Exotic physics signatures at CMS

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(on behalf of CMS collaboration)

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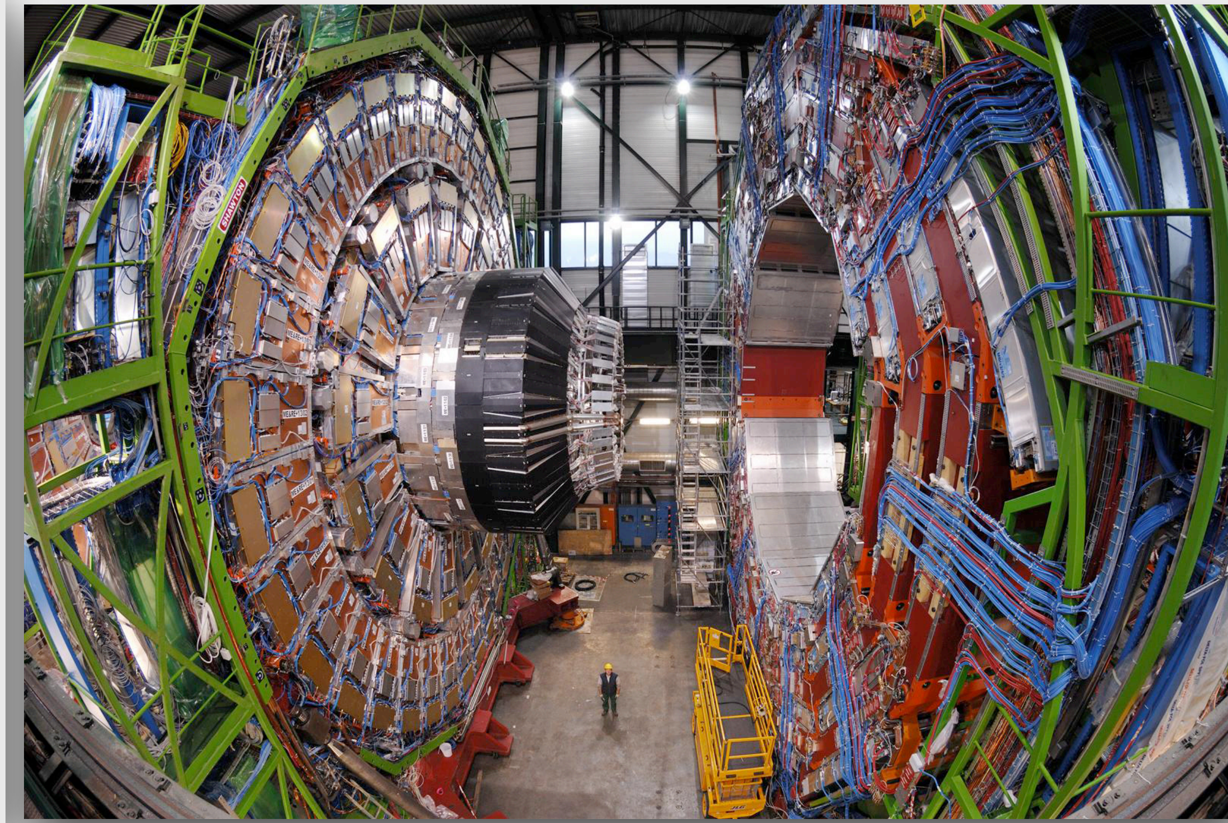
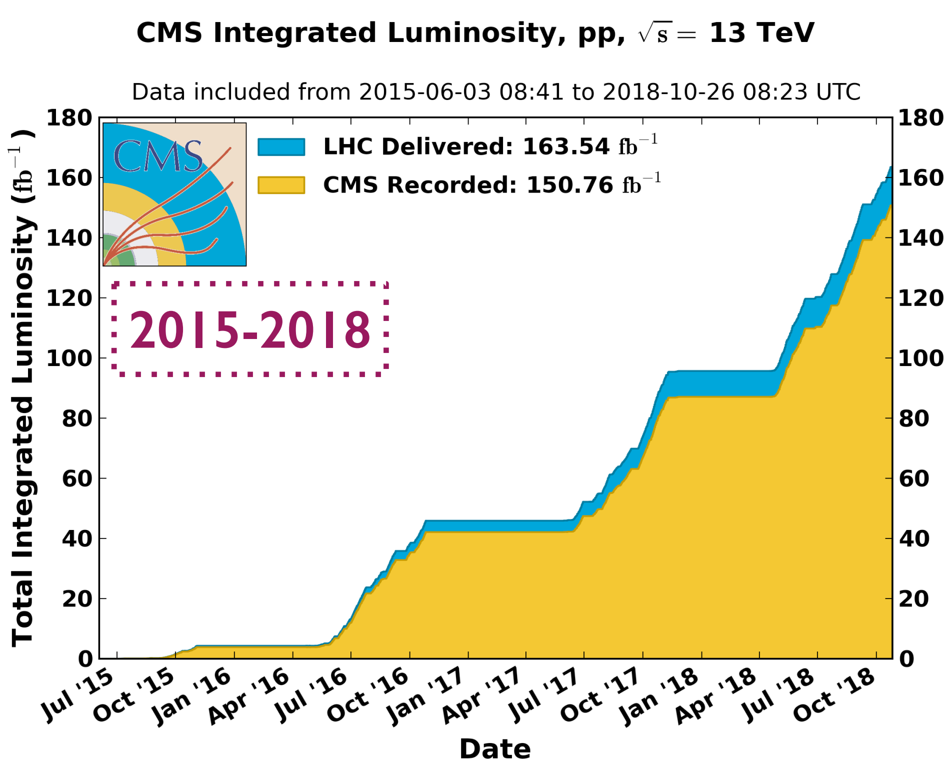
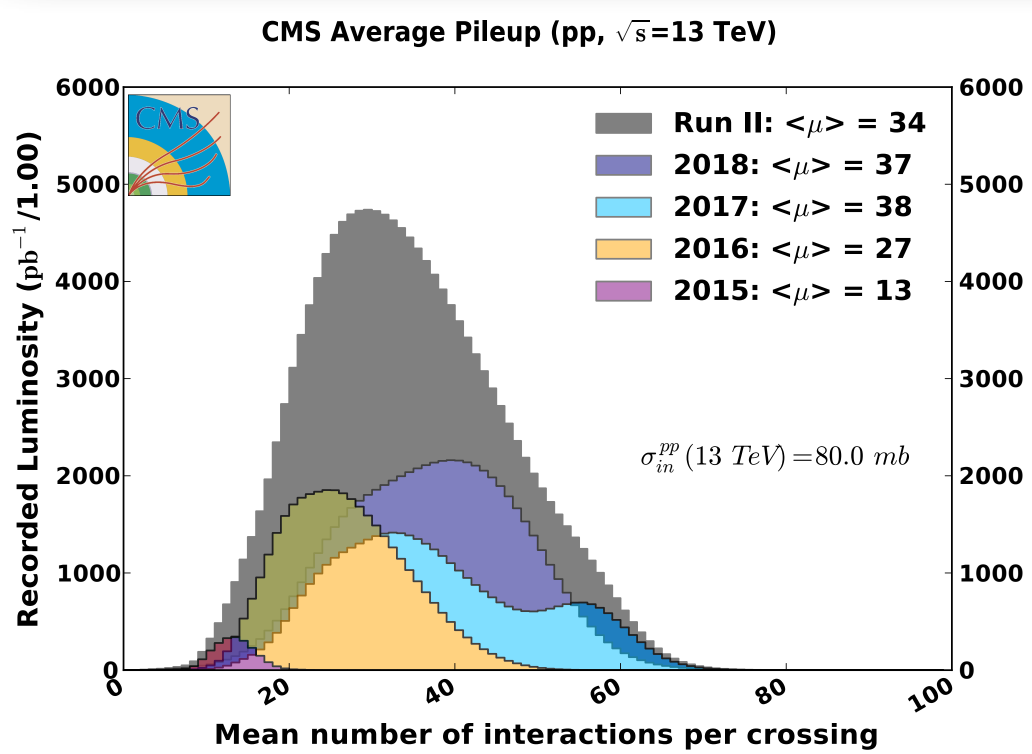
Introduction

- CMS (Compact muon solenoid) : a multipurpose detector at the LHC ring resulted in the discovery of Higgs Boson in 2012
- With successful data taking during Run-II and having several upgrades for implementing fast electronics, CMS has recorded up to ~139 fb^{-1} of data from 2016-2018 at 13 TeV
- This led to more precise SM measurements and better understanding of standard model physics
- Opened doors to explore rare physics signatures beyond standard model physics

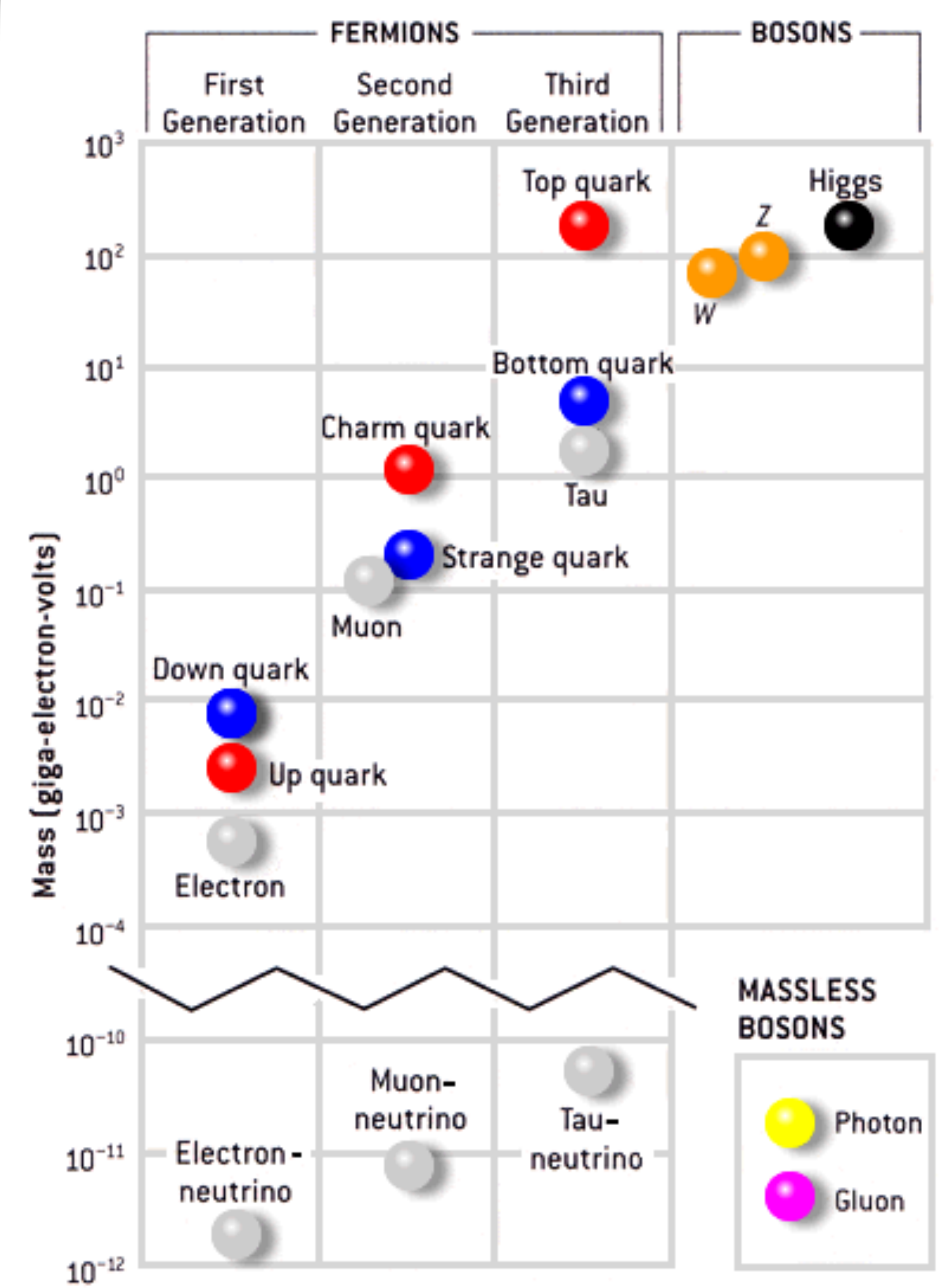






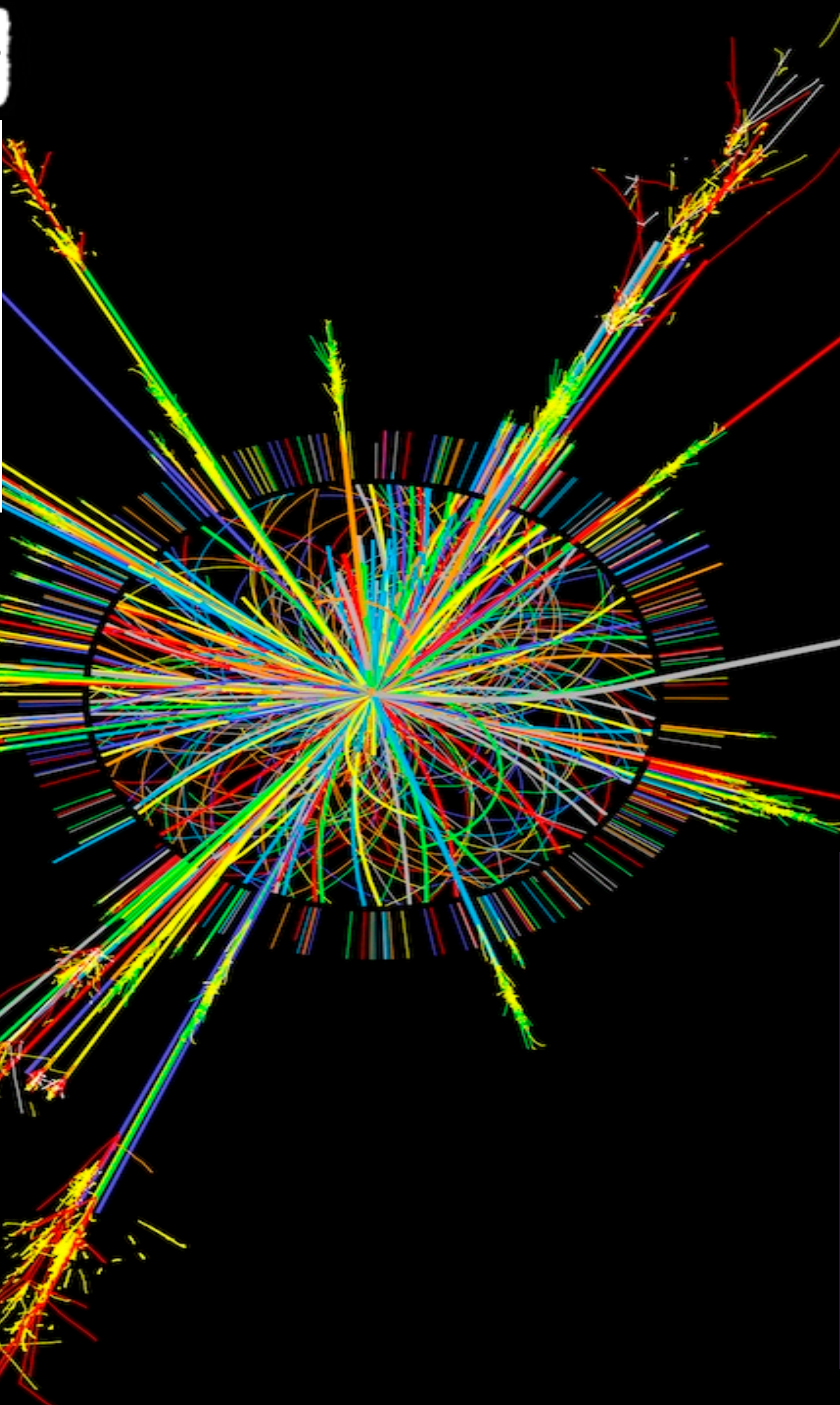
Why looks for exotic signatures?

- Standard model successfully explains the structure of matter and the forces acting between them. Still, it fails to answer many important questions:
  - Inclusion of the forth fundamental force i.e gravitational force
  - Why only 5% of matter made of ordinary SM particles?
  - Why there are only three families of quarks and leptons?
  - Is there a more fundamental theory of which the Standard Model is a low energy approximation?

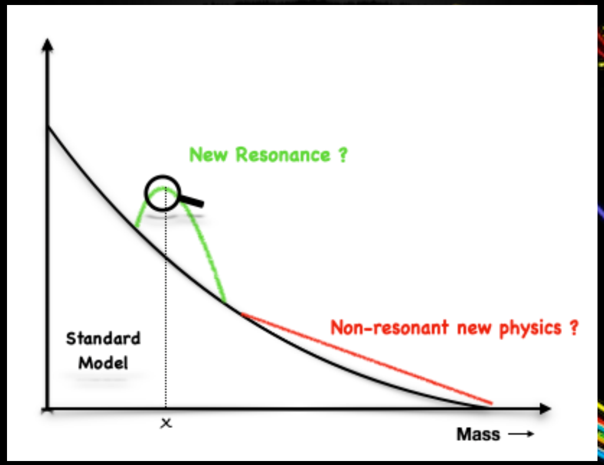


To answer such questions , new models beyond standard model have evolved with time and predicts "new phenomena" at the "TeV" scale

What do we look for Beyond SM?

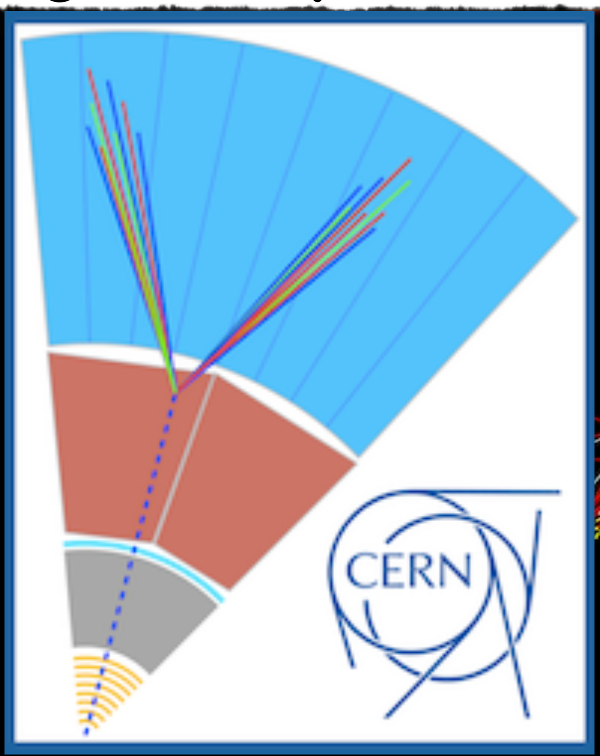


New resonance ?

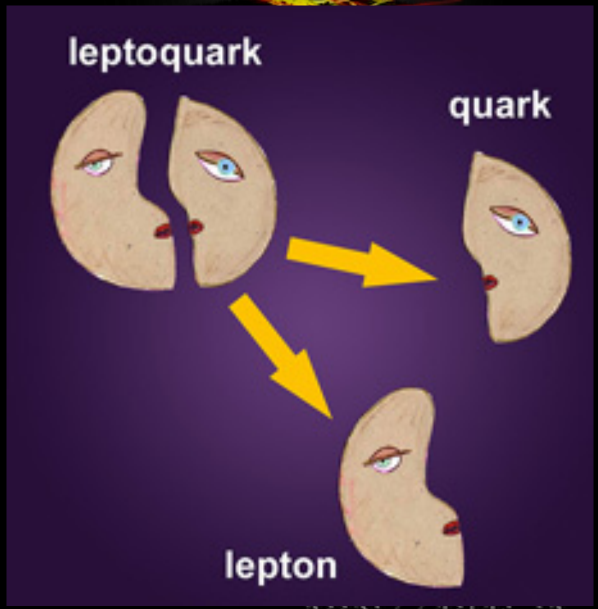


Dark matter ?

Long lived particles ?



New quarks?

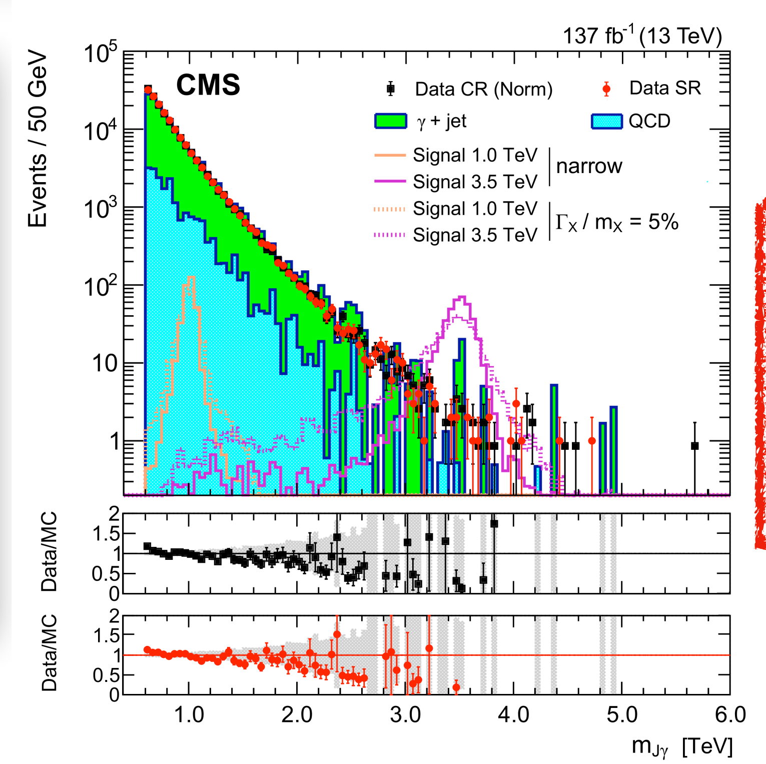


NEW

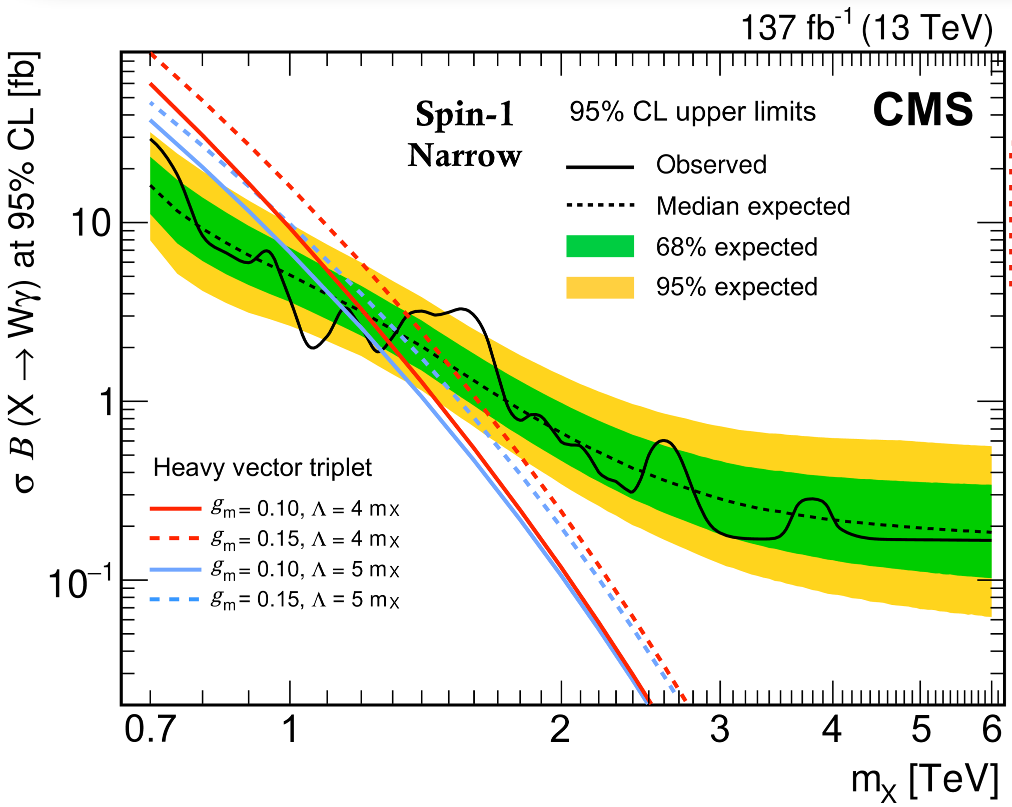
$W\gamma$ resonances

Full Run 2 dataset

- Hadronic decays of W bosons leading to single large-radius jet (AK8) with two sub-jets
- Boosted jet topology due to high Lorentz boost of the W boson
- “Soft drop” (SD): jet grooming algorithm to remove soft, wide-angle radiation coming mainly from QCD

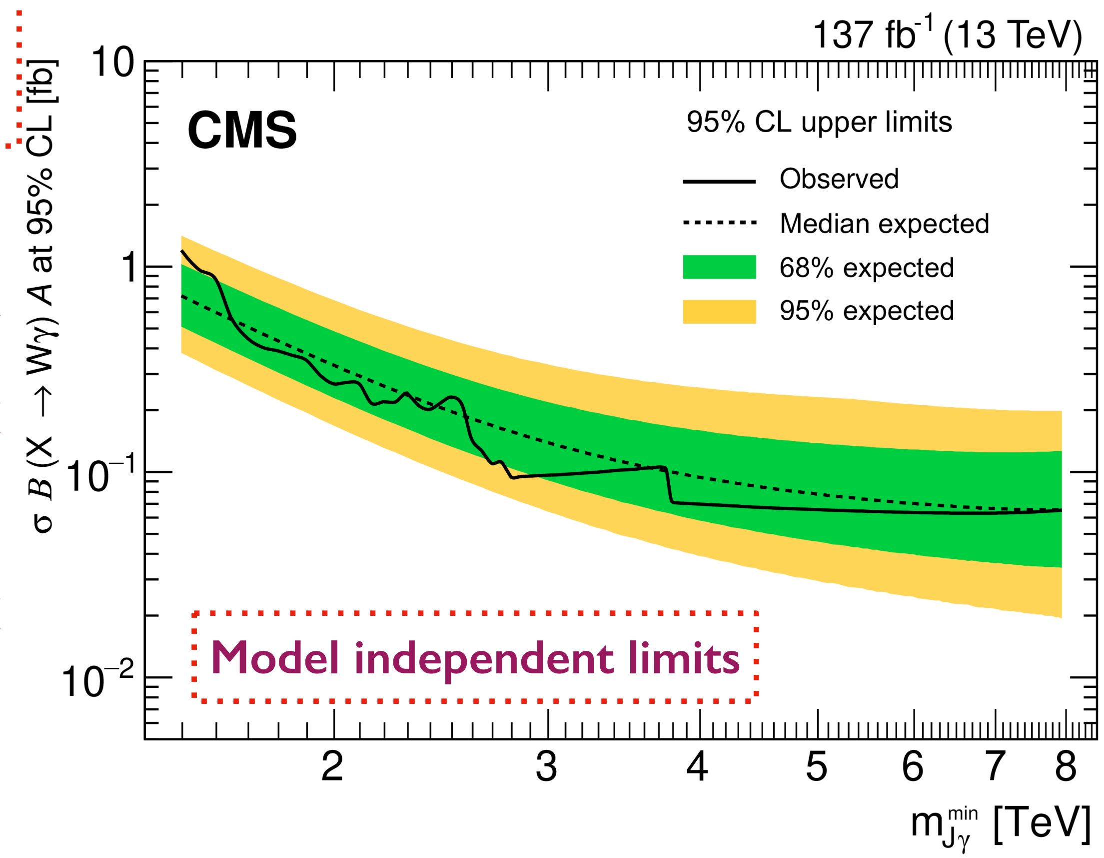


No significant excess over smoothly falling background is observed



Considered both spin hypothesis

benchmark heavy scalar (vector) triplet bosons with masses between 0.75 (1.15) and 1.40 (1.36) TeV are excluded at 95% CL



Model independent limits

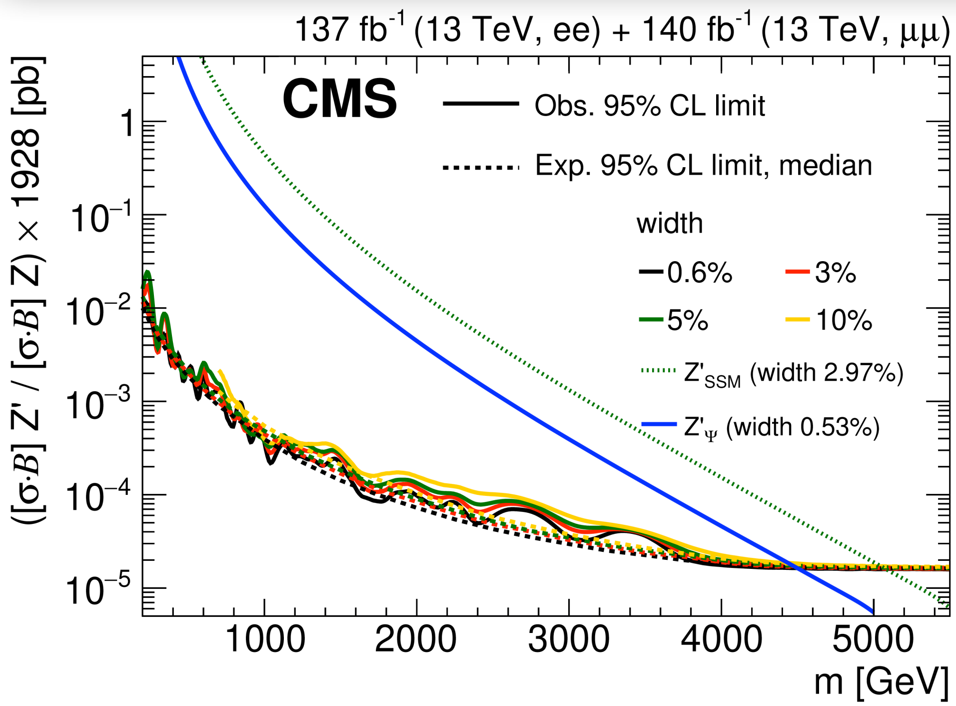
Excess around 1.58 TeV with local significance of 2.8 σ is examined to be a statistical fluctuation in data

ee & $\mu\mu$ resonances

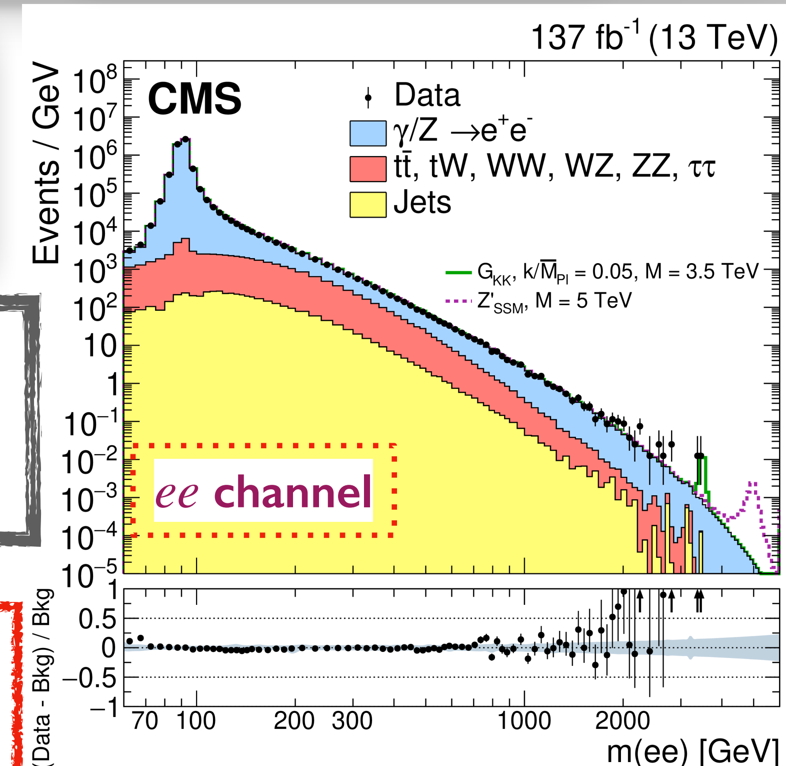
CMS : arXiv:2103.02708

Full Run 2 dataset

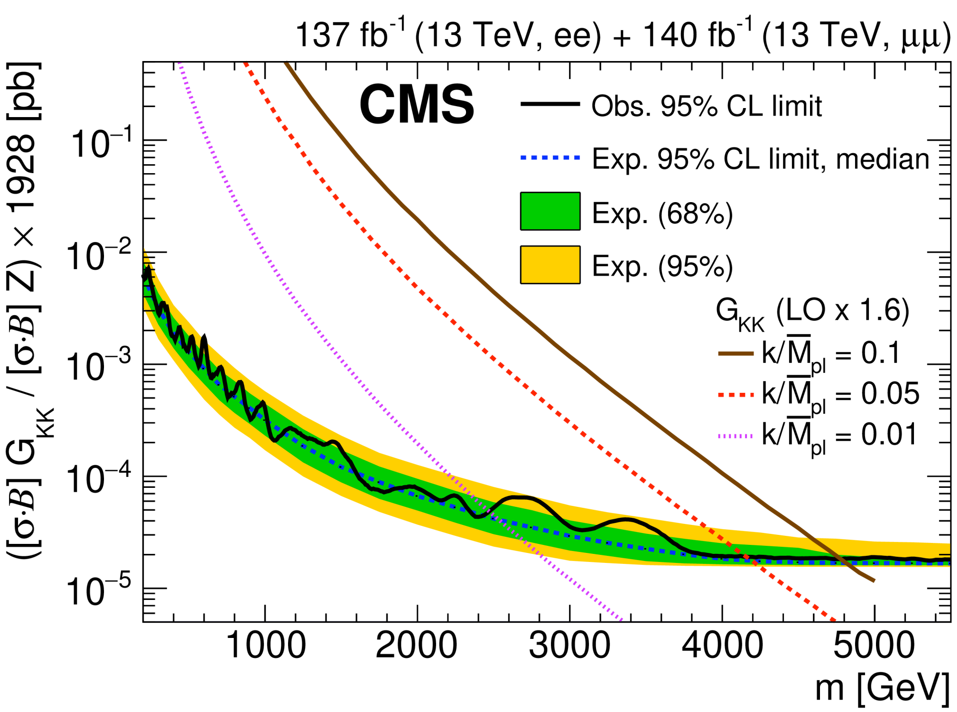
- Search for Spin-1particles and Spin-2 gravitons
- Lepton flavor universality tested at TeV scale by comparing the $\mu\mu$ and *ee* mass spectra NEW



Most stringent limits to date on the masses for various spin-1 particles, spin-2 gravitons in the RS model

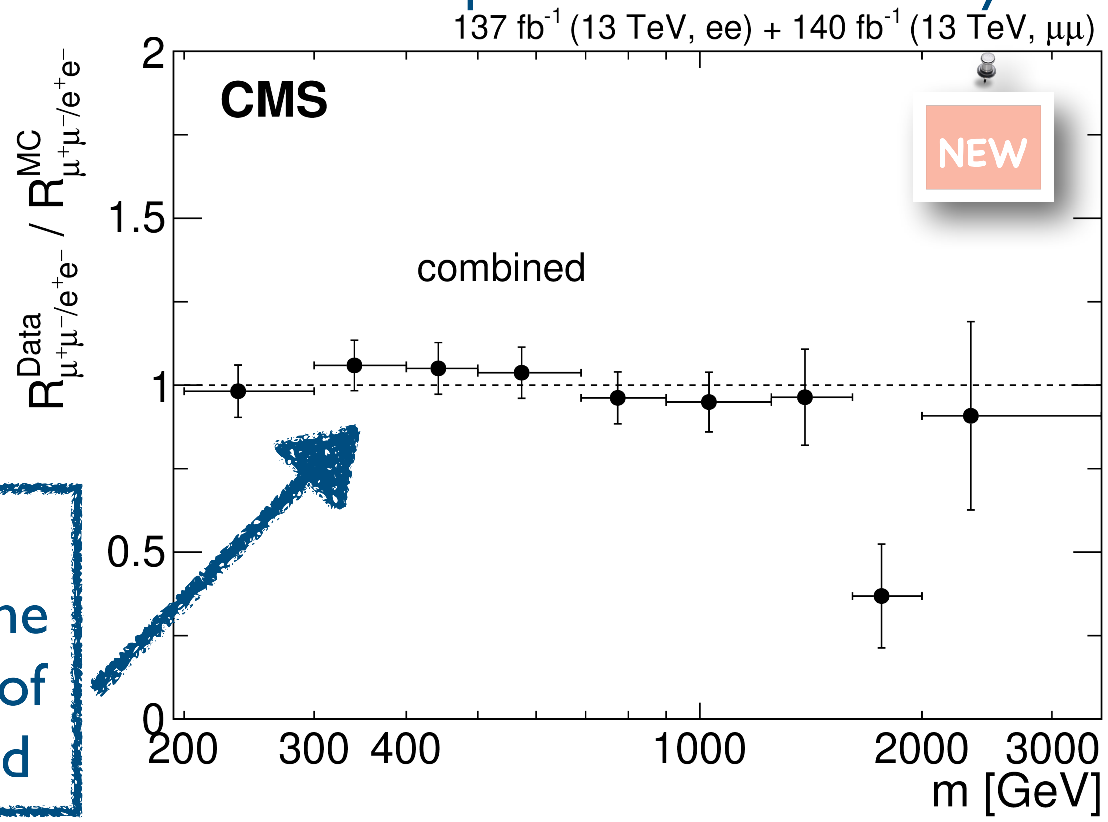


Lower mass limits of 5.15 (4.56) TeV are set at $Z'_{SSM}(Z'_{\psi})$ model



Lower mass limits of 2.47–4.78 TeV are set for Spin-2 gravitons in RS model

Lepton flavor universality Test



No significant deviation from the SM expectation of unity is observed

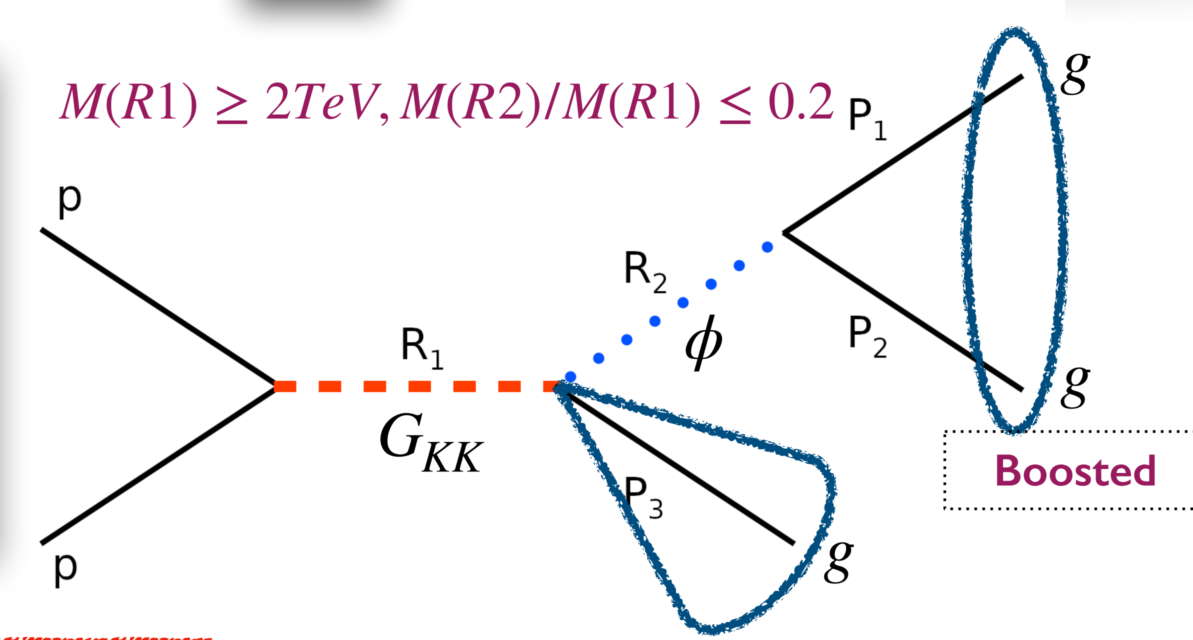
Trijet resonances : $G_{KK} \rightarrow ggg$

CMS : PAS-EXO-20-007

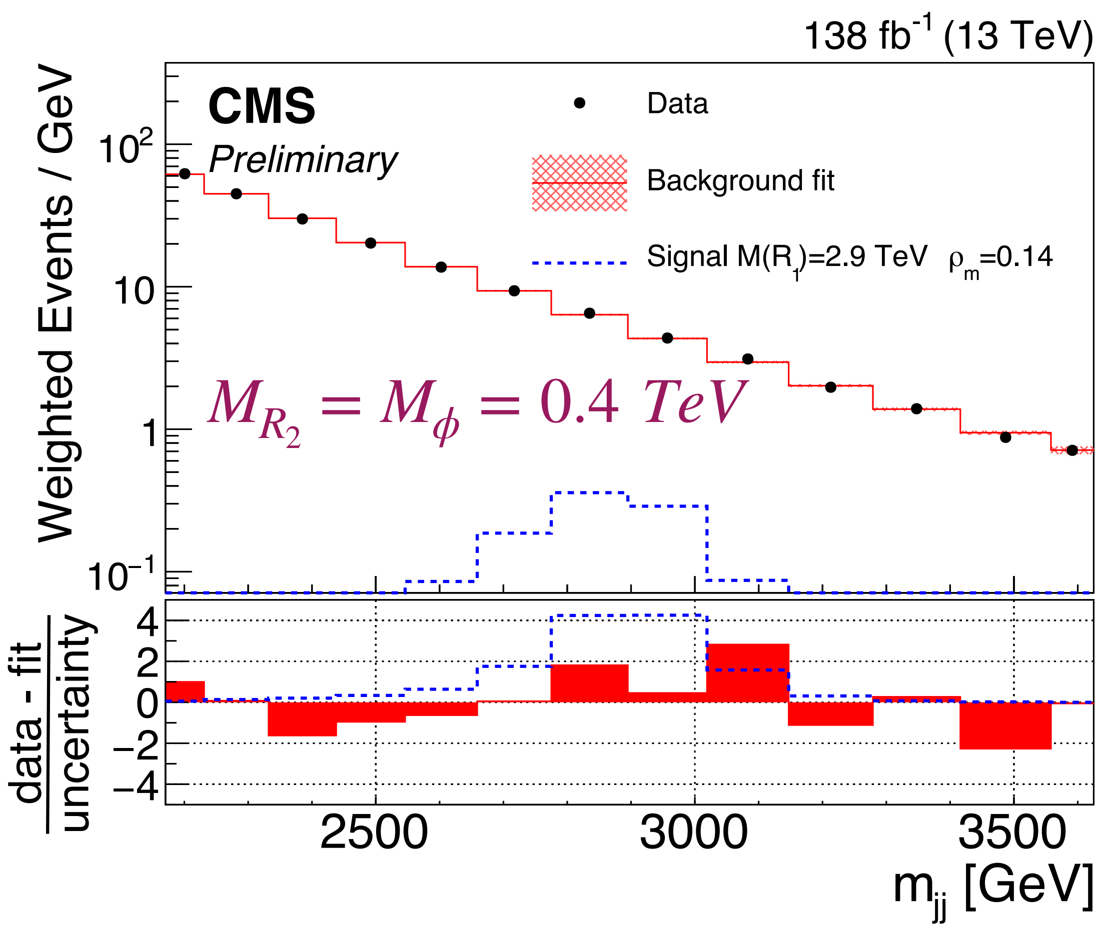
NEW

Full Run 2 dataset

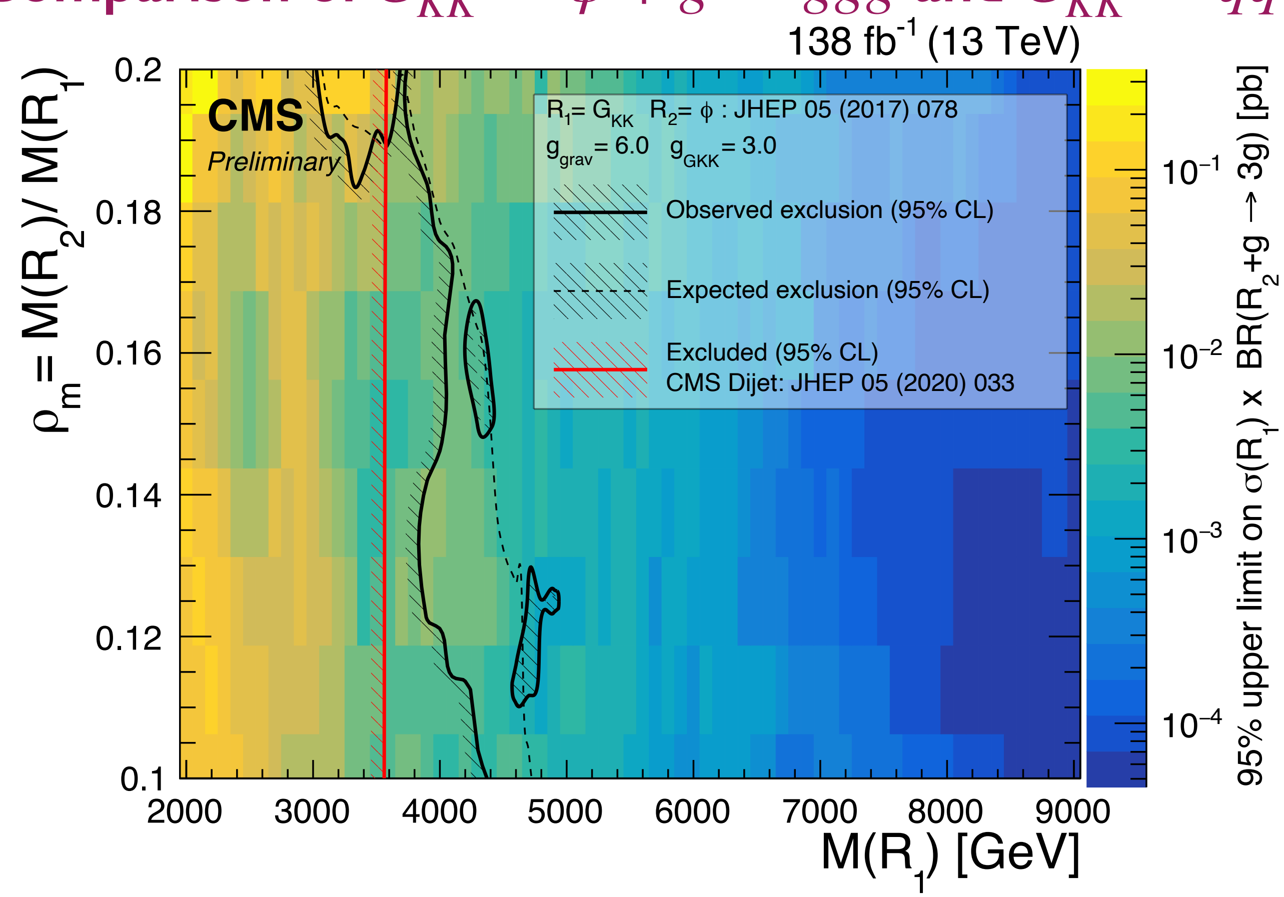
- First LHC results for a trijet resonance with a boosted dijet and a single jet
- KK gluon (R_1) decays into 3 SM gluons ($P_1, P_2$and P_3) via a radion (R_2)(spin-0)
- Boosted dijet reconstructed as a single jet with two body jet sub-structure



No statistically significant excesses above the background predictions are observed.



Comparison of $G_{KK} \rightarrow \phi + g \rightarrow ggg$ and $G_{KK} \rightarrow q\bar{q}$

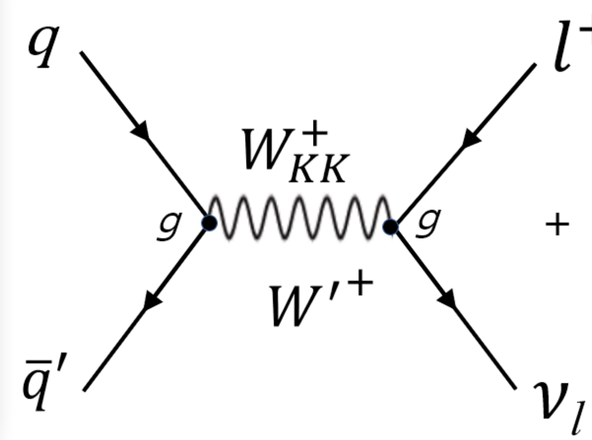


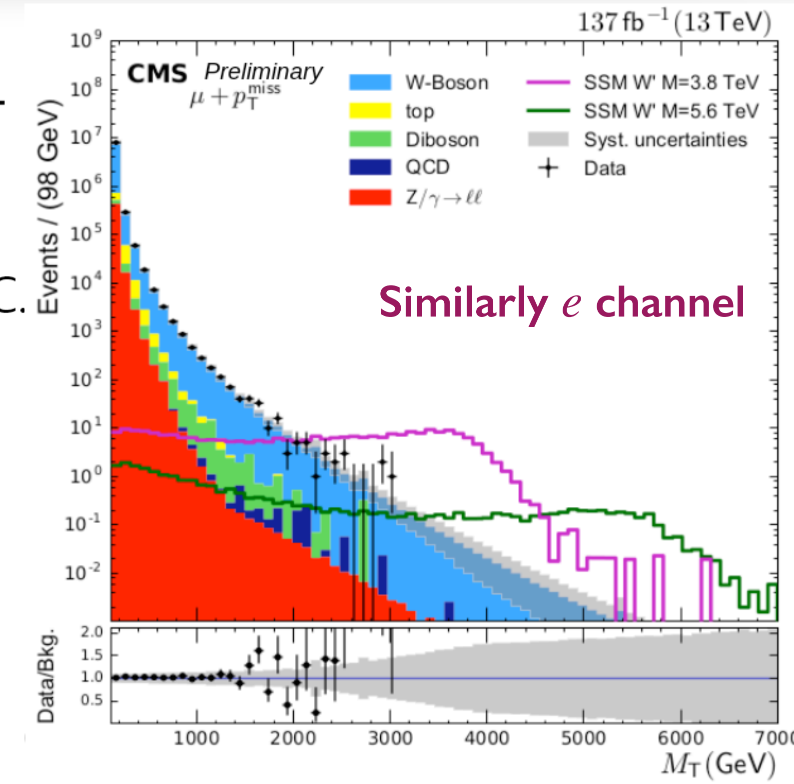
Heavy charged boson ($W' \to \ell\nu$)

CMS : PAS-EXO-19-007

Full Run 2 dataset

- W' decaying to e/μ + MET is probed
- Single high p_T lepton back-to-back with p_T^{miss}
- Angular difference between lepton p_T and p_T^{miss} ($\Delta\phi(p_T, p_T^{miss}) \sim 0.8\pi$)
- $M_T(\ell, MET)$: Final fit variable

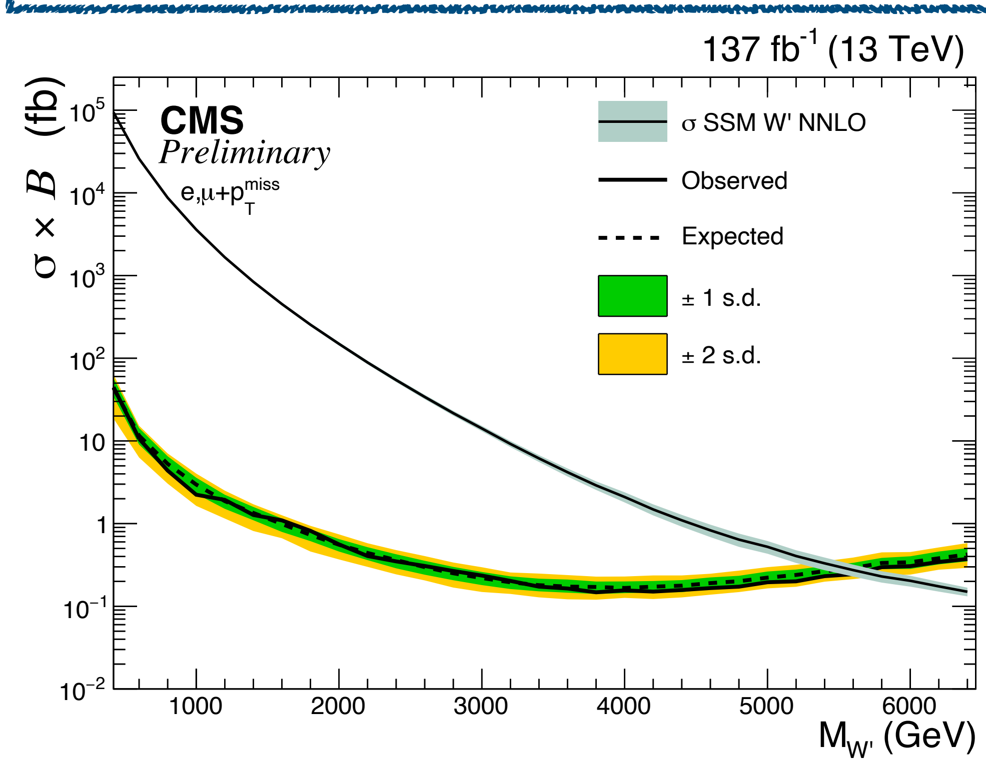




Effective field theory (EFT) interpretations quantify potential deviations from SM expectations through the oblique electroweak W parameter

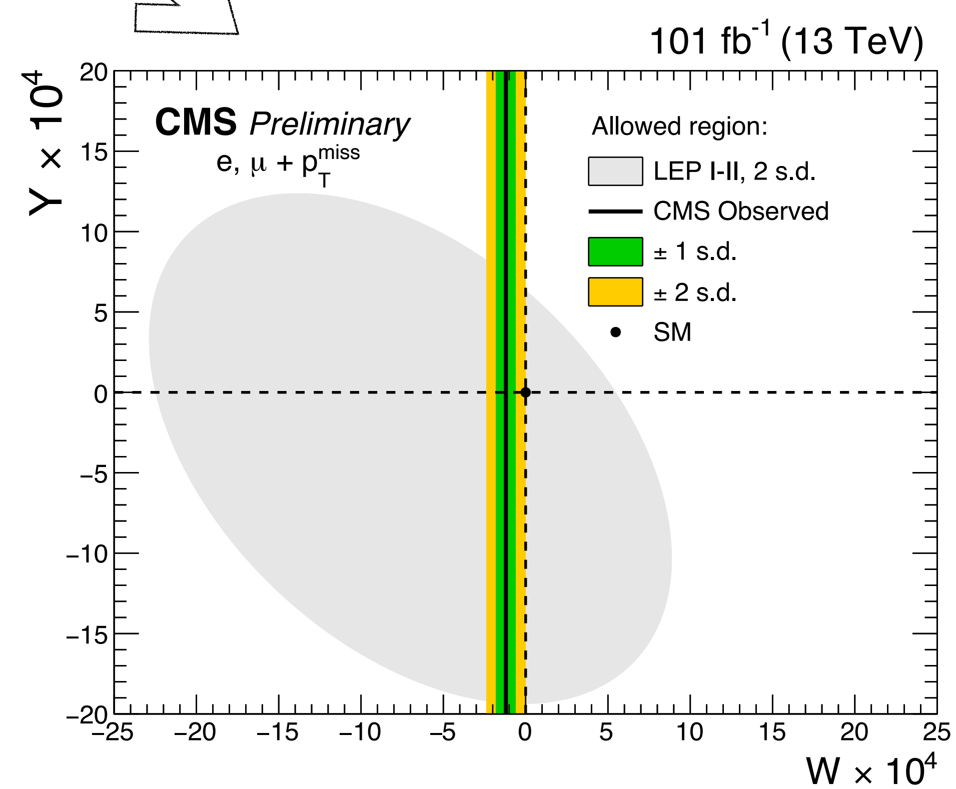
First constraints on W and Y parameters

No significant deviation from the SM background is observed



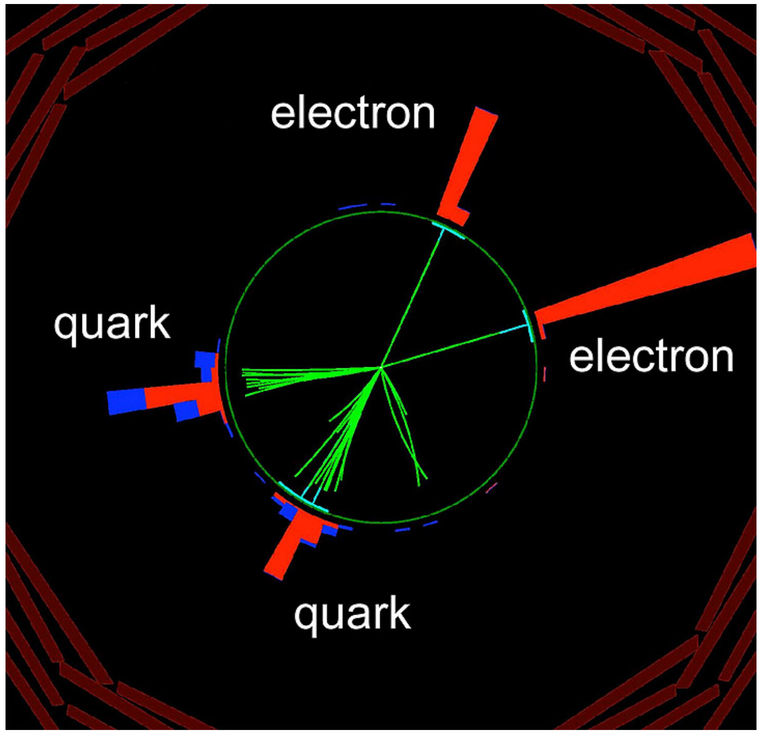
Fit results using 2017+2018 data : $W = -12^{+5}_{-6} \times 10^{-5}$

best exclusion limit obtained is 5.7 TeV on the mass of a sequential standard model W' boson

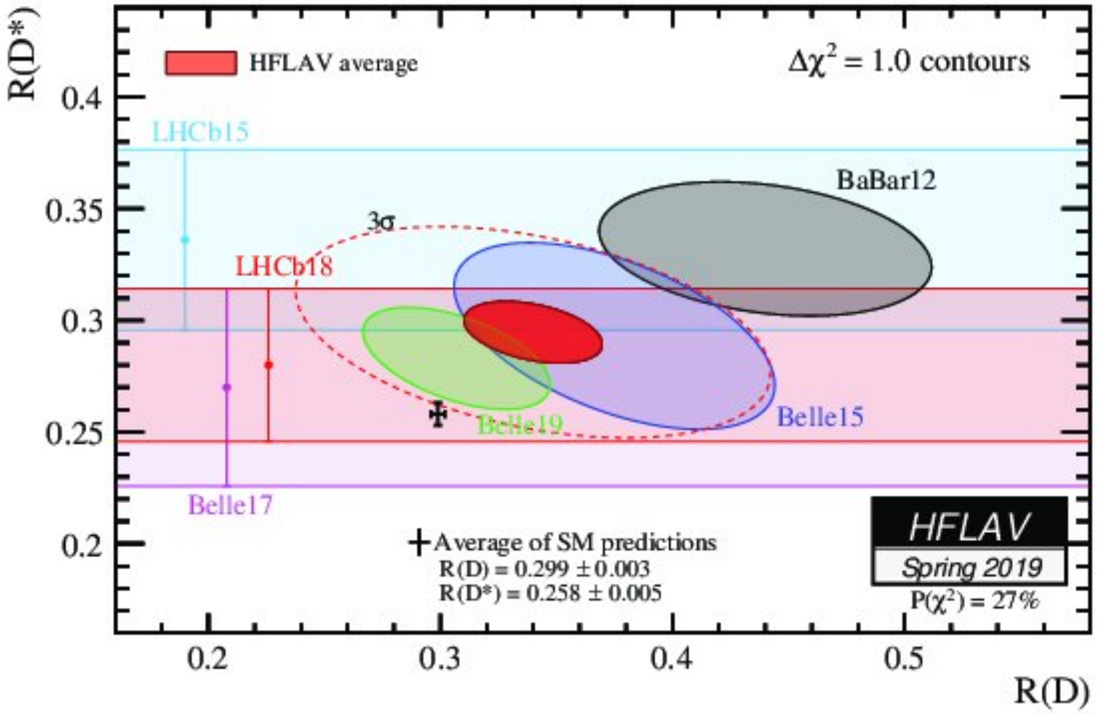


Leptoquark searches (LQs)

- LQ appears in many BSM models to answer the question: **Why same number of generation for leptons and quarks**
- Leptoquarks carry both lepton and baryon number
  - carry fractional electric charge (+2/3e, -1/3e: up/down types)
  - decay in lepton-jet
- Motivated by models such as grand unified theories, technicolor models, compositeness scenario and R-parity violating supersymmetry



provide an explanation fora series of anomalies observed in the measurement of B meson decays in charged-current ($b \to c\ell\nu$) and neutral b ($b \to s\ell\ell$) processes observed by Babar, Belle and LHCb

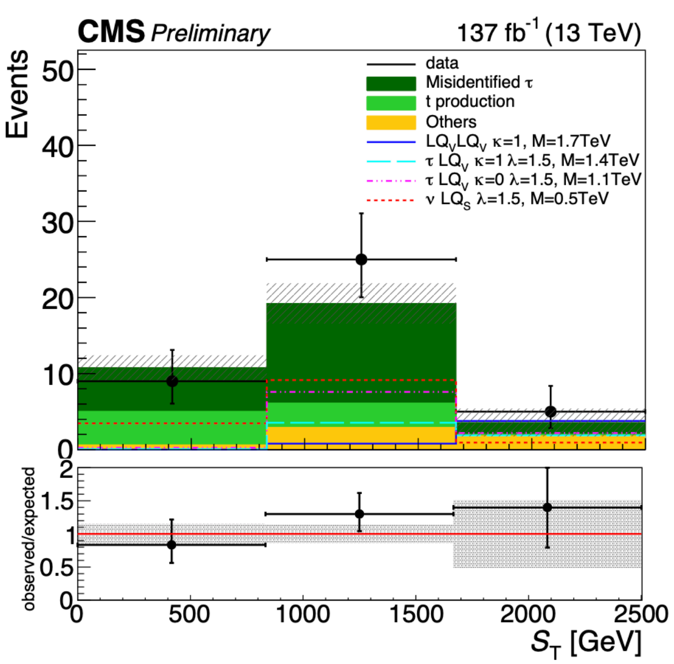


Probing for Leptoquarks

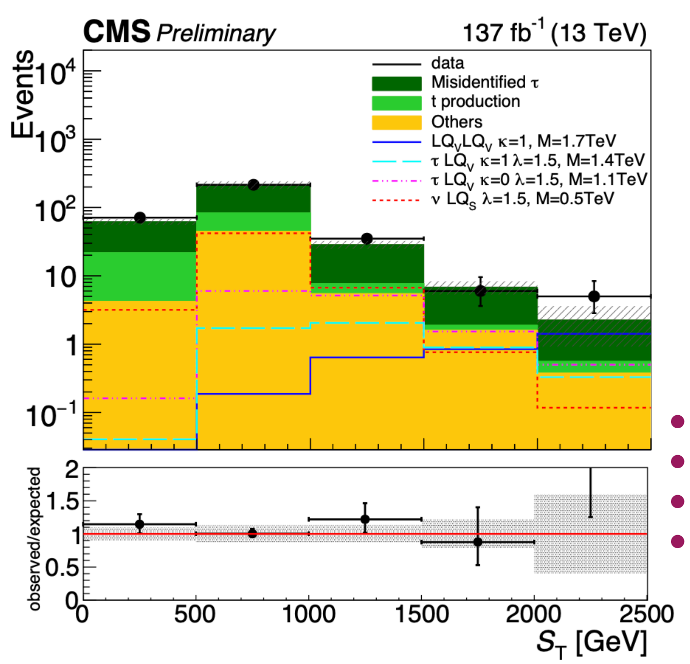
CMS : arXiv:2012.04178

Full Run 2 dataset

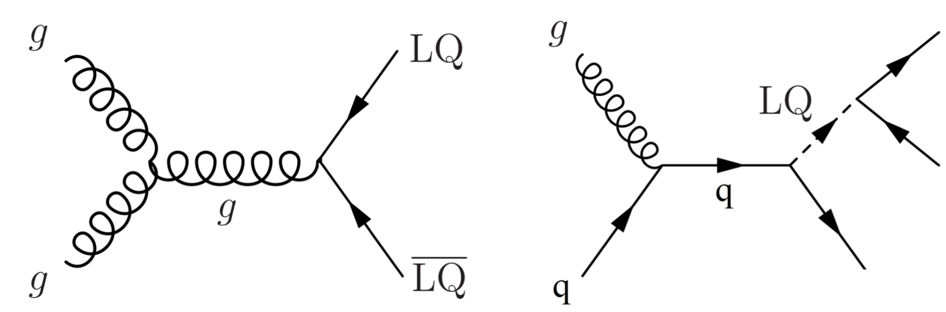
- Third generation vector leptoquarks : pair + single production modes
- Couples to a top quark plus a τ lepton (tτ) or a bottom quark plus a neutrino (bν, scalar LQ), or else to tν or bτ (vector LQ), leading to the final states t$\tau\nu$b and t$\tau\nu$
  - high p_T^{miss}, high H_T, one hadronic top candidate and one hadronic τ



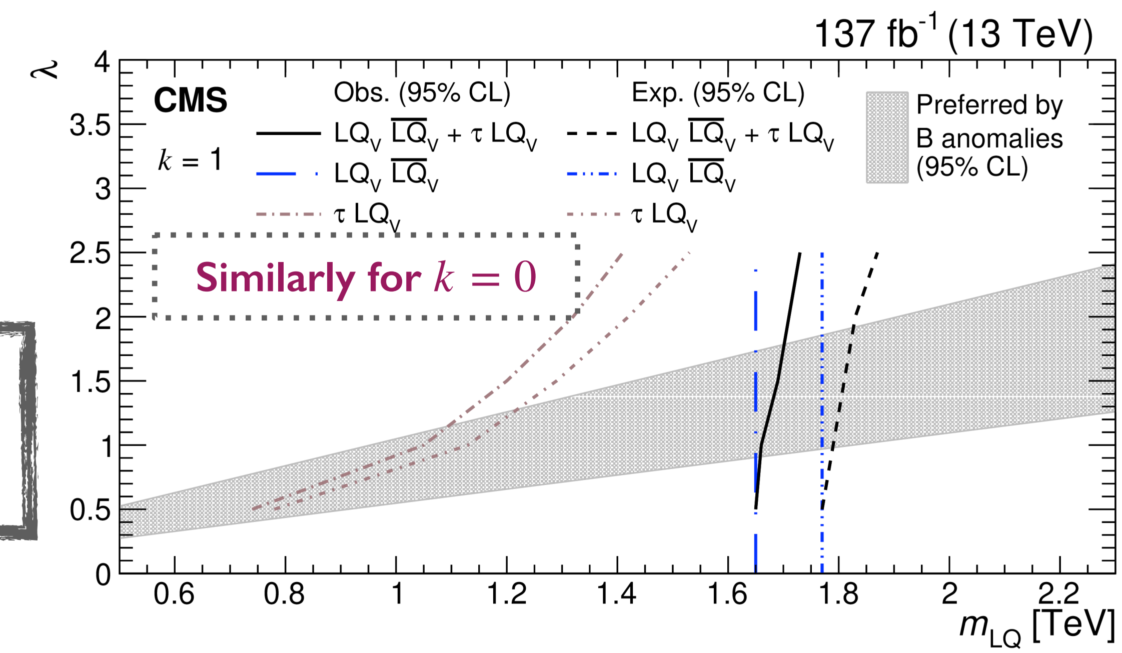
hadronically decaying top quark reconstructed in the **merged topology**



hadronically decaying top quark reconstructed in the **resolved topology**



Major backgrounds: real top production checked in control region and backgrounds from misidentified τ from data



Similarly for $k = 0$

Lower limits at 95% CL are set on the LQ mass in the range 0.98-1.73 TeV, depending on the LQ spin and the LQ-lepton-quark vertex coupling λ, and assuming equal branching fractions for the two LQ decay modes considered

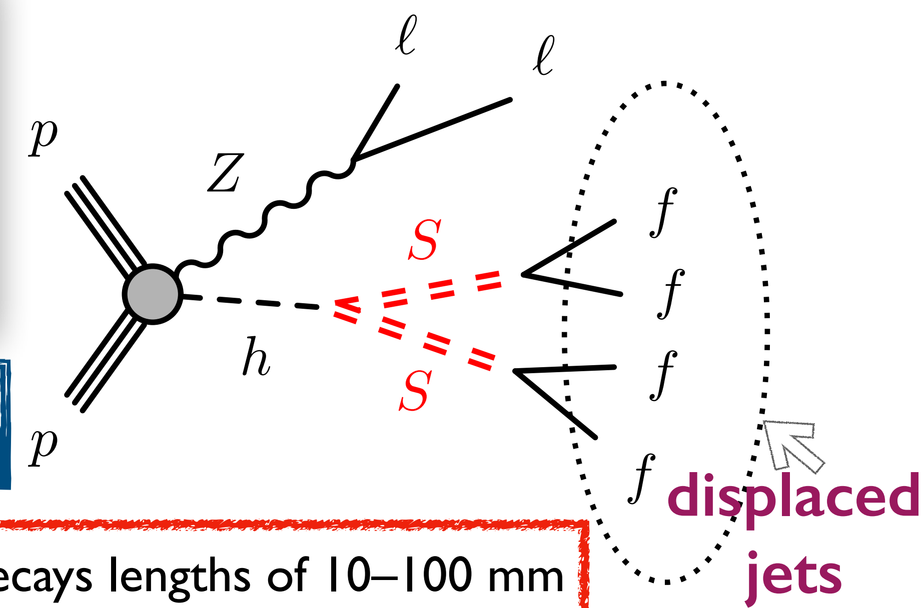
Regions to the left of lines are excluded!!

Exotic Higgs decays ($ZH \to ZSS \to 4\ell 4b$)

CMS : PAS-EXO-20-003

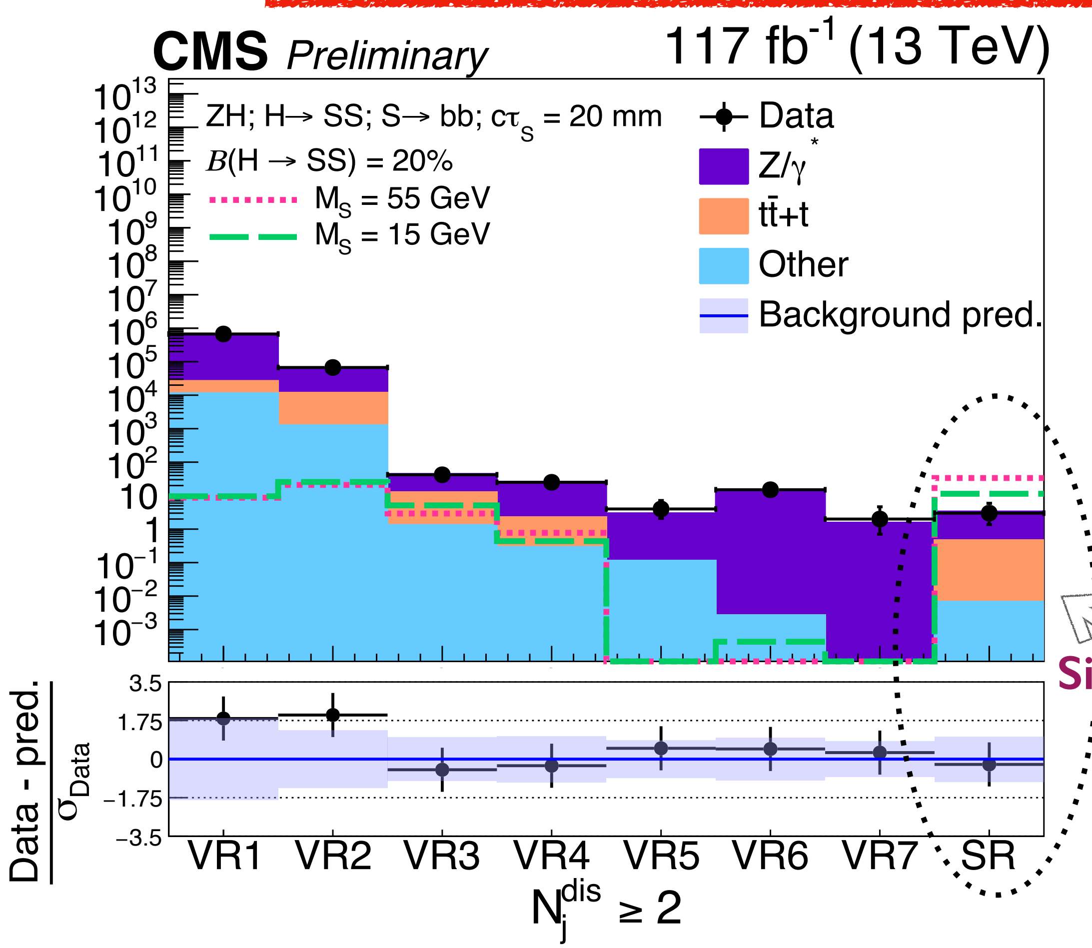
Full Run 2 dataset

- Targeting "exotic decays" to Long Lived particles produced in association with Z boson
- Z decays to ee or $\mu\mu$ providing sensitivity to light (<15 GeV) LLPs
- Prompt dilepton + $\geq$ 2 displaced jets with hits in tracker volume

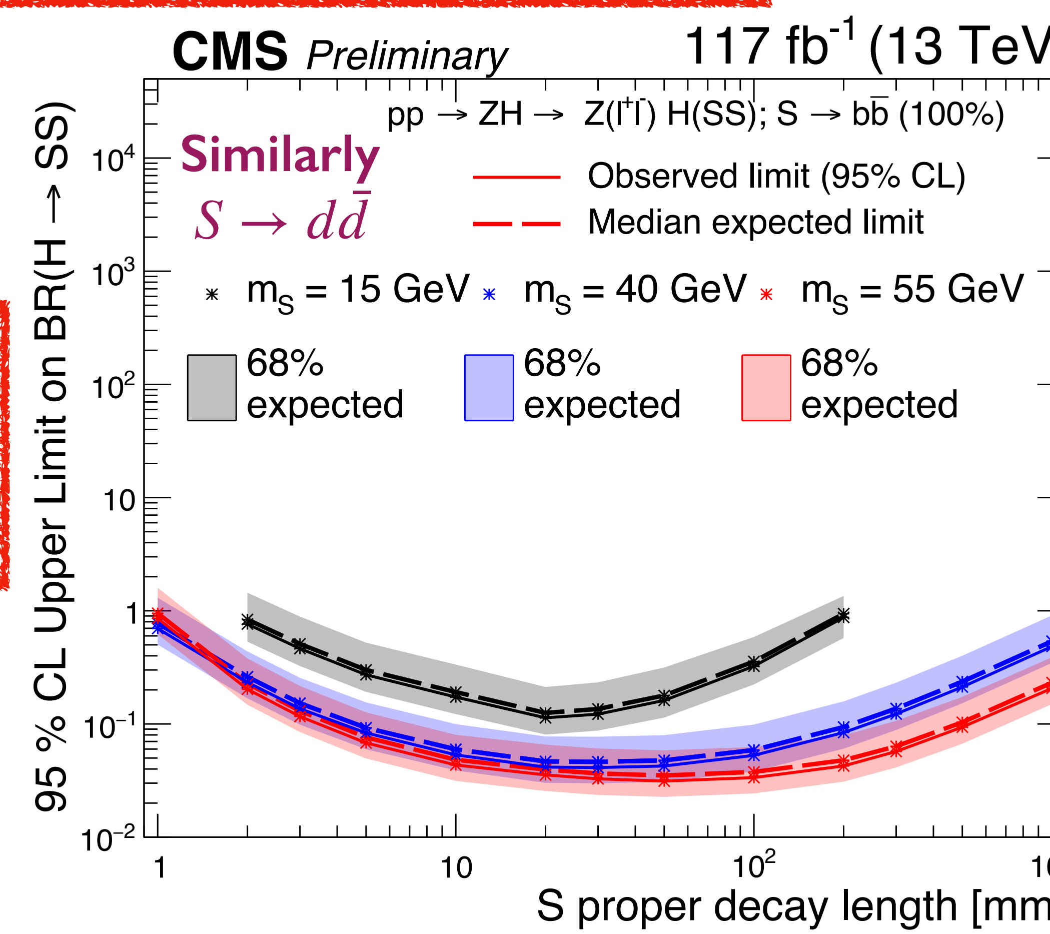


Most stringent constraints on Higgs decaying to light (< 15GeV) LLPs $\to b\bar{b}$

$H \to SS$ branching ratio is constrained to be below 5–10% for proper decays lengths of 10–100 mm and masses between 40 and 55 GeV



No significant deviation from the SM background is observed

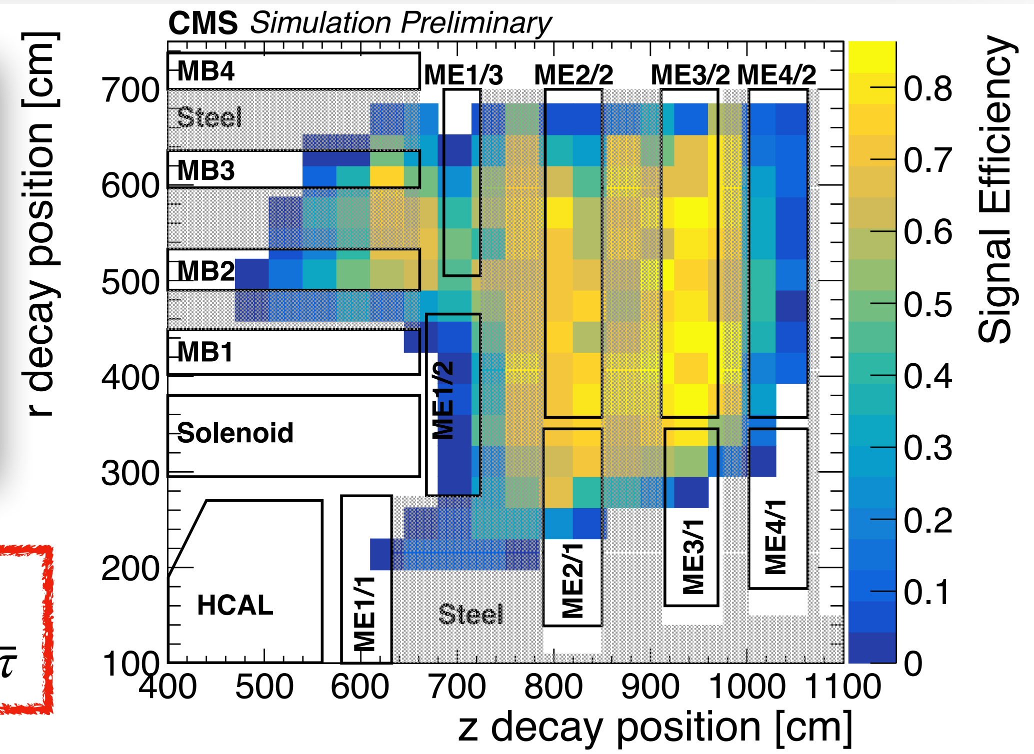


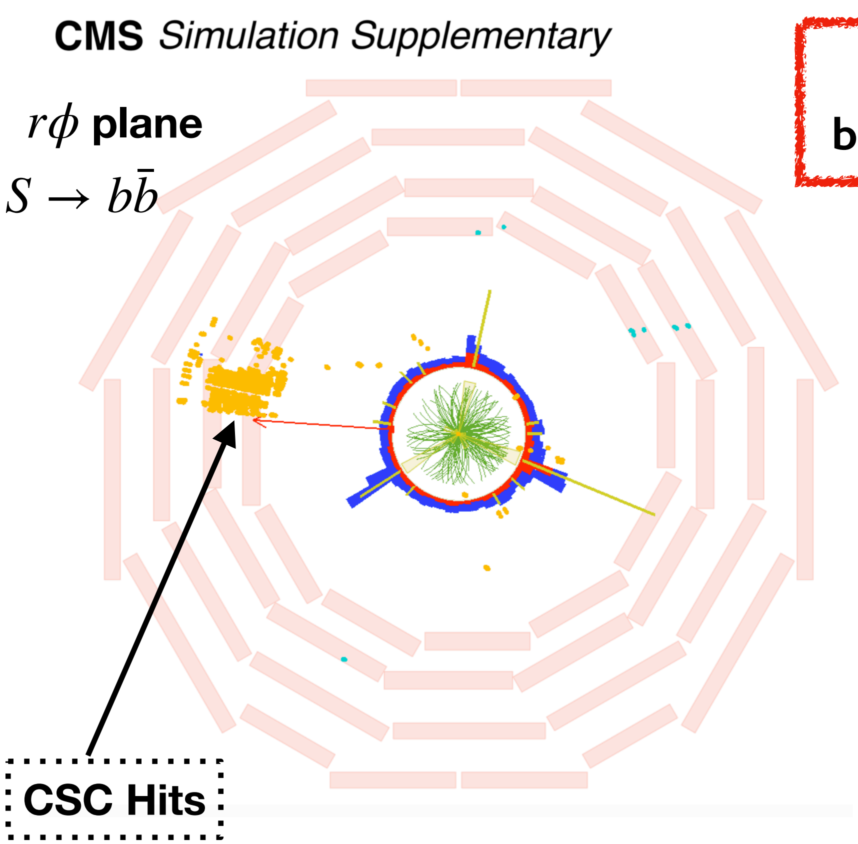
Exotic Higgs decays ($H \to SS \to 4j$)

CMS : arXiv:2107.04838

Full Run 2 dataset

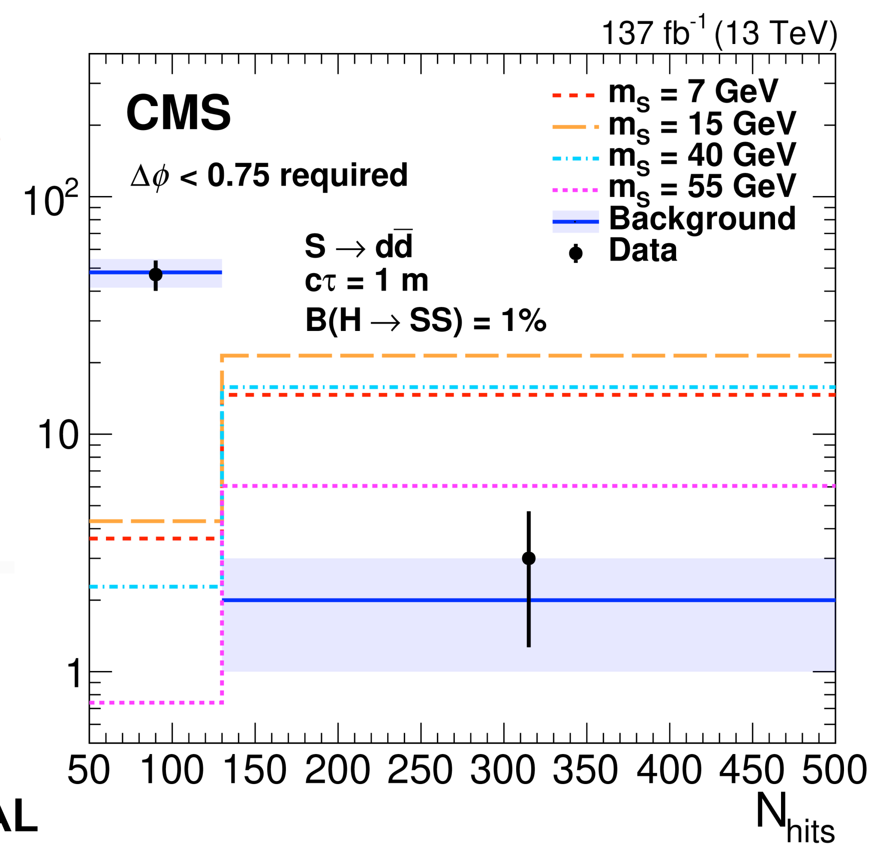
- First CMS search for long lived "hadronic showers" in the endcap muon system
- Magnetic flux-return yoke (steel) + CSC used as a sampling calorimeter (4 layers)
- Clusters are built in the CSCs with [-5, 12.5] ns cluster timing

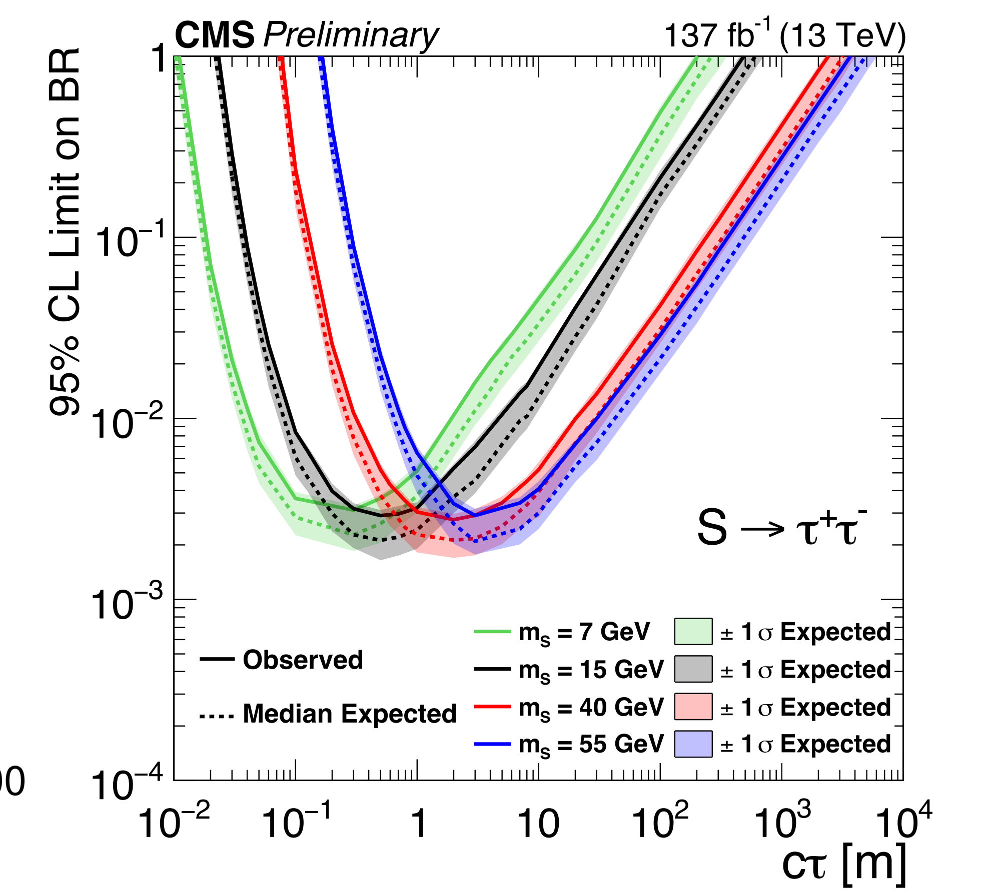




Green lines : tracks
Yellow lines : jets
Red arrow : MET direction
Red and Blue cones : ECAL and HCAL energy deposits

No significant deviation from the SM background is observed in $d\bar{d}, b\bar{b}$ and $\tau\bar{\tau}$



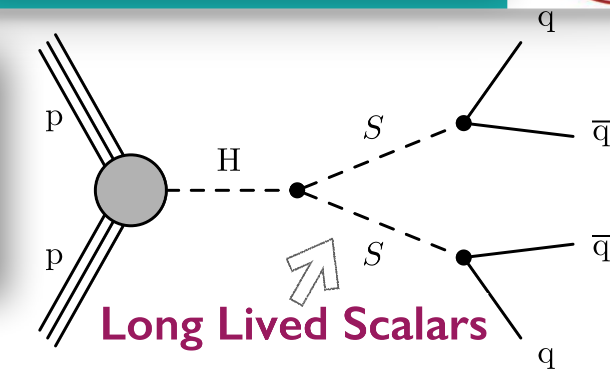


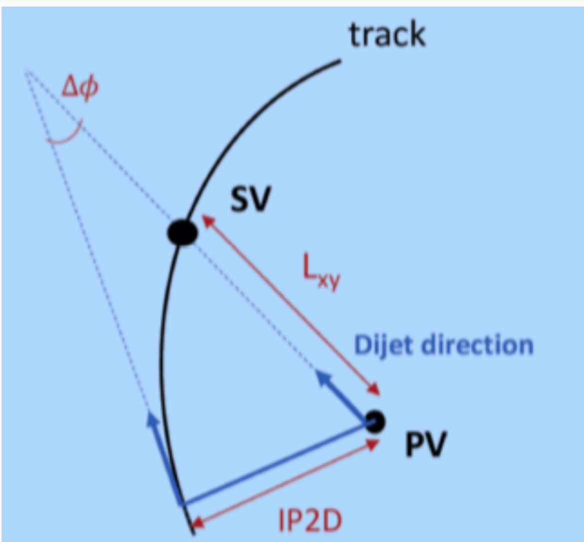
Exotic Higgs decays → displaced jets

CMS : arXiv:2012.01581

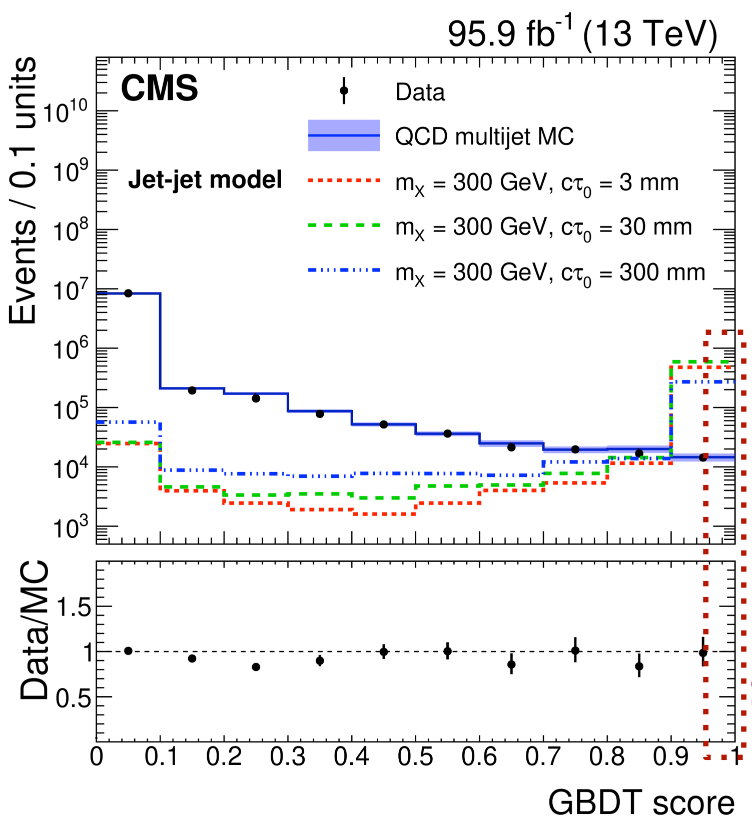
Full Run 2 dataset

- Distinctive topology: pair of jets originating at a secondary vertex
- Models targeted : LLP decaying to q-qbar, Exotic decays of Higgs: gg→H→2S, S→qq ($c\tau \sim 1$mm to 1m)



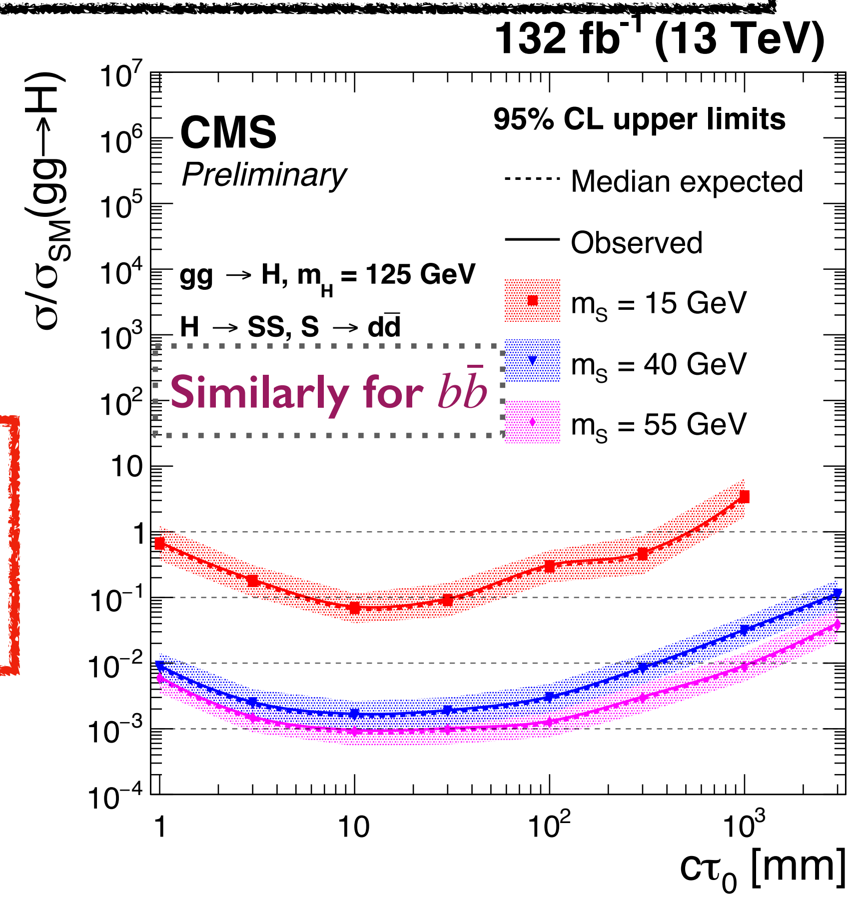


- A dedicated secondary vertex reconstruction is performed
- Dominant background : QCD multijet
- Gradient Boosted decision tree (GBDT) which includes variables like vertex track multiplicity, signed IP2D and Lxy



branching fractions (>1%) are excluded for $c\tau_0$ between 1 and 340 mm with $m_S \geq 40$ GeV (for light flavor quarks)

branching fractions (>10%) are excluded for $c\tau_0$ between 1 and 530 mm with $m_S \geq 40$ GeV (for $b\bar{b}$)

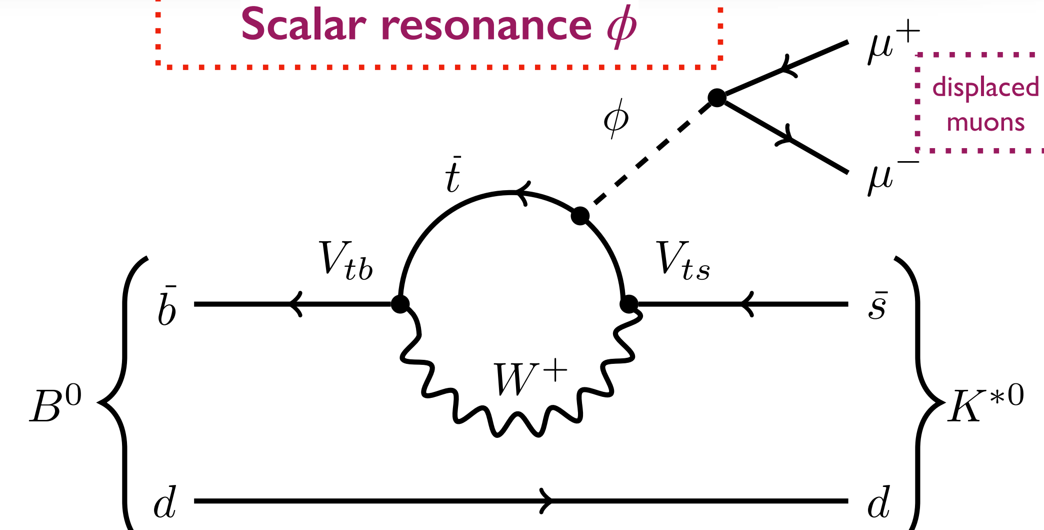


Probing for very low mass bosons

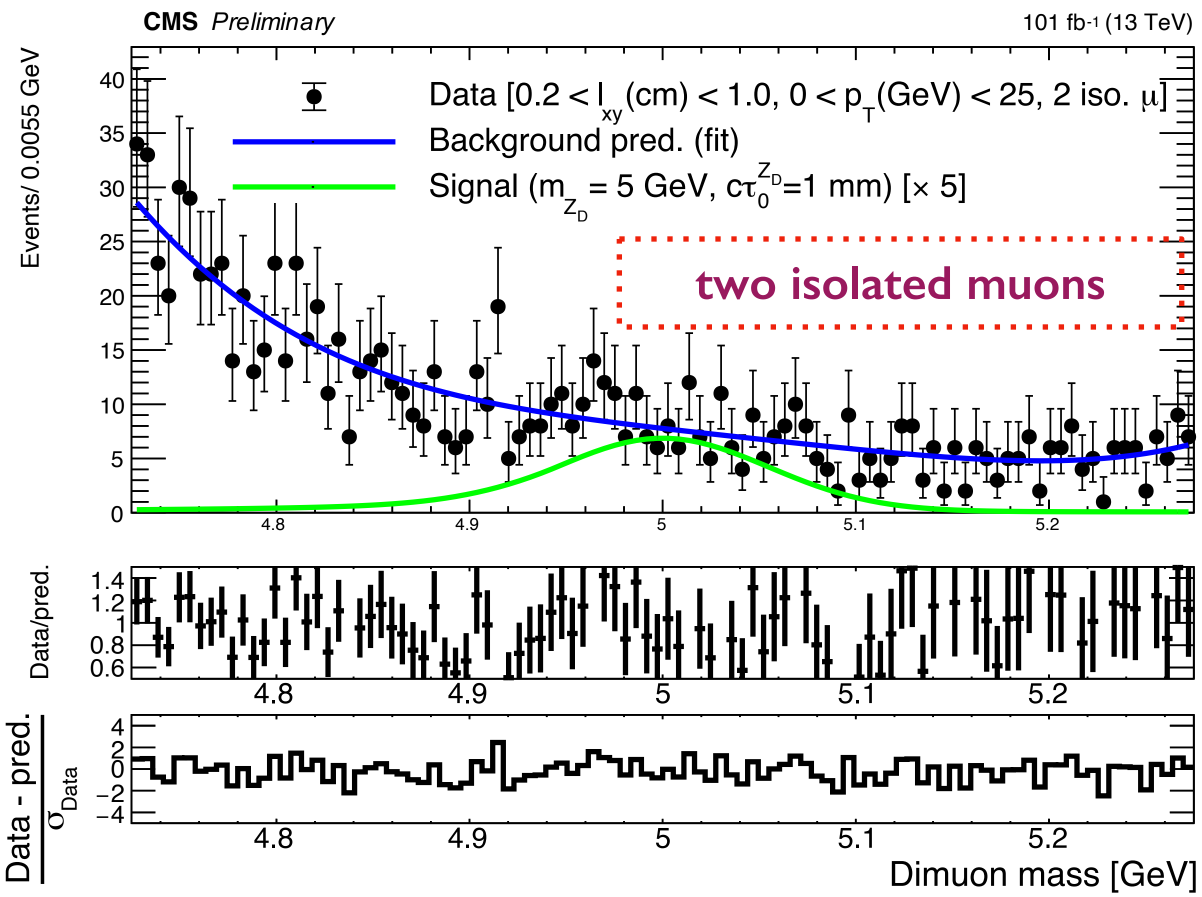
2017-2018 dataset

- Dedicated dimuon trigger stream with low transverse momentum thresholds to select displaced muons with transverse displacement range $I_{xy} < 11cm$ from the interaction point
- Explored inaccessible phase-space at low dimuon mass
- Bump hunt in mass range : 0.3 - 50 GeV
- Most stringent constraints to date on the BSM signal models in a wide range of signal mass and lifetime hypotheses

Scalar resonance ϕ

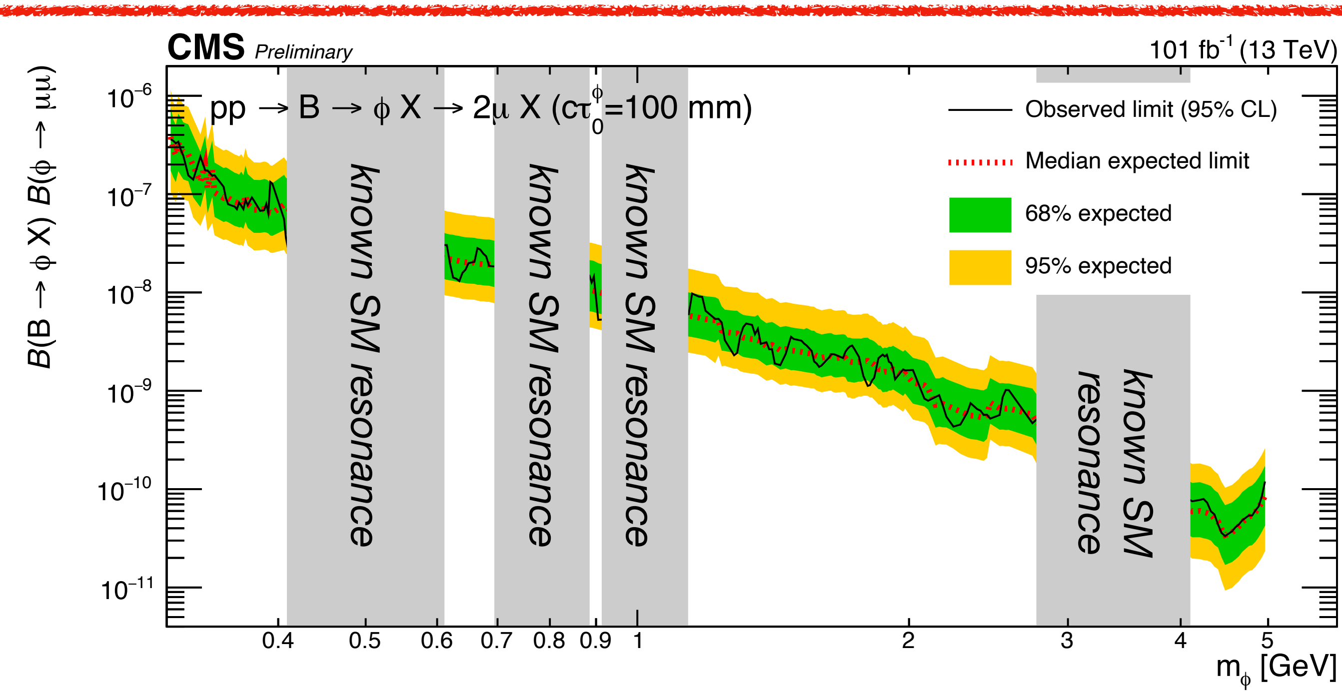


On shell long lived resonance in the decay of B-hadron



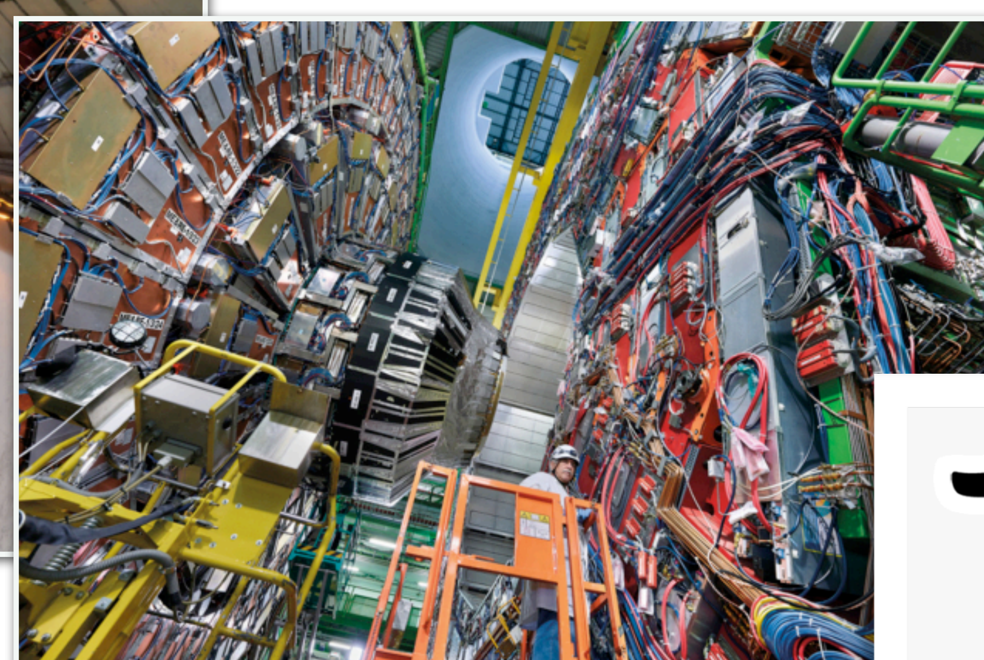
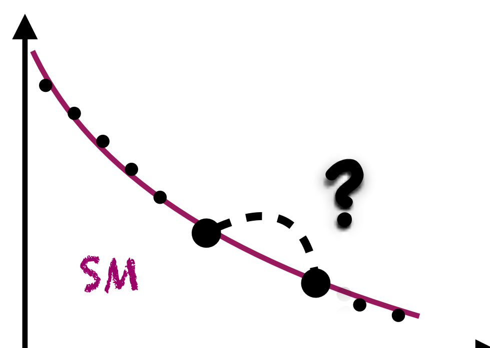
No significant excess over smoothly falling background is observed

Limits set for $c\tau_0^{\phi}$: 1 mm, 10 mm and 100 mm



To Summarize…

- Wide range of searches with all possible final states for exotic signatures at CMS probing in multi-dimensional phase space
- Many new searches and results with Run2 data
- Rise in new techniques and tagging algorithms for Run3 (going to start next year)
- New tools using ML are in practice now!!
- Excited to look for "Exotic signatures" with upgraded detector with advanced technology

Additional Slides

EXO Summary plot