CMS searches for new physics in hadronic final states

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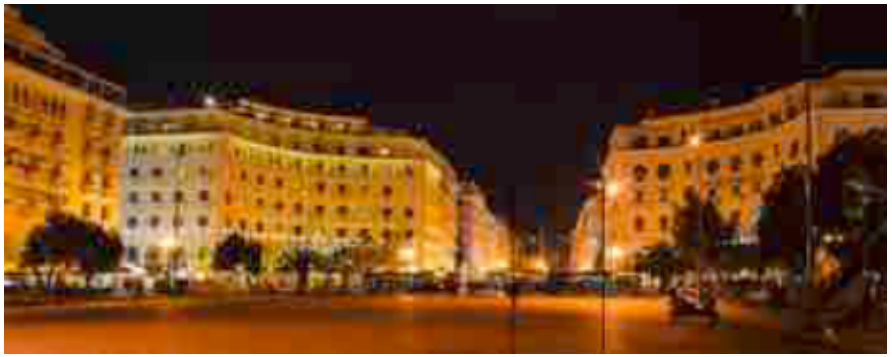
on behalf of the CMS collaboration



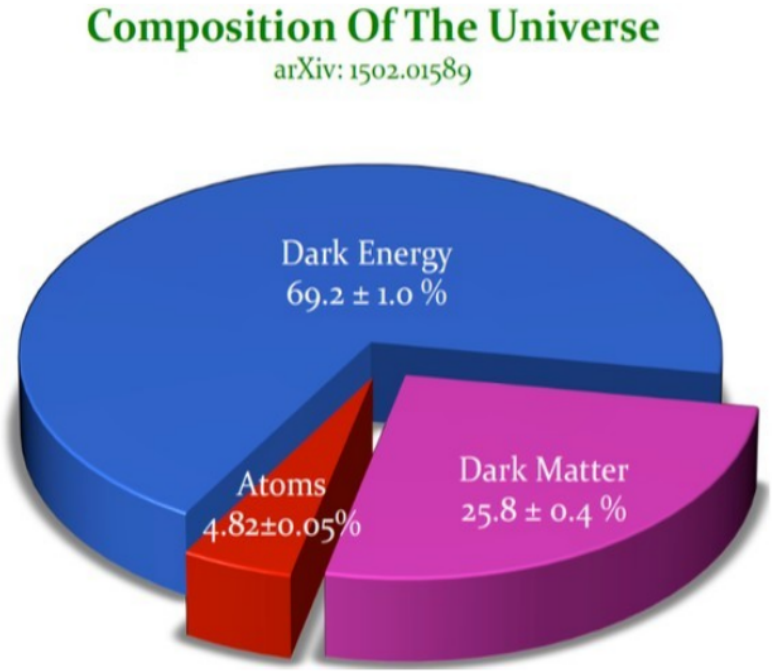
HEP2022: 39th Conference on Recent Developments in HEP and Cosmology, 15-18 Jun 2022, Thessaloniki

Outline

- Motivation
- Methodology
- Searches for new physics in hadronic final states
  - only selected results using the full Run II data will be shown
  - many more results are available at CMS EXO public results.
- Summary

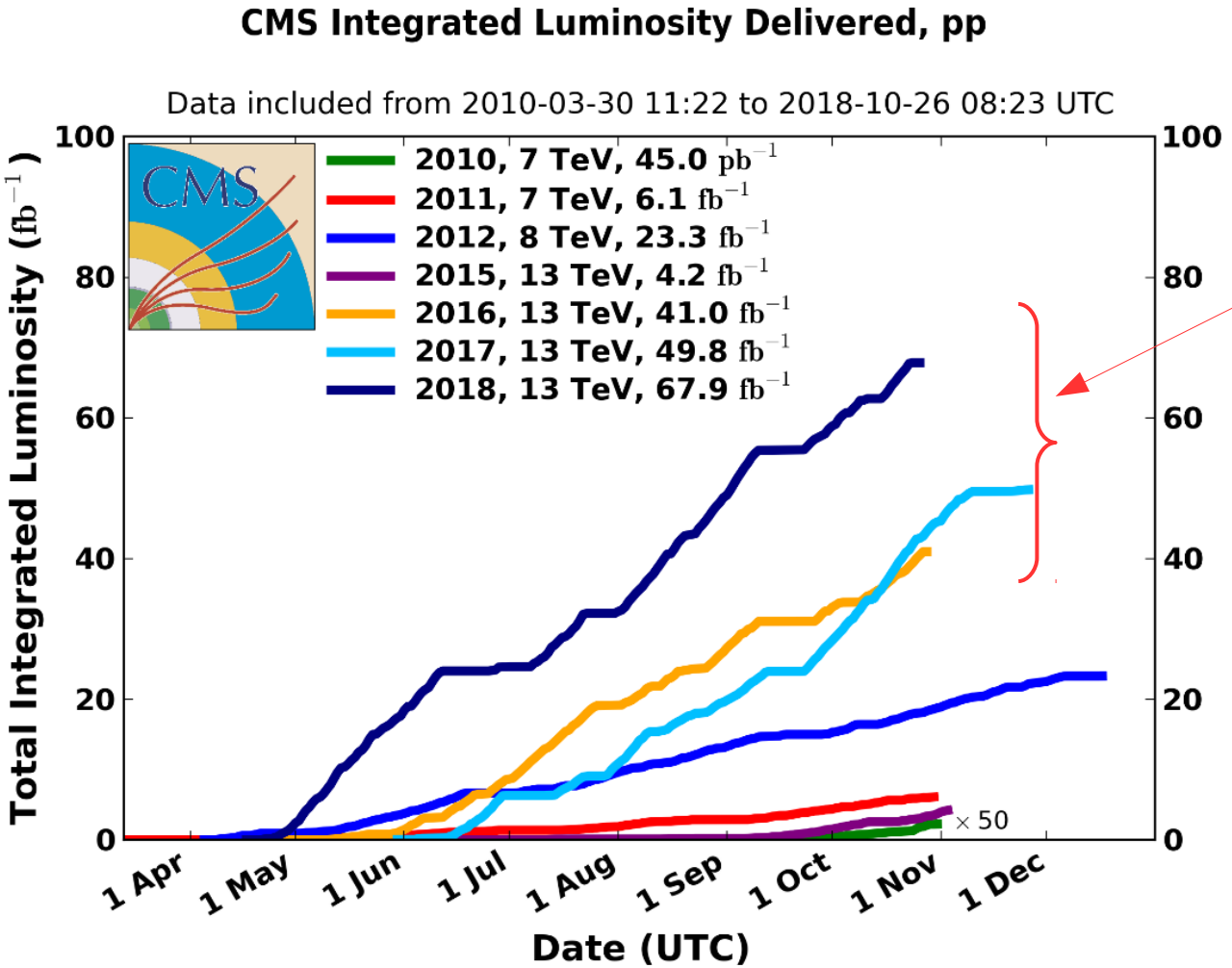
Motivation

- The Standard Model (SM) of particle physics is incomplete:
  - Why is there an imbalance of matter and antimatter in the universe?
  - How does gravity fit into our model?
  - Why do quarks and leptons come in three generations? Are they elementary particles?
  - What is 95% of the Universe made of?



- Many models of physics that extend the SM often require new particles that couple to quarks and/or gluons and decay to jets.

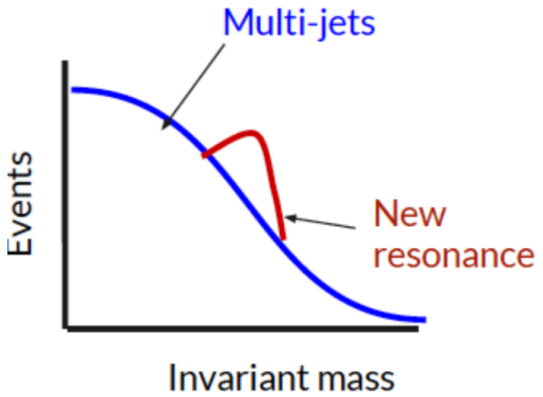
The LHC accelerator



- **Full Run II** consists from **2016-2018 data:** total integrated luminosity: **138 fb^{-1}**
- LHC Accelerator had an excellent performance so far.
- Expected the same in Run III.

General Analysis Methodology

- **Analysis Strategy**: search for a narrow or wide resonance on top of a smoothly falling background.



- **Background Estimation**:
  - Data-driven: Fitting the invariant mass with an empirical function.
  - Semi data-driven: i) Predicting the SM background from control regions with transfer factors to the signal region from simulation. ii) Simulation used for the background predictions, with control regions utilized to constraint the simulation.

- **Signal Modeling**: Intrinsic signal shape, either narrow (with width smaller than the detector resolution) or broad or using generic gaussian shape.

- **Limit Extraction & Significance Estimation**: the jet invariant mass spectrum is fit using the estimated background and signal templates with systematics as nuisance parameters. For limit estimation, the test statistic is the profile likelihood ratio.

Jet resonance searches in CMS

There is a variety of recent resonance searches in CMS, with jets in final states using data from Run II.
A selection of recent Full Run II results will be discussed in this talk:

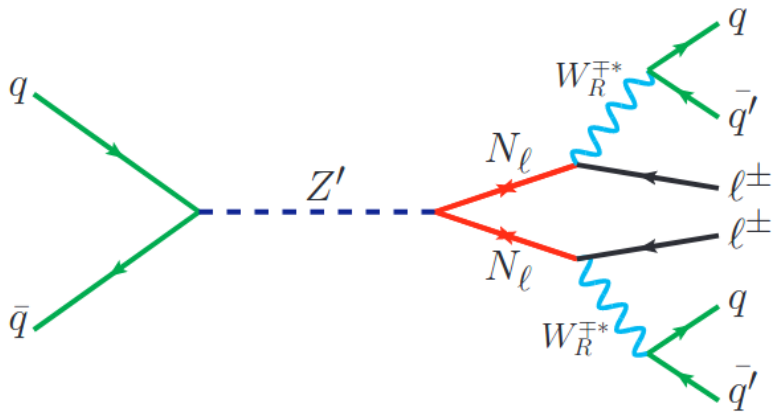
- Search for Z′ bosons decaying to **pairs of heavy Majorana neutrinos** (**CMS-EXO-20-006**)
- Search for narrow resonances in the **b-tagged dijet mass** spectrum (**CMS-EXO-20-008**)
- Search for high-mass resonances decaying to **a jet and a Lorentz-boosted resonance** (**CMS-EXO-20-007**)
- Search for **resonant and nonresonant** production of **pairs of dijet** resonances (**CMS-EXO-21-010**)

Pairs of Majorana Neutrino Search

CMS-EXO-20-006

Experimental Signature:

- Two same-flavor leptons and four jets.
- The kinematics of two leptons and jets depends on $m_N/m_{Z'}$ => resolved and boosted probe



SR	N(AK8 jet)	N(tight leptons)	N(AK4 jet)
SR1 (0AK8)	$=0$	$=2$	≥ 4
SR2 (1AK8)	$=1$	≥ 1	≥ 2
SR3 (2AK8)	≥ 2	—	—

- Reconstruct m_N as m_{jjl} and $m_{Z'}$ minimizing m_{jjl} asymmetry

Backgrounds:

Main: $t\bar{t}$ and Drell-Yan Others: dibosons, W+jets and single top quarks.
The main backgrounds are estimated using control regions.

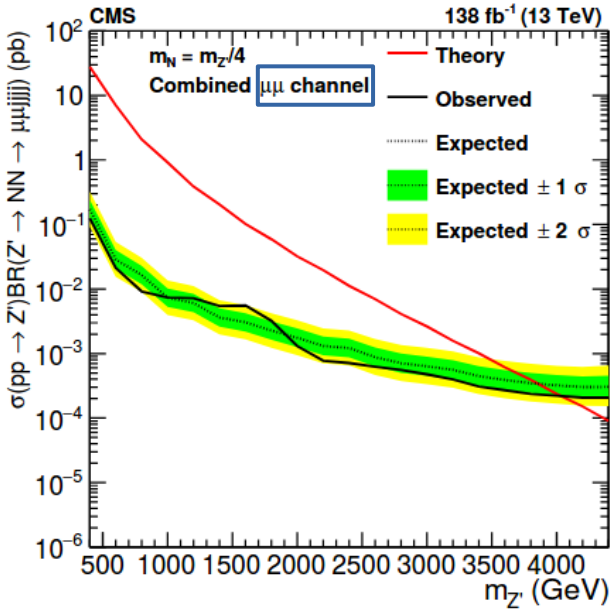
Signal Model:

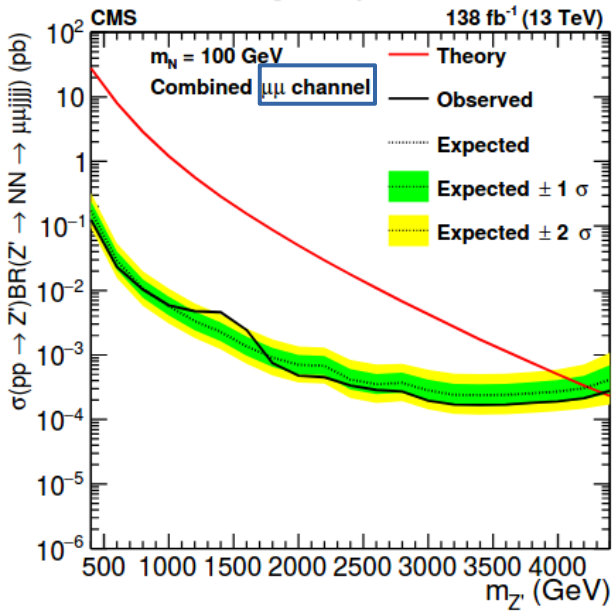
Left-right symmetry model (LRSM): 3 additional gauge bosons: $W^{\pm}_R$, and Z' and 3 right-handed neutrinos (N_e, N_μ, N_τ).

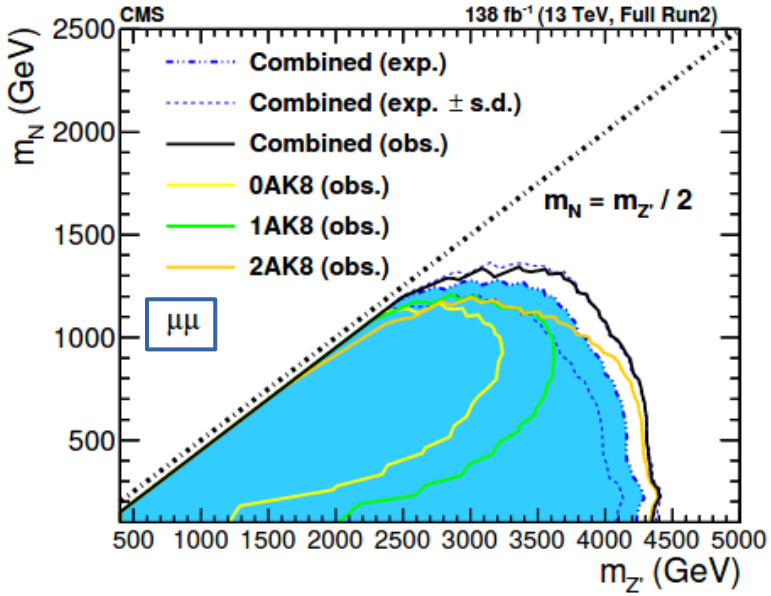
Results on pairs of Majorana Neutrino Search

CMS-EXO-20-006

- **Maximum likelihood fit in the mass of Z' performed in the SRs (simultaneous fit with CRs).**





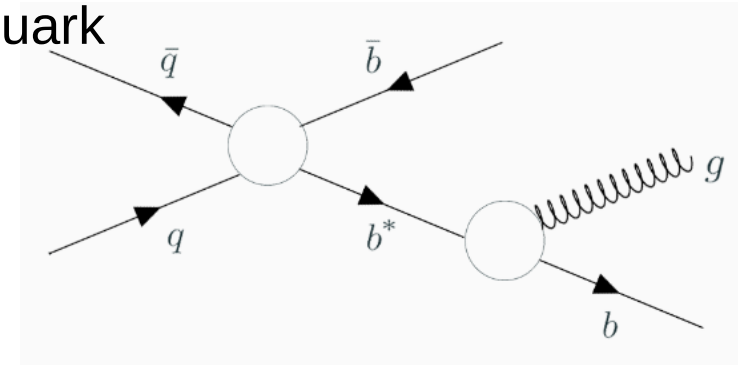


- **The first results of this process using the Run 2 data.**
- **The most restrictive direct limits in the phase space of $m_{Z'}$ vs. m_N to date.**

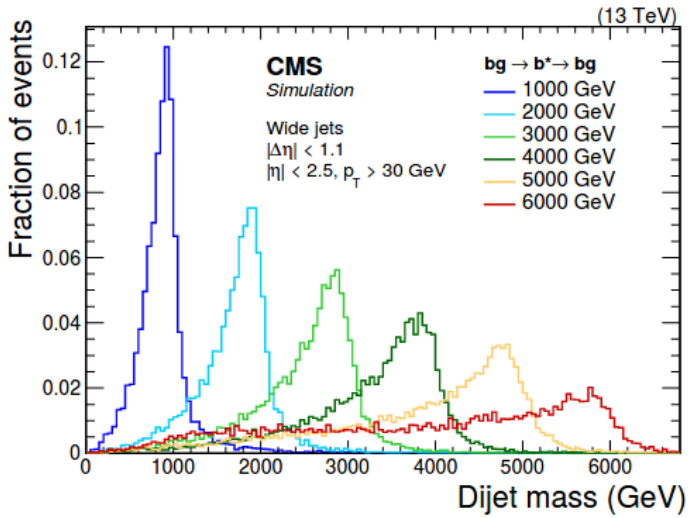
Di-b-jets Search

CMS-EXO-20-008

Experimental Signature:
Two jets, with at least one jet originating from a b quark (b-tagged using the DeepJet tagger.)



Main backgrounds:
Multijet QCD production estimated with a data-driven method, using several parametric functional forms.



Signal Models:

b* -> bg

- Quark Compositeness
- Considered two production modes:
  bg→ b* and qq→ b*+b

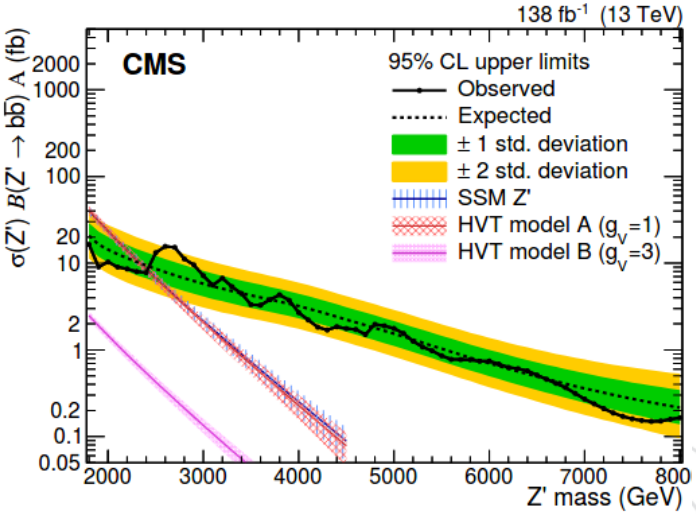
Z' -> bb

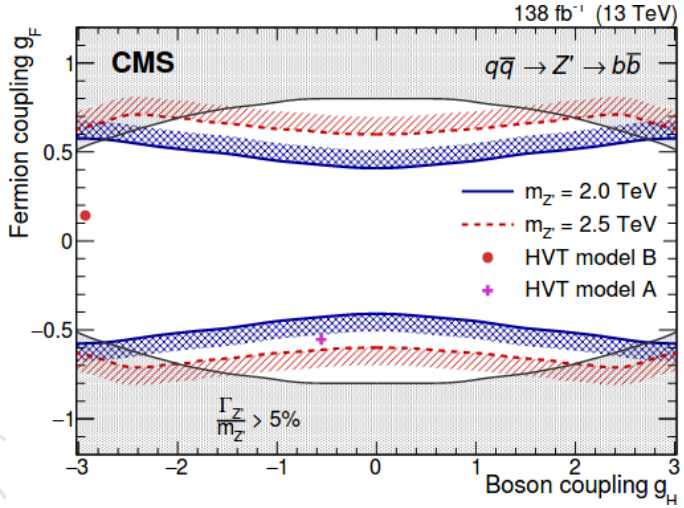
- Sequential SM (SSM) or Heavy Vector Triplet (HVT) model with i) similar coupling to fermions as to gauge bosons (Model A) and ii) suppressed fermionic couplings (Model B).

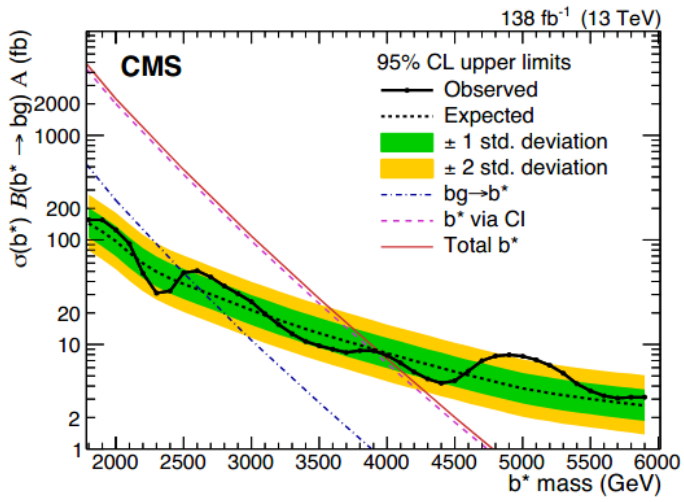
Results on Di-b-jet Search

CMS-EXO-20-008

- **Maximum likelihood fit in the dijet mass performed in the SR.**







- Z' masses between 1.8 and 2.4 TeV at 95% CL are excluded, new HVT model explored, limits are set on the coupling strengths of the HVT boson to SM bosons and fermions.
- Excited b quarks with mass from 1.8 to 4.0 TeV are excluded at 95% CL. **This is the most stringent exclusion of excited b quarks to date.**

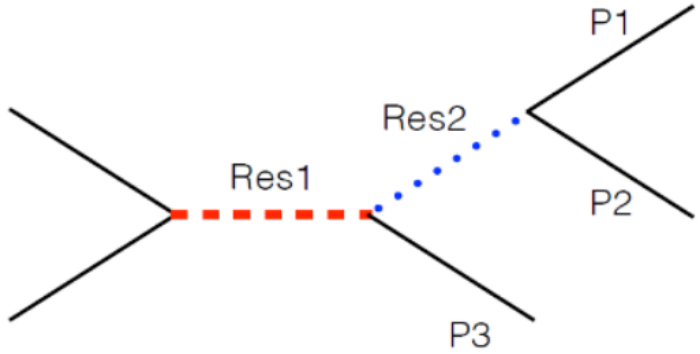
Di-tri-jets Search

CMS-EXO-20-007

Experimental Signature:

Two large-radius (wide) resolved jets, one coming from R2 (R2-jet) and one coming from the third parton (P3-jet):

- pp → R1 → R2+P3 → (P1+P2) +P3
- P1, P2, P3 are gluons



Main backgrounds:

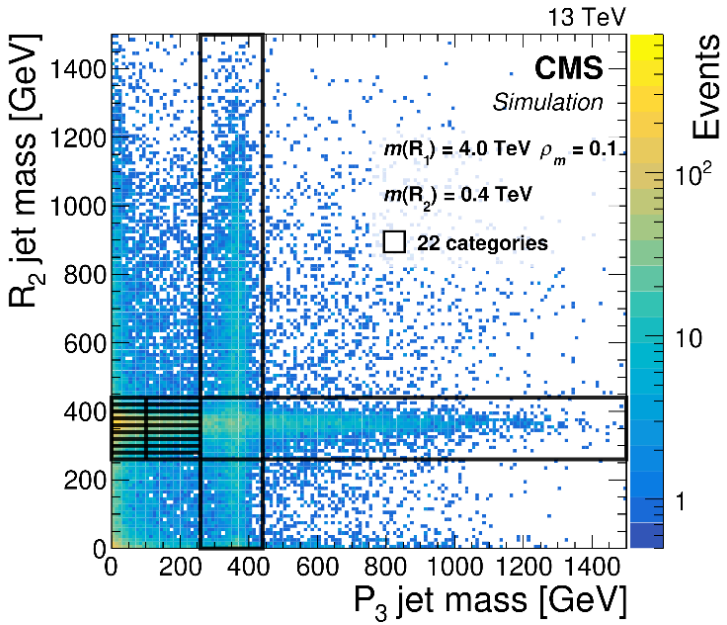
Multijet QCD production estimated with a data-driven method, using several parametric functional forms. Discrimination between signal and QCD background, by exploiting jet substructure information and kinematics of the decay.

Signal Models:

Warped extra dimensions where R1 is a KK gluon (GKK), R2 is a radion (φ)

- GKK → φg → ggg (trijet)

Search largely model independent.

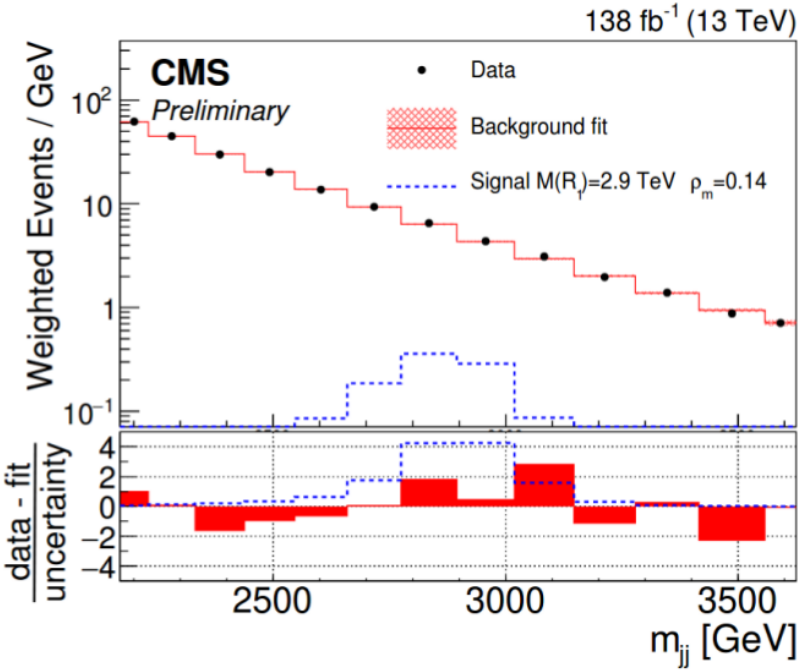


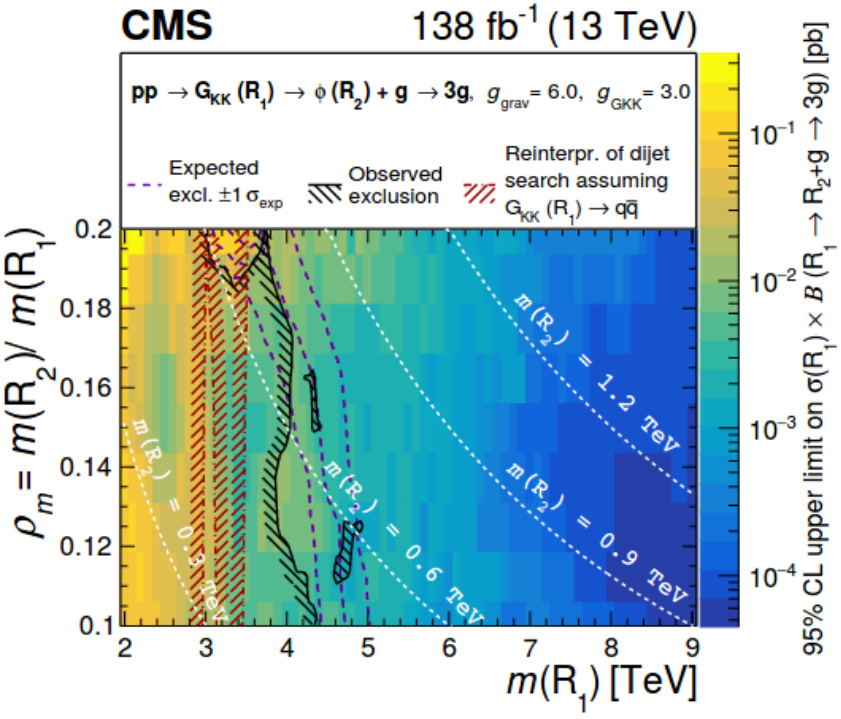
22 SRs defined in the m(R2)/m(P3) plane.

Results on Di-tri-jets

CMS-EXO-20-007

- **Maximum likelihood fit in the dijet mass performed in the SRs.**



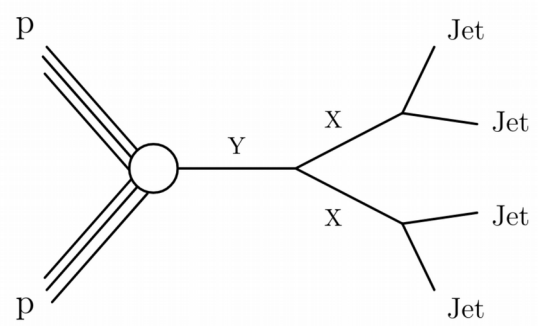


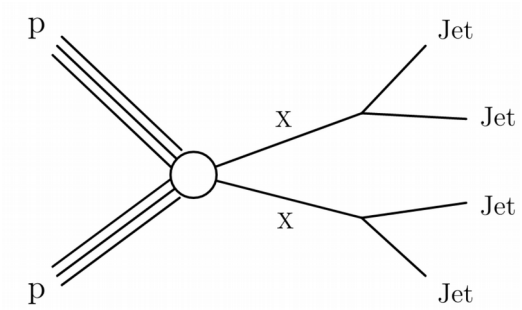
- **Excess: 1.8 σ global (3.2 σ local) → look into on Run III.**
- By exploring a novel experimental signature, **we extend significantly the experimental exclusion of this benchmark model** of new physics at the LHC.

Paired Dijet Search

CMS-EXO-21-010

Experimental Signature:
Four or two resolved jets paired to same mass resonances.





Main backgrounds:
Multijet QCD production estimated with a data-driven method, using several parametric functional forms.

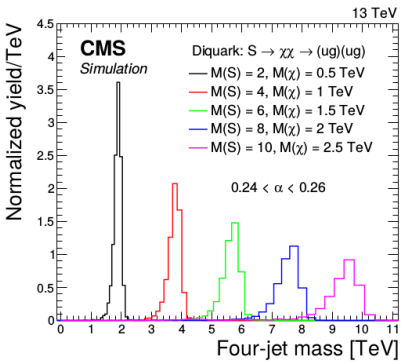
Signal Models:
Two modes of pair production of dijet resonances

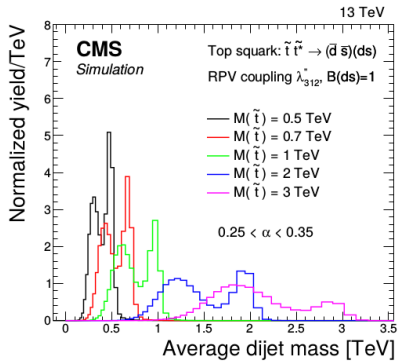
- **Resonant** → Benchmark model: Diquark decaying to vector-like quarks which decay to an up quark and gluon.

$$uu \to S \to \chi\chi \to (ug)(ug)$$

- **Non-resonant** → Benchmark model: R-parity violating stop pairs decaying to a d and s quark.

$$pp \to \tilde{t}\tilde{t}^{*} \to (\bar{d}\bar{s})(ds)$$

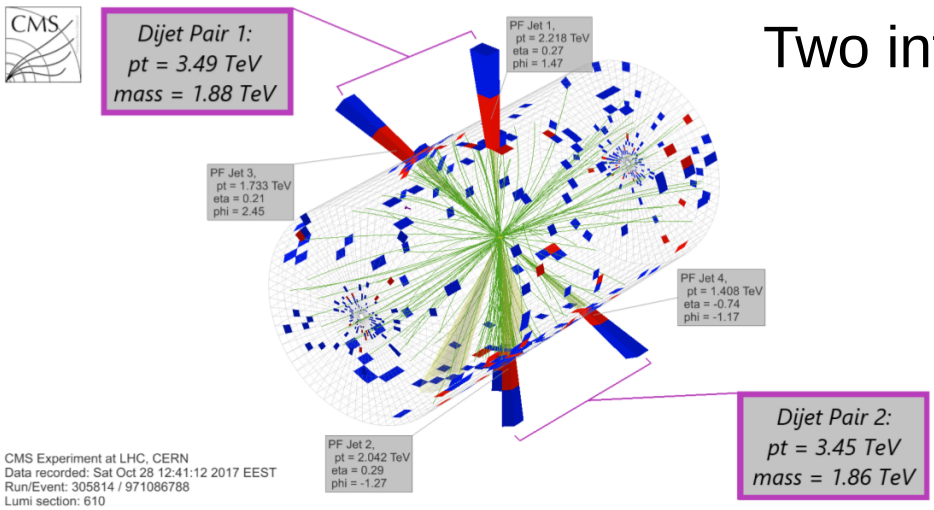


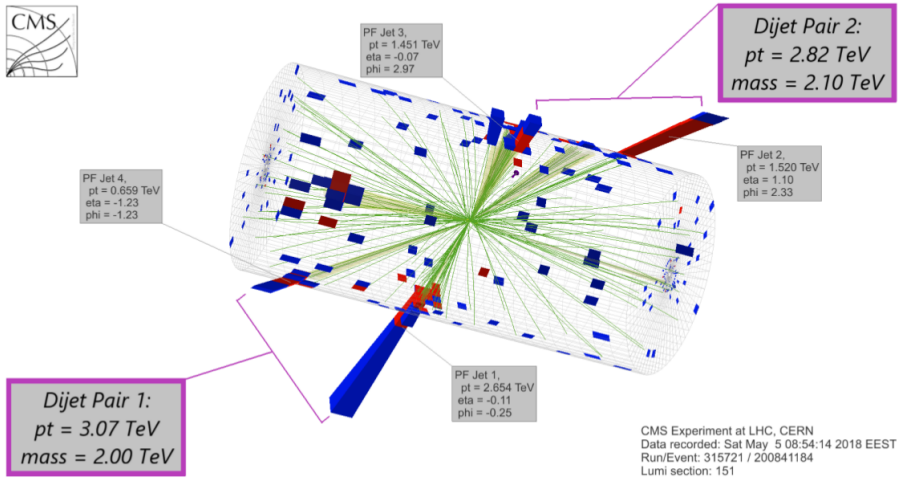


Search largely model independent.

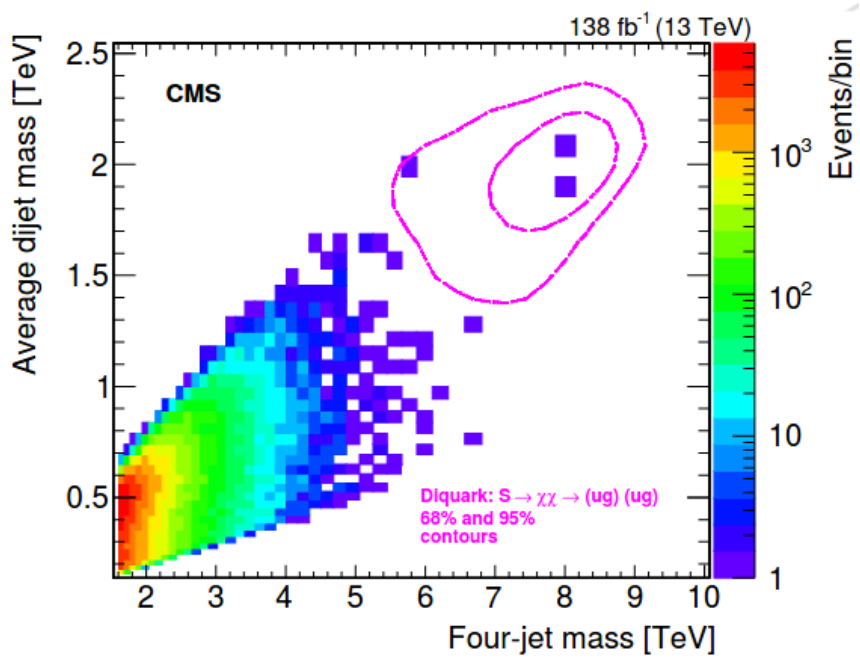
Resonant search

CMS-EXO-20-010





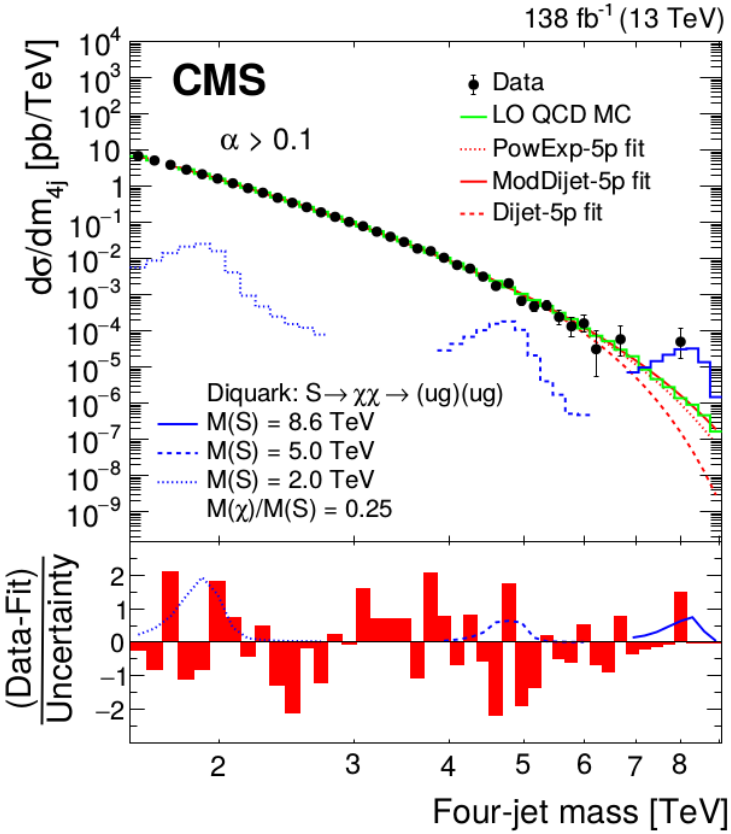
Two interesting events found in this analysis.

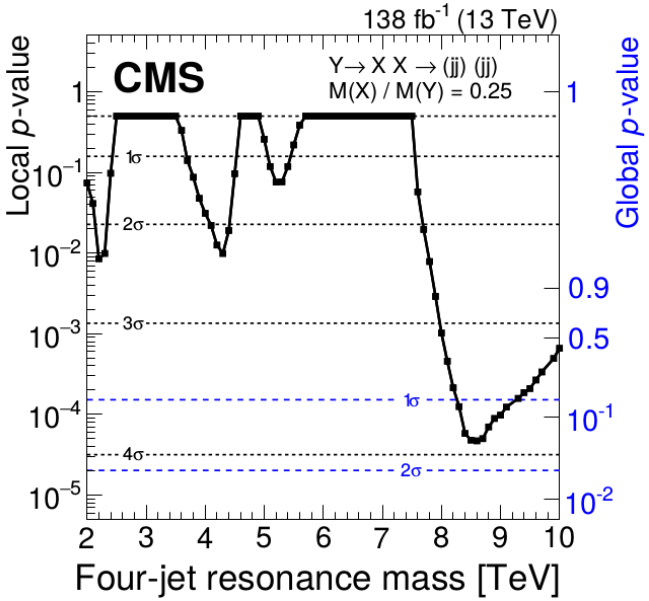


Results of resonant search

CMS-EXO-20-010

- **Maximum likelihood fit in the four jet mass performed in the SRs**





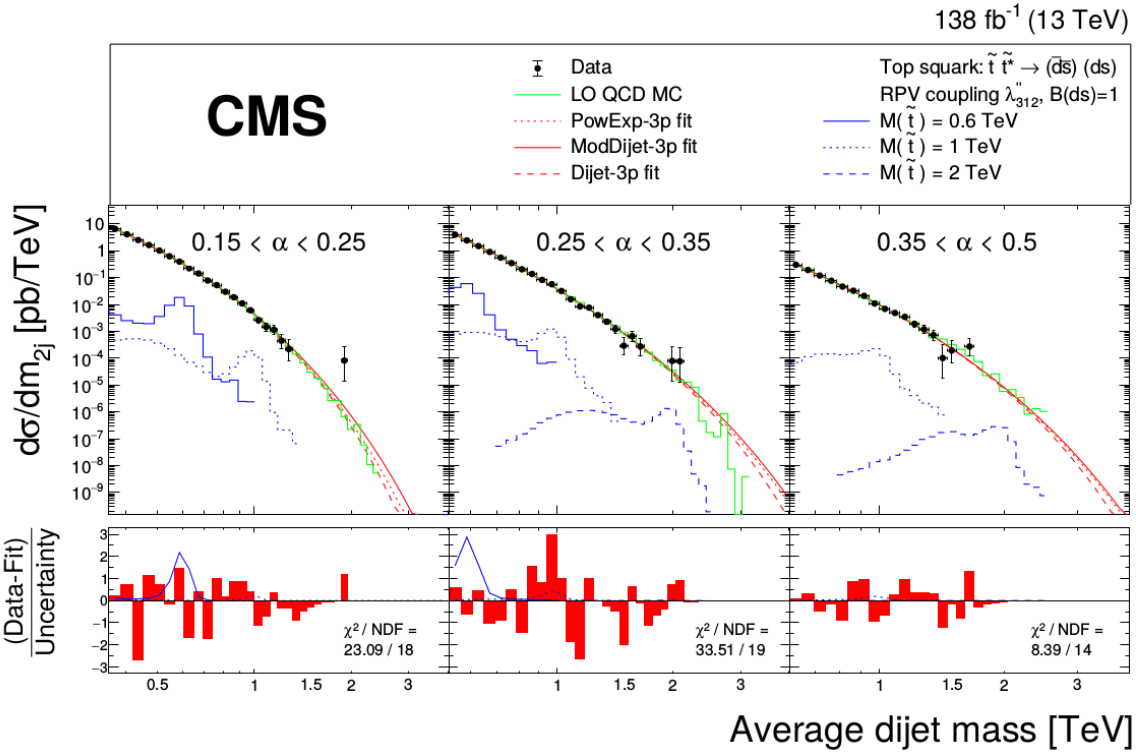
Excess: 1.6 σ global (3.9 σ local) → look into on Run III.

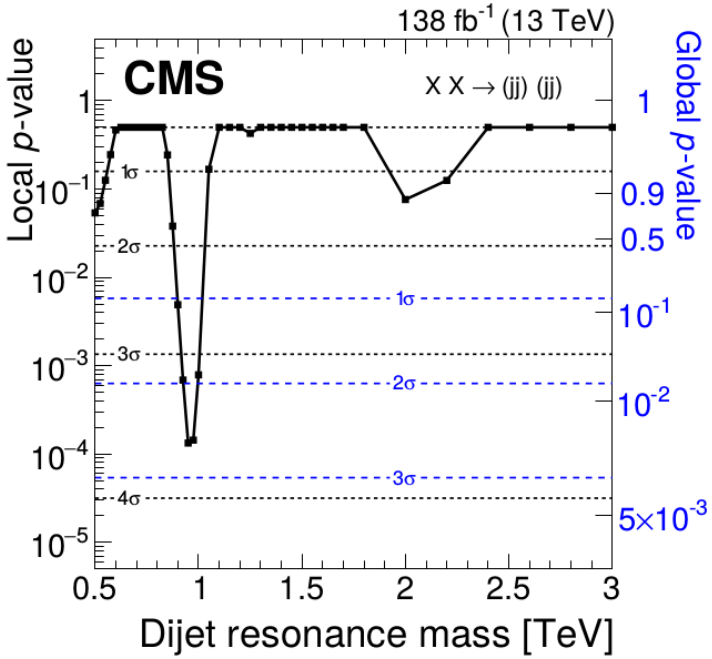
- These are the **first LHC limits on resonant pair production of dijet resonances via high mass intermediate states.**

Results of nonresonant search

CMS-EXO-20-010

- **Maximum likelihood fit in the average dijet mass performed in the SRs.**





- **Excess: 2.5 σ global (3.6 σ local) → look into on Run III.**
- **Results significant extend the previous limits.**

Summary

- **Hadronic final states offer great sensitivity to many models of new physics.**

- Searches for hadronic resonances in CMS were presented:
  - No significant deviations from SM so far but several excesses to keep an eye and to drive us where to look next.
  - Constraints in several benchmark models.

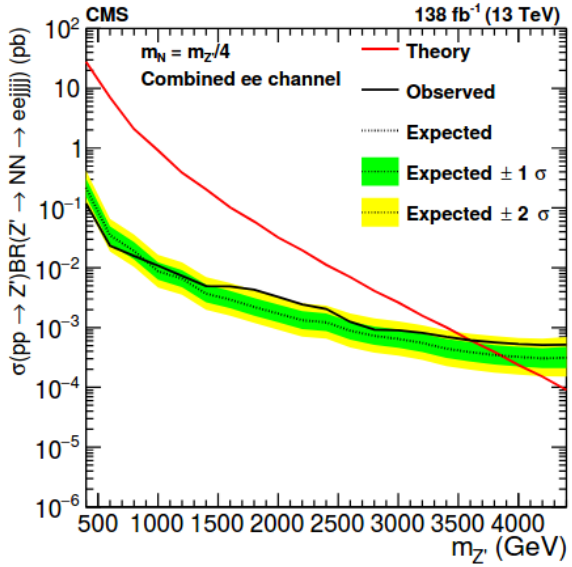
- Significant **improvements** due to
  - Data driven methods to estimate the background.
  - Jet sub-structure techniques.
  - Increased luminosity with full Run II datasets.
  - New final states are explored.

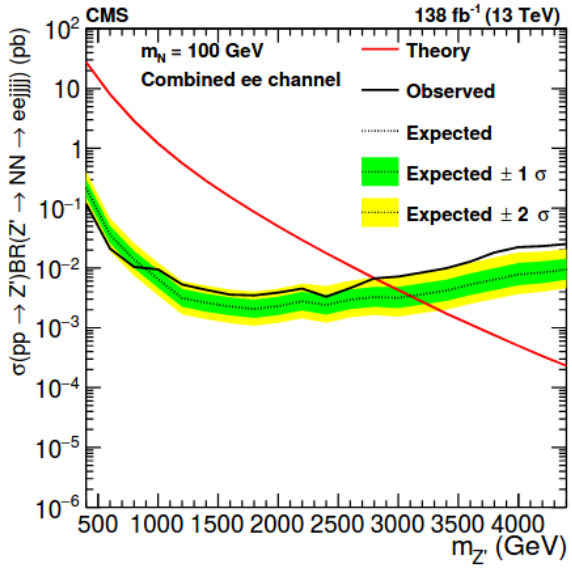
- **Hope that with all the improvements and advancements on reconstruction, trigger, analysis approaches and techniques, we should be able to fully exploit the Run III discovery potential and either make a discovery, or improve limits beyond luminosity scaling.**

Thank you!

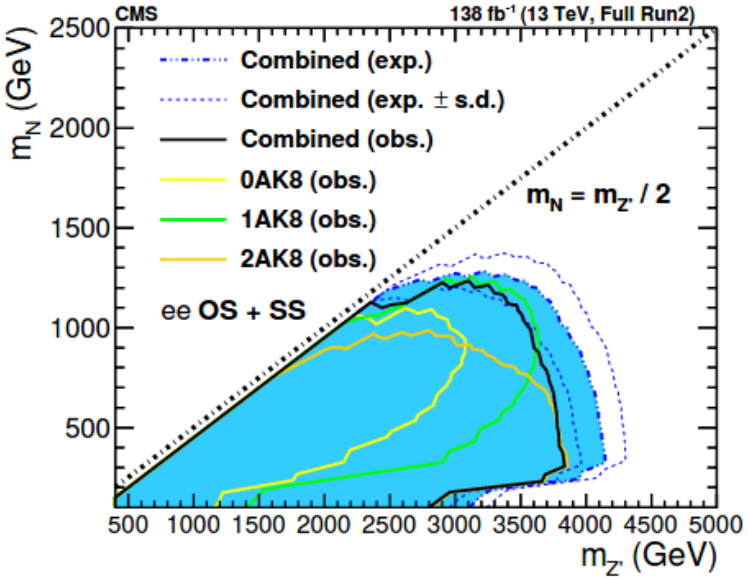
Back up

Pairs of Majorana Neutrino Search



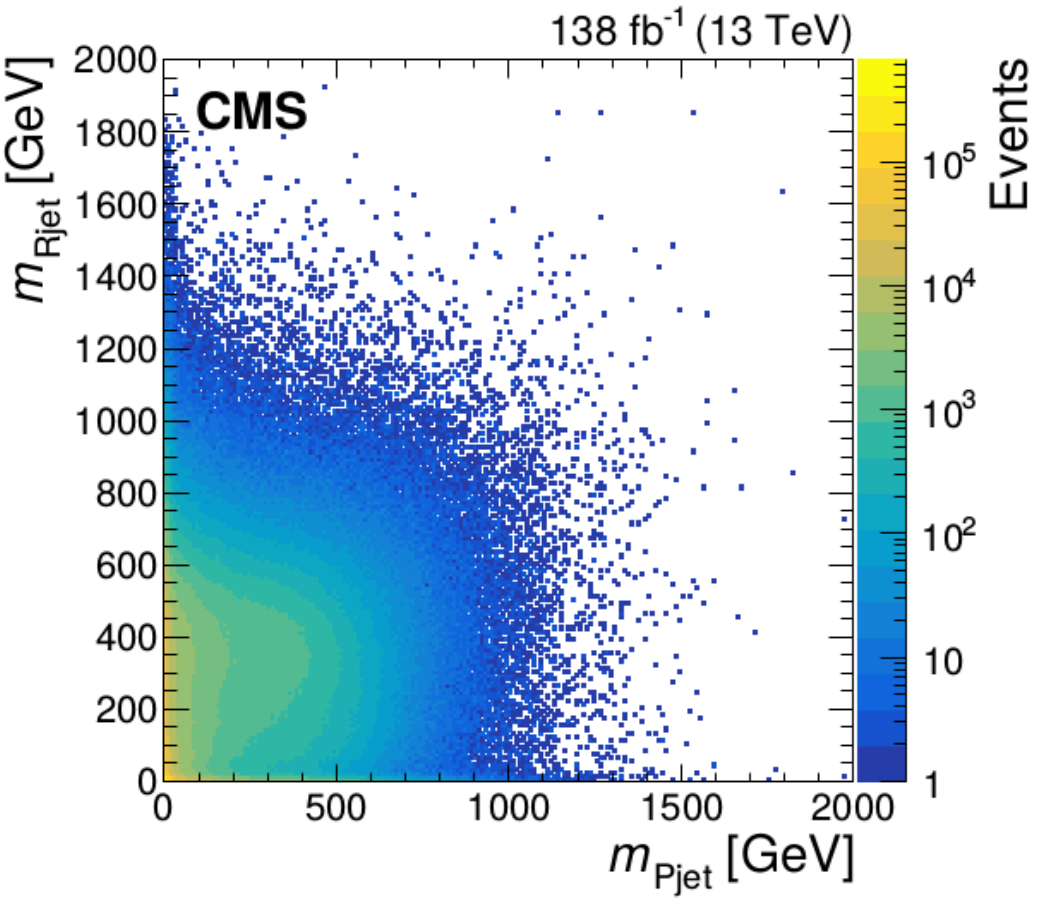


Electron channel



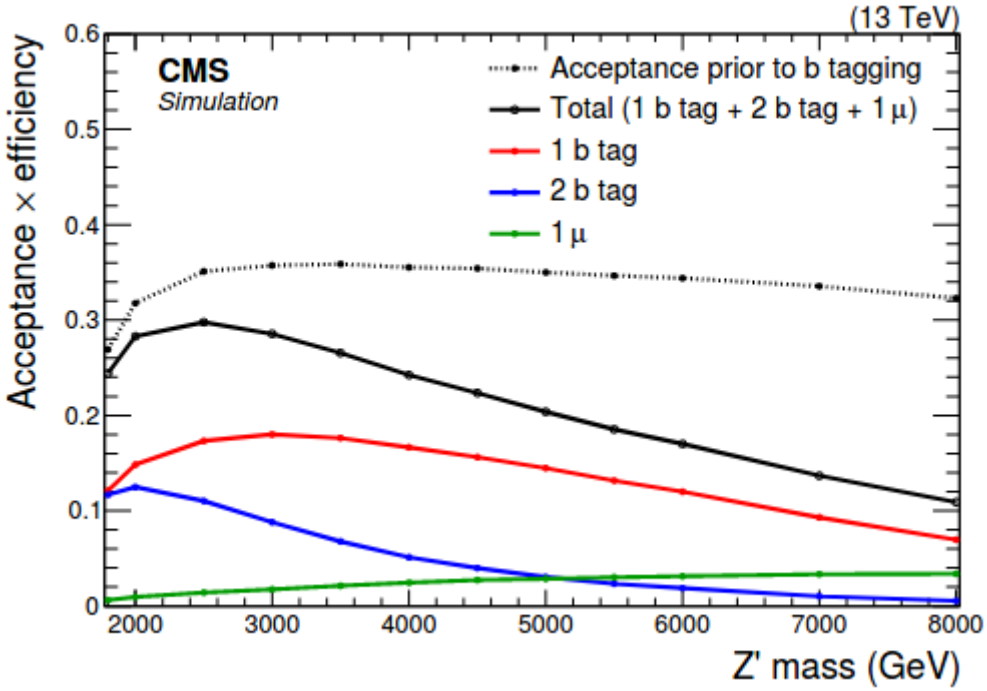
Di-tri-jets Search

QCD



Smooth pattern with a **weak correlation between the two observables**.

Di-b-jets Search



Paired Dijet Search