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Search for an L_μ-L_τ gauge boson using $Z \rightarrow 4\mu$ events in pp collisions at $\sqrt{s}$=13 TeV

Results are based on **CMS-PAS-EXO-18-008**

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On the behalf of CMS Collaboration

Outline

- **Introduction and motivation**
- **Analysis overview and strategy**
  - Event Selection
  - Signal and background modelling
  - Systematic uncertainties
- **Results**
- **Summary**

CMS-PAS-EXO-18-008

Introduction: an L_μ-L_τ model

- The Standard Model is widely believed to be incomplete
  - Does not provide an explanation of many observations, e.g. dark matter, matter-antimatter asymmetry, and flavor.
- An additional U(1)’ gauge symmetry is one of the simplest extensions in SM
  - Only certain generation dependent couplings are allowed to keep the theory anomaly free
  - Differences in lepton family numbers are all anomaly free
  - **L_μ-L_τ** is the least constrained experimentally
    - Only couples to 2nd and 3rd leptons generation

Multiplet	$L_{L\mu} = \begin{pmatrix} \nu_{L\mu} \\ \mu_L \end{pmatrix}$	μ_R	$L_{L\tau} = \begin{pmatrix} \nu_{L\tau} \\ \tau_L \end{pmatrix}$	τ_R
Charge	1	1	-1	-1

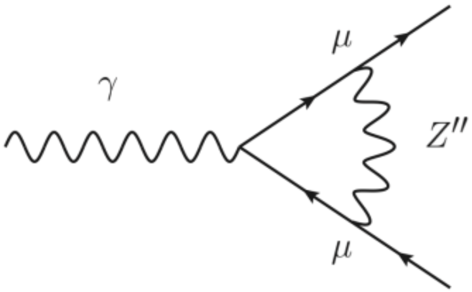
$$\mathcal{L}_{Z'} = -(g_L'^{ij} \overline{L}_{Li} \gamma^\mu L_{Lj} + g_R'^{ij} \bar{l}_{Ri} \gamma^\mu l_{Rj}) Z'_\mu$$

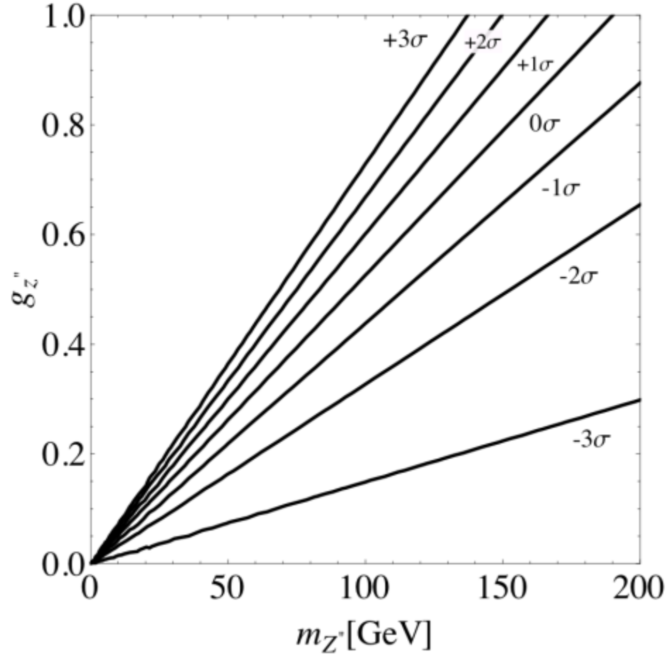
where g′ are arbitrary dimensionless couplings to the SM leptons

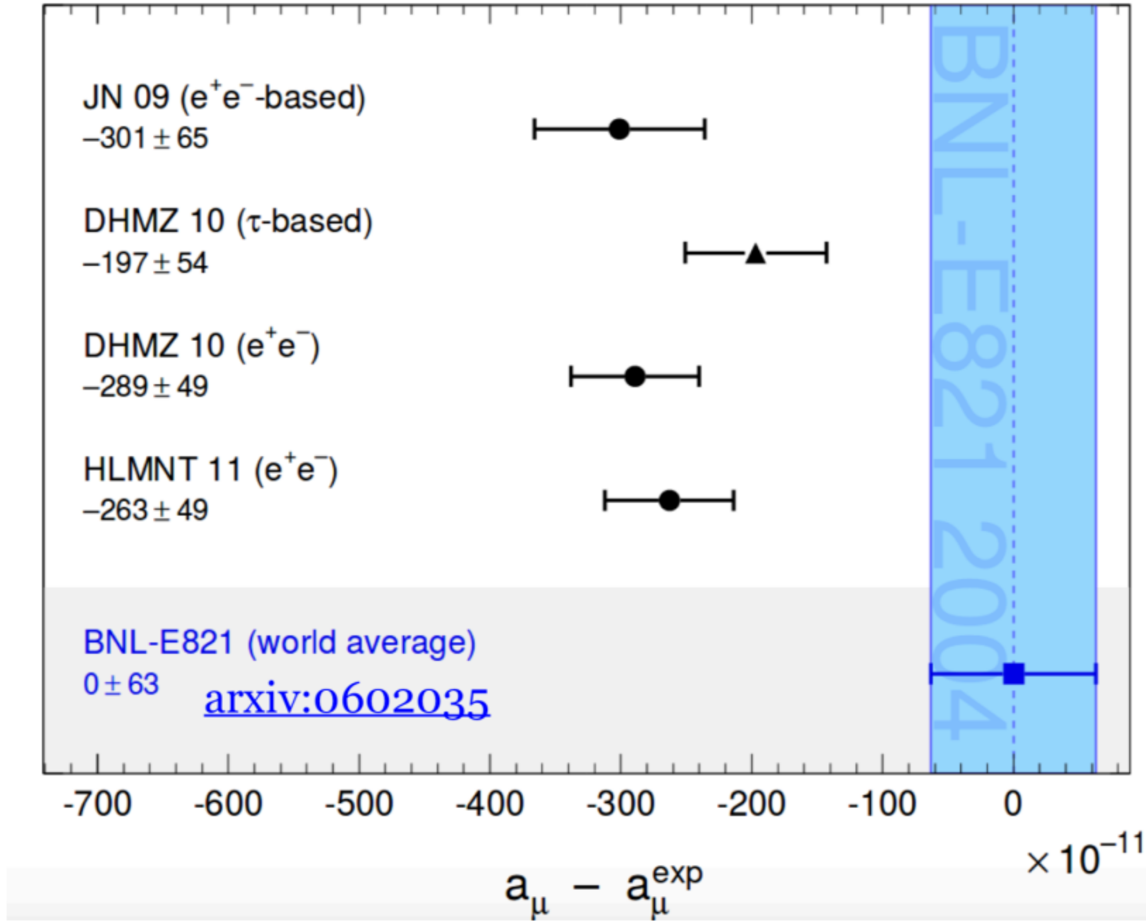
https://arxiv.org/pdf/1609.04026.pdf

Explanation of $(g-2)_\mu$ anomaly

- Longstanding tension in the measured value of $(g-2)_\mu$ can be explained by the L_μ-L_τ model for appropriate values of the mass and coupling



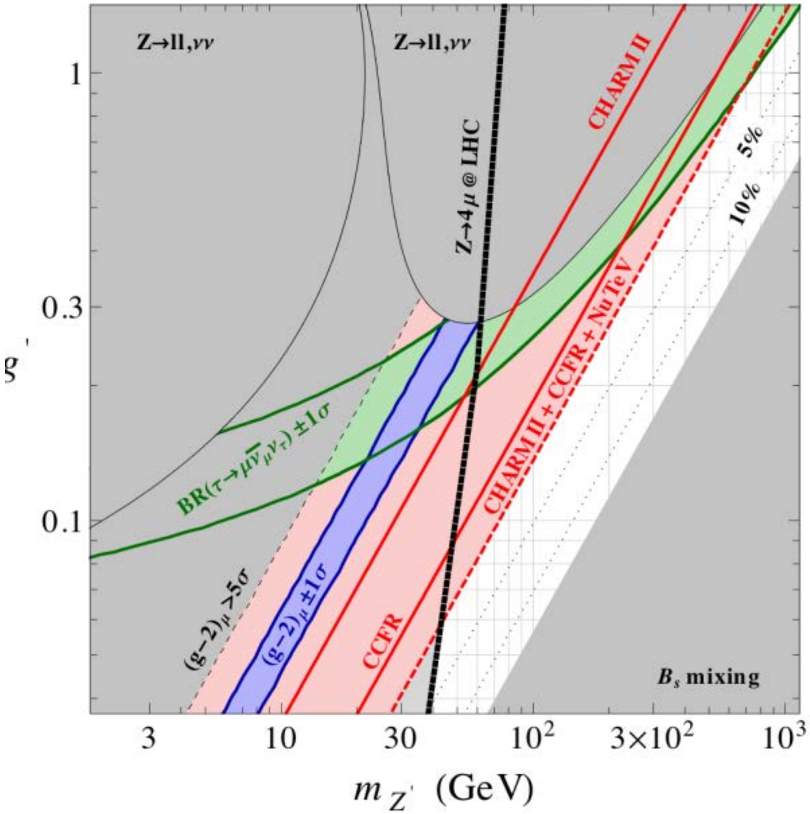




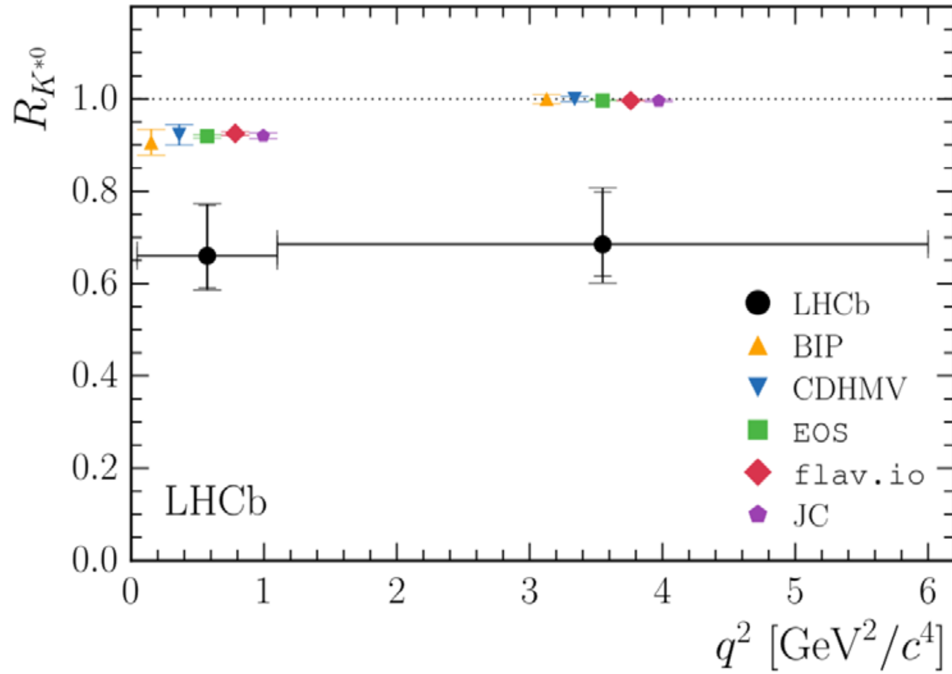
Explanation of b→sμμ anomalies

LHCb has measured the quantity R(K*) to be about 2.5 sigma below the SM prediction, pointing to potential Lepton Flavor Universality Violation

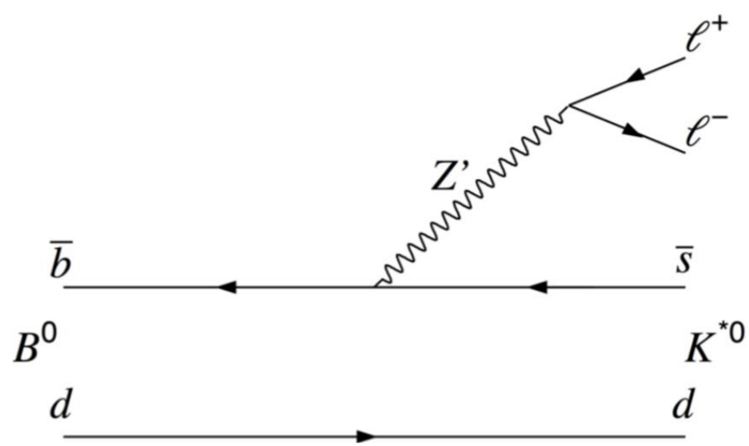
arxiv:1403.1269



arxiv:1705.05802

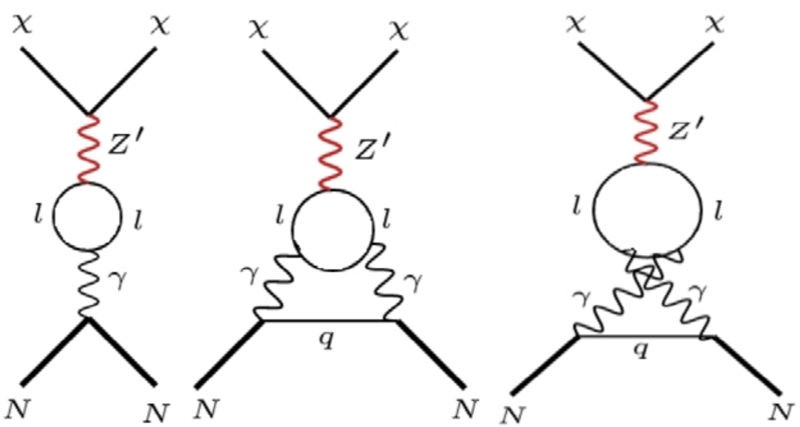


Can be explained by the L_μ-L_τ model if there are also interactions with quarks



Explanation of no DM signal

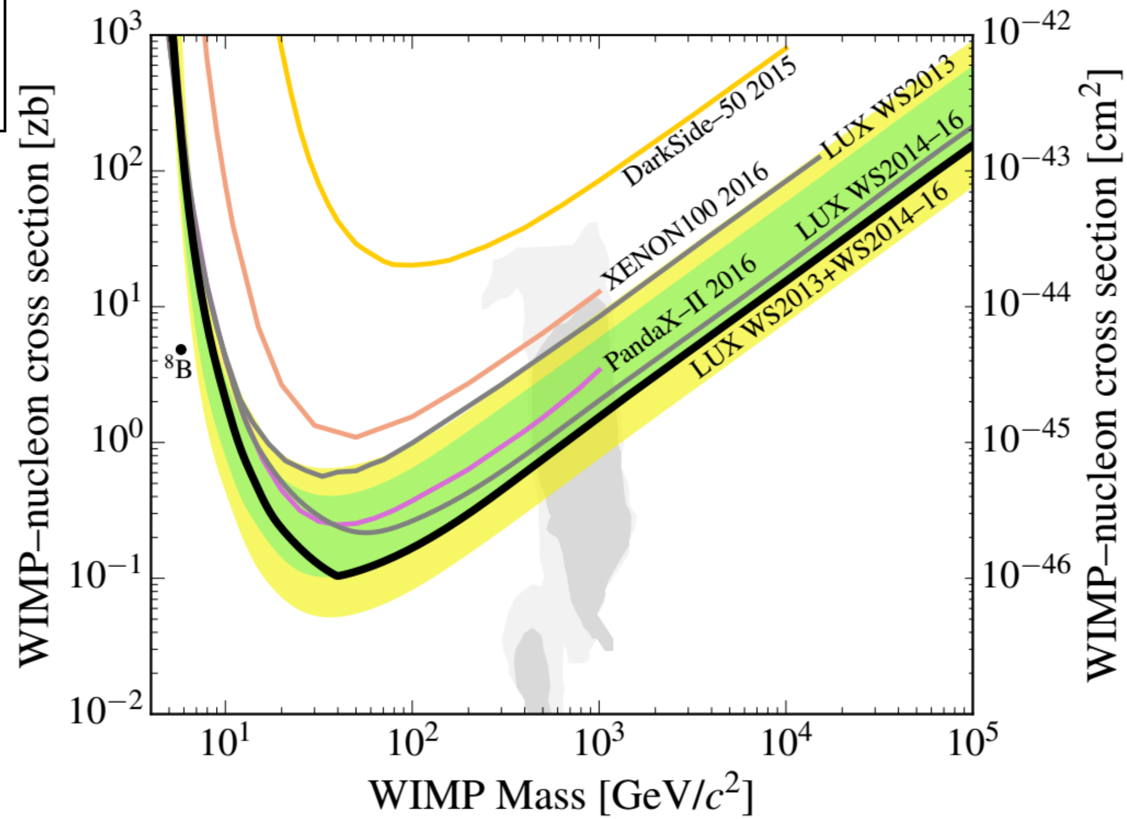
The lack of DM signal at Direct Detection experiments can be alleviated if the mediator is leptophilic, as in the Lμ-Lτ model



$$\sigma_{SI} = \frac{1}{A^2}\frac{\mu_N^2}{9\pi}\left(\frac{\alpha_{\rm em}\, Z\, g'^2 q_\chi q_l}{\pi m_{Z'}^2}\log\left(\frac{m_\mu^2}{m_\tau^2}\right)\right)^2$$

arxiv:1609.04026

arXiv:1608.07648

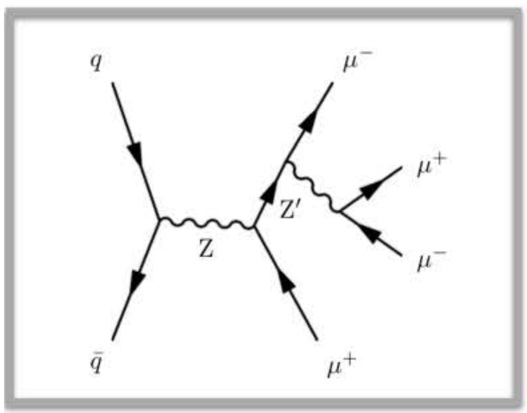


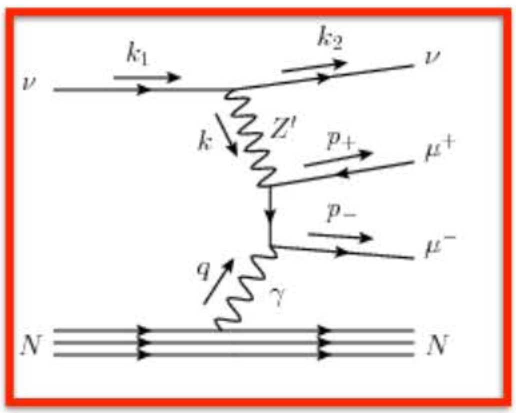
Can be explained by the L_μ-L_τ model if there are also interactions with quarks

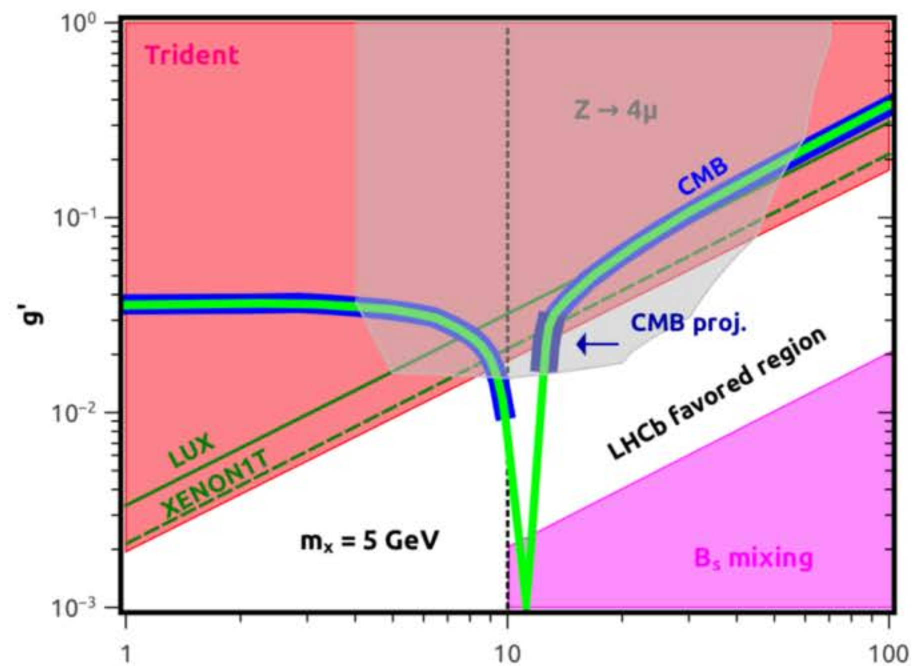
Constraints on L_μ-L_τ Model

- Strongest constraints on the L_μ-L_τ model come from the "Neutrino Trident" process and the rate of Z → 4μ at the LHC
  - LHC constraints come from reinterpretation of ATLAS B(Z→4μ) measurement at 7 and 8 TeV, does not make use of specific Z' kinematics
- DM relic density and b→sμμ anomaly explanation allowed for a bounded parameter space, muon $(g-2)_\mu$ explanation disfavored by Trident measurement

arxiv:1609.04026



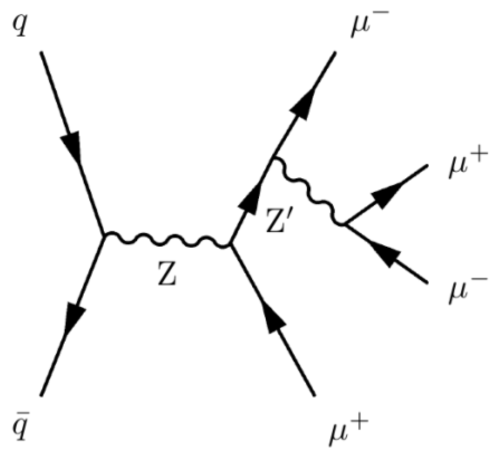




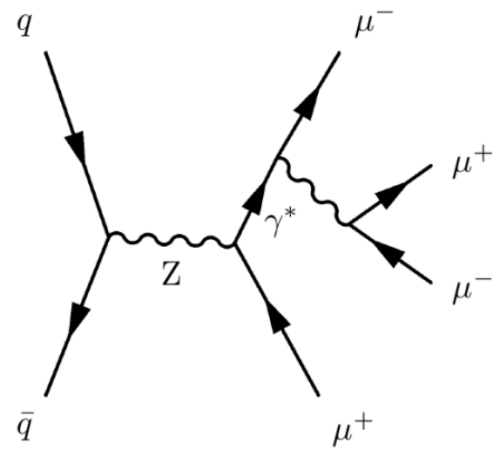
6

Event Signature and Motivation

Signal



Background



- The Z boson provides an extremely clean source, four muons in final state with Z' to μ+μ-
  - Almost background free
  - After requiring 4 muons there is only irreducible Z→4μ background (estimated by simulation)
  - Reduced by orders of magnitude by reconstructing the Z’ candidate
  - Excellent mass resolution, higher reconstruction efficiency
- Cut-and-count search with a sliding mass window
- Statistically limited after final selection

Data, Triggers, MC Simulation

- Full 2016/2017 dataset corresponding to 77.3 fb^{-1} of integrated luminosity
  - Luminosity uncertainty 2.6% for 2016 and 2.3% for 2017
- We use an OR of Single, Double and Triple muon triggers for muons passing the identification and isolation requirements:
  - Global or Tracker muons with ghost removal pT>5 GeV, $|\eta|<2.4$, dxy<0.5cm, dZ<1cm, SIP<4 (Loose)
  - PF muon with $\Delta\beta$ corrected PF Iso($\Delta R=0.3$)<0.35 (Tight)
- MC simulation samples: (for Z' and background)
  - To estimate background rate, optimize event selection, evaluate acceptance and systematic uncertainties
  - Signal (LO in pQCD): with MadGraph5 aMC@NLO
  - Background (NLO): POWHEG 2.0 and MCFM for qq and gg initiated process resp.
  - MPI simulation: PYTHIA 8.212 tune CUETP8M1
  - Detector effects: Geant4

Object Reconstruction and Selection

Based on H→4μ analysis

- Reconstruct Z candidates from OSSF muon pairs which satisfy **:**

  $4.0 < m(\mu^+\mu^-(\gamma)) < 120$ GeV

- For each ZZ candidate, Z_1 candidate is selected with $\mu^+\mu^-(\gamma)$ closest to the PDG mass, the other as Z_2 :
  - $12 < m(Z_1) < 120$ GeV
  - $4.0 < m(Z_2) < 120$ GeV
  - $p_T(\mu) > 5.0$ GeV
  - $m(\mu\mu) > 4$ GeV
  - Leading $p_T(\mu)$> 20 GeV, Sub-leading pT(μ) > 10 GeV
  - Removed overlapping muons (ΔR>0.02 between each muon)
  - $80 < m(4\mu) < 100$ GeV
- FSR photon recovery algorithm per lepton
  - Pre-selection of $p_T(\gamma)$>2 GeV, |η|<2.4, PF Iso. < 1.8
  - Electron SC veto
  - $\Delta R(\gamma, \mu)/(E_T^{\gamma})^2 > 0.012$, and $\Delta R(\gamma, \mu) > 0.5$
  - FSR photons removed from muon isolation computation

Search Strategy

- The Z' candidate is most often reconstructed as Z_2 for m(Z')<42.65 GeV and as Z_1 for m(Z')>42.65
- Cut-and-count search using $m(Z_1)$ or $m(Z_2)$ with a sliding window
- 2% mass window requirement optimized simultaneously for significance and exclusion limit

Irreducible Background Estimation

- Estimated from MC
- A polynomial function is used to parameterize and smooth the expected background yield in the 2% mass window as a function of the Z' mass hypotheses, for both $m(Z_1)$ and $m(Z_2)$
- MC Statistical uncertainty is 3% for qq, 15% for gg
  - Negligible from gg in our phase space because of less cross section

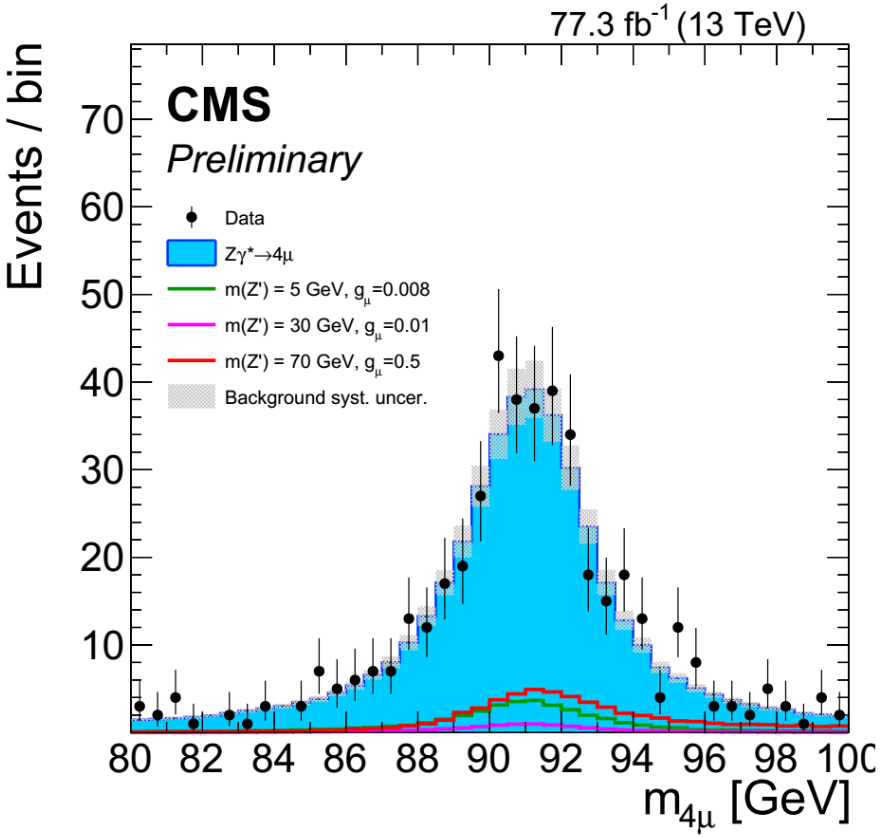
Systematic Uncertainties

Summary of relative systematic uncertainties	
Common experimental uncertainties	
Luminosity	2.6 (2.3) %
Trigger and muon identification/reconstruction efficiencies	4.9 %
theory systematic uncertainties	
QCD scale (gg)	$\pm$ 3.9 %
PDF set (gg)	$\pm$ 3.5 %
Bkg K factor (gg)	$\pm$ 10 %
QCD scale ($q\bar{q} \rightarrow 4\mu$ and signal)	+3.5/-4.2 %
PDF set ($q\bar{q} \rightarrow 4\mu$ and signal)	+3.1/-3.4 %
Signal related uncertainties	
MC statistical uncertainty	1.4%
Interference effect	5 %
Muon energy scale	0.1%
Muon resolution	2%
Background related uncertainties	
MC statistical uncertainty (gg)	15.0%
MC statistical uncertainty ($q\bar{q} \rightarrow 4\mu$)	3.0%

- Total Systematic uncertainty ~8%, Background Poisson statistical uncertainty always greater than 22% after final selection
- Uncertainties are correlated between 2016 and 2017

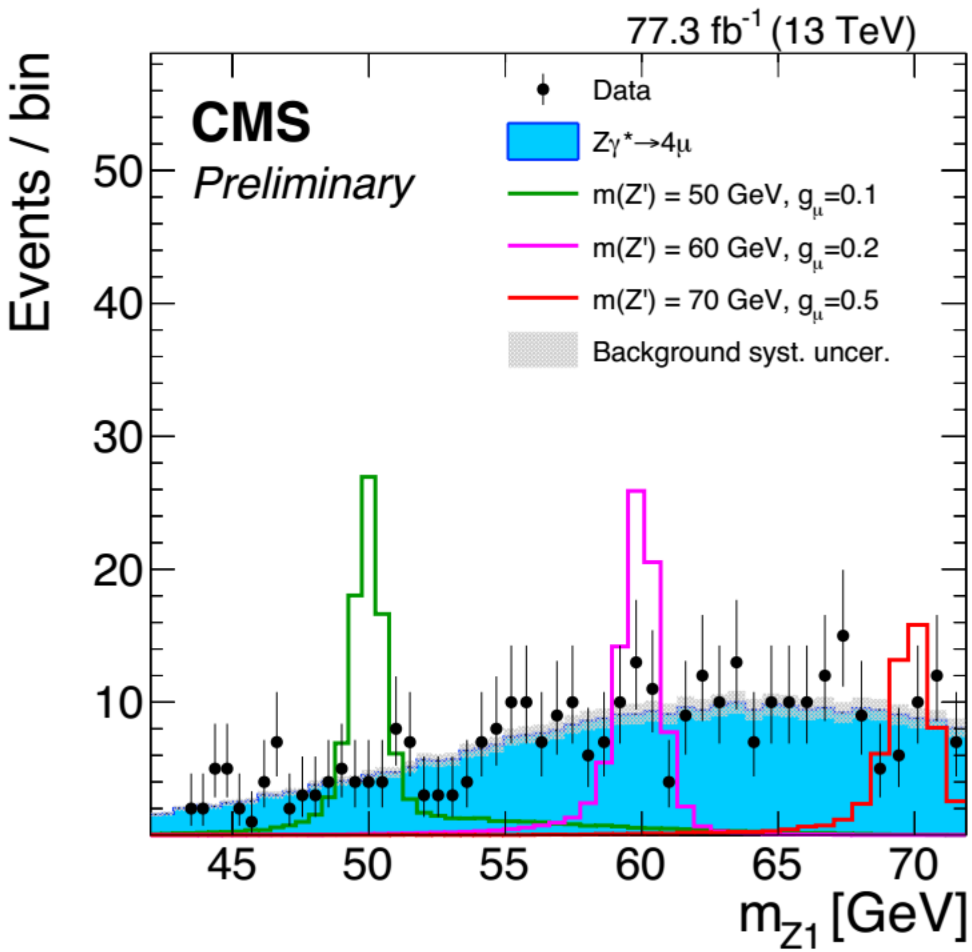
Results: Distributions

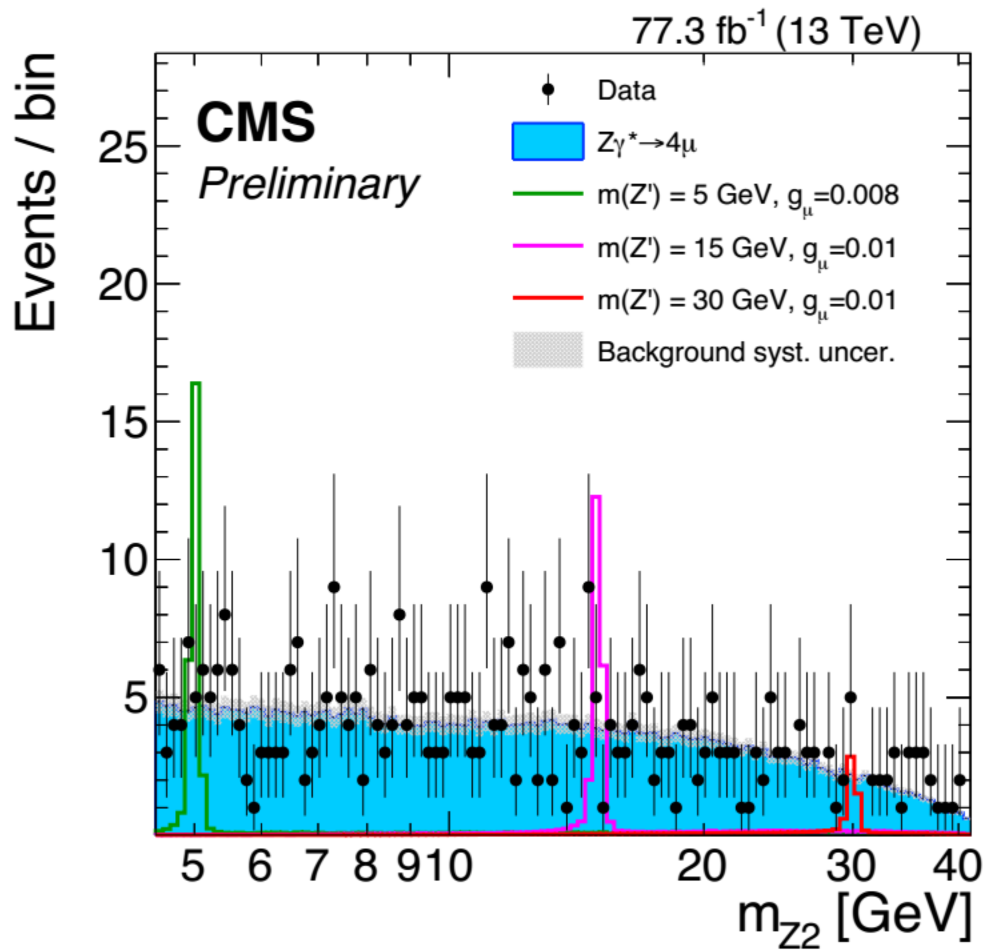
- The number of expected background and signal events and the number of observed candidate events after the full selection with 80< $m_{4\mu}$<100 GeV.
- The uncertainties in the signal predictions are purely systematic uncertainties, while in the background predictions the uncertainties also include the statistical uncertainty.



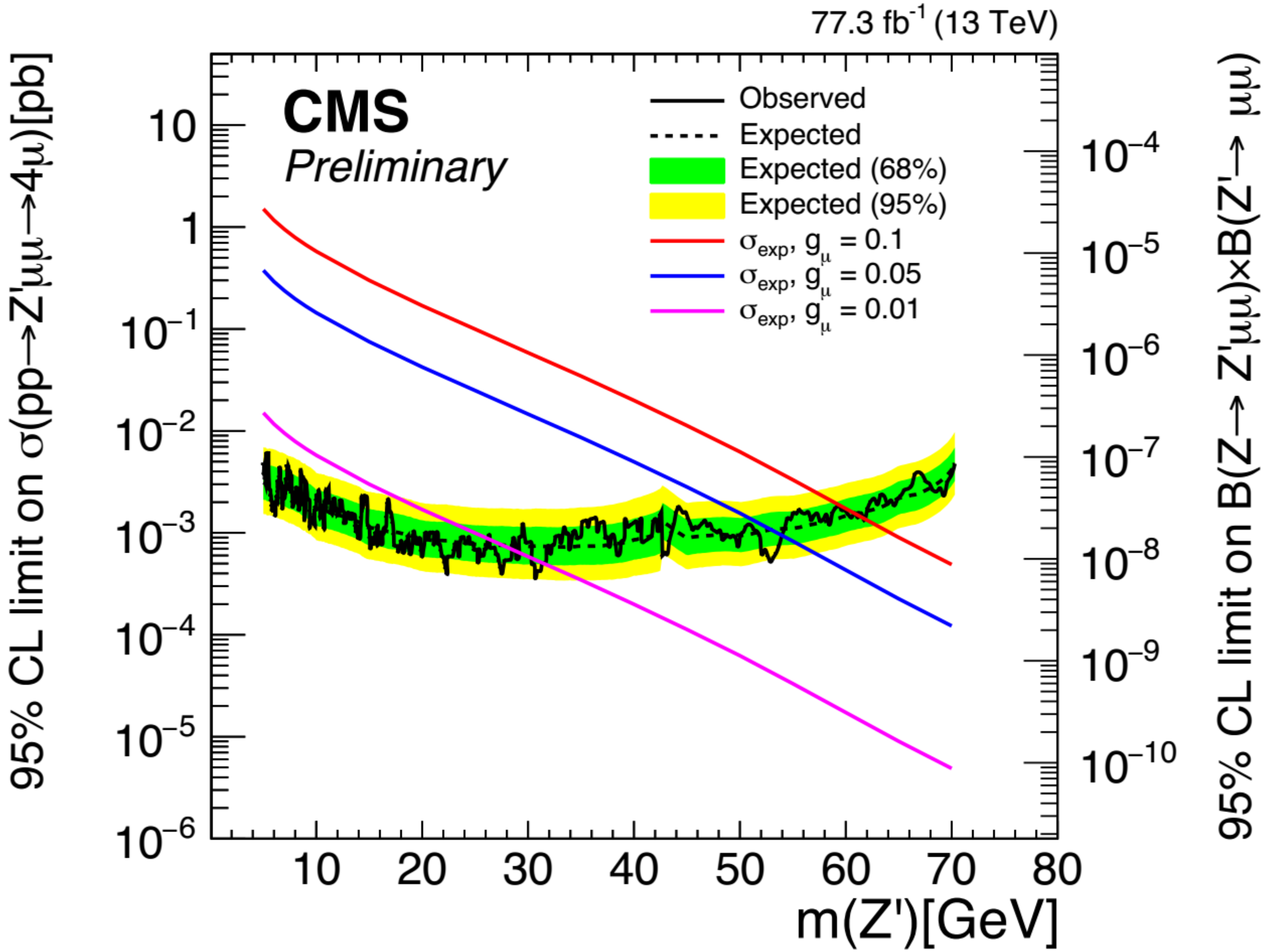
	Background	$m(Z') = 5\,\text{GeV}$ g_μ=0.008	$m(Z') = 15\,\text{GeV}$ g_μ=0.01	$m(Z') = 70\,\text{GeV}$ g_μ=0.5	Observed Data
$80 < m_{4\mu} < 100\,\text{GeV}$	423.0±39.2	37.1±3.7	31.4±3.1	53.8±5.4	441
$4.9 < m(Z_2) < 5.1\,\text{GeV}$	9.2±3.1	23.3±2.3	–	–	13
$14.7 < m(Z_2) < 15.3\,\text{GeV}$	7.7±2.8	–	18.9±1.9	–	6
$68.6 < m(Z_1) < 71.4\,\text{GeV}$	34.9±6.5	–	–	36.0±3.6	35

Results: Distributions

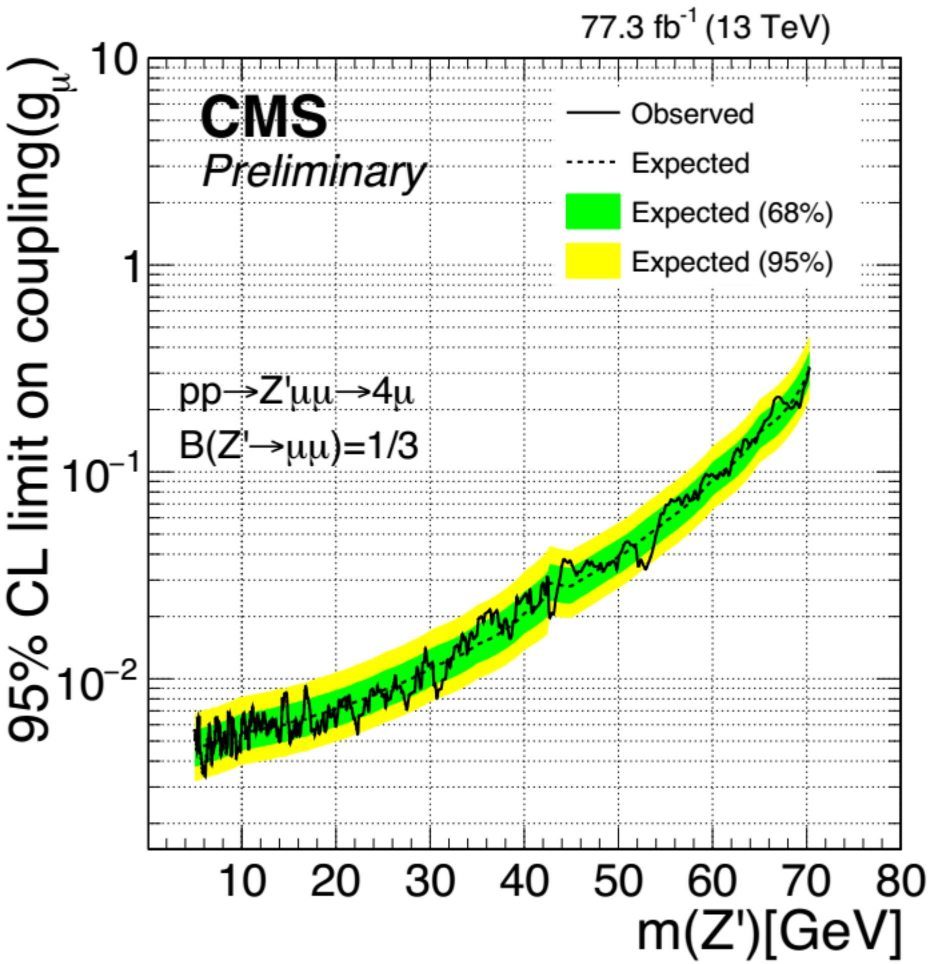


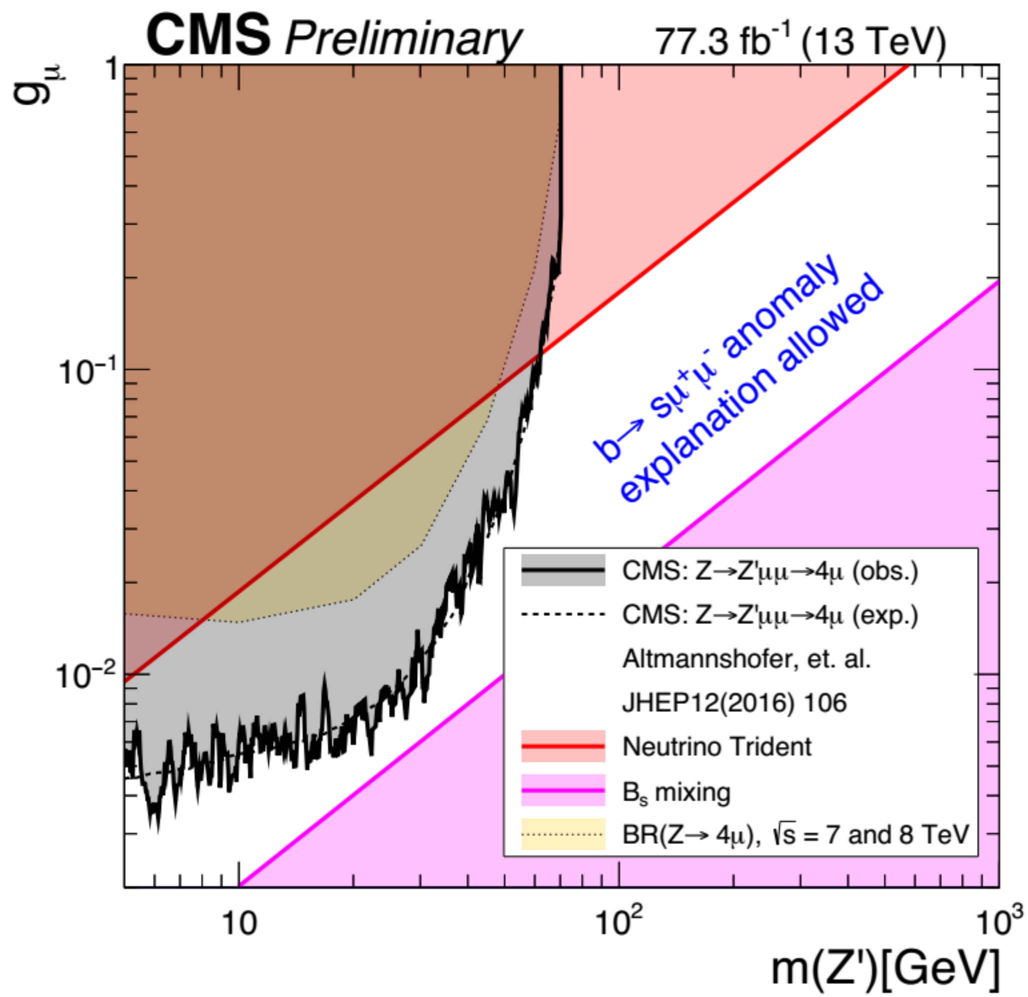


Results: Limits on Cross Sections and Branching Ratios



Results: Limits on Gauge Coupling Strength





Summary

- L_μ- L_τ model is a simple extension of the SM which can explain several anomalous experimental observation
- We have presented the first dedicated search for this model at the LHC using $Z \rightarrow 4\mu$ events in the full 2016+2017 dataset (77.3 fb^{-1})
- No excess is observed in the signal region, and we have derived constraints on the model parameter space, significantly extending the exclusion into previously allowed regions
- PAS is made public at LHCP2018
  - IHEP contributions: contact, editors and pre-approval talk
- CWR is now over; target journal for paper is PLB


Thank
you