Searches for new resonances decaying to leptons, photons or jets with CMS

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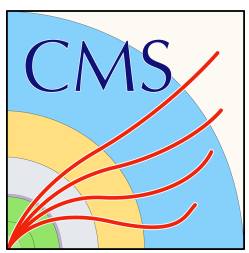


EPS-HEP 2019 - Ghent, July 11

Why search for new resonances?

We know our understanding of physics is incomplete. There are open questions such as

- What is the nature of dark matter? Dark energy?
- How to solve the incompatibility between the Standard Model (SM) and General Relativity at high energies.

New physics theories have been proposed to explain these and other questions.

- e.g. supersymmetry (SUSY), grand unification models, models with extra dimensions.
- Looking for new resonances predicted by these models is a good way to test them.
- It's also important to have model-independent searches, we never know what new physics might be out there.

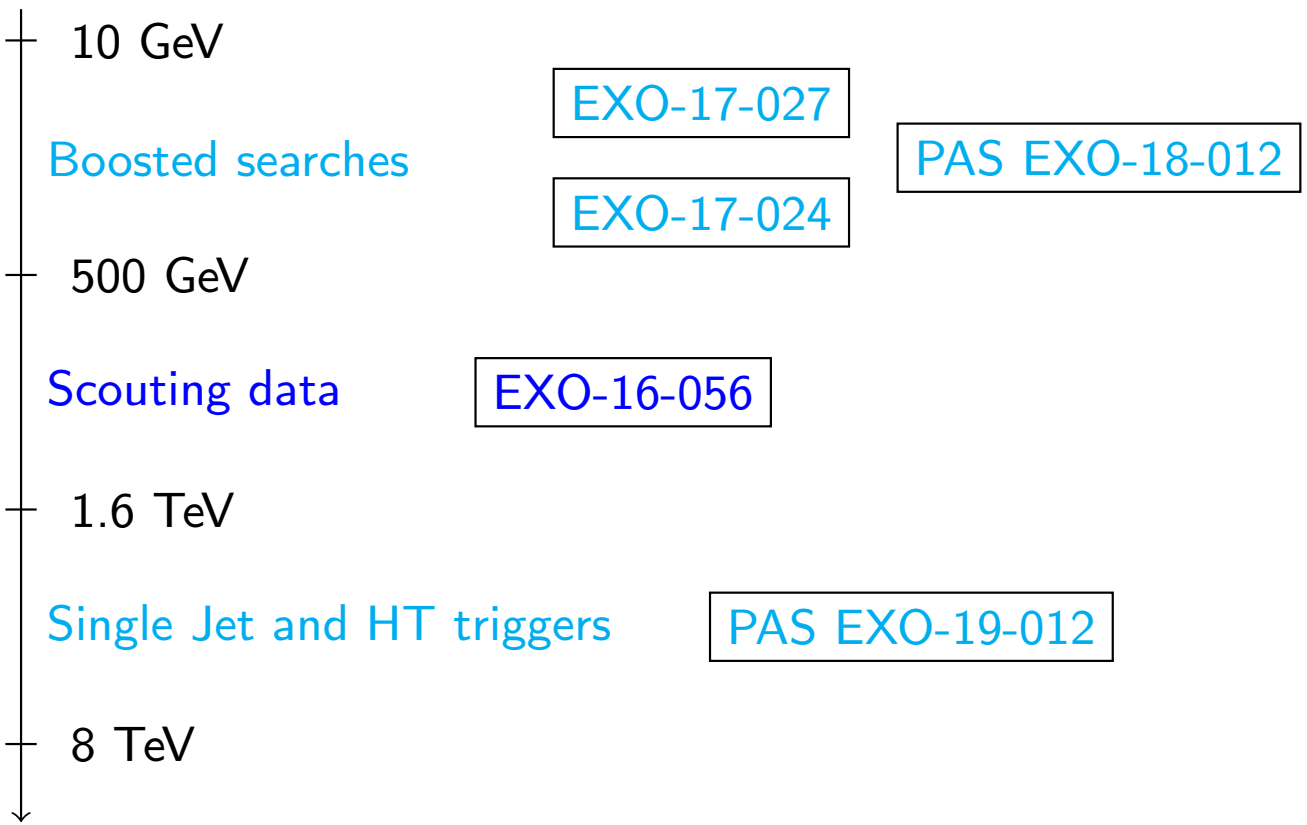
New resonance searches at CMS

Great variety of recent searches for new resonances in CMS.
Included in this presentation (clickable links!) :

- Final states with jets
  - High-mass dijet: CMS PAS EXO-19-012, JHEP 08 (2018) 130.
  - Boosted two-parton searches: PRD 99 (2019) 012005, CMS EXO-17-027, CMS PAS EXO-18-012.
  - Pair-produced 3-jet resonances: PRD 99 (2019) 012010.
- Leptonic final states
  - Dilepton: CMS PAS EXO-19-019.
  - Multilepton: CMS PAS EXO-19-002.
  - Lepton and missing energy (in backup slides) : JHEP 06 (2018) 128, PLB 792 (2019) 107.
- Diphoton final state (in backup) : PRD 98 (2018) 092001.

Jet resonance searches

Searches for new resonances in two-parton (qq, qg, gg) final states have been performed for invariant masses all the way from ∼10 GeV to almost 8 TeV. Different trigger strategies are needed for different mass ranges.



High mass dijet searches

New paper with full Run2 data: CMS EXO-19-012

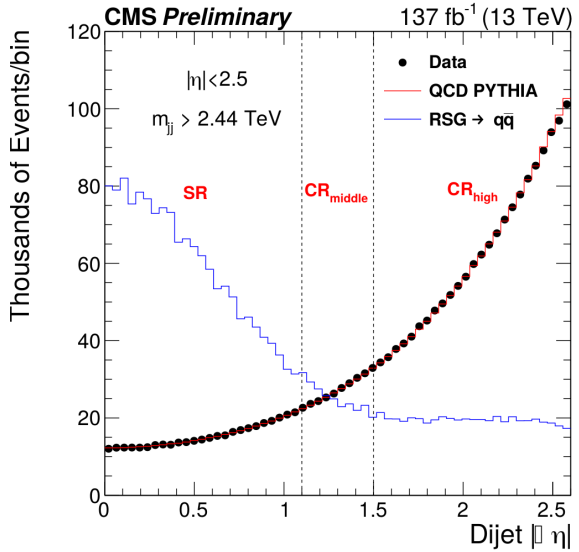
- Trigger: H_T and single-jet.
- Wide jet construction: $\Delta R < 1.1$.
- QCD multijets bg suppressed by $|\Delta\eta| < 1.1$.
- QCD modeled by $\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3\ln(x)}}$ where $x = \frac{m_{jj}}{\sqrt{s}}$.
- New data-driven method (based on $|\Delta\eta|$ side-bands): enhances sensitivity to broad resonances:

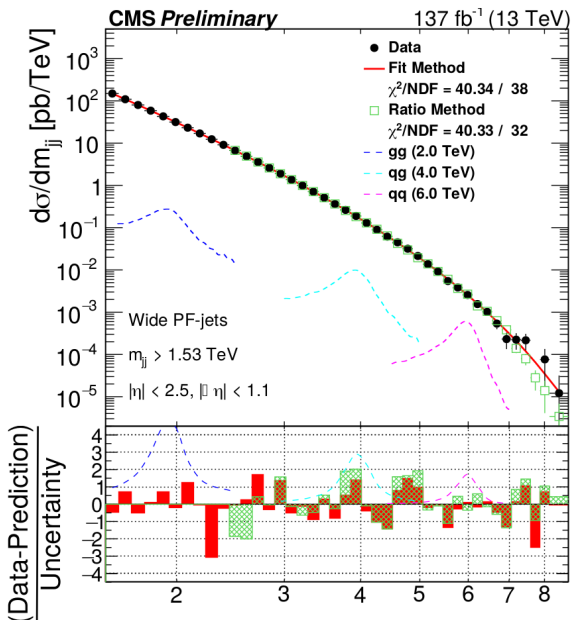
$$N_{\mathrm{SR}}^{\mathrm{Prediction}} = R \cdot N_{\mathrm{CR_{high}}}^{\mathrm{Data}}$$

$$R = C \cdot \frac{N_{\mathrm{SR}}^{\mathrm{Simulation}}}{N_{\mathrm{CR_{high}}}^{\mathrm{Simulation}}}$$

$$C = \frac{R_{\mathrm{aux.}}^{\mathrm{Data}}}{R_{\mathrm{aux.}}^{\mathrm{Simulation}}} = p_0 + p_1 \cdot \left(\frac{m_{\mathrm{jj}}}{\sqrt{s}}\right)^3$$

$$R_{\mathrm{aux.}} = \frac{N_{\mathrm{CR_{middle}}}}{N_{\mathrm{CR_{high}}}}$$



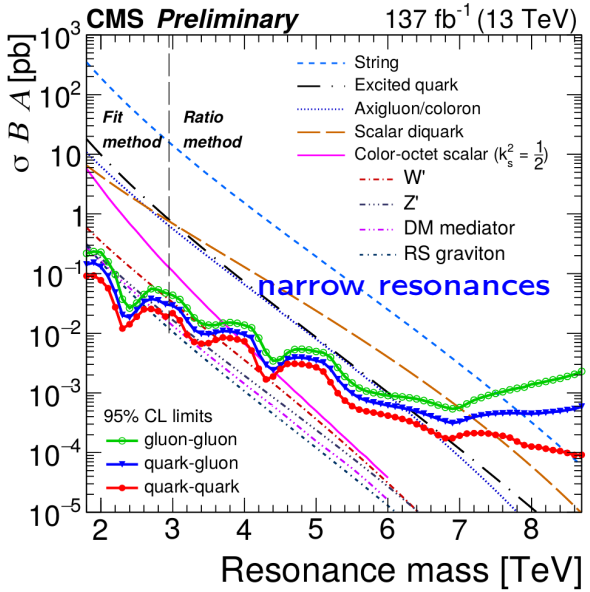


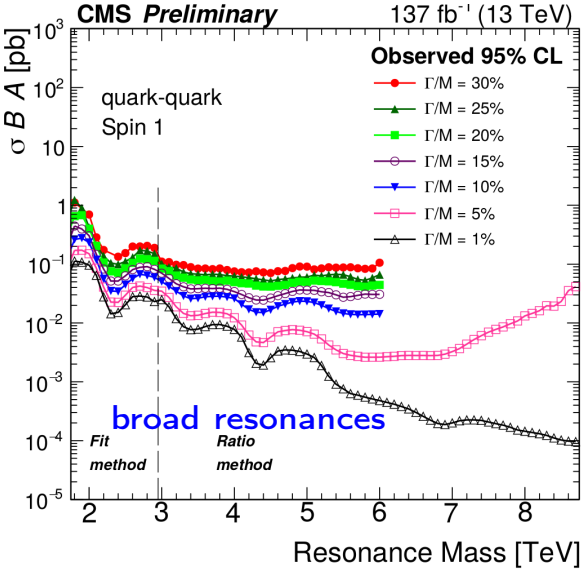
High mass dijet searches: results

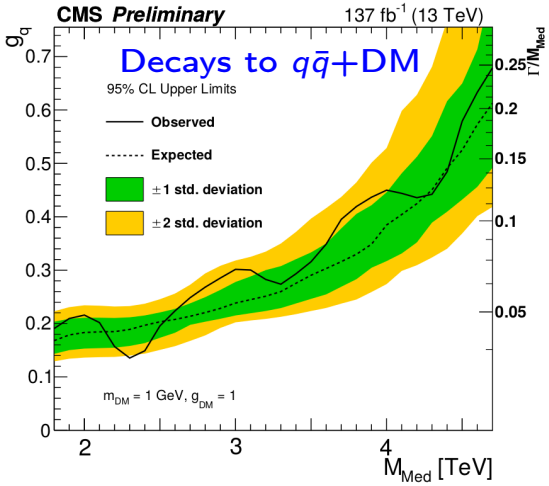
Limits considerably improved since JHEP 08 (2018) 130.

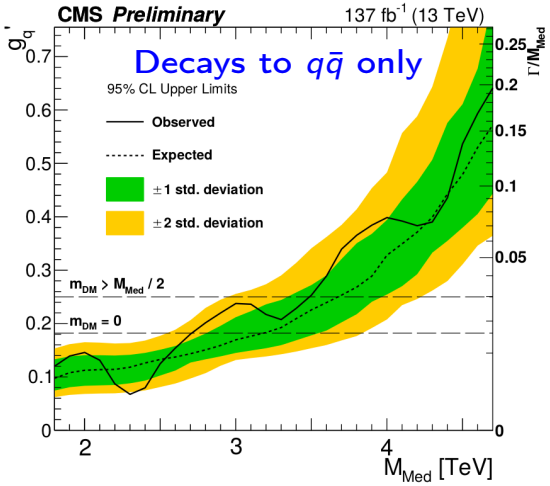
Excluded mass ranges (TeV) at 95% CL:

Model	Old	New
String resonances	<7.7	<7.9
Scalar diquarks	<7.2	<7.5
Axigluons/colorons	<6.1	<6.6
Excited quarks	<6.0	<6.3
Color-octet scalars	<3.4	<3.7
SM-like W'	<3.3	3.6
SM-like Z'	<2.7	<2.9, 3.1-3.3
RS gravitons	<1.8, 1.9-2.5	<2.6
DM mediators	<2.6	2.8





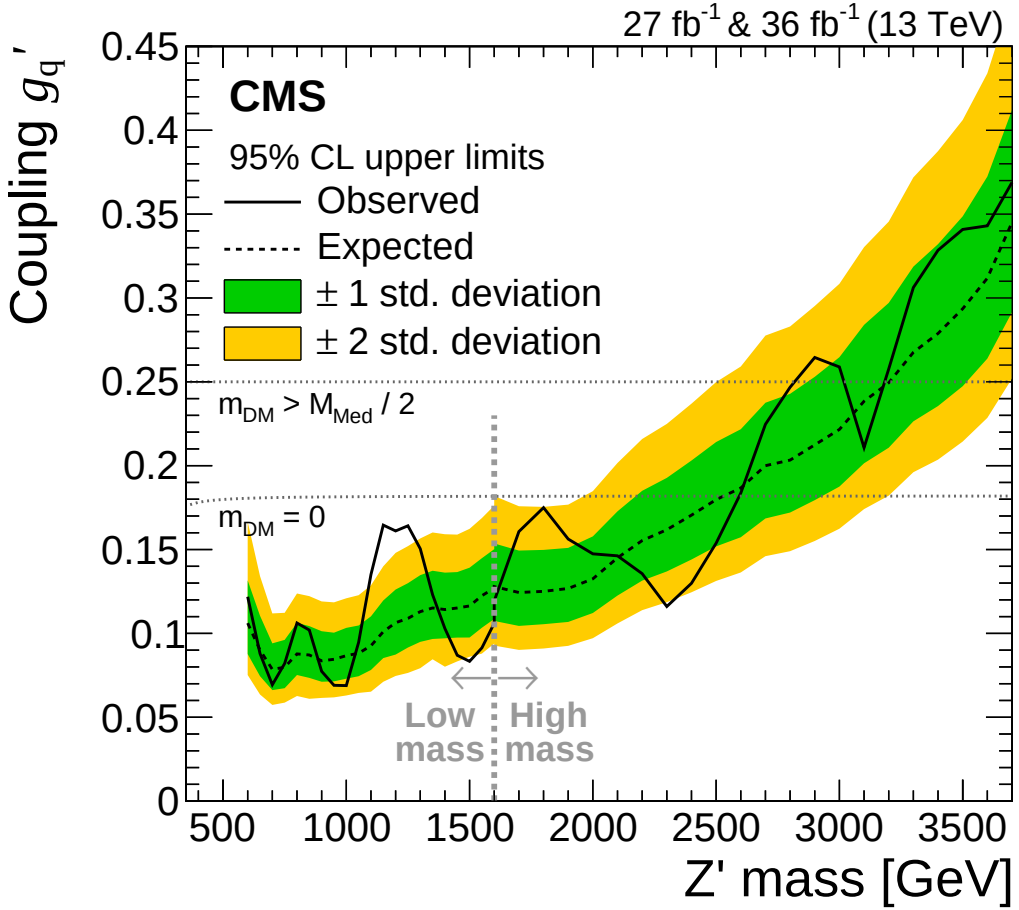




Intermediate mass searches

JHEP 08 (2018) 130 - CMS EXO-16-056 - has results for 0.49 TeV $< m_{jj} <$ 1.6 TeV, with scouting data.

- Limited event reconstruction, calo-jets only.
- Trigger: $H_T > 250$ GeV.
- 2016 data, only 27 fb^{-1} because of a loss of trigger efficiency in part of the data.
- QCD background fit with one extra parameter:
$$\frac{\mathrm{d}\sigma}{\mathrm{d}m_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3\ln(x)+P_4\ln^2(x)}}.$$
- Otherwise same strategy as the high-mass search.



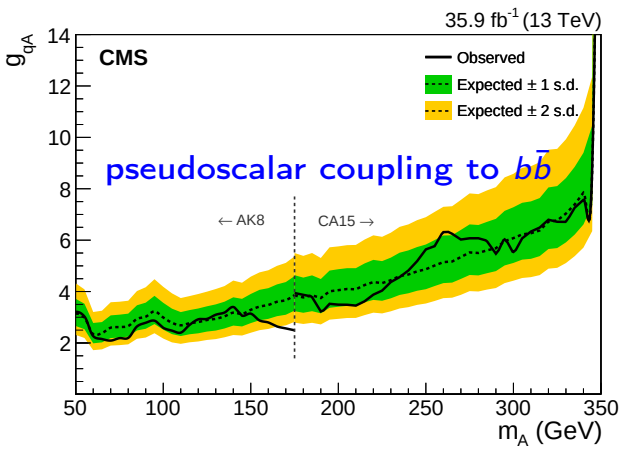
Low mass (boosted) searches

For dijet masses lower than ∼500 GeV, it's no longer possible to trigger directly on the jets we wish to study. Even the scouting trigger thresholds are too high.

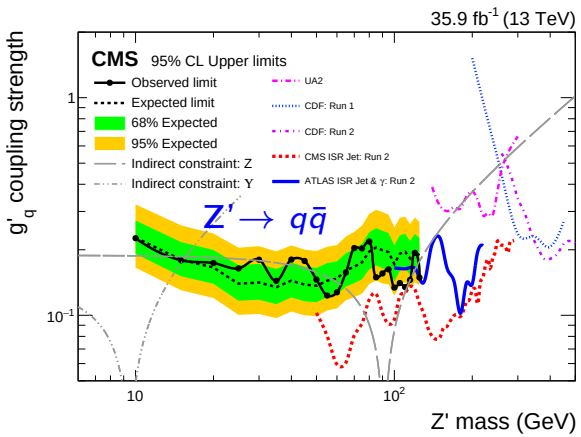
Instead, we look for boosted events, with initial state radiation (ISR).

- The two partons recoil against a high p_T photon or jet.
- In practice, search for one large-radius jet with a two-pronged substructure.
- Soft-drop mass algorithm to remove soft and wide-angle contributions to the jet.

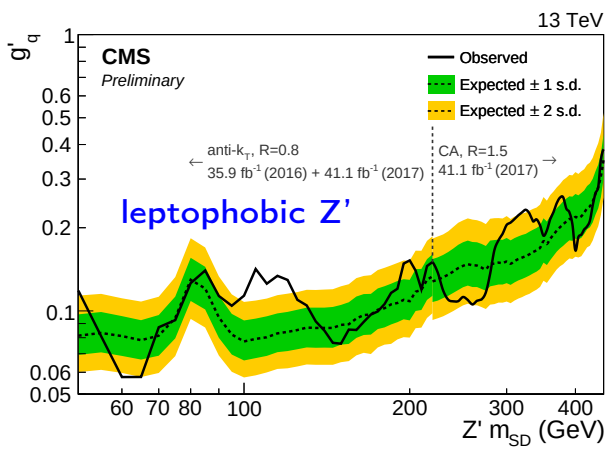
EXO-17-024
PRD 99 (2019) 012005



EXO-17-027
Submitted to PRL



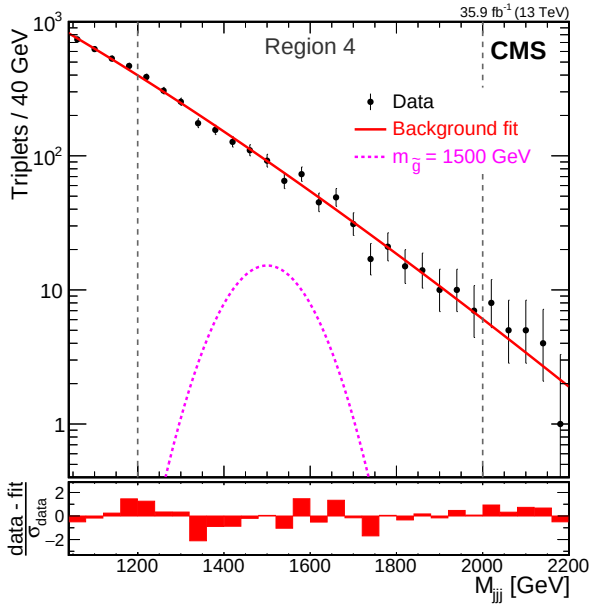
PAS EXO-18-012

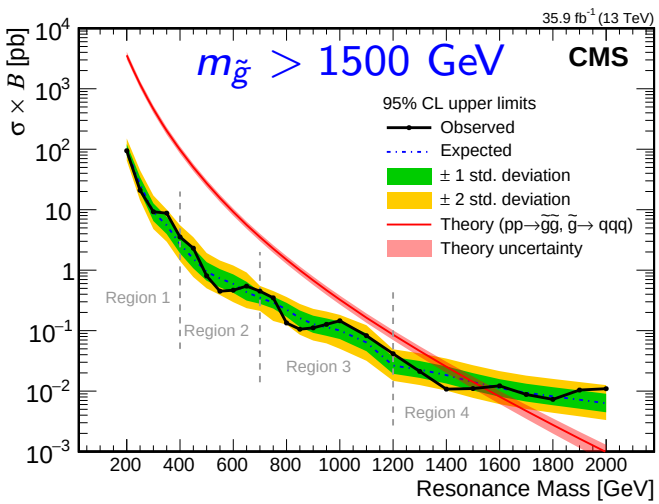


Pair-produced three-jet resonances

PRD 99 (2019) 012010 - CMS-EXO-17-030

- Theoretical model: RPV gluinos ($\tilde{g}$).
- QCD multijets bg and combinatorial noise.
  Discriminating variables:
  - Mass asymmetry between the two jet triplets
  - Dalitz variables, which exploit topological differences between signal and bg
  - "Delta cut", which exploits the fact that the bg mass scales with the scalar jet p_T sum, while the signal mass doesn't.
- QCD+combinatorial bg fit to a smooth function. In higher mass regions, it's the same as in the dijet searches.
- More details in Kin Ho Lo's presentation.

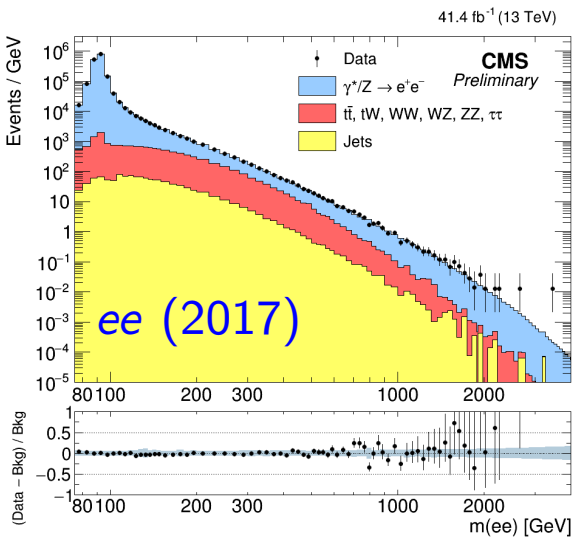


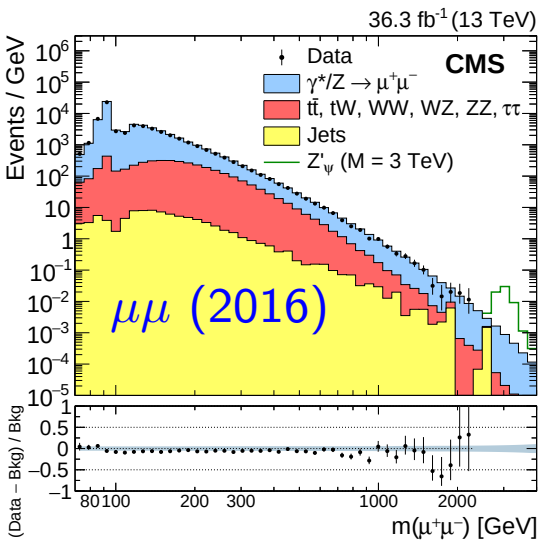


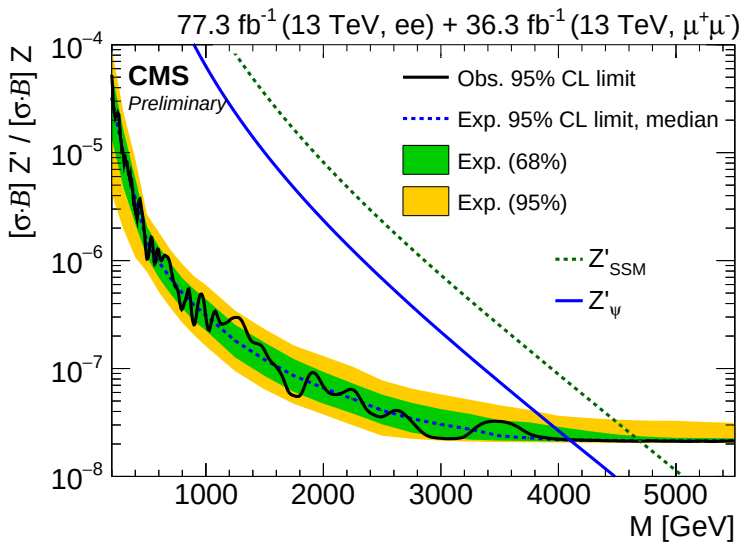
Dilepton searches

JHEP 06 (2018) 120 - CMS-EXO-16-047: Z' $\rightarrow ee/\mu\mu$, with 2016 data.
CMS PAS EXO-18-006 added 2017 data to the ee final state.

- Selections as model independent as possible.
  - Triggers: single electron and single muon.
  - Electrons: HEEP ID, optimized for high energies.
  - Muons: isolation, dedicated ID when $p_T > 200$ GeV.
- Backgrounds with real leptons estimated from simulation, normalized to data.
- QCD multijet background estimated by a data-driven method.





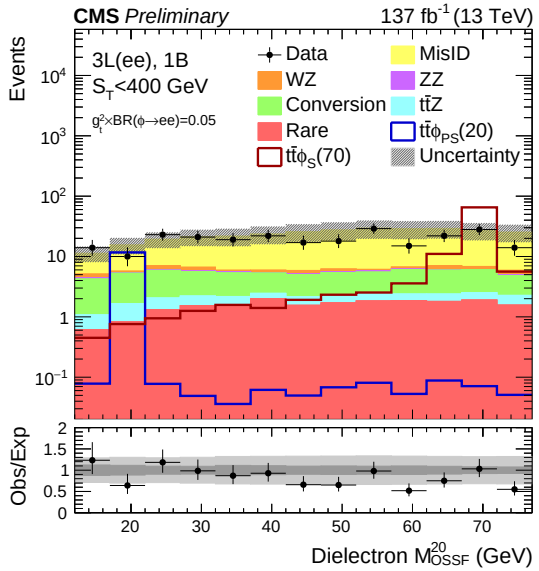


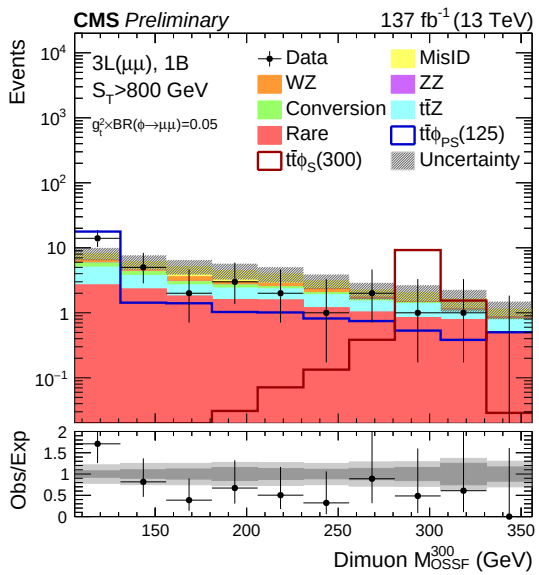
Limits (combined): $m_{Z'_{SSM}} > 4.7$ TeV, $m_{Z'_{\psi}} > 4.1$ TeV

Multilepton searches

CMS PAS EXO-19-002

- Resonant model tested: new light (pseudo)scalars, produced in association with $t\bar{t}$: $gg \to t\bar{t}\phi \to bq\bar{q}\ \bar{b}l^-\nu\ l'^+l'^-$
- Events with 3+ leptons are selected.
- Trigger: single electron or muon.
- Two mass ranges: 15-75 GeV and 108-340 GeV.
- Instead of cutting, inclusive binning of the following discriminating variables:
  - S_T (scalar p_T sum of leptons and jets + $\not{E}_T$).
  - number of b-jets (0, 1+).
  - number of leptons (3, 4+).
- Irreducible background estimated from simulation, non-prompt bg from data-driven methods.
- Analysis variable: "attractor mass" of the opposite sign same flavor (OSSF) fermions.
  - 20 GeV for the low mass region: M^{20}_{OSSF}
  - 300 GeV in the high mass region: M^{300}_{OSSF}





Multilepton searches: results

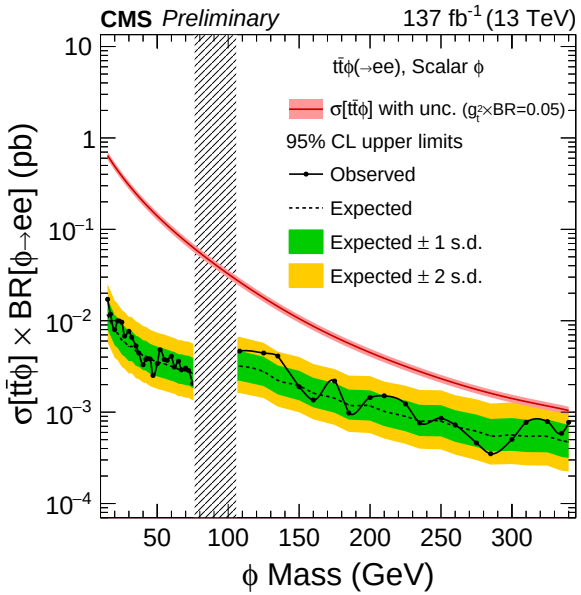
One of the first analysis with full Run2 results.

Assuming $g_t = 1$, branching ratio limits on new scalar (pseudoscalar) bosons $\rightarrow ee/\mu\mu$:

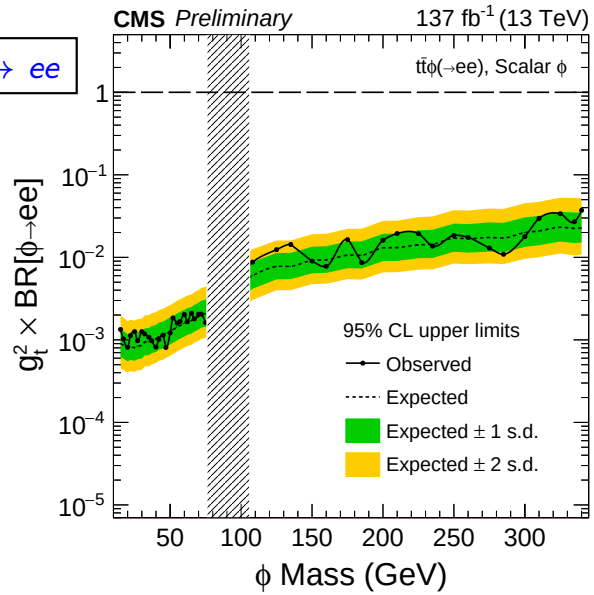
< 0.003 (0.03) for the low mass range.

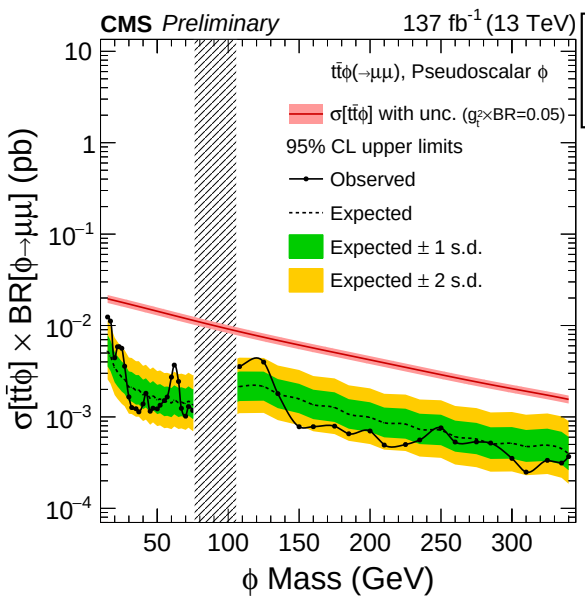
< 0.04 (0.03) for the high mass range.

Check out Maxi's talk for the non-resonant part!

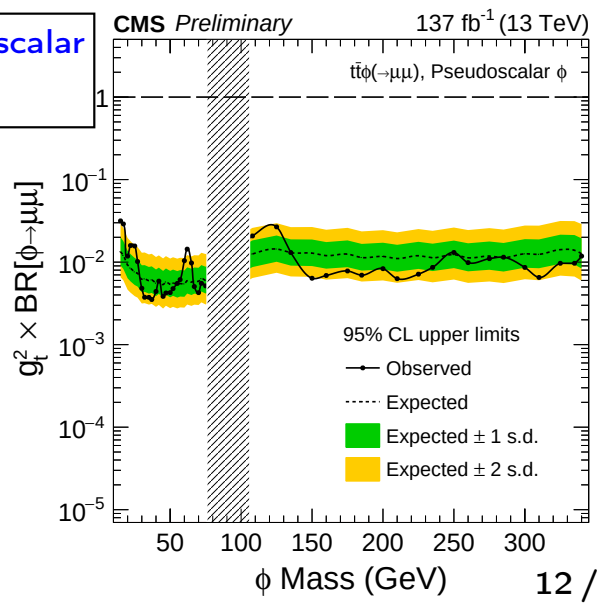


scalar $\rightarrow ee$





pseudoscalar $\rightarrow \mu\mu$



Summary

Many resonance searches in CMS. Too many to summarize in one slide!
11 papers covered in this talk, others could not be included, such as:

- PRD 98 (2018) 112014 - CMS-EXO-17-021: Search for pair-produced resonances decaying to quark pairs.
- JHEP 05 (2018) 148 - CMS-EXO-17-011: Search for a heavy right-handed W boson and a heavy neutrino in events with two same-flavor leptons and two jets.
- JHEP 04 (2018) 073 - CMS-EXO-16-058: Search for lepton-flavor violating decays of heavy resonances and quantum black holes to $e\mu$ final states.
- Many SUSY searches, covered in dedicated talks.

Still a productive research area in CMS, more results with full Run2 data are coming soon.

- New techniques used to improve sensitivity and broaden scope of searches.
- Scouting is becoming ever more important to extend the mass reach at lower resonance masses.

Stay tuned for the many other resonance results yet to come!

Backup

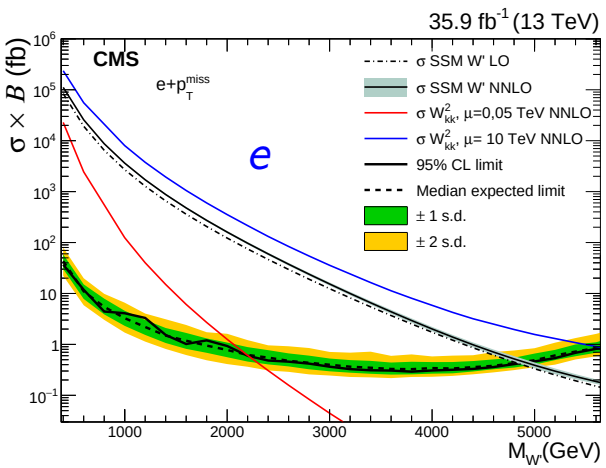
Lepton + $\not{E}_T$

Two recent CMS papers about searches in $l + \not{E}_T$ final states:

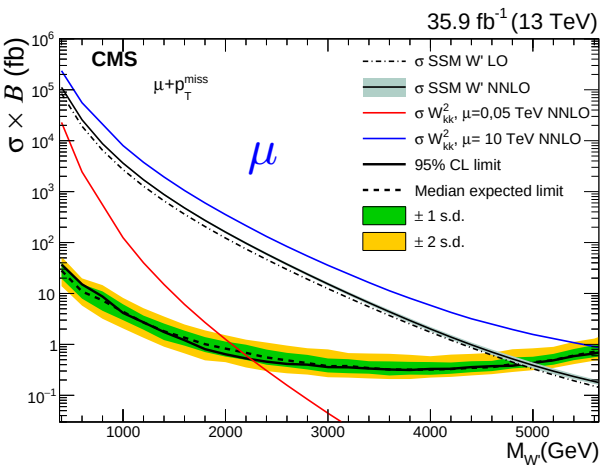
- JHEP 06 (2018) 128 - CMS-EXO-16-033, where $l = e,\ \mu$.
- PLB 792 (2019) 107 - CMS-EXO-17-008, where $l = \tau$.

Similar analysis strategies:

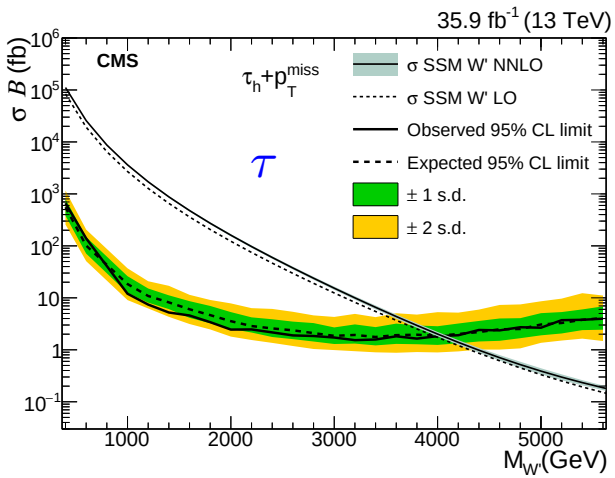
- e/μ analysis: single $e/\mu/\gamma$ trigger
- τ analysis: cross-trigger requiring a hadronic τ (τ_h) and $\not{E}_T$.
- e/μ are reconstructed in a similar way as in the dilepton search.
- Taus: only well-reconstructed and identified τ_h are considered.
- Final analysis variable: transverse mass $M_T(l, \not{E}_T)$.



$M_{W'_{SSM}} > 5.0$ TeV



$M_{W'_{SSM}} > 4.9$ TeV

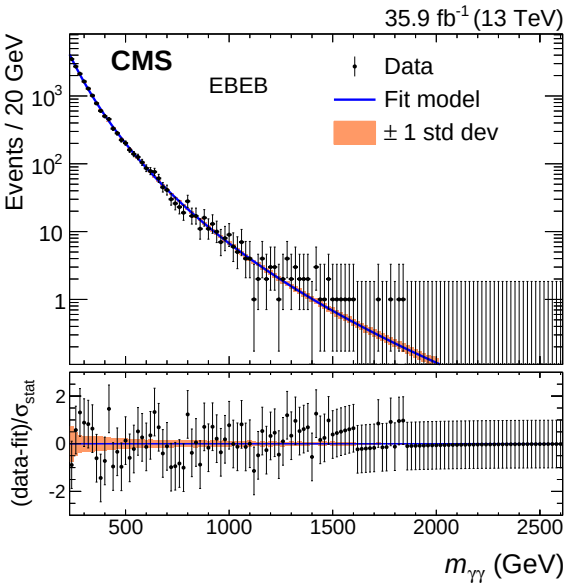


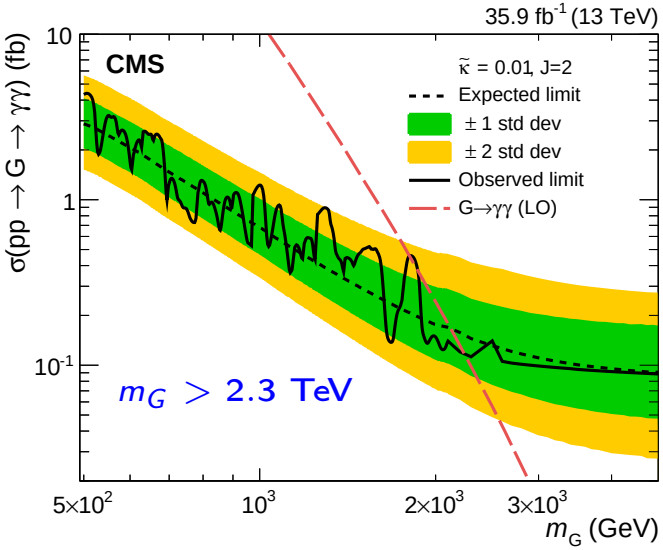
$M_{W'_{SSM}} > 4.0$ TeV

Diphoton searches

Latest results from PRD 98 (2018) 092001 - CMS-EXO-17-017.

- Trigger: double photon with $p_T > 60$ GeV.
- Photon ID criteria to suppress electron and jet misID.
- Diphoton vertex reconstructed by MVA algorithm.
- Dominant background: prompt SM diphoton, fit to a function:
  $f(m_{\gamma\gamma}) = m_{\gamma\gamma}^{a+b\,\log(m_{\gamma\gamma}/\mathrm{GeV})}$





Spin-2
RS gravitons