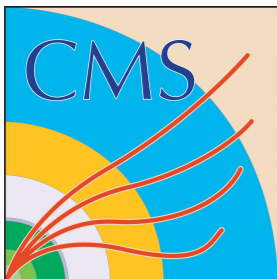


# **CMS - BSM short talk**

## **2022 LHC Days in Split**

### **October 4, 2022**

Dylan Apparau  
IPHC, Strasbourg, France  
On behalf of the CMS Collaboration



# Introduction

- A lot of Beyond the Standard Model (BSM) searches are conducted in CMS
- I'll present some results from **Beyond 2 Generations (B2G), Exotica (EXO) and Supersymmetry (SUS) groups**
  - ▶ Search for new vector bosons ( $Z'$ ,  $W'$ )
  - ▶ New scalars (top squark)
  - ▶ New fermions ( $q^*$ ,  $b^*$ )
  - ▶ Signature of Extra Dimension (Graviton, Radion, Quantum Black Holes)
- All searches are conducted:
  - ▶ with **Run2 data for an integrated luminosity of  $138 \text{ fb}^{-1}$**
  - ▶ Several **analysis techniques used** (3D fit, BDT use to maximise S/B, ...)

B2G-20-009

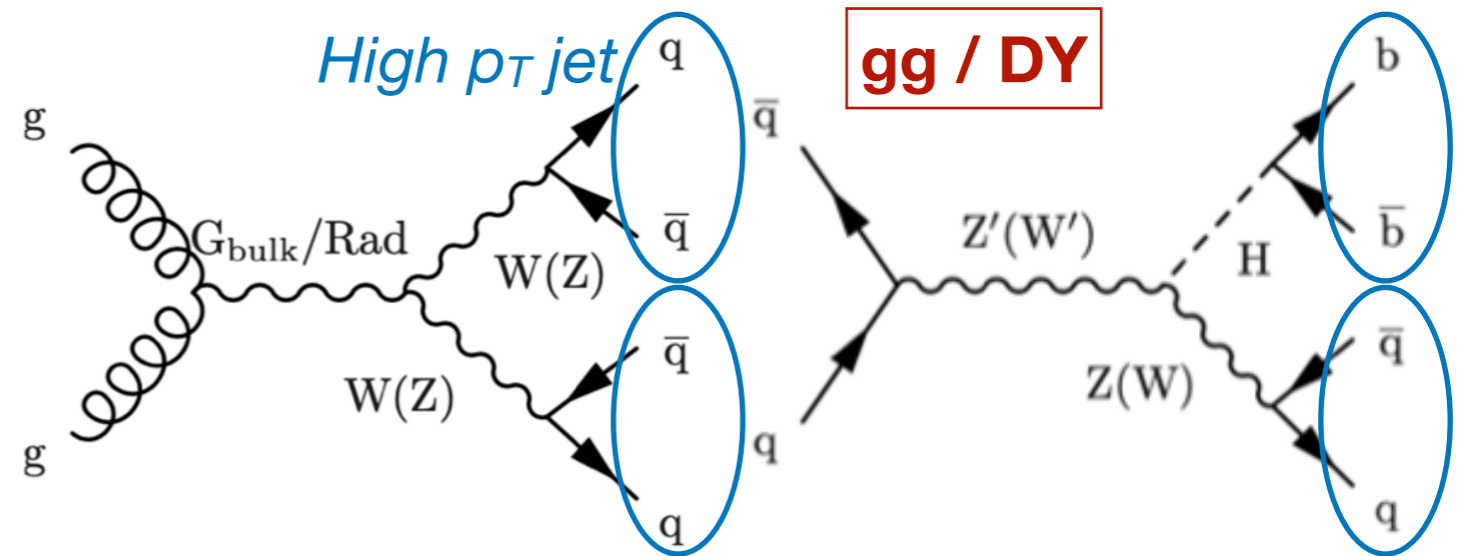
Search for new heavy resonances decaying to  $WW$ ,  $WZ$ ,  $ZZ$ ,  
 $WH$ , or  $ZH$  boson pairs in the all-jets final state in proton-  
proton collisions at  $\sqrt{s} = 13$  TeV

*March 2022*

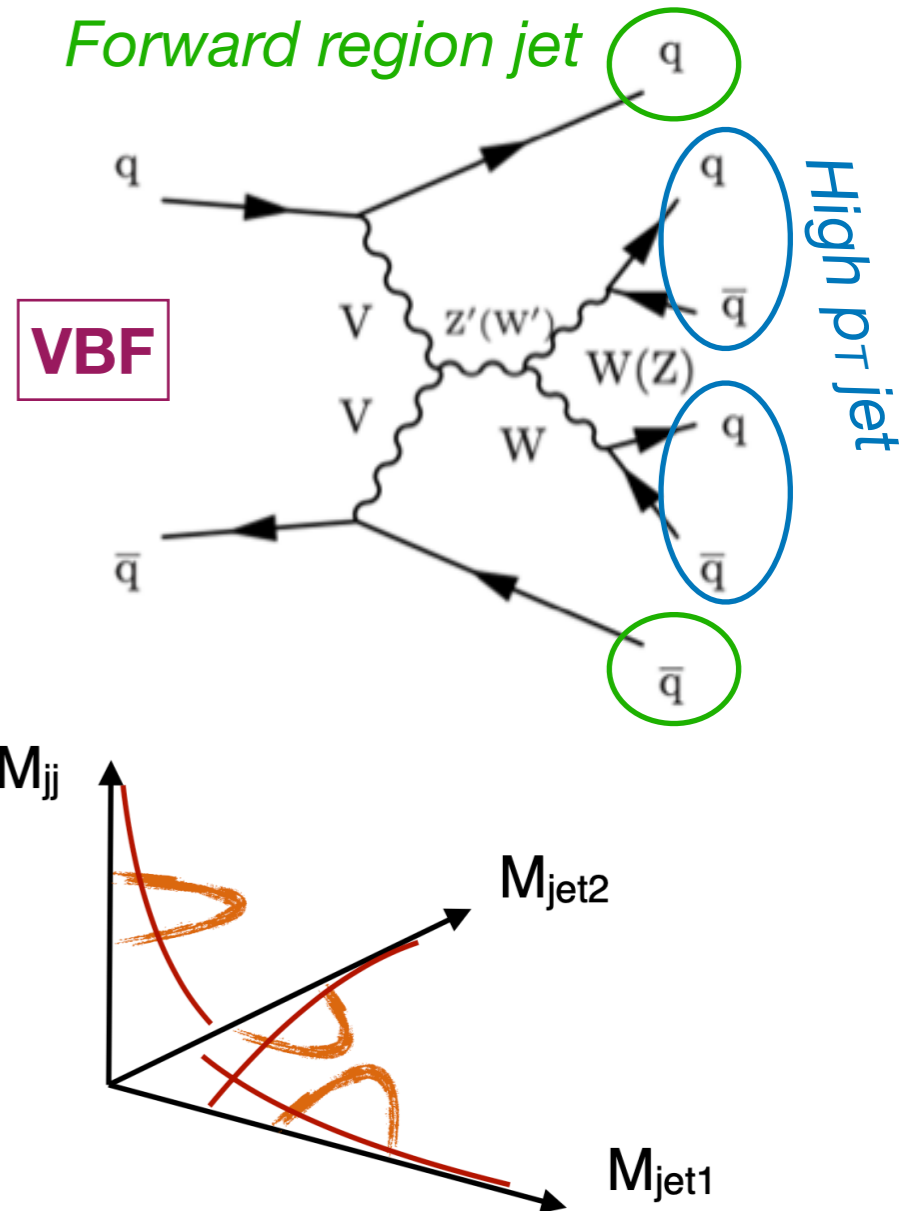
# Search for heavy resonances — models and strategy

High  $p_T$  jet

- Search for:
  - ▶ **Spin-1** :  $W' \rightarrow WZ$  /  $WHbb$ ,  
 $Z' \rightarrow WW$  /  $ZHbb$
  - ▶ **Spin-2** :  $\text{BulkG} \rightarrow WW$  /  $ZZ$
  - ▶ **Spin-0** :  $\text{Radion} \rightarrow WW$  /  $ZZ$
- $1.3 \text{ TeV} \leq M_X \leq 6.0 \text{ TeV}$

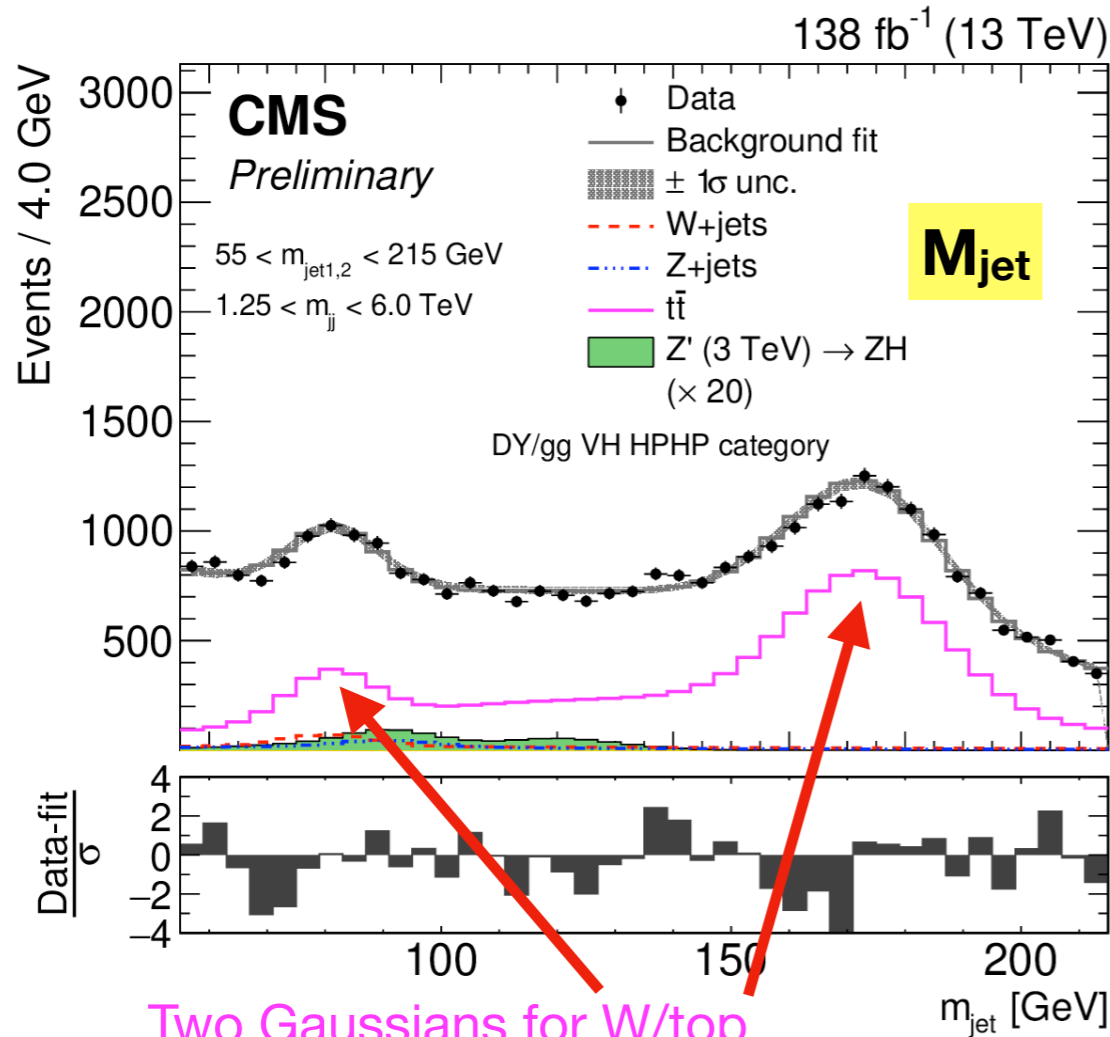
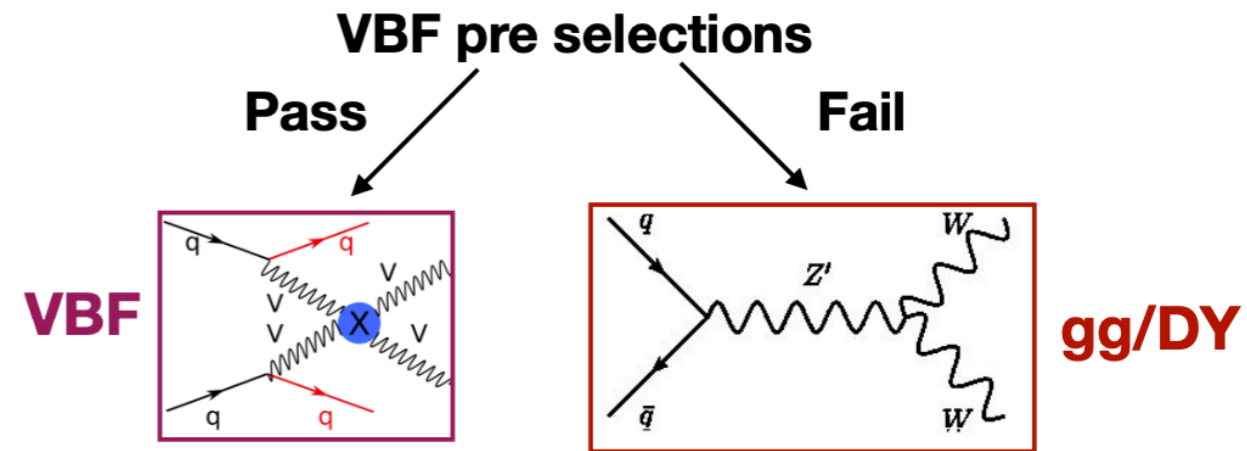


- Strategy:
  - ▶ Select **2 high- $p_T$  wide jets**  
+ **2 jets in the forward region for VBF**  
(vector boson fusion)
  - ▶ **3D bump hunt**  
**Signal is resonant** in 3D:  $M_{\text{jet1}}, M_{\text{jet2}}, M_{\text{jj}}$   
Main background: **QCD, smoothly falling**
  - ▶ **Data-driven background prediction**, with  
a max. likelihood fit

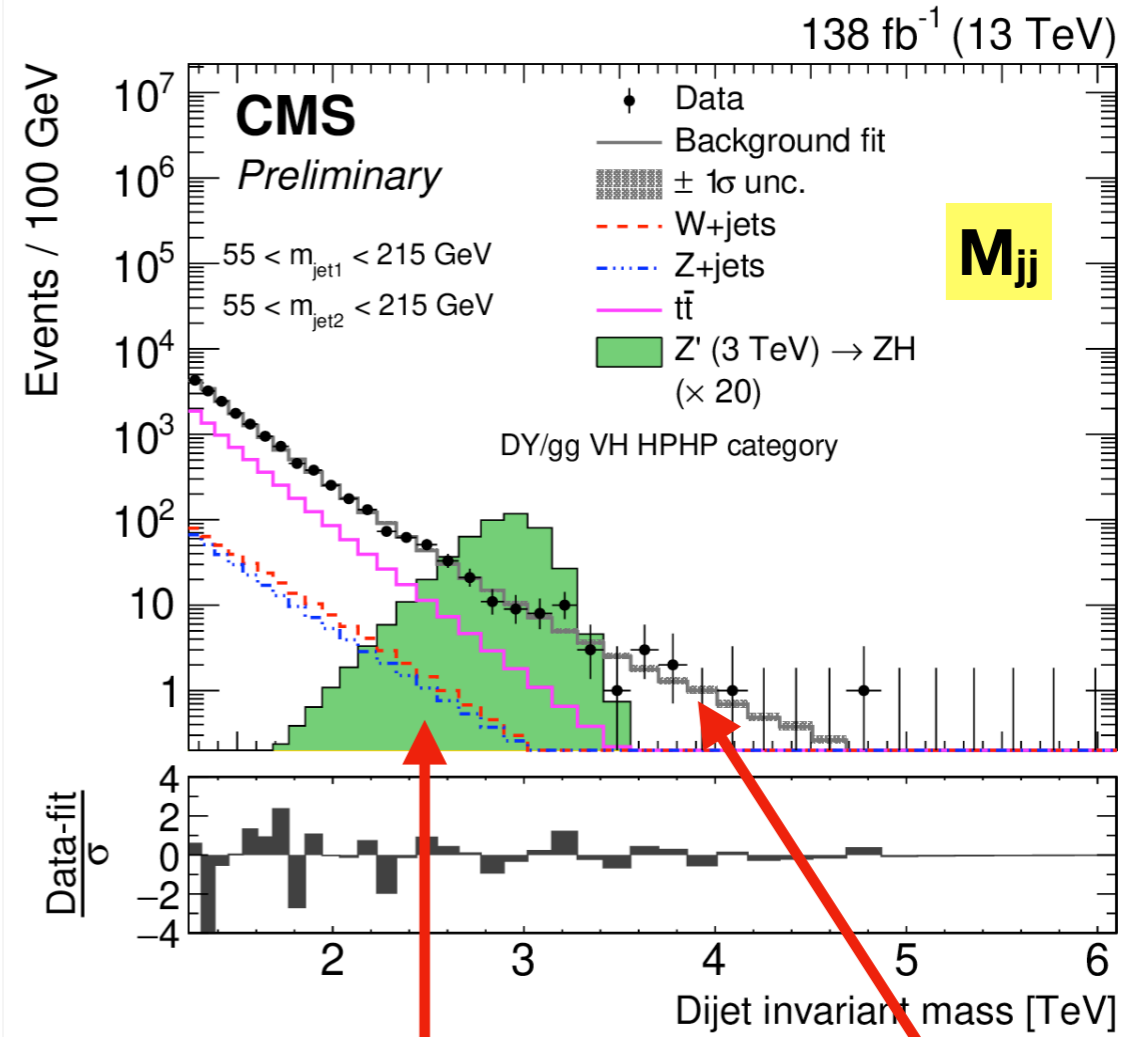


# Search for heavy resonances — categories & S/B modelling

- Two orthogonal categories  
 ⇒ **VBF** & **gg / DY**
- Divided in:
  - ▶ **VH: H-tag enriched** ( $H/Z \rightarrow bb$ )
  - ▶ **VV: V-tag enriched** ( $V \rightarrow qq$ )
- Subcategories defined by the **purity of the tagging**



Two Gaussians for W/top  
 +ErfExp for non-resonant  
 (single quark or g misidentified)



Double-sided Crystal Ball  
 functions for signal

Templates from fit

# Search for heavy resonances — results

- **Upper limits at 95% CL** on the resonance masses

- ✓ Radion  $\rightarrow$   $VV$  : 2.7 TeV

- ✓ Heavy vector triplet (HVT) models

- \*  $W' \rightarrow WZ$  /  $WH$  : 4.4 / 4.0 TeV

- \*  $Z' \rightarrow WW$  /  $TH$  : (1.3-3.1, 3.3-3.5) / 4.0 TeV

- \*  $V' \rightarrow VV+VH$  /  $VV$  /  $VH$  : 4.8 / 4.5 / 4.2 TeV

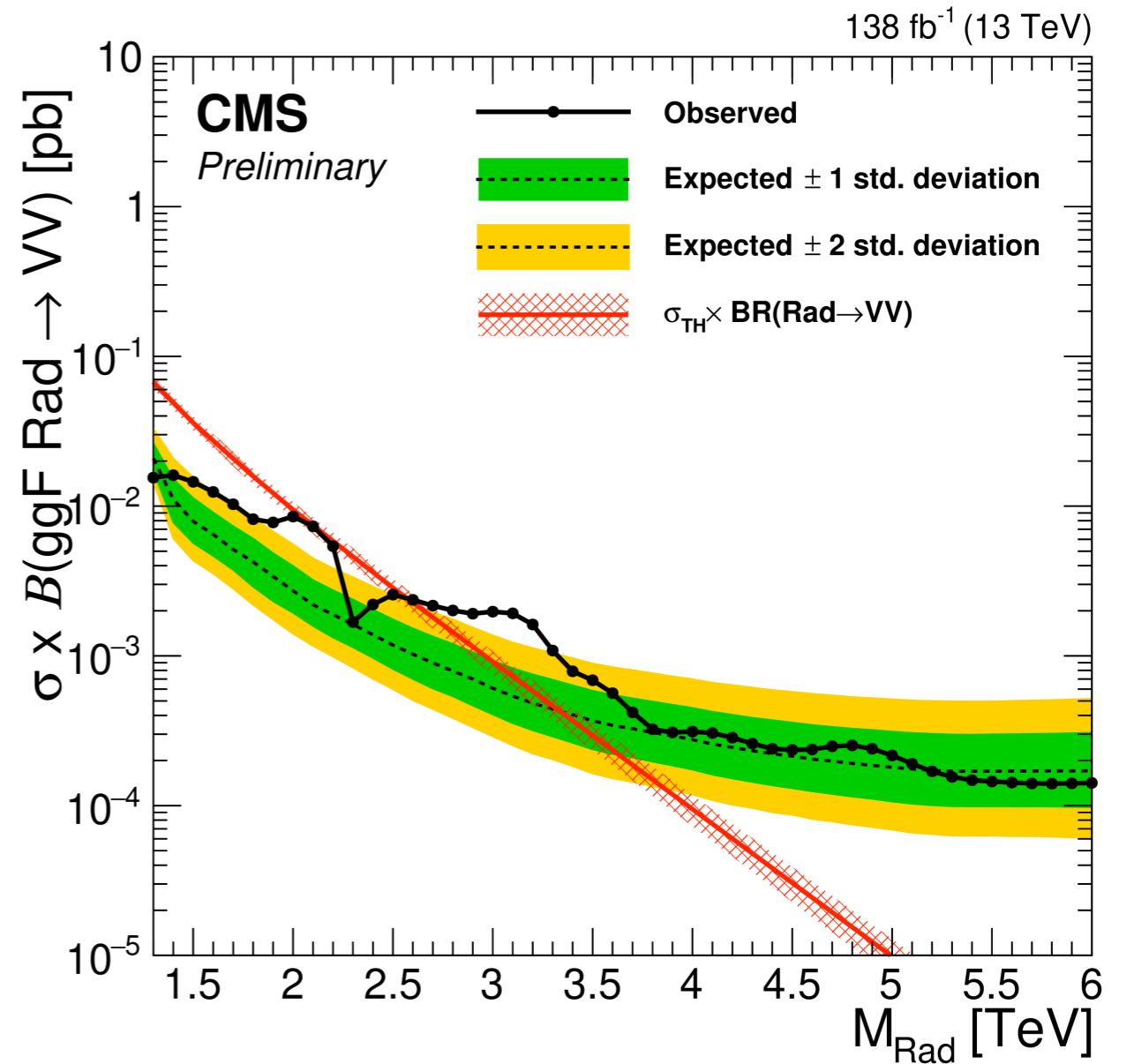
- ✓  $G_{\text{bulk}} \rightarrow VV$  : 1.4 TeV

- **Two excesses are observed** (2.1 and  $\sim$ 2.9 TeV)

- ▶ In  $VV$  decay modes only

- ▶ **Local significance:  $3.6\sigma$**

- ▶ **Global significance:  $2.3\sigma$**



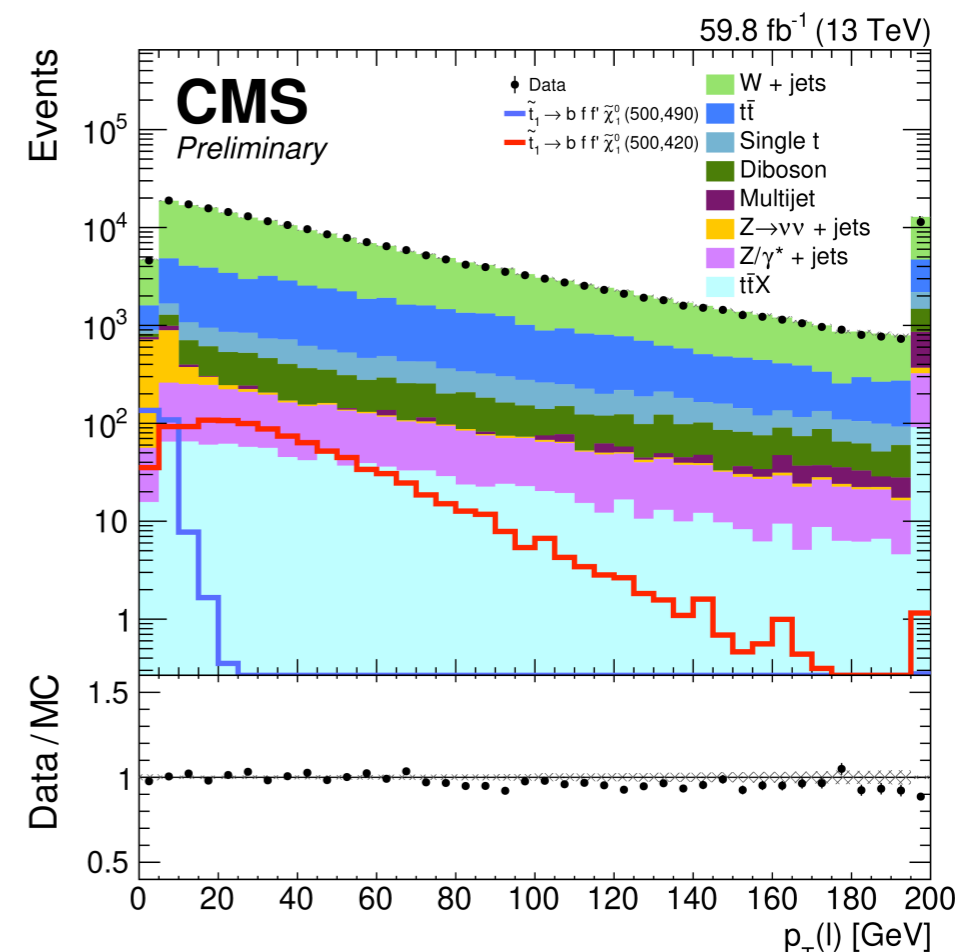
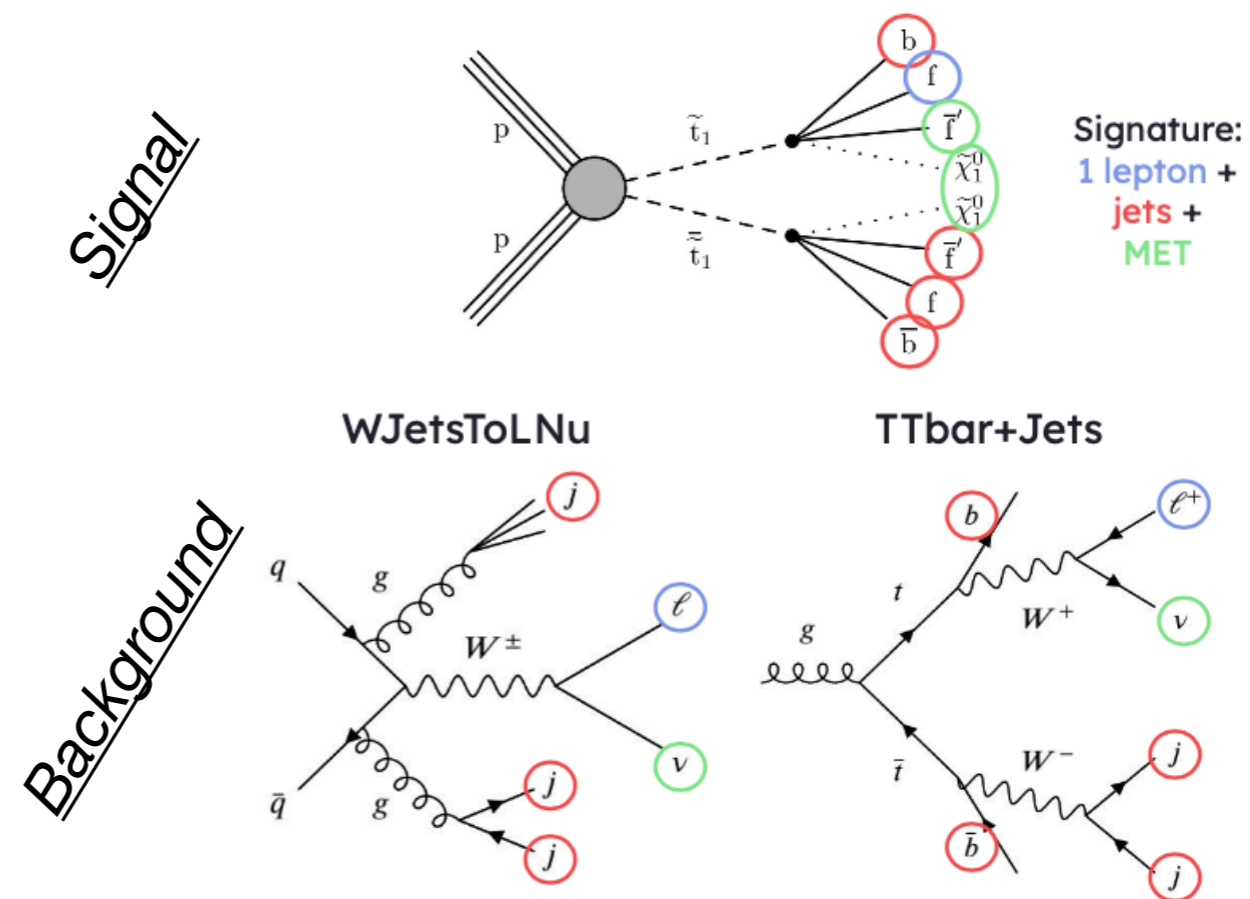
SUS-21-003

Search for top squarks decaying via the four-body model  
in single-lepton final states from Run 2 of the LHC

*June 2022*

# Search for stop in compressed scenarios — search strategy & selection

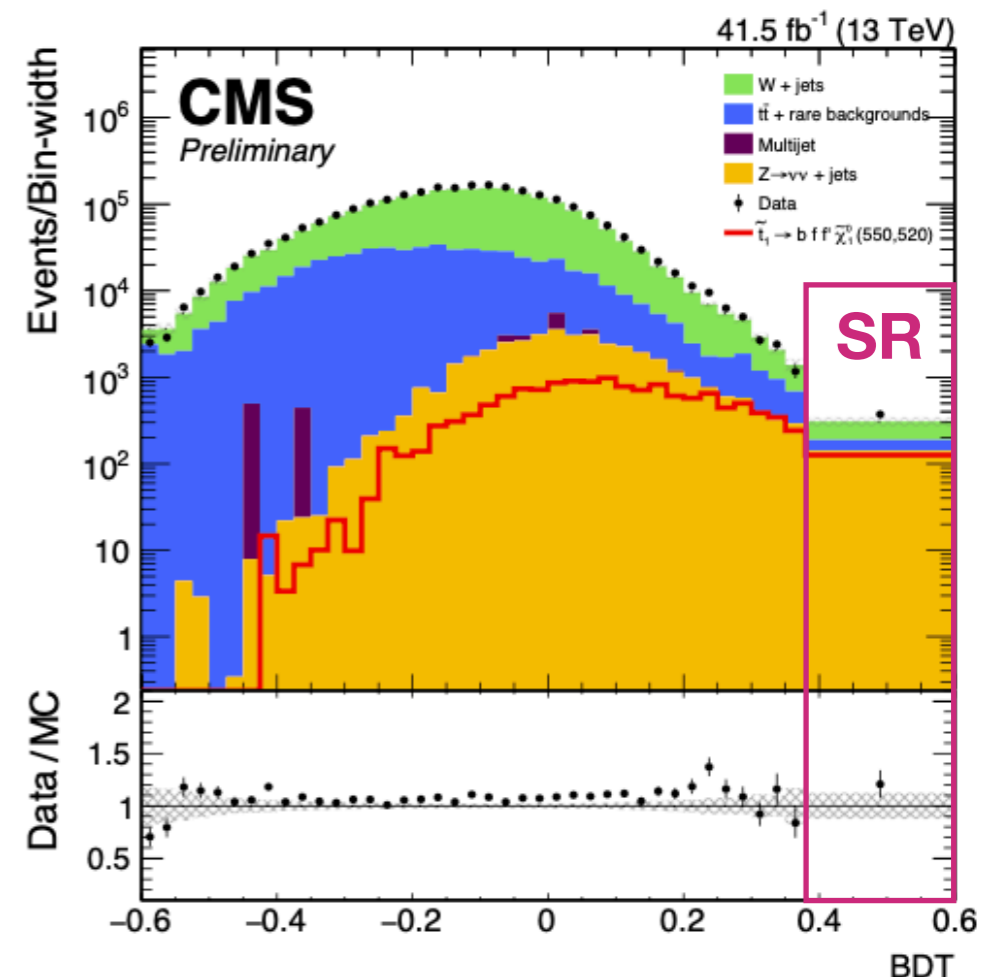
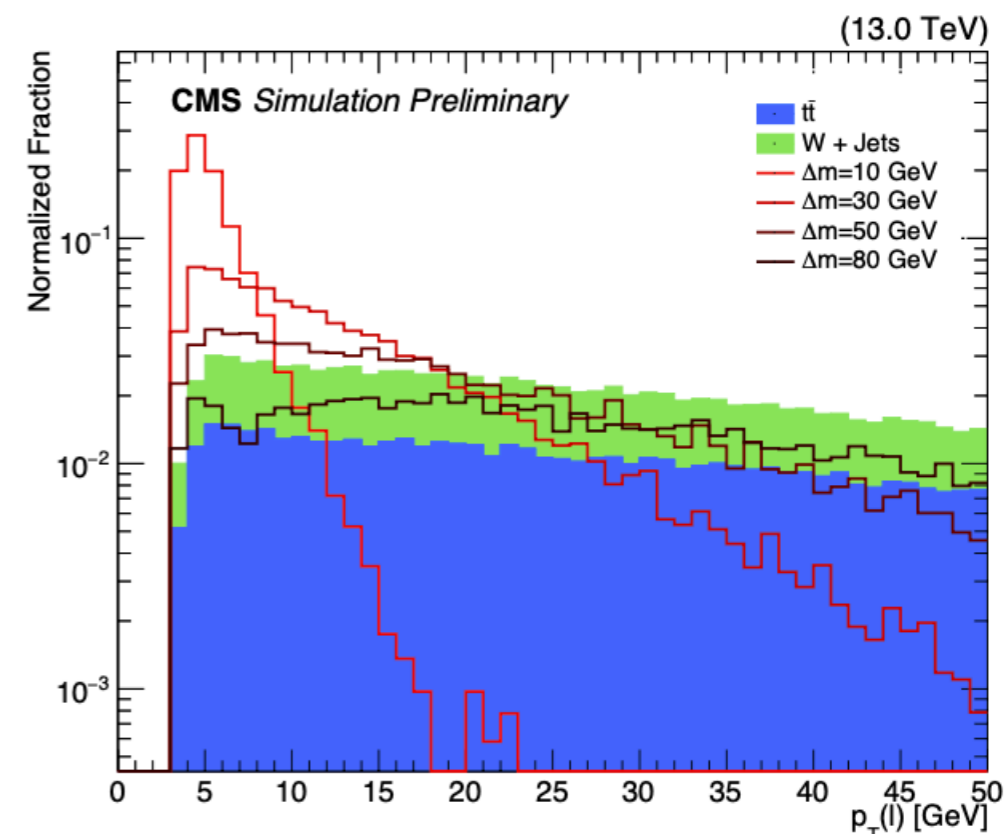
- **Target: top squark pair production** in compressed scenario ( $\Delta m = m_{\tilde{t}} - m_{\tilde{\chi}^0} < m_W$ ), 4-body decays  
 $\tilde{t}_1$ : possible **lightest squark**  
 $\tilde{\chi}_1^0$ : **LSP**, weakly interacting and neutral
- **Background:**  $W$ +jets,  $t\bar{t}$ , DY+jets, single top, QCD
- **Search strategy & selection:**
  - ▶ **1 lepton final state**
  - ▶ **High  $p_T$  jet**
  - ▶  **$p_T^{\text{miss}} > 280$  GeV and  $H_T > 200$  GeV**
  - ▶ S/B discrimination based on 8 **BDTs** trained for different  $\Delta m$  scenarios
  - ▶ **Counting experiment** in 8 SR after cut on BDT output
- Highly benefiting from low  $p_T$  lepton
  - electron down to 5 GeV
  - muon down to 3.5 GeV





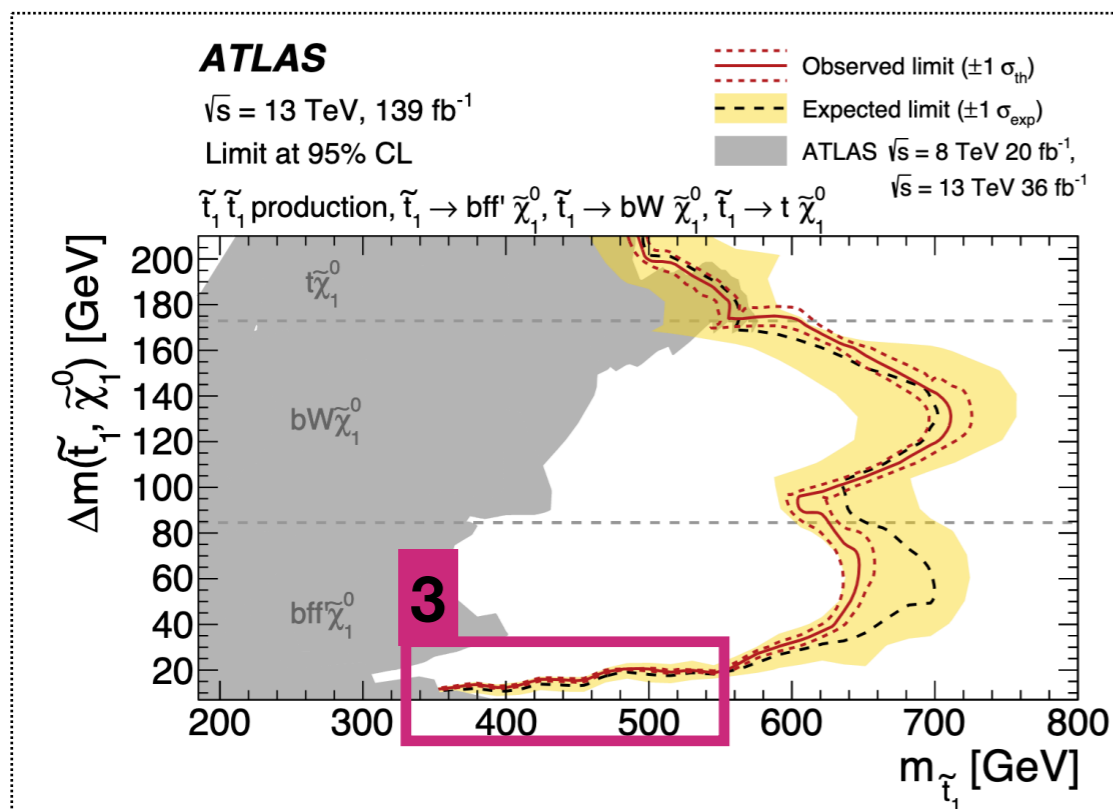
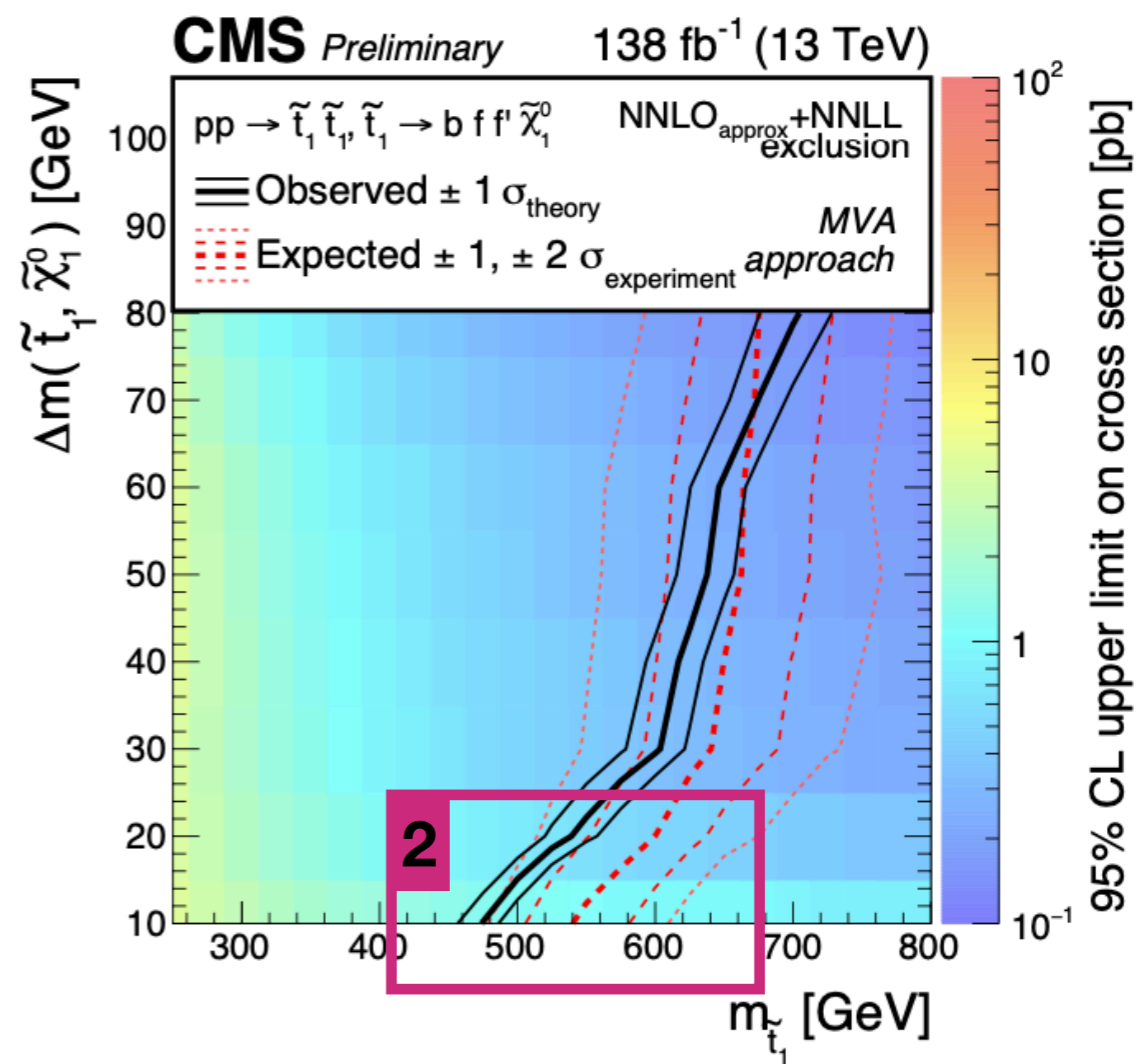
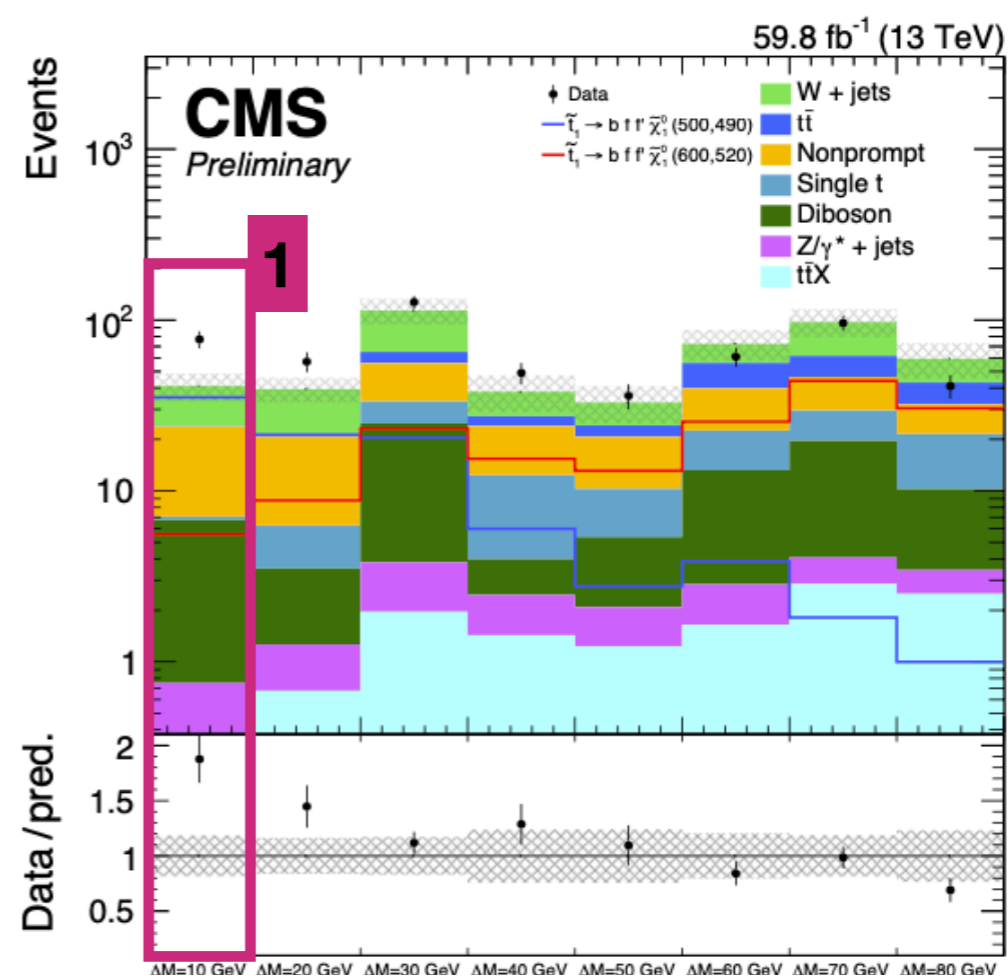
# Search for stop in compressed scenarios — BDT strategy & background prediction

- BDTs inputs:
    - ▶ **MET:**  $p_{T}^{\text{miss}}$ ,  $M_T$
    - ▶ **Lepton:**  $p_T$ ,  $\eta$ , charge
    - ▶ **Jet:**  $p_T$  of the leading jet,  $p_T$  of the b-tagged jet,  $N_{\text{jets}}$ ,  $H_T$
    - ▶ **B-tagging:**  $\Delta R(l, b)$ , highest b-tag discriminant value
  - BDT output **checked in validation region (VR) kinematically close to the search region (SR)**
  - SR defined **cutting on the BDT output** and optimised using sensitivity of previous analysis
- 
- Main processes: **W+jets** and  **$t\bar{t}$**  with prompt lepton & processes with non-prompt lepton (arise from misidentified lepton)
    - ▶ Prompt background prediction
      - Control region (CR) at low BDT score enhanced in **W** (0 loose  $b$ ) or  **$t\bar{t}$**  ( $\geq 1$  tight  $b$ )
      - Estimated using MC-derived transfer function between the CR and the SR
    - ▶ Non-prompt background prediction
      - Estimated in data via tight-to-loose method



# Search for stop in compressed scenarios — results

- **$\sim 2.5\sigma$  deviation for  $\Delta m = 10$  GeV** **1**
- **Excess visible** in the limit plot at low  $\Delta m$
- 2**
  - ▶ Expected exclusion at 540 GeV
  - ▶ **Observed exclusion at 475 GeV**  $\Delta m = 10$  GeV
- **Compare to SUS-18-004** (2/3-leptons final state)
  - ▶ Also 1-2 $\sigma$  effect at  $\Delta m = 10$  GeV
- Compare to **ATLAS** (in 1-lepton final state)
  - 3** ▶ Less sensitive for  $\Delta m < 20$  GeV
  - ▶ Similar for larger  $\Delta m$



**BRAND NEW RESULTS !**

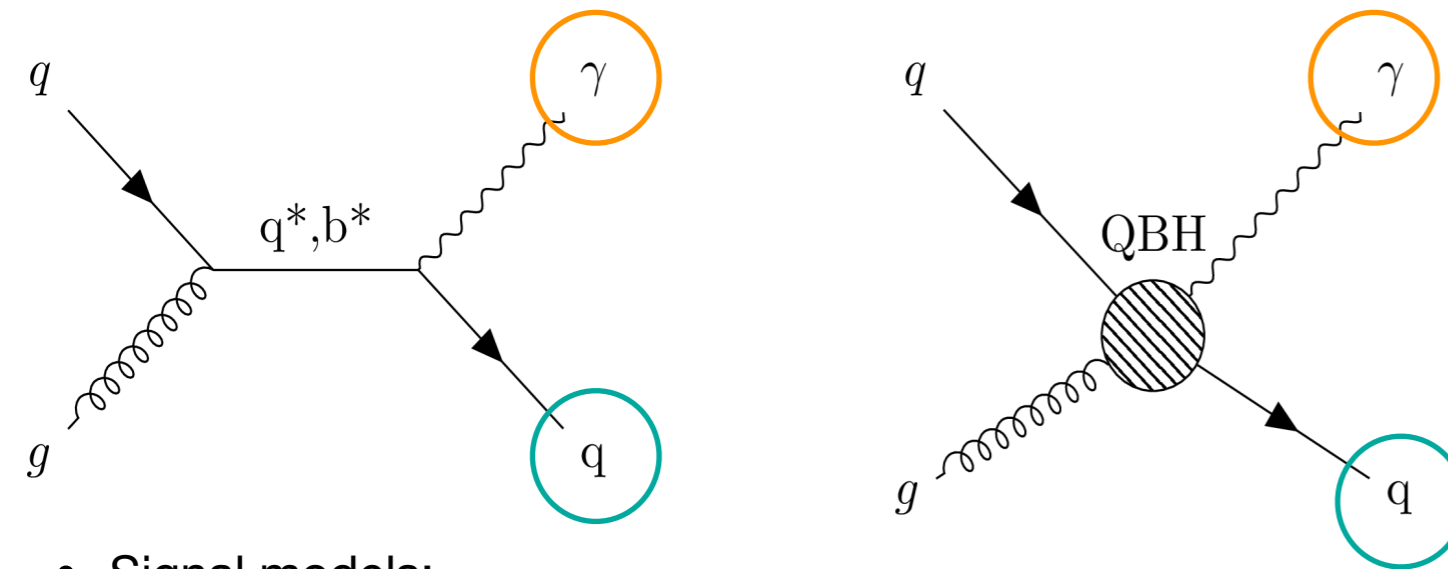
EXO-20-012

Search for resonance production in events with a  
photon and jet with the CMS experiment

*September 2022*

# Search for excited quarks and black holes — models & strategy

**BUMP!**



- Signal models:

- ▶ **Excited state of quarks ( $q^*$ ) and heavy flavour quarks ( $b^*$ )**
- ▶ **Quantum Black Hole (QBH)**  $\Rightarrow$  models with extra dimension

- Possible states:

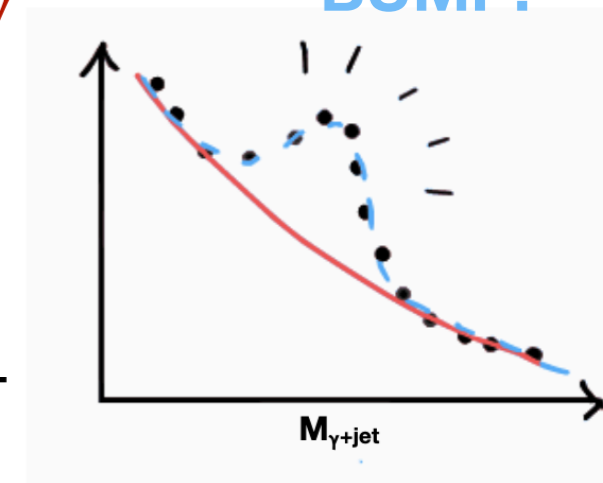
- ▶ jet+jet
- ▶ **✓  $\gamma$ +jet**
- ▶  $\gamma$ + $\gamma$

- SM background for  $\gamma$ +jet are:

- ▶ **QCD with overlapping photons**
- ▶ **EWK background** ( $W\gamma$  and  $Z\gamma$  decaying hadronically)

- Strategy:

- ▶ Good **high  $p_T$  photon** ( $p_T > 240$  GeV) + **jet** ( $p_T > 30$  GeV)
- ▶ **Jets** for signal:
  - $q^*$  and QBH: **jets merged to form wide-jet** ( $\Delta R < 1.1$ ) with  $p_T > 170$  GeV to capture final state radiation
  - $b^*$ : at least one jet passing **DeepJet merged to form wide-jet** with medium working point
- ▶ Search for a **bump in  $\gamma$ +jet invariant mass** in **categories**
  - $q^*$  / QBH search
  - $b^*$   $\Rightarrow$  b-tag and 0b-tag (medium tag)
- ▶ Data-driven background: **fit the mass distribution with polynomial function**



# Search for excited quarks and black holes — background prediction

- The  $\gamma$ +jet invariant mass distribution **fit with the function**

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

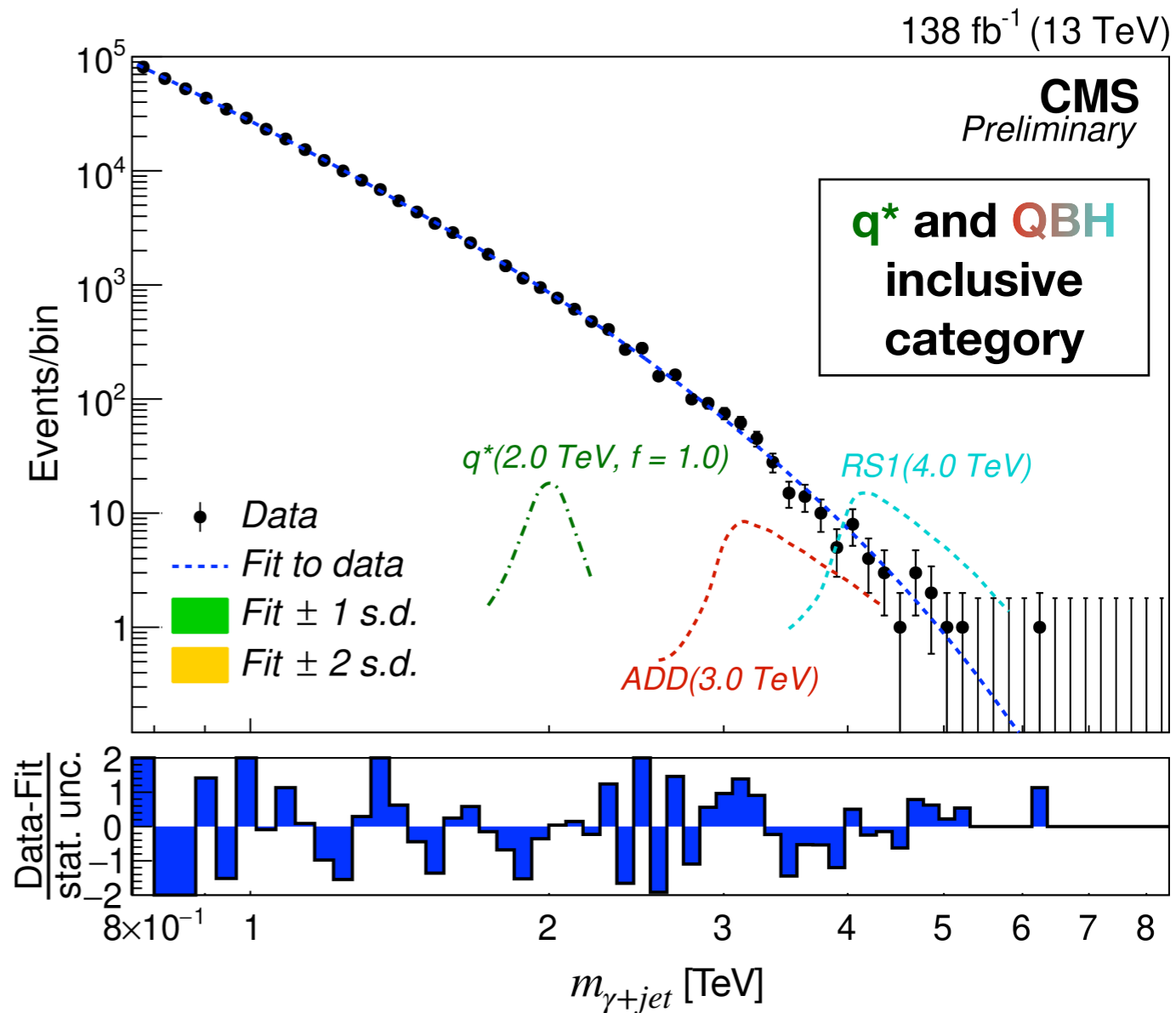
in the different categories

- The mass distribution **binning is driven from  $\gamma$ +jet mass resolution**

- Bias study**, due to the choice of function form:

- ▶ **Pseudo-dataset distributions** are generated
- ▶ Bias estimated by constructing **pull distributions** for each mass hypothesis and each alternate function

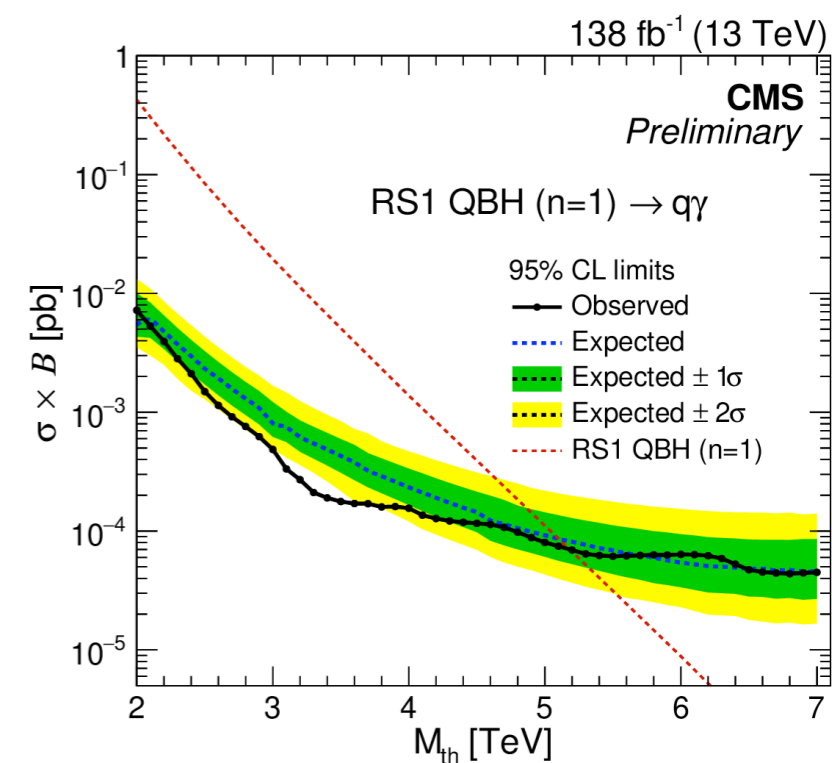
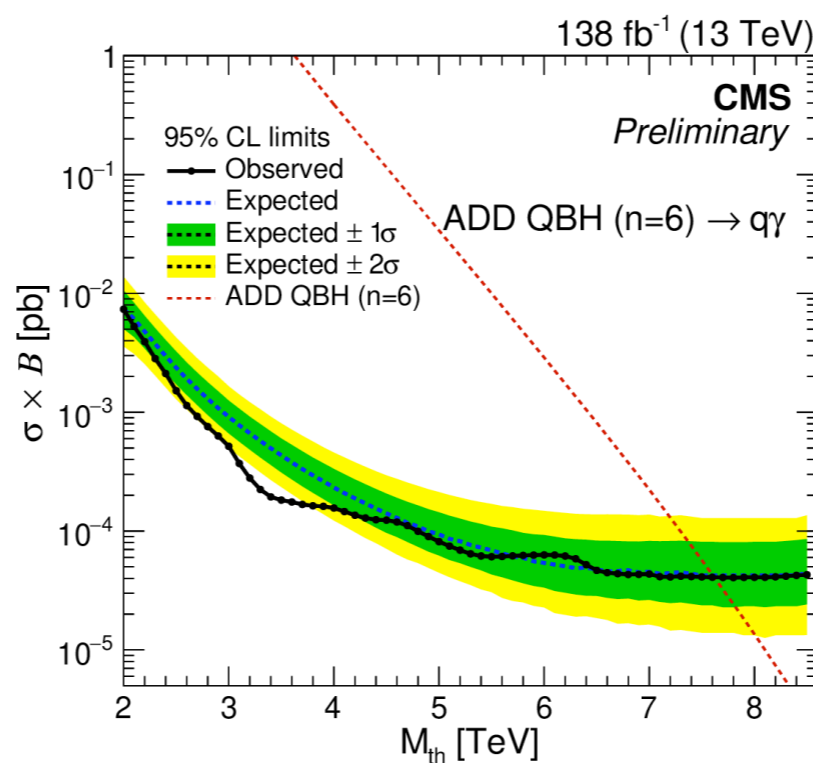
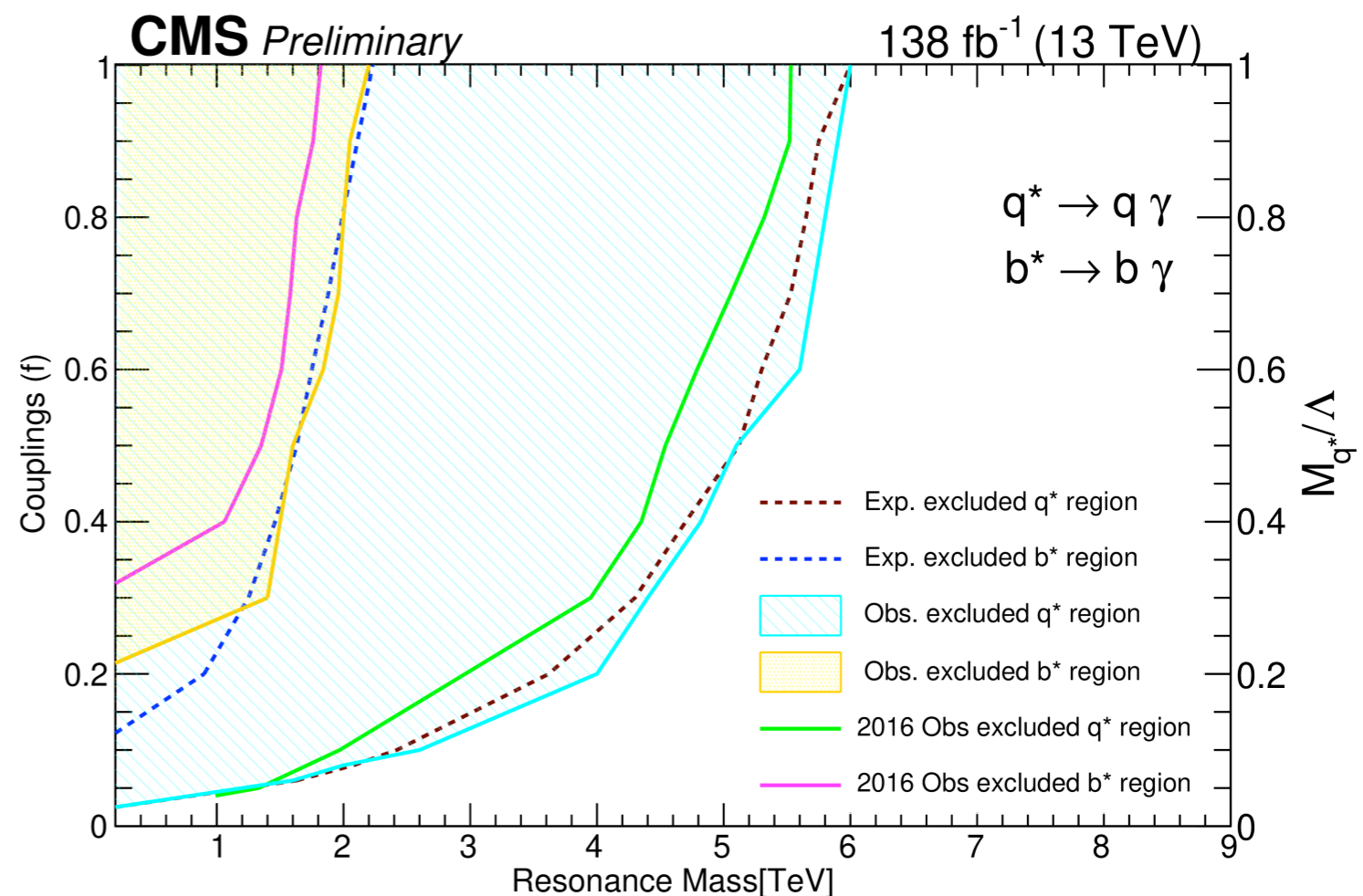
⇒ Contribute ~11% to the total uncertainty, no effect on sensitivity





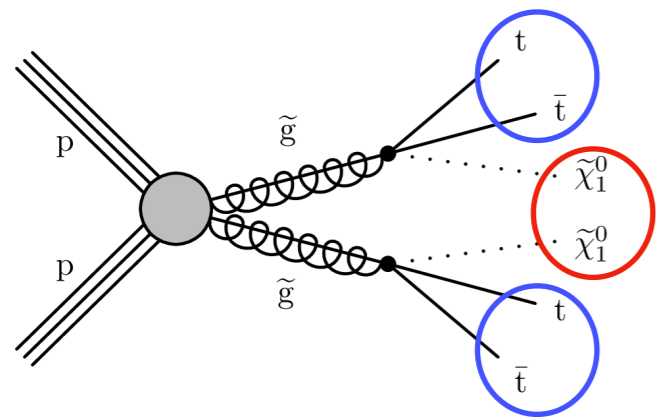
# Search for excited quarks and black holes — results

- **Limits are set** on the mass of signals:
  - ✓  $q^*$  : 6.0 TeV
  - ✓  $b^*$  : 2.2 TeV
  - ✓ ADD QBH (n=6) : 7.5 TeV
  - ✓ RS1 QBH (n=1) : 5.2 TeV
- **Gain with full Run2 dataset** of in average +300-400 GeV for  $q^*$  and  $b^*$
- ADD (n=6) and RS1 (n=1) QBH models excluded up to 7.1 TeV and 4.4 TeV by the ATLAS experiment with luminosity  $36.7 \text{ fb}^{-1}$

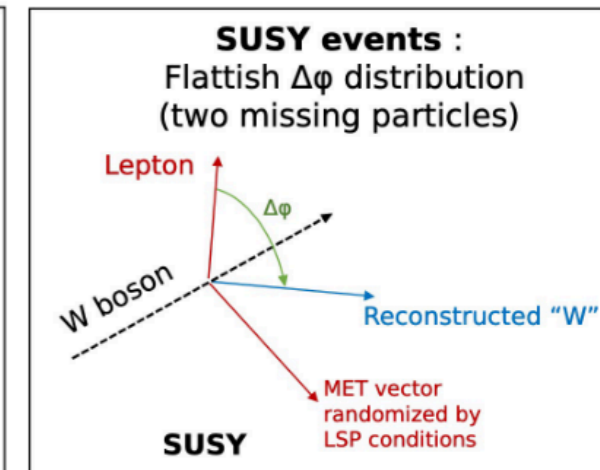
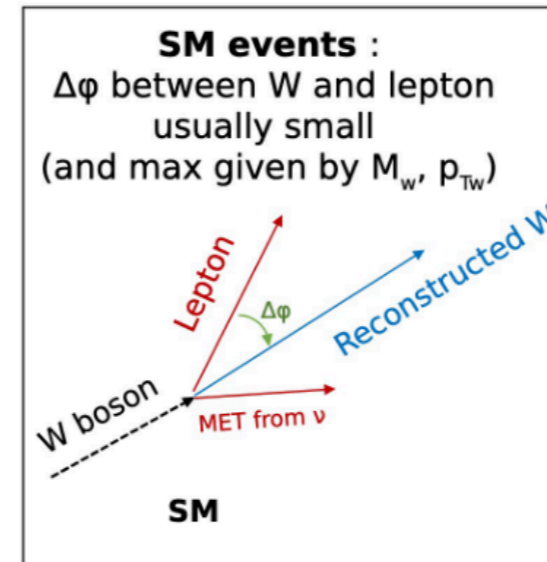
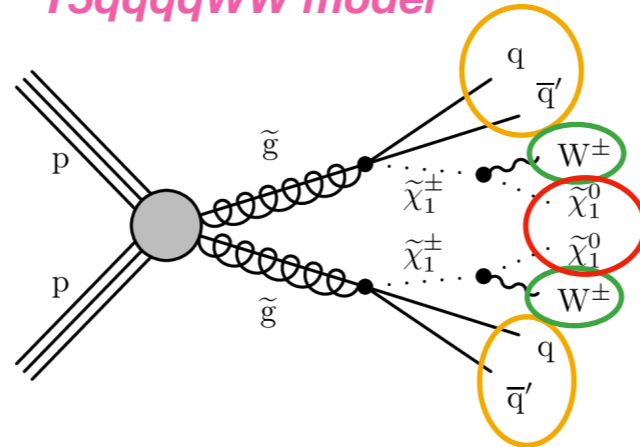


Search for supersymmetry in final states with a **single electron or muon using angular correlations and heavy object tagging** in proton-proton collisions at  $\sqrt{s} = 13$  TeV

*T1tttt model*



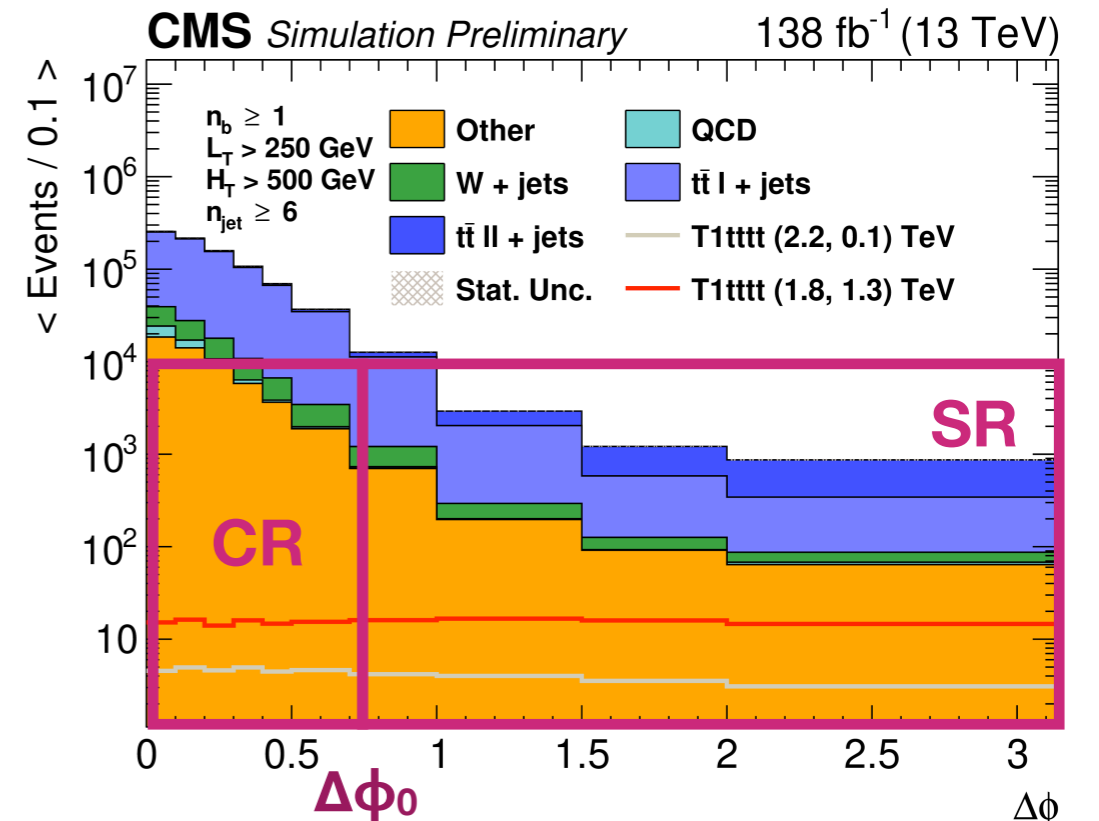
*T5qqqqWW model*



• Targets:

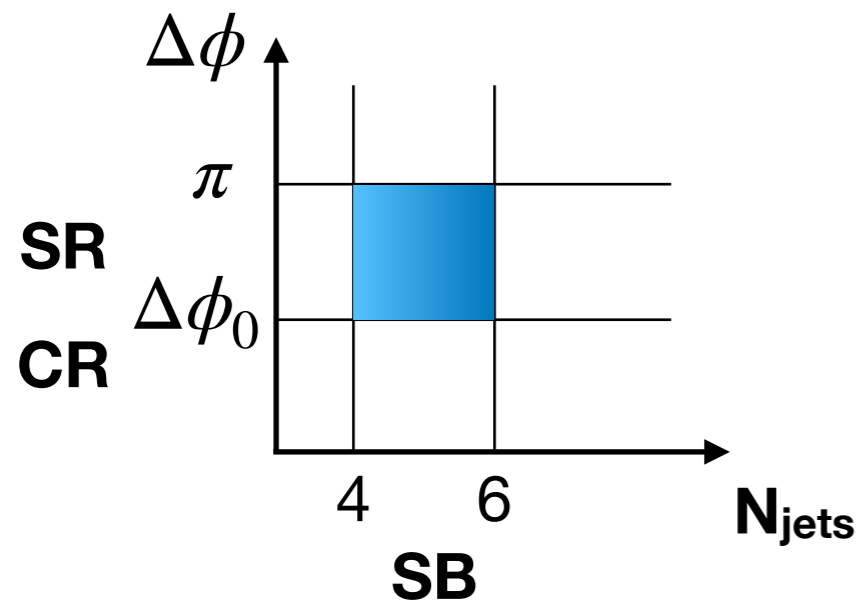
- ▶ SUSY events with **exactly one lepton, jets and high MET**
- ▶ **SR with b-tags and with 0b-tag**
- ▶ SM processes with same signature:  $t\bar{t}$ , W+jets, non-prompt leptons

• Main discrimination variable:  $\Delta\phi(W, l)$

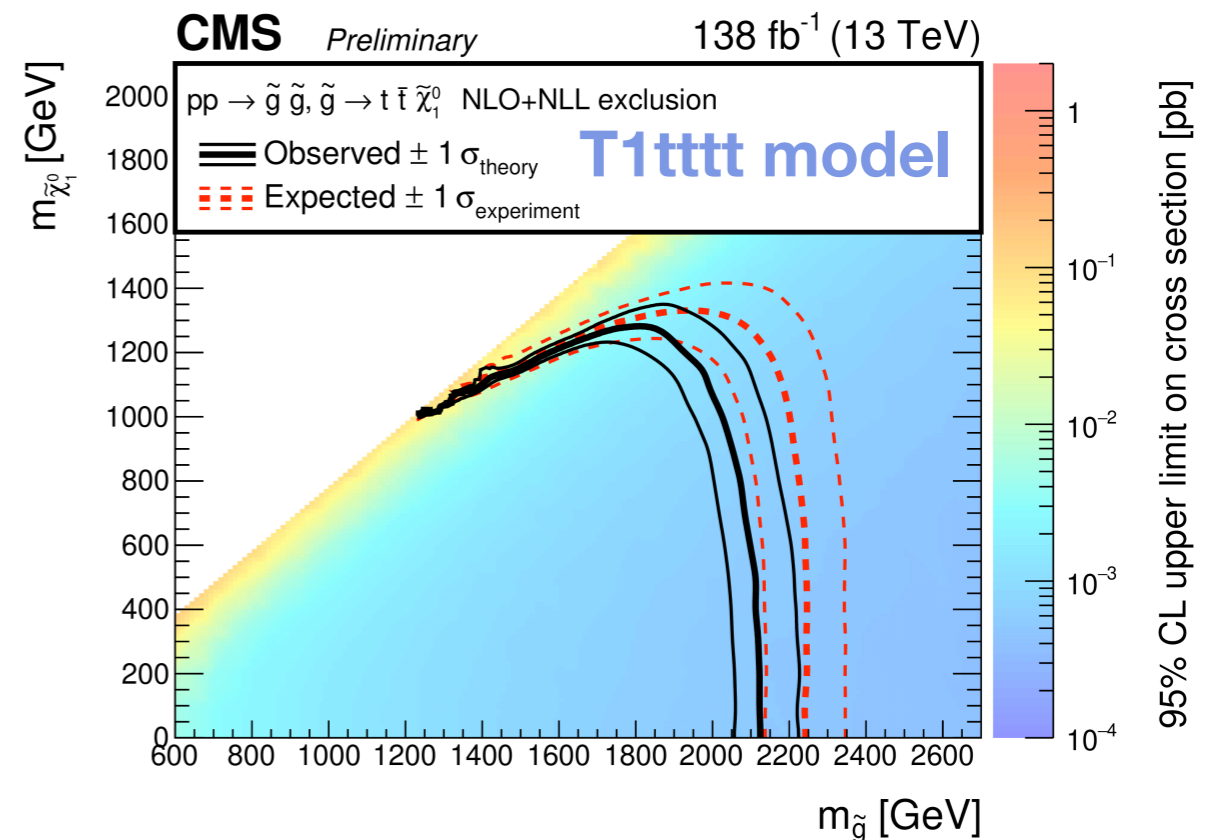


# SUSY with single lepton final state — background and results

- Background prediction:
  - ▶ Data-driven (ABCD) based on  $N_{\text{jets}}$  and  $\Delta\phi$
- Categories: 44 bins binned in
  - ▶  $L_T = |p_T^l| + |MET|$
  - ▶  $H_T$
  - ▶  $n_{\text{b-tag}}$
  - ▶  $n_{\text{top-tag}}$

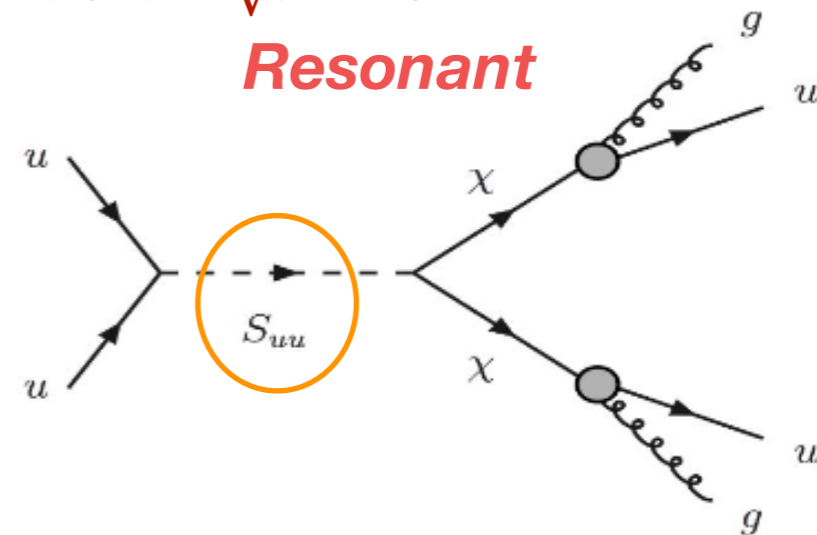
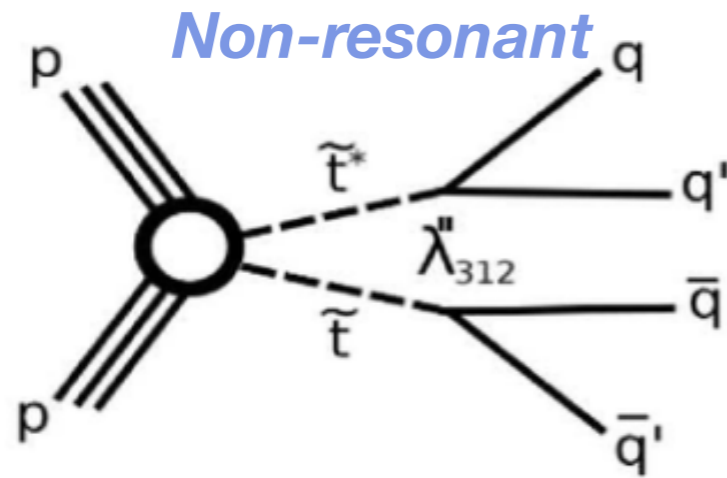


- Upper limits on the production cross section at 95% CL
  - ▶ **T1tttt model:**  
observed limit about one std. deviation lower than expected, because of the observation of 2 events in the last category while only  $0.24 \pm 0.16$  events expected
  - ▶ **T5qqqqWW model:**  
observed limit agrees with the expected limit over most of the mass range





Search for **resonant and non-resonant production of pairs of identical dijet resonances** in pp collisions at  $\sqrt{s} = 13$  TeV



- Search targets:

- ▶ **Pair-production of new particles decaying to two jets, resulting in a four jet final state**

- ▶ Production mode:

- **Non-resonant:**  $pp \rightarrow XX \rightarrow (jj)(jj)$

- Benchmark model: **R-parity** violating stop pairs

- **Resonant:**  $pp \rightarrow Y \rightarrow XX \rightarrow (jj)(jj)$

- Benchmark model: **Diquark** decaying to vector-like quarks

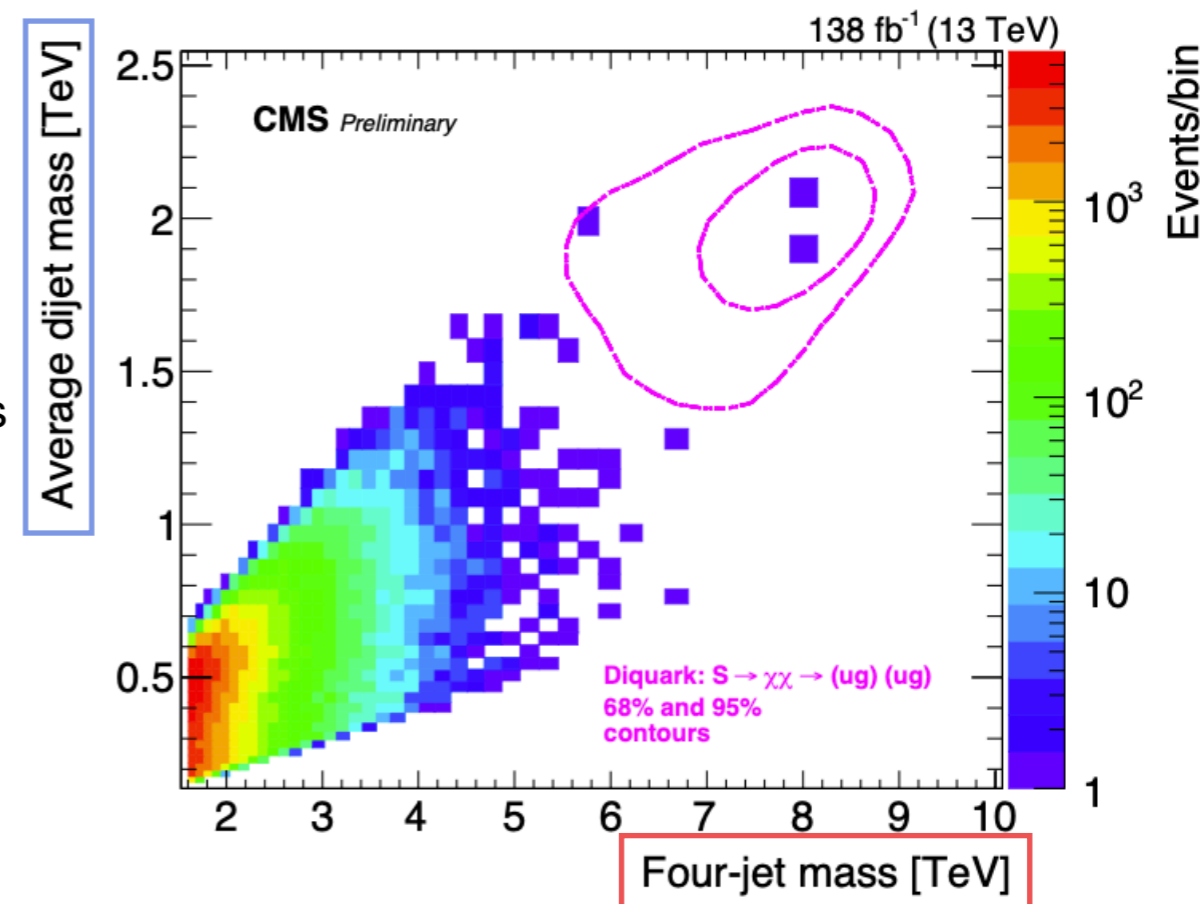
- Search variables: **average dijet mass** & **four-jet mass**

- Binning categories: 13 bins defined with  $\alpha = m_{jj}/m_{4j}$

- Background prediction in  $\alpha$  bins:

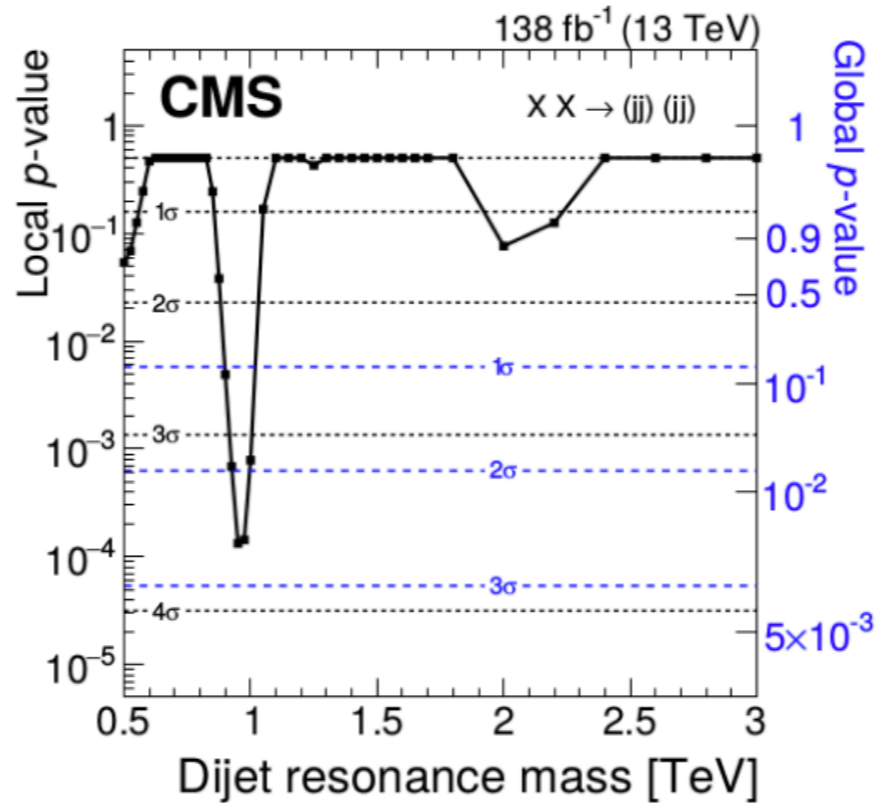
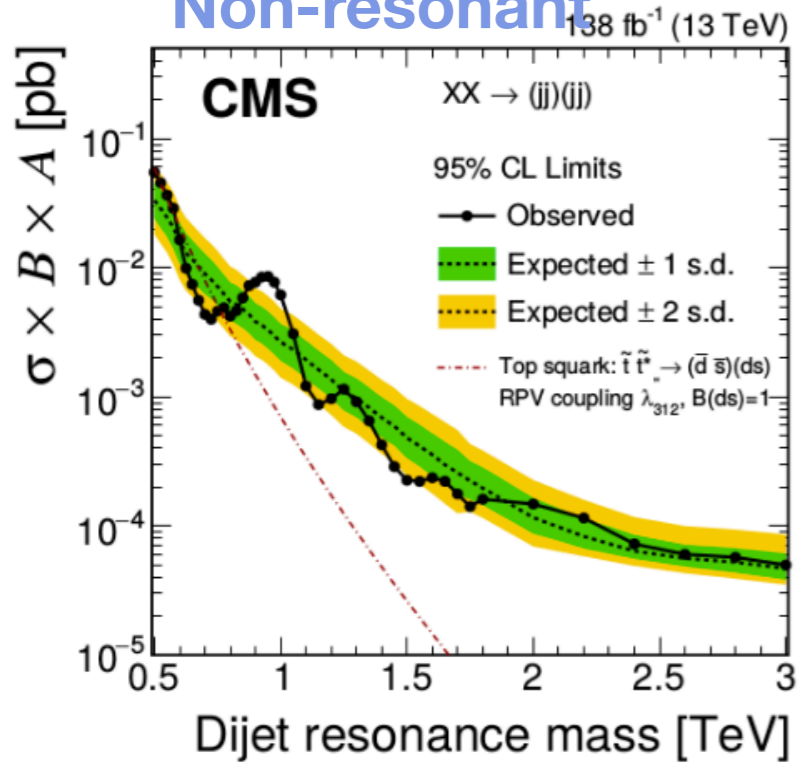
- ▶ Main source: **QCD multijet production**

- ▶ **Fit mass distributions**  $m_{jj}$  and  $m_{4j}$  with empirical functional forms

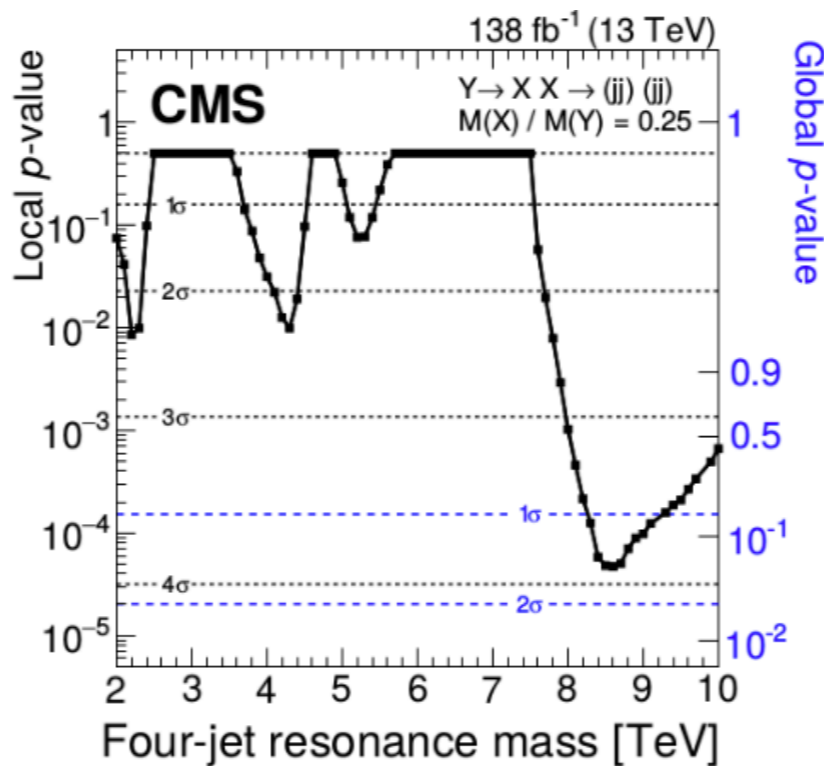
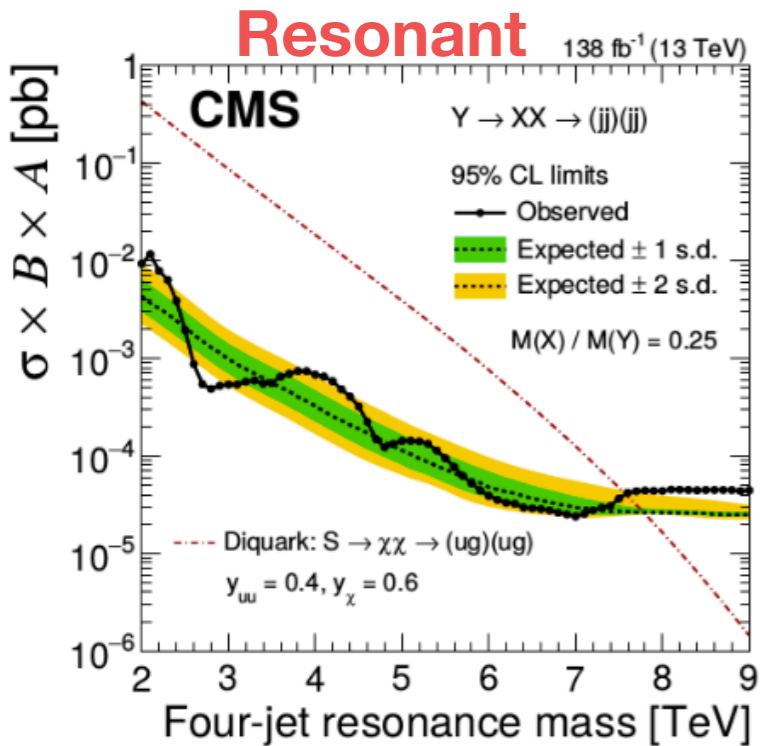


# Search for resonant and non-resonant production of pairs — overview and results

## Non-resonant



## Resonant



### Results:

- **Non-resonant search:**
  - Exclude top squark masses below  **$\sim 770 \text{ GeV}$**  (previous result in CMS at 520 GeV)
  - Highest local significance of  **$3.6\sigma$**  ( **$2.5\sigma$  global**) for a resonance mass at 1 TeV
- **Resonant search:**
  - Highest local significance of  **$3.9\sigma$**  is observed ( **$1.6\sigma$  global**) for a mass of 8.6 TeV

# Conclusion

- Unless **no significant excess** observed, **limits are given** for several BSM models
- These results are a **little part of the whole CMS results**
  - ▶ **B2G:**
    - <http://cms-results.web.cern.ch/cms-results/public-results/publications/B2G/index.html>
    - <http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/B2G/index.html>
  - ▶ **EXO:**
    - <http://cms-results.web.cern.ch/cms-results/public-results/publications/EXO/index.html>
    - <http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/EXO/index.html>
  - ▶ **SUSY:**
    - <http://cms-results.web.cern.ch/cms-results/public-results/publications/SUS/index.html>
    - <http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/SUS/index.html>
- All these **results should not be here without the effort of DPGs (detector performance) and POGs (particle object)** to give us very high quality data, thank you very much!
- **Run2 is finished but analyses still ongoing** on these data
- **Run3 began!** We're all in starting-blocks to find new physics, thanks to new triggers developed during the Long Shutdown