Searches for new heavy resonances in the dilepton channel

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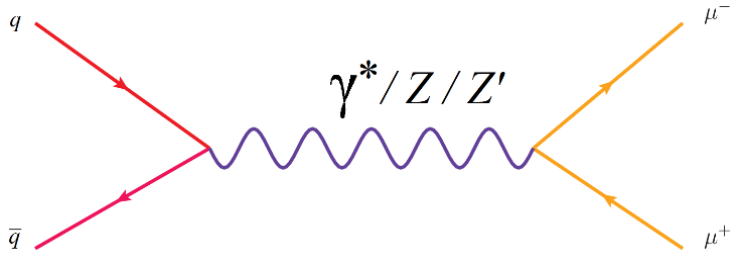
SM processes and beyond

Motivation to search for new physics

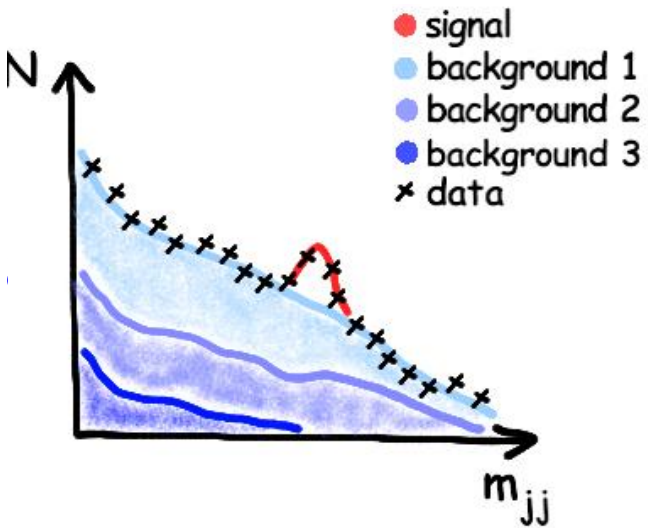
- Many theoretical scenarios beyond the Standard Model predicts phenomena that can be discovered in the channel with a pair of muons;
- The Drell-Yan process - $q\bar{q} \to \gamma/Z^0/Z' \to l^+l^-$ - is one of the critical tests of the SM. In SM the process is calculated with great precision: NNLO QCD & NLO EW;
- Test the Standard Model on a new energy scale (~ several TeV);
- Events with a pair of muons have a simple experimental signature;
- The Compact Muon Solenoid (CMS) experiment at the LHC is optimized for measuring high pT muons (up to several TeV).

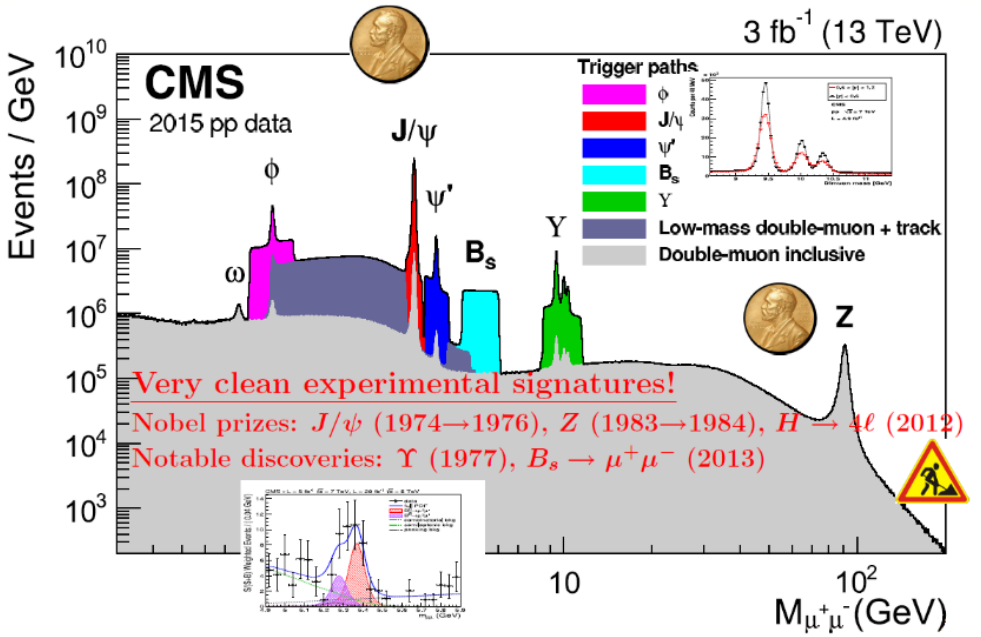


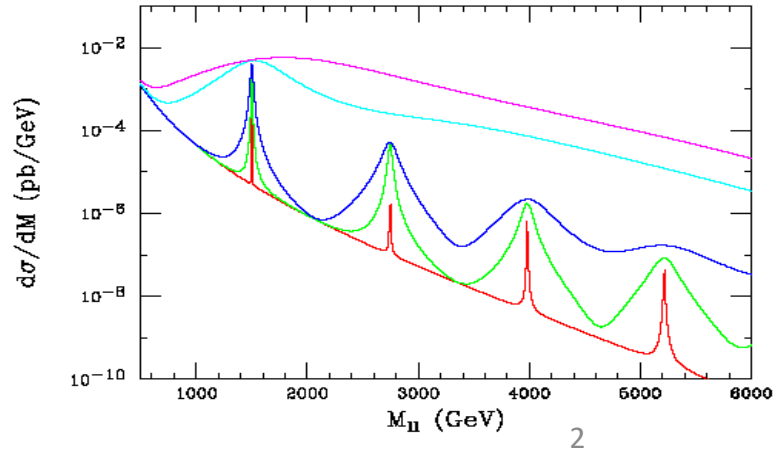
New Physics ($Z'/Z_{KK}/G_{KK}$) contributions to SM processes:

- Spin-1 resonances
- Spin-2 resonances
- Non-resonant signals
- Rare Higgs Decays *($H \to \mu\mu$)*

Signals: di-leptons resonance states in high (~TeV) invariant mass range ⇒ new particles would be observed as a bump, excess in the mass spectrum





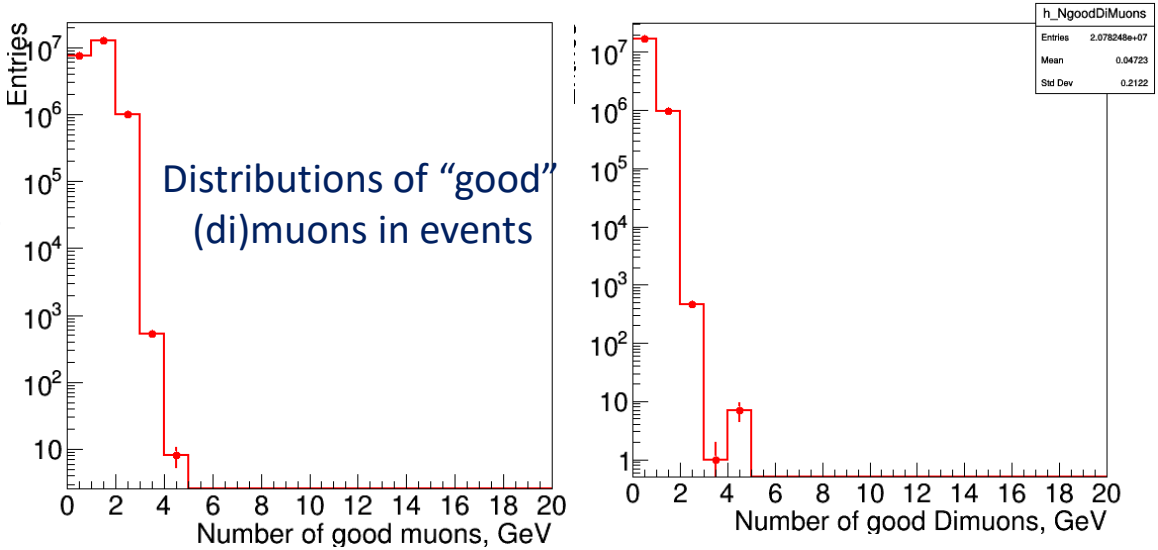


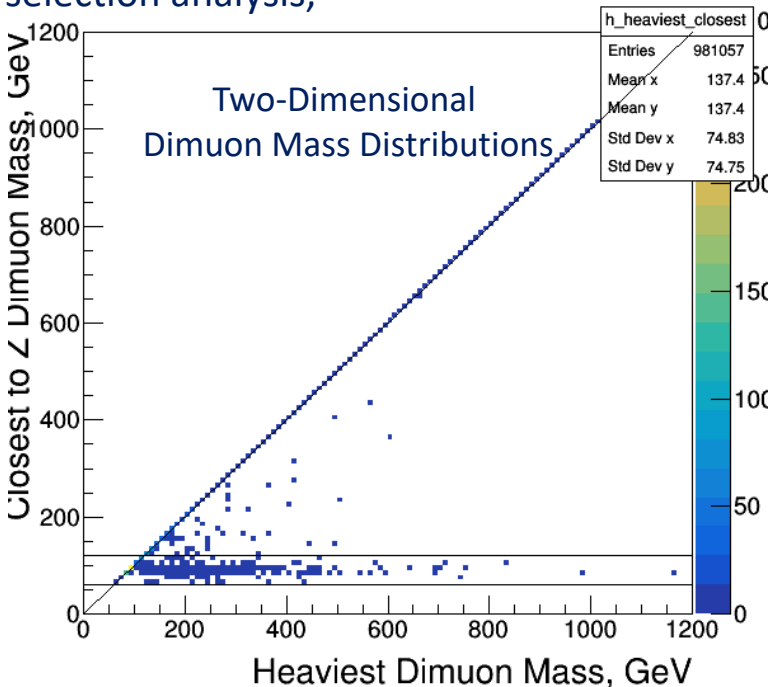
Selection of dimuons in events with more than two muons

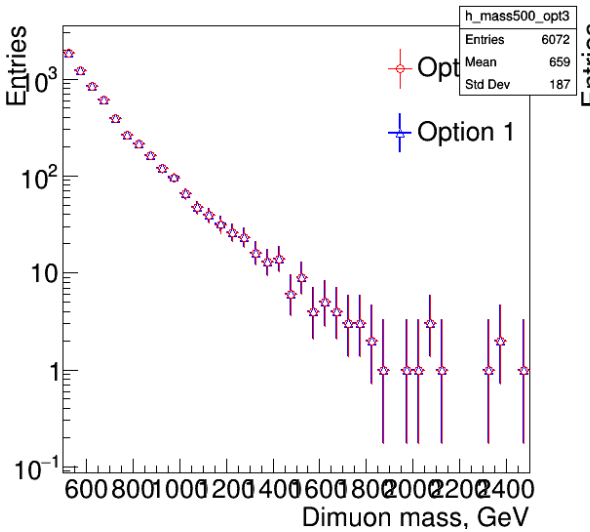
- In events with more than 2 “good” muons there are several possible ways to pair up them.
- There was a purpose to check different ways to combine them.
- The idea was:

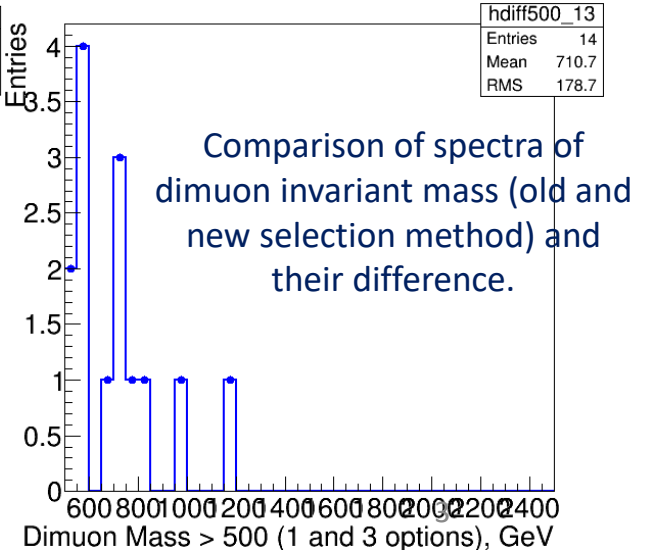
  if a pair has invariant mass within 20 GeV window around Z^0 boson mass, then that pair, otherwise take highest p_T pair.
  Pairs from Z^0 should be excluded from Z' analysis.

- A method for selecting muon pairs was proposed, tested and accepted.
- As a result, in the muon pair selection analysis, an additional selection criterion is applied.
- This also helps to reduce the physical backgrounds of dibosons production in the ZZ and WZ channels.



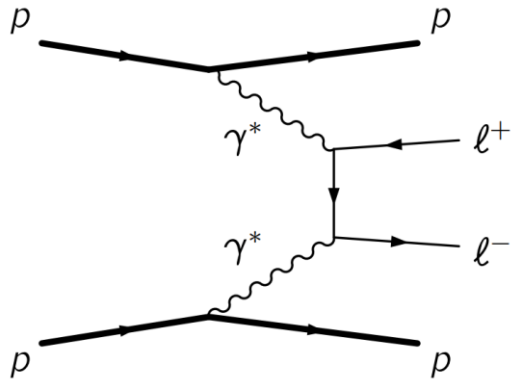






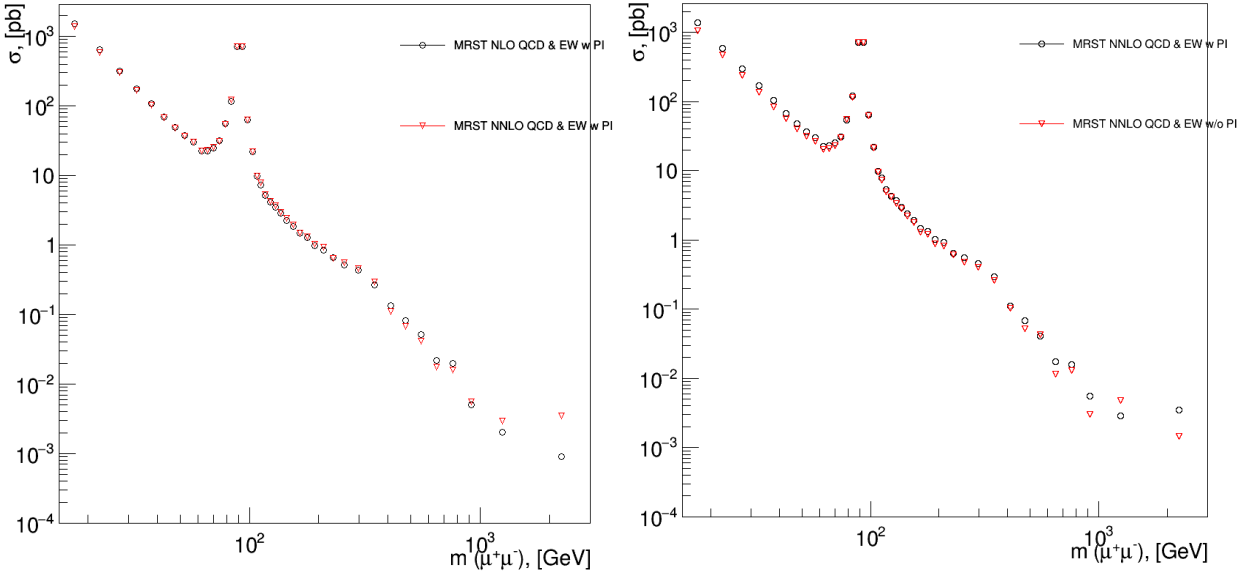
Photon-induced background

Photon-induced (PI) processes – The production of high invariant mass opposite sign lepton pairs in gamma-gamma collisions, where photons radiated by the incoming protons collide.

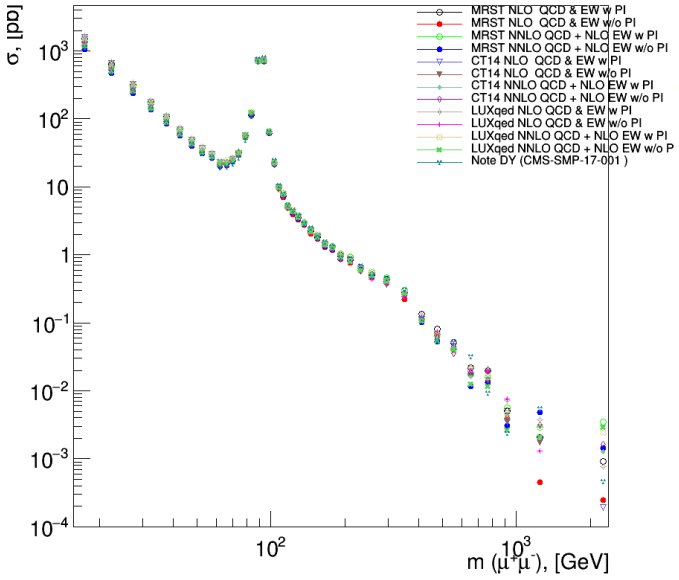


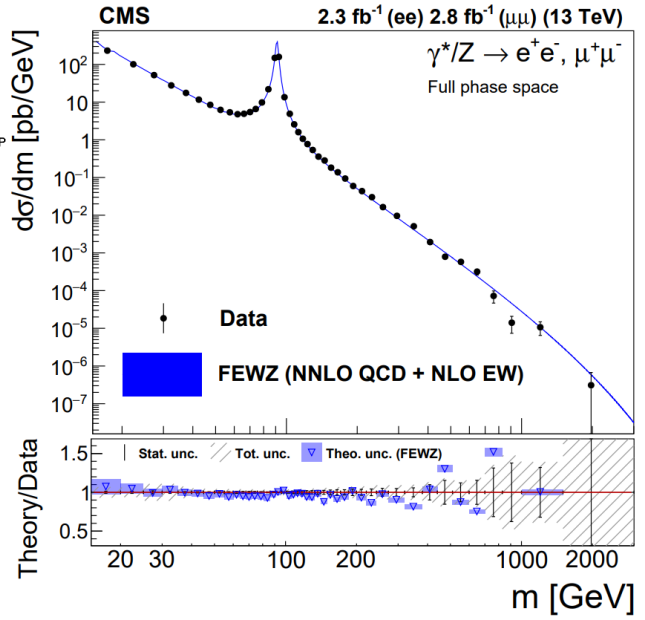
- In addition to DY, pairs of leptons *ee*, *μμ* (and also WW, ZZ pairs, etc.) can be produced in gamma-gamma interactions;
- To calculate this process, one needs PDFs that include the photonic component.

FEWZ (Fully Exclusive W and Z Production) has been used for calculating leading order (LO), next-to-leading order (NLO), and next-next-leading order (NNLO) Drell-Yan processes.



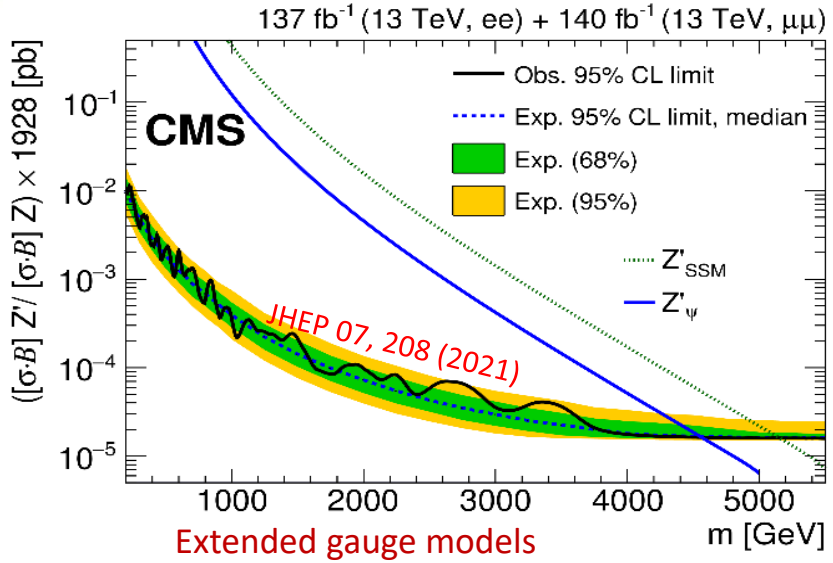
Comparison of cross sections in NLO and NNLO QCD orders and with and without PI contribution (for PDF MRST2004qed_proton)



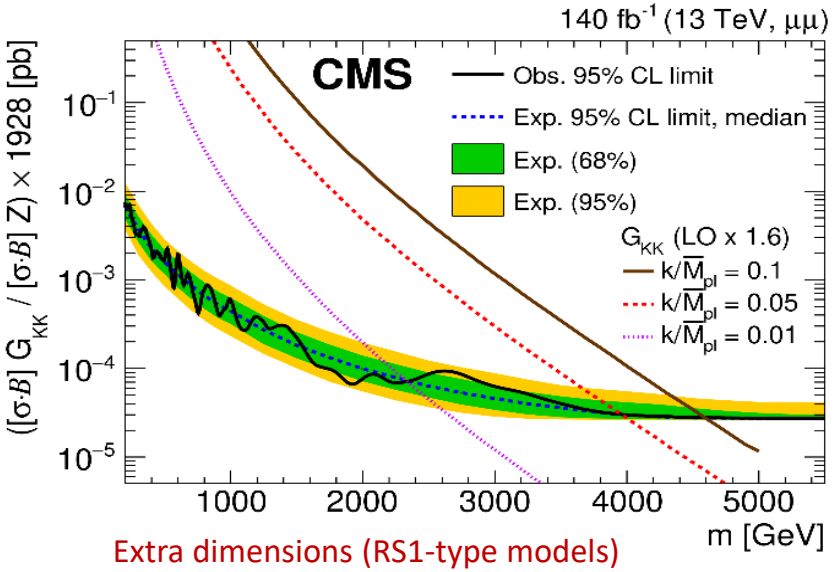


Comparison of cross-section distributions depending on the invariant mass of various PDFs in NLO and NNLO orders, as well as comparison with cross-sections for DY from JHEP 12 (2019) 059.

Heavy Resonances: Z′ and RS1 Limits



Extended gauge models



Extra dimensions (RS1-type models)

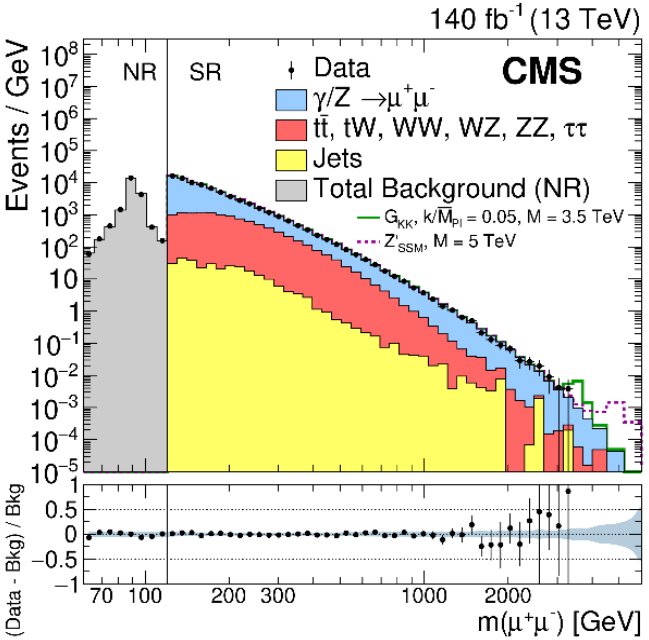
The likelihood function is based on probability density functions (pdf) that describe the signal and background contributions to the invariant mass spectra

$$\mathcal{L}(m|R_\sigma, M, \Gamma, w, \alpha, \beta, \kappa, \mu_B) = \frac{\mu^N e^{-\mu}}{N!} \prod_{i=1}^{N} \left(\frac{\mu_S(R_\sigma)}{\mu} f_S(m_i|M, \Gamma, w) + \frac{\mu_B}{\mu} f_B(m_i|\alpha, \beta, \kappa) \right)$$

Background: $m^\kappa e^{\alpha m + \beta m^2 + \delta m^3}$

$$R_\sigma = \frac{\sigma(pp \to Z' + X \to \ell\ell + X)}{\sigma(pp \to Z + X \to \ell\ell + X)}.$$

The use of this R ratio eliminates the uncertainty in the integrated luminosity and reduces the dependence on the experimental acceptance, trigger, and offline efficiencies



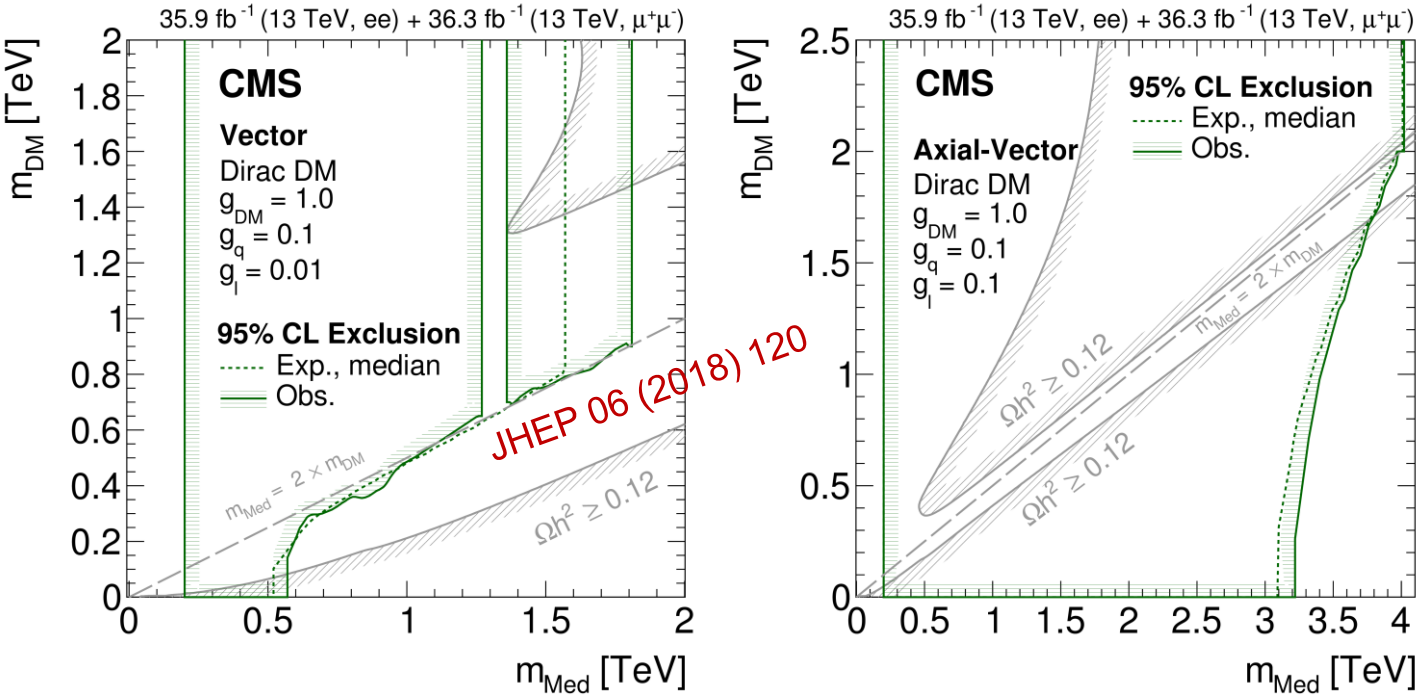
✓ The corresponding 95% CL limits are set

The observed limits are

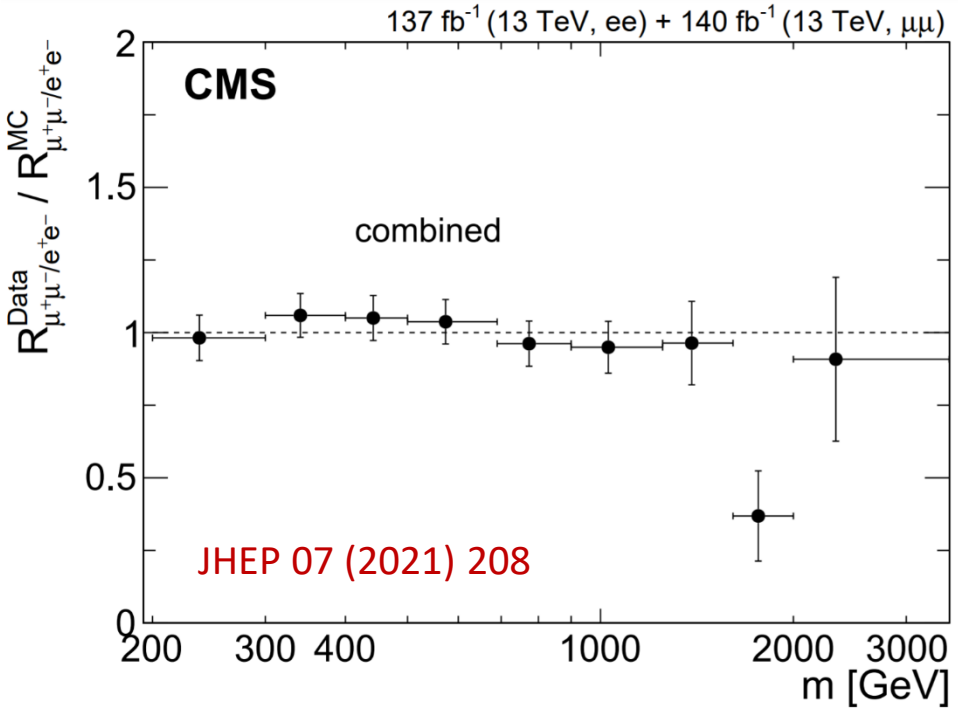
- 5.15 TeV for the Z'_{SSM}
- 4.56 TeV for the Z'_{ψ}.
- for G_{KK}, mass limit is 2.47 TeV (c=0.01)
- for G_{KK}, mass limit is 4.16 TeV (c=0.05)
- for G_{KK}, mass limit is 4.78 TeV (c=0.1)

Dark Matter and LFU

Dark Matter candidates and spin-1 high-mass mediator



Lepton flavor universality



Conclusions

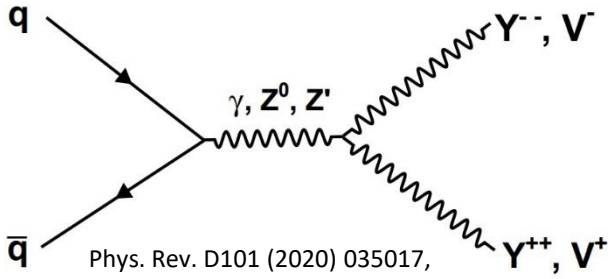
- The method for selecting muon pairs has been developed as additional selection criterion in Z' analysis; This method has been used for the data analysis;
- Complete statistics of Run2 2016-2018 is processed;
- The simulation of Photon-induced background was carried out using FEWZ generator in the NNLO QCD + NLO EW order;
- The cross section distributions for various PDFs were obtained;
- In progress: data processing of Ultra Legacy (UL) 2016, UL17 & UL18 and simulation Photon-induced using FEWZ with CMS selection criteria.
- Future: process Run3 CMS data and analysis of events with same-sign muons to search for new physics

- Back up slides

Study of same-sign of muon pairs

Doubly-charged bosons also appears in various SM extensions.

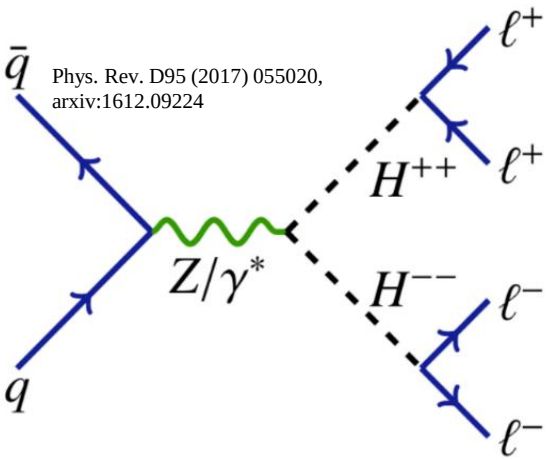
- Doubly Charged Higgs Bosons $H^{\pm\pm} \rightarrow l^{\pm} l^{\pm}$
  - *Seesaw mechanism*
- Doubly-Charged Bileptons
  - *Extension of the EW gauge symmetry $SU(3)_C \otimes SU(3)_L \otimes U(1)_X$ (model "331")*



Phys. Rev. D101 (2020) 035017, arXiv:1911.12783

The analysis was carried out on Run 2 data (2016-2018).

- Selected events with same charged muon pairs (++/--).
The invariant mass distribution is plotted for the data of the entire Run2



Phys. Rev. D95 (2017) 055020, arxiv:1612.09224

The invariant mass distribution of the sums of same charged (++ and --) muon pairs for the complete statistics Run2, as well as the total sum.