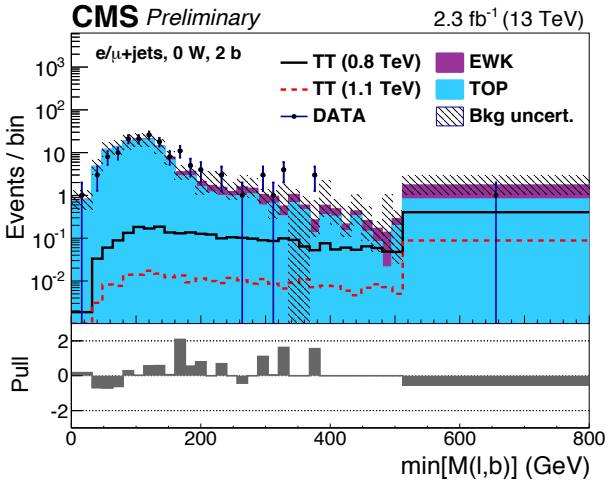


VLQ $T_{2/3}$ pair production

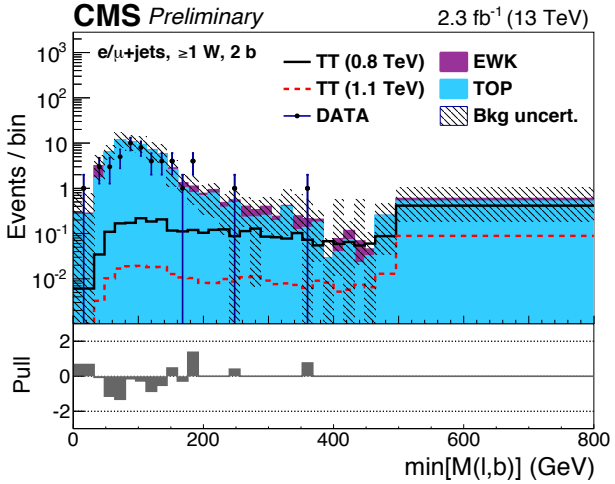
B2G-16-002

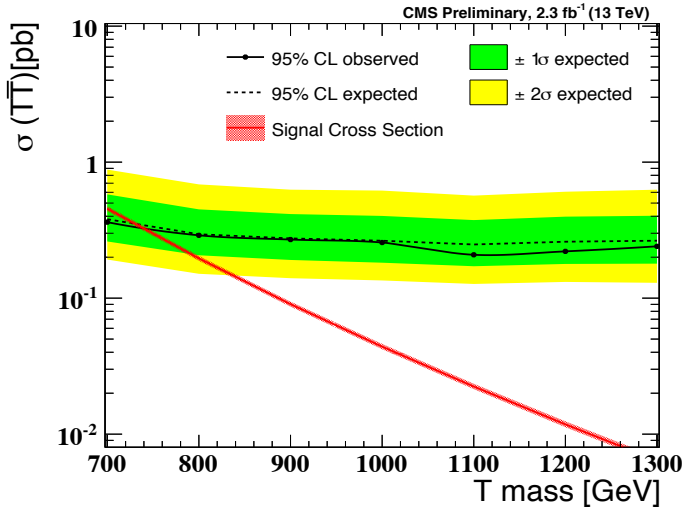
- Minimum mass(lepton, b-tag) is a powerful variable in this busy environment

0 W-tagged signal region



≥ 1 W-tagged signal region





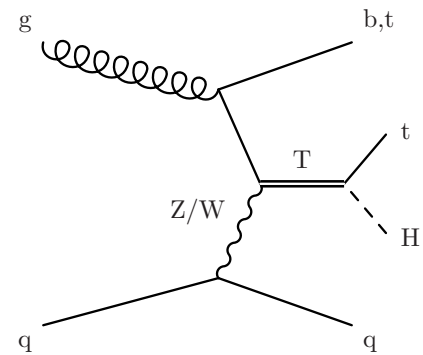
- A combination of these exclusive search regions are performed for the final result
- Analysis sensitivity probes $T_{2/3}$ up to 750 GeV

Improved result w.r.t Run I: 750 vs 696 GeV

VLQ $T_{2/3}$ single production

B2G-15-008

- Single production of $T_{2/3}$ (first CMS result)
  - Handedness (right/left)
  - Coupling dependent cross-section
  - Various production mechanisms

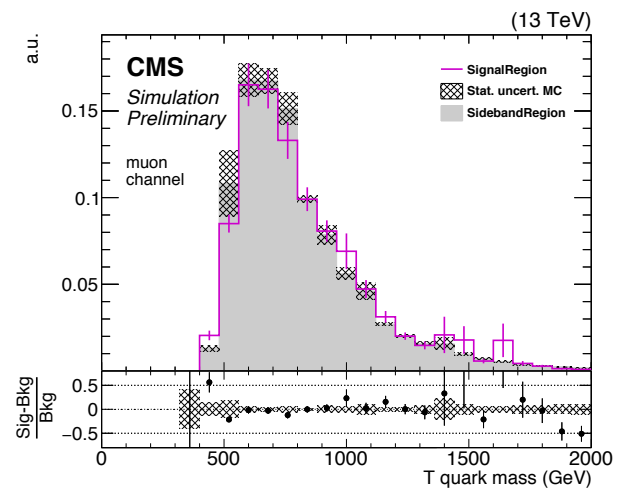


Forward jet becomes distinct to the single production

- Search is performed with the single lepton (e/μ) + forward jet + boosted Higgs tagging requirement
- Additional kinematic selections for back-to-back topologies
- The search is resonance-type with the invariant mass selected through a χ^2 fit

$$\chi^2 = \left(\frac{M_{\mathrm{H,MC}} - M_{\mathrm{H,rec}}}{\sigma_{\mathrm{M_H,MC}}}\right)^2 + \left(\frac{M_{\mathrm{t,MC}} - M_{\mathrm{t,rec}}}{\sigma_{\mathrm{M_t,MC}}}\right)^2 + \left(\frac{\Delta R(\mathrm{t,H})_{\mathrm{MC}} - \Delta R(\mathrm{t,H})_{\mathrm{rec}}}{\sigma_{\Delta R,\mathrm{MC}}}\right)^2$$

- The data driven bkg estimation from the sideband region
  - No forward jet
  - One b-tagged subjet in Higgs

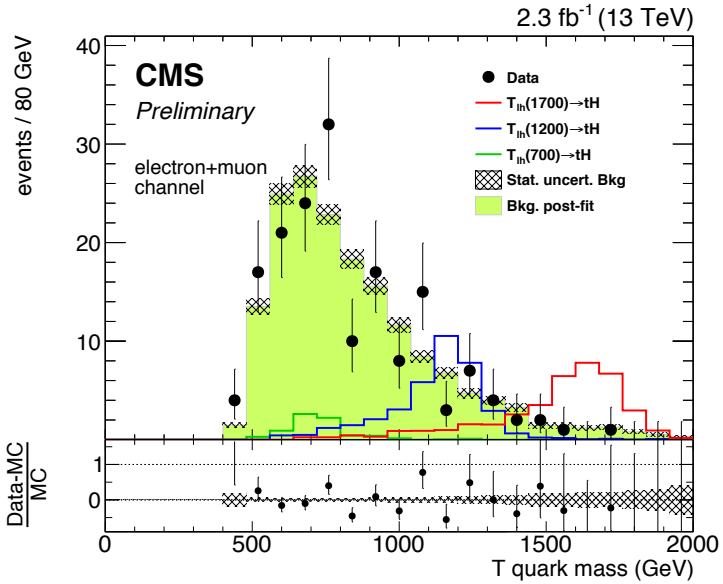


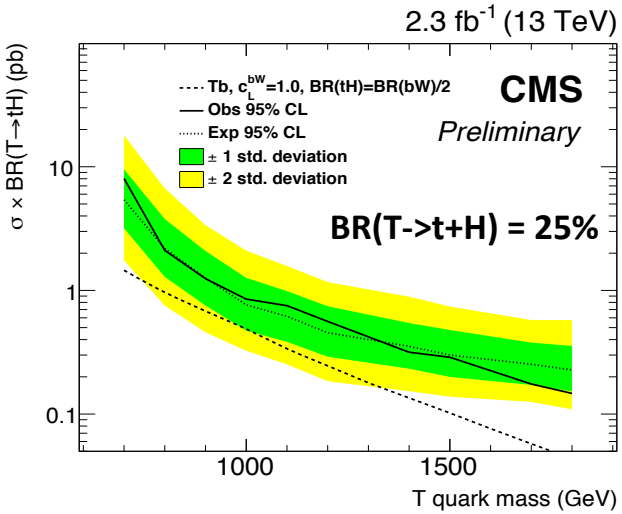
VLQ $T_{2/3}$ single production

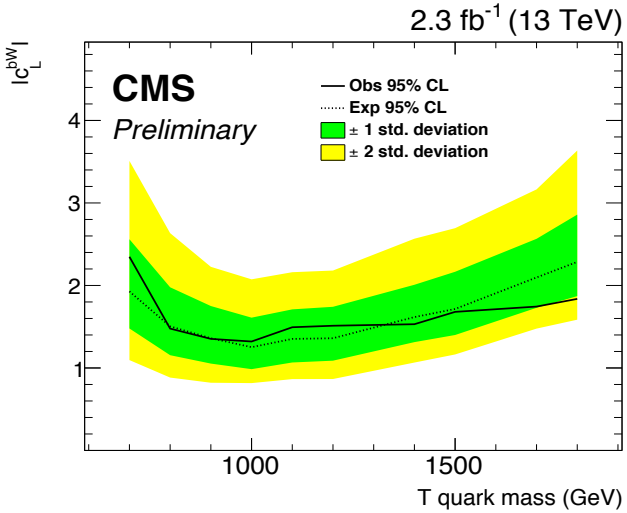
B2G-15-008

- Handedness influences the kinematics
  - Separate results for Right and left handedness
- Final result is obtained from the fit to data under the background only hypothesis, bkg shapes are taken from the sideband

First ever result for the coupling at 13 TeV





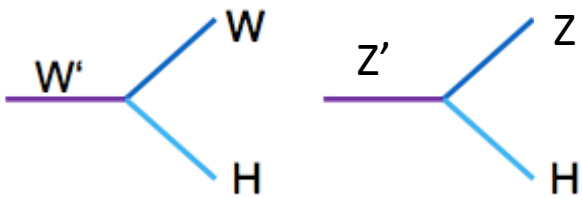


Results for left-handed coupling (right-handed result in backup)

Di-boson searches

B2G-16-003

- Heavy W' and Z' production with narrow width (Generalized model within "Heavy Vector Triplet")



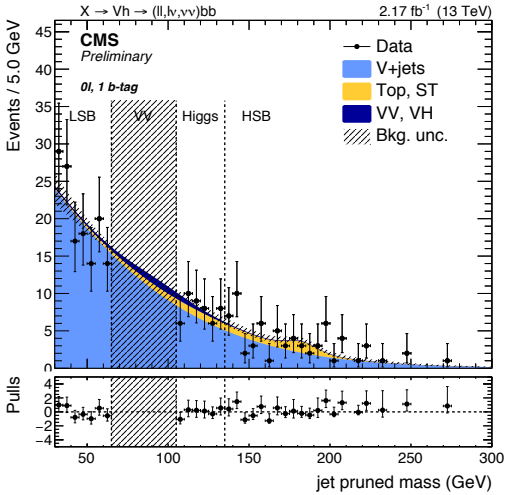
Width of Z'/W' is 0.1% of their masses

- Search is performed with a variety of final states

  Z -> ν + ν
  Z-> di-lepton
  W-> l + ν
  } + Boosted Higgs tag

- The main bkg exhibits the "fake" Higgs tagged jet, which is estimated from the jet mass sidebands

- Other backgrounds (ttbar, top) normalization obtained from dedicated control regions

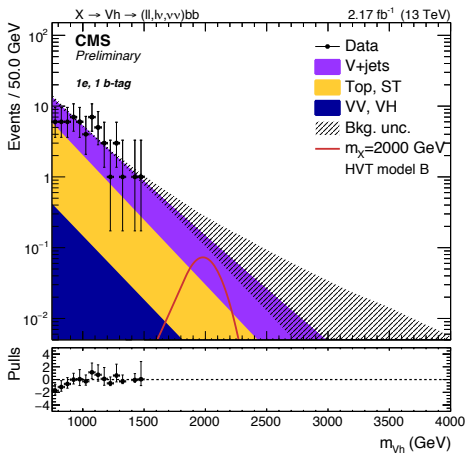


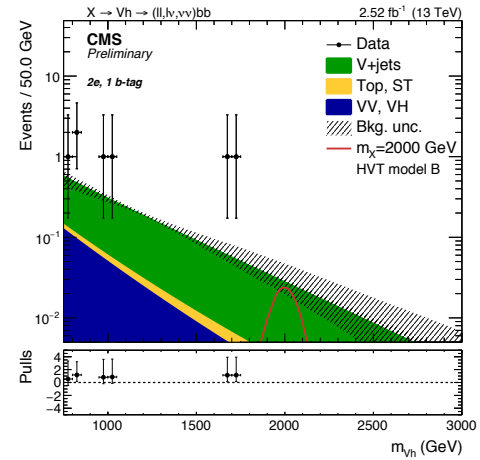
Regular jet can "fake" Higgs tag

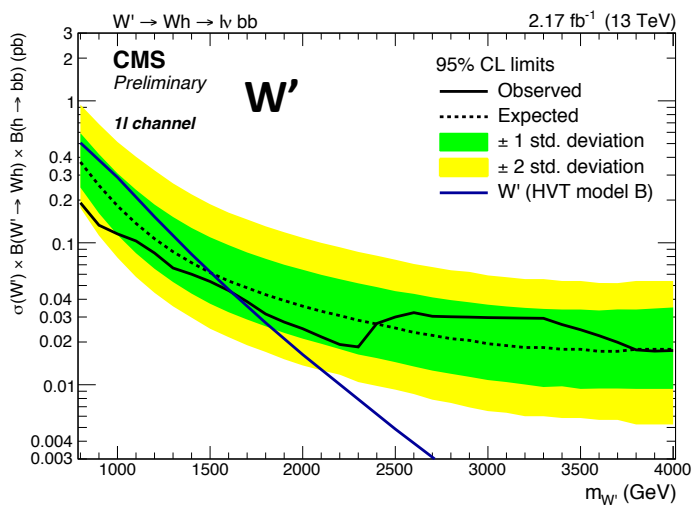
Di-boson searches

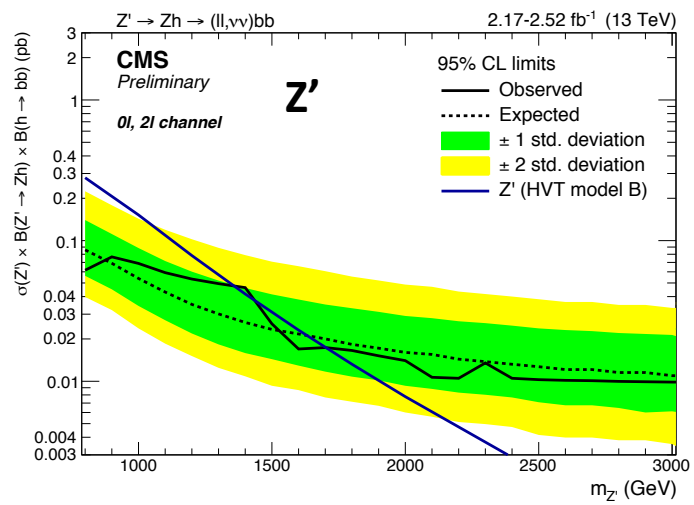
B2G-16-003

- The final mass peak ($M_{W'}$ or $M_{Z'}$) is determined in the functional form after the fit to data







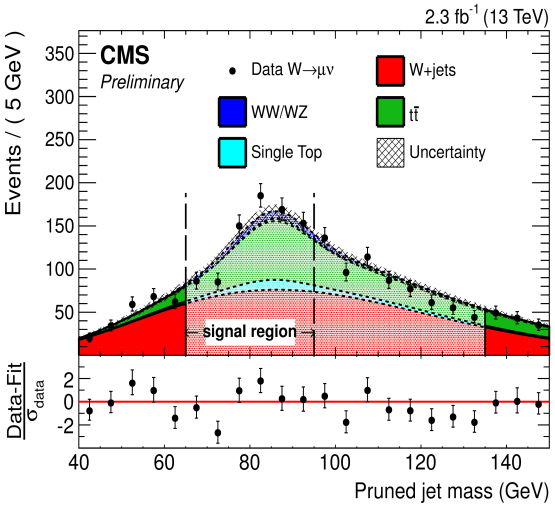


The upper limit on the cross-section x BR ranges 10 – 200 fb

Di-boson searches with low mass extension

B2G-16-004

- Di-boson production via the bulk graviton (Warped Extra Dimension) (extended to low masses region where the ATLAS&CMS see some excess)
- Search is performed with a lepton, E_T^{miss} and W-tagged jet in 0 b-tag region
- Analysis is orthogonal to WH/ZH/HH resonance searches
  - Tighter W mass window 65-95 GeV
- The main bkg W+Jet faking the W-tag is estimated from the jet mass sideband ($Jet_M < 65$ & $Jet_M > 95$ GeV)
- Other backgrounds (ttbar) normalization obtained from dedicated control regions



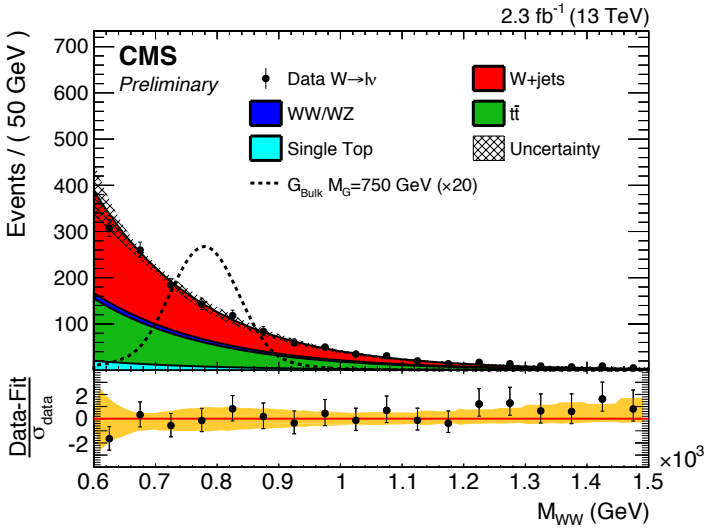
Di-boson searches with low mass extension

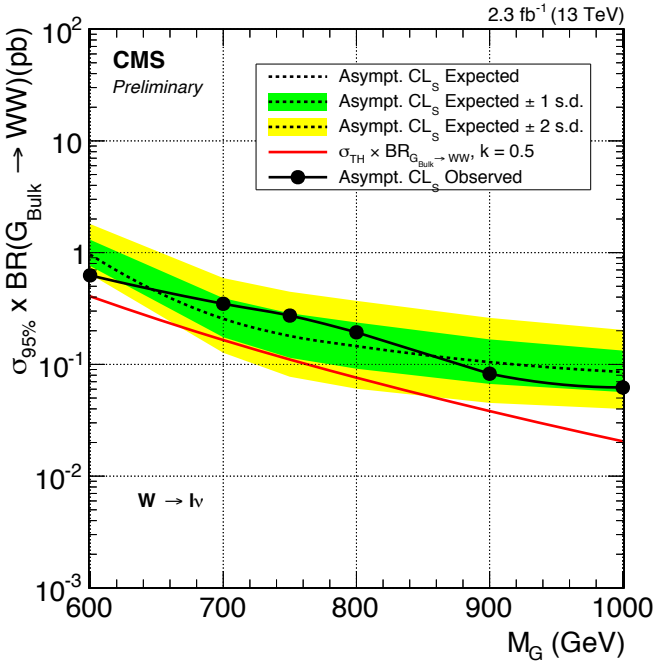
B2G-16-004

- Resonance search is performed using the W^+W^- peak

$$\alpha_{MC}(m_{WW}) = \frac{F^{W+jets}_{MC,SR}(m_{WW})}{F^{W+jets}_{MC,SB}(m_{WW})},$$

W+jet shape is modeled via the transfer factor from the sideband





Limits on the cross-section ranges from 623 to 63 fb

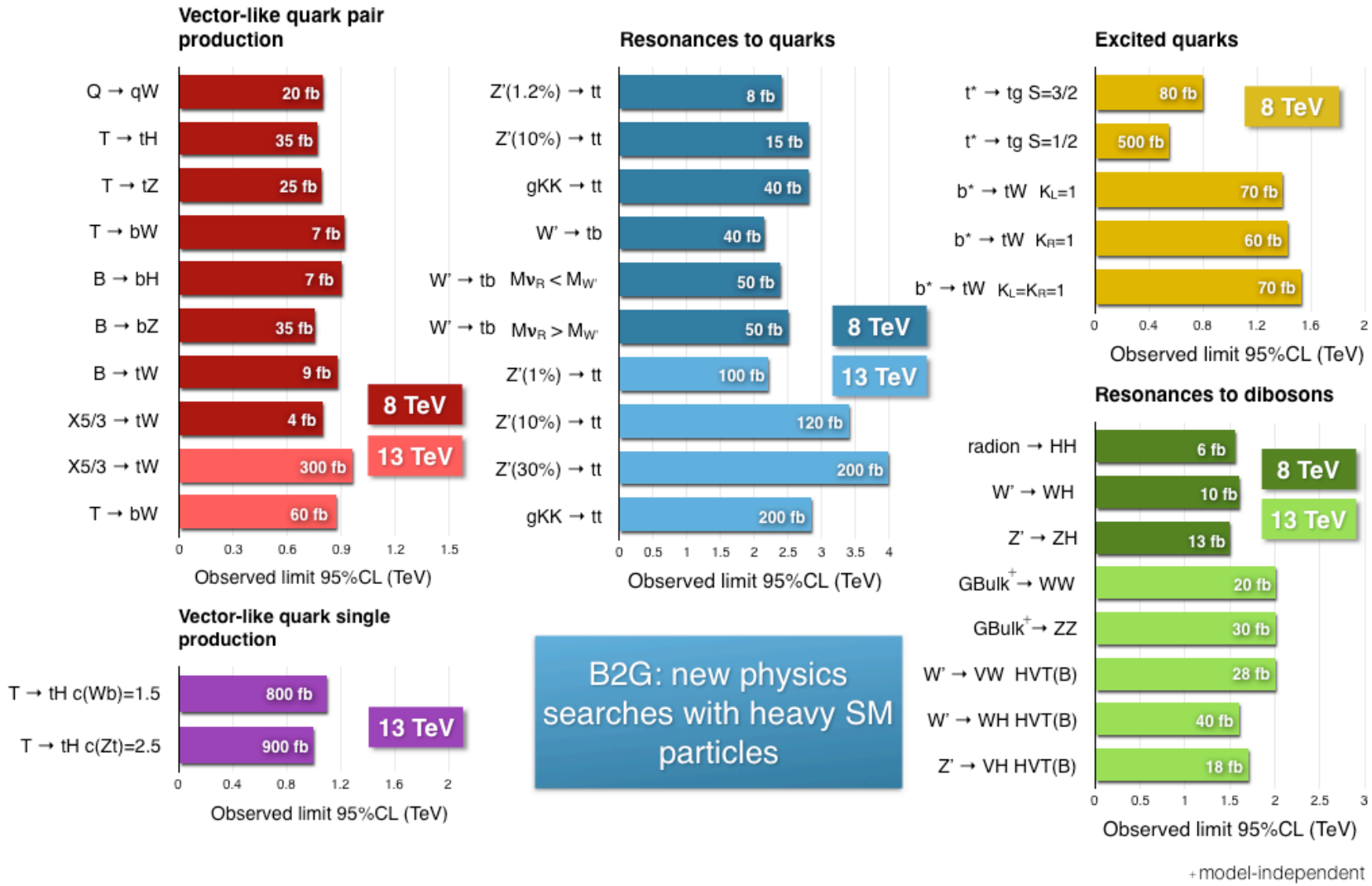
This final state yields the most stringent result for the gluon induced fusion signals

Summary

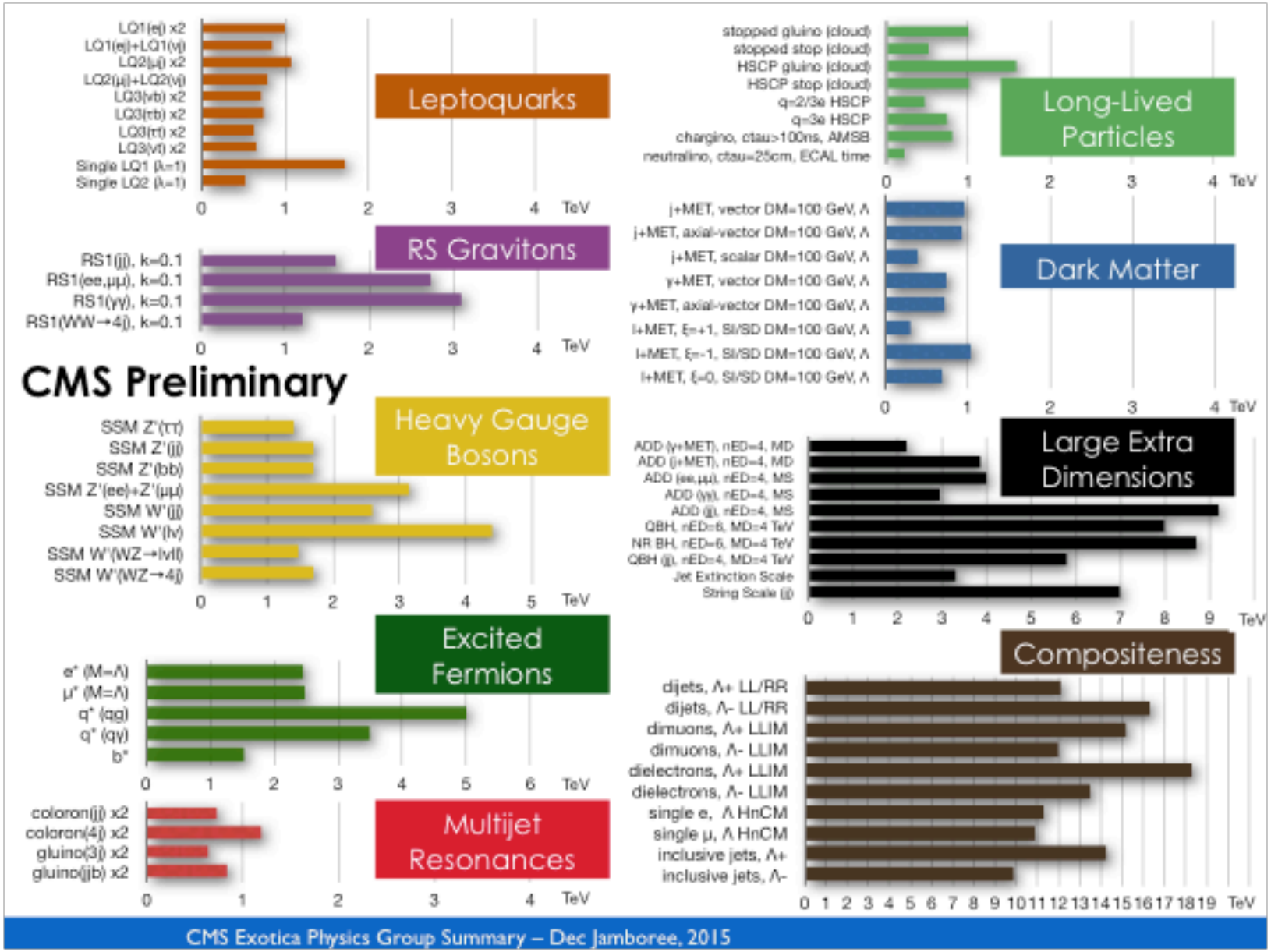
- A large number of models/scenarios are being probed by the CMS collaboration with Run II data
- Some analyses have reached or overpassed the Run I sensitivity with a small chunk of data (2.3 fb^{-1}) at 13 TeV
- Searches for resonances and heavy fermions show no excesses with this small data
- New approaches/models are being actively pursued by the groups

Backup

Glance at Run II Preliminary Results

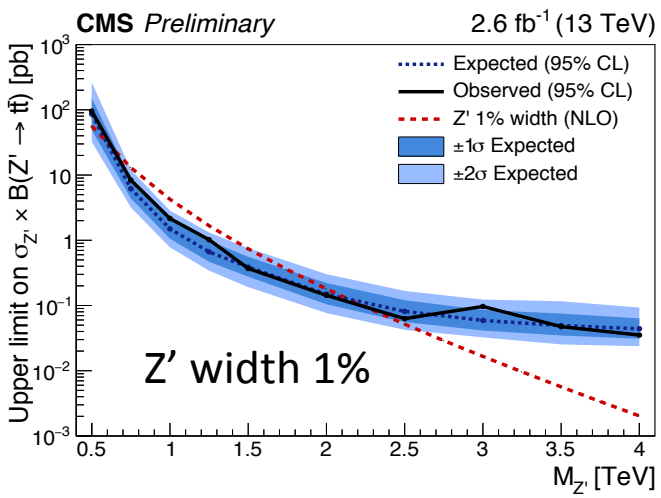


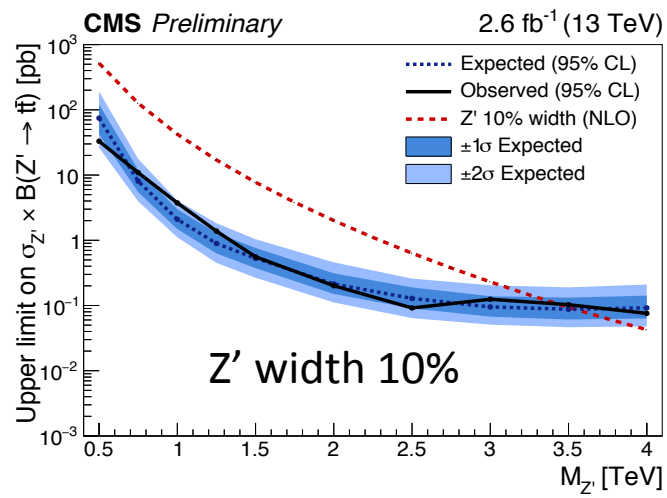
Glance at Run II Prelimenary Results

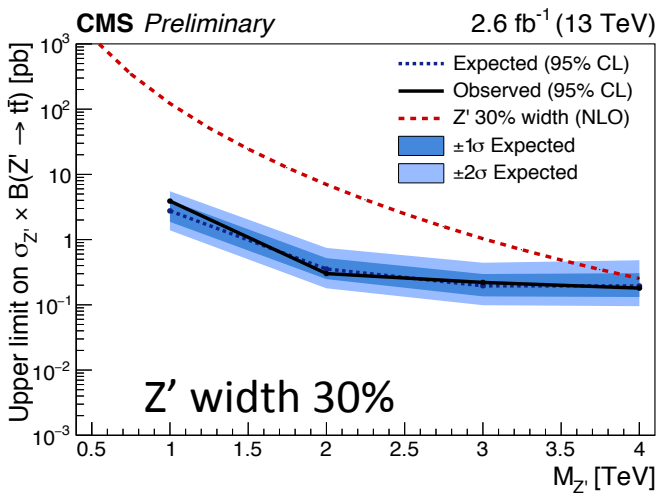


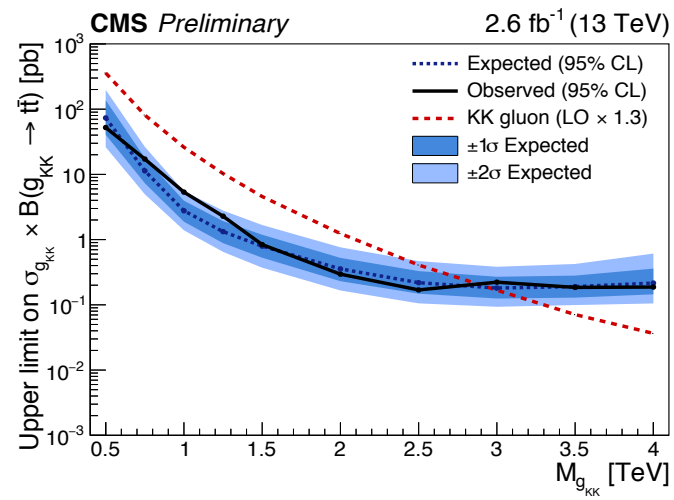
Top pair production

B2G-15-002





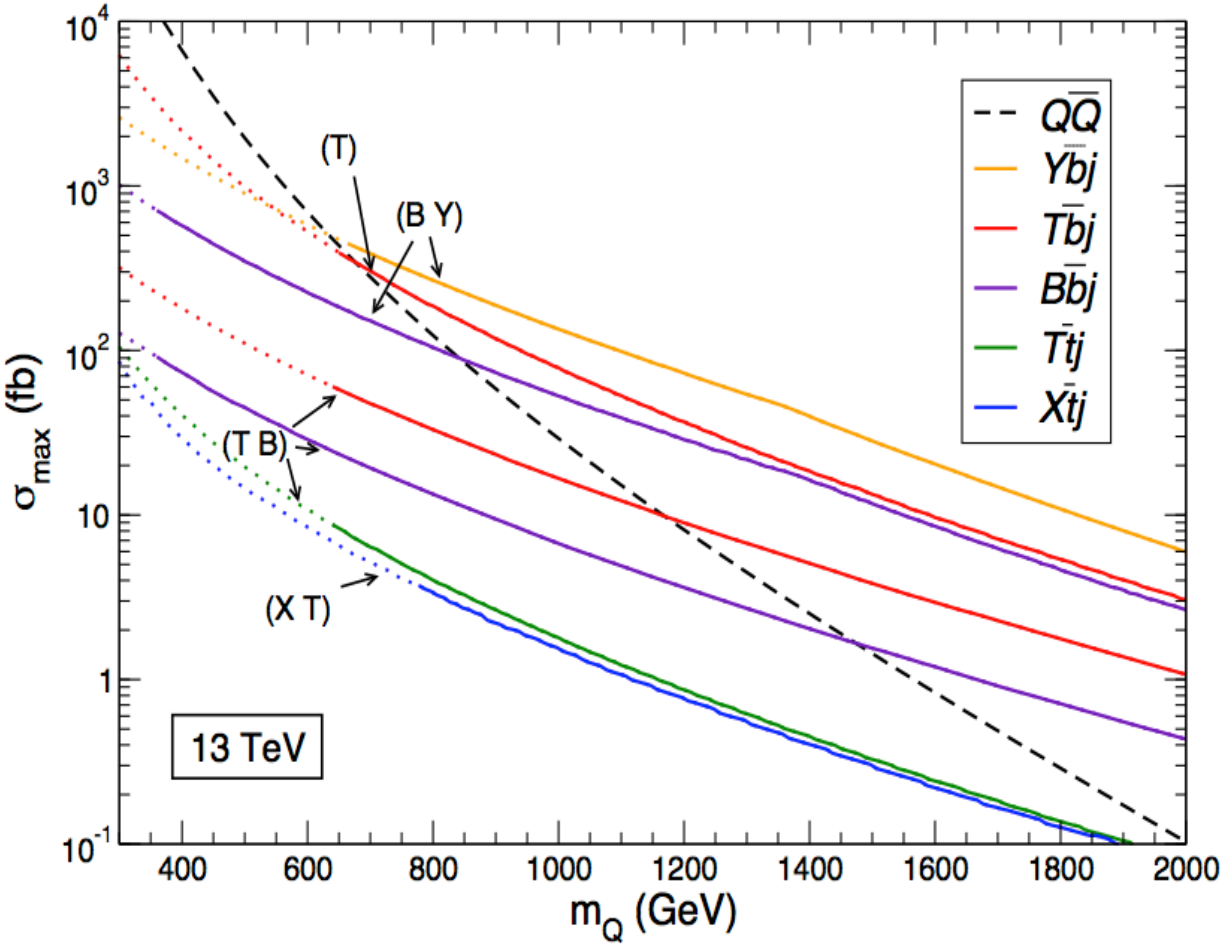




Results are interpreted for KK and Z' scenarios

VLQ production cross-sections

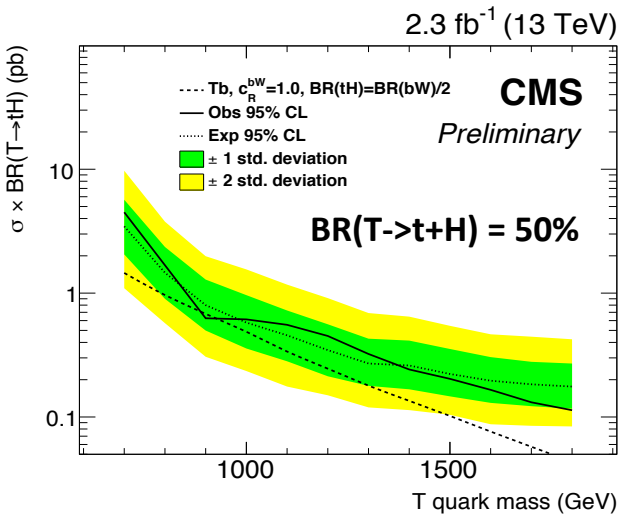
arXiv:1306.0572

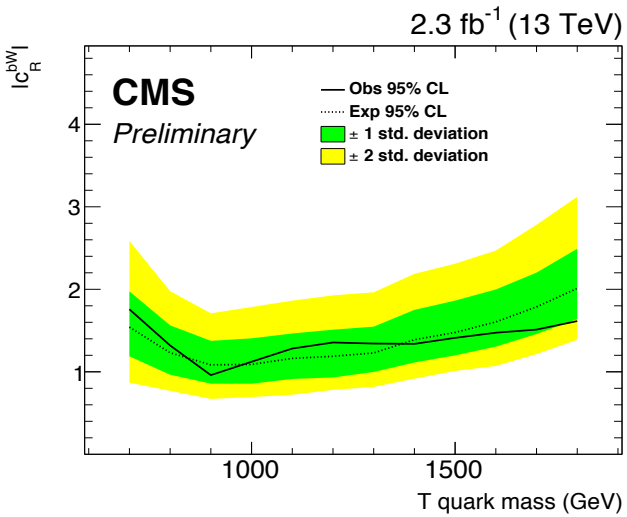


Maximum allowed cross-sections

VLQ $T_{2/3}$ single production

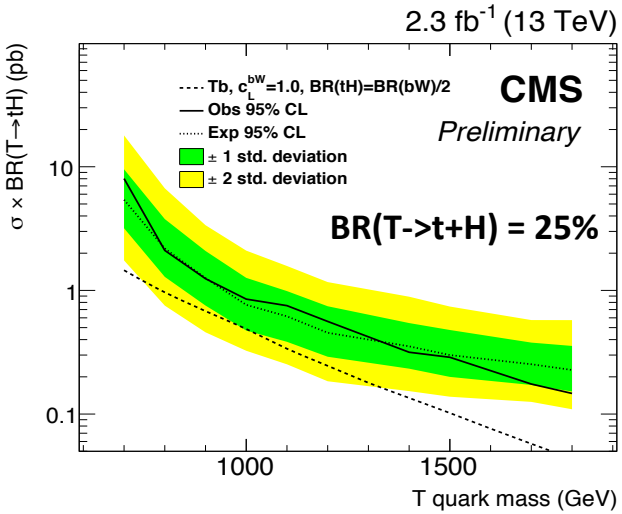
B2G-15-008

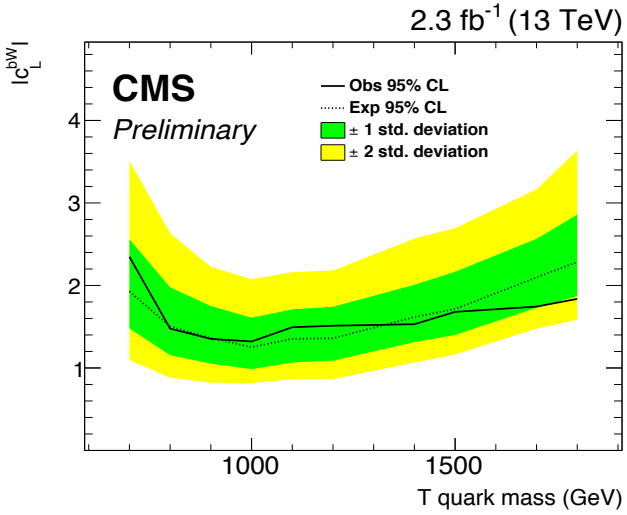




p p -> b + T production

right-handed coupling

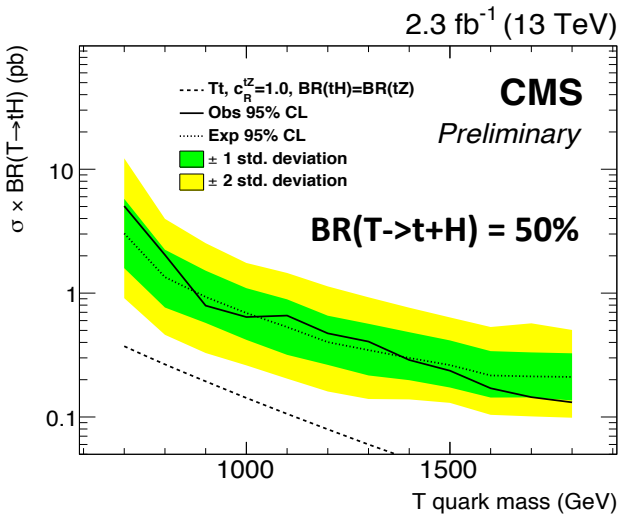


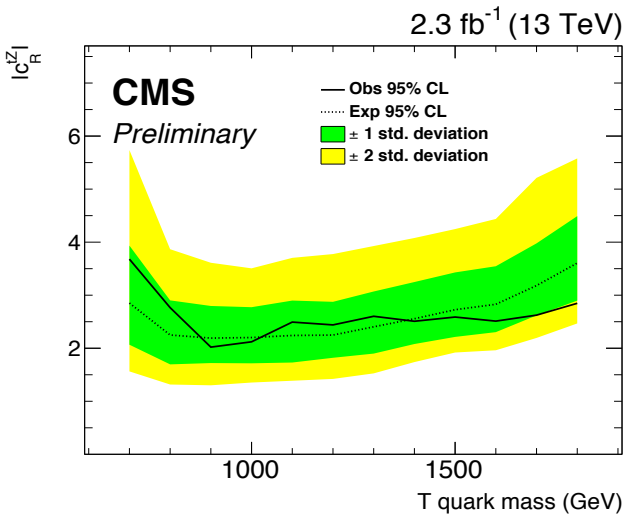


left-handed coupling

VLQ $T_{2/3}$ single production

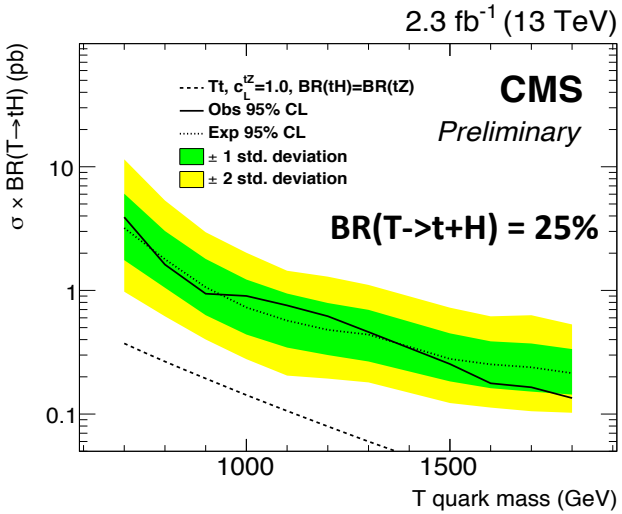
B2G-15-008

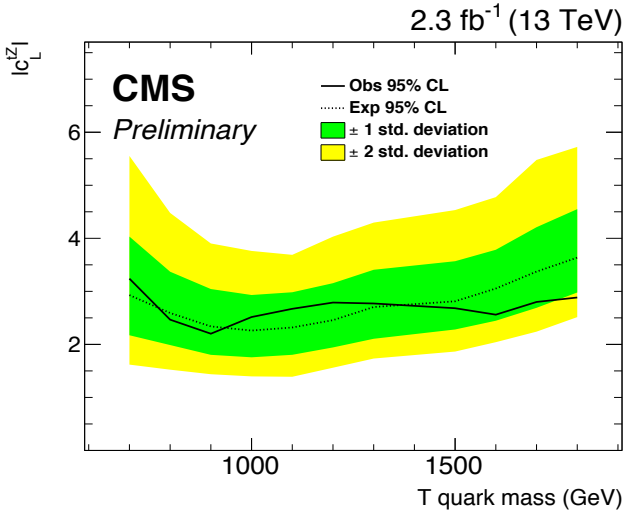




p p -> t + T production

right-handed coupling

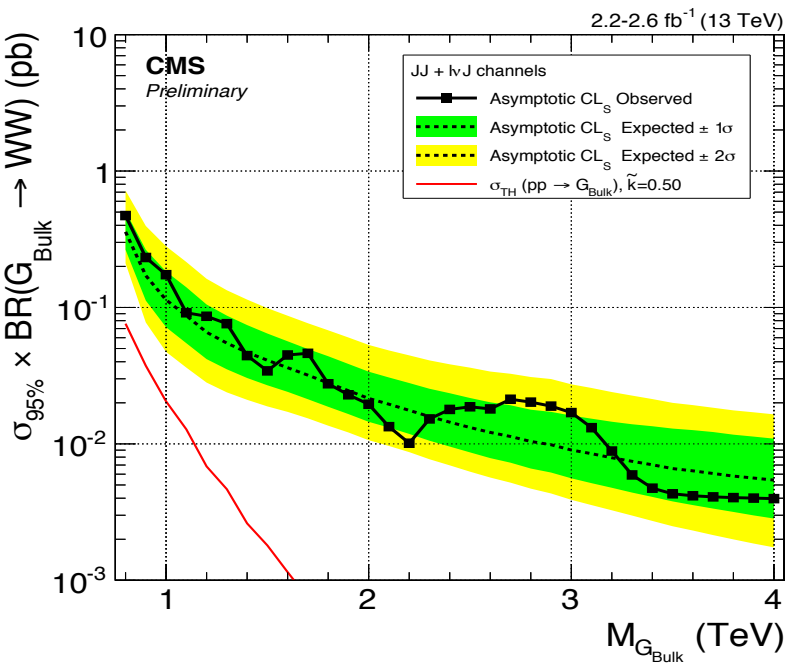


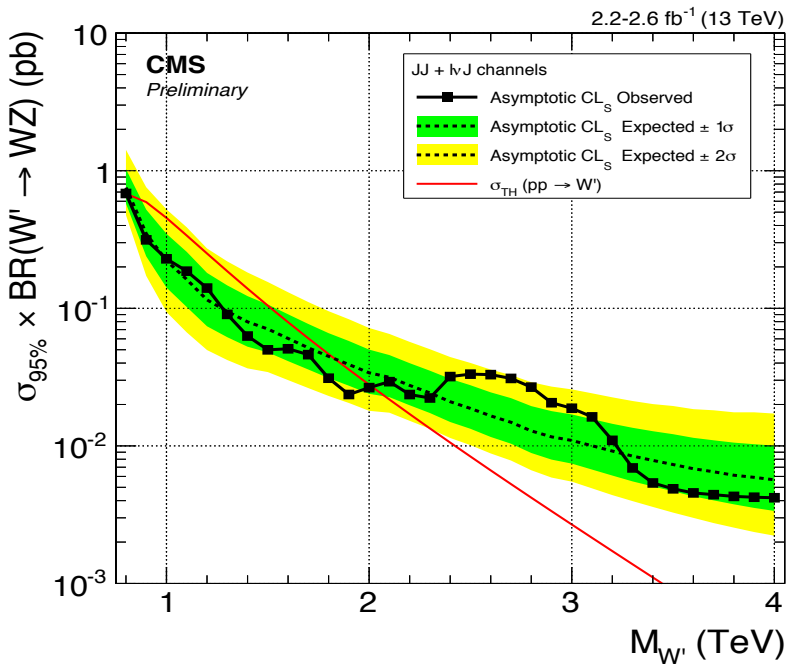


left-handed coupling

Di-boson searches

EXO-15-002





Combined results for the resonance-> WW/WZ/ZZ