Searches for heavy resonances in the dilepton channel with the CMS detector at the LHC

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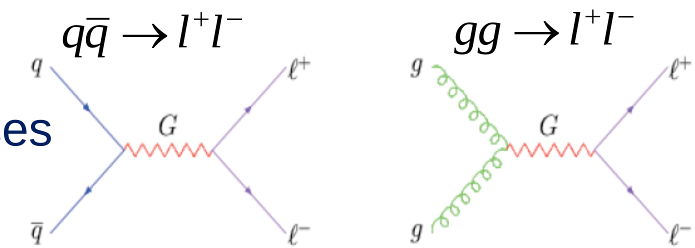
Landscape of Signals

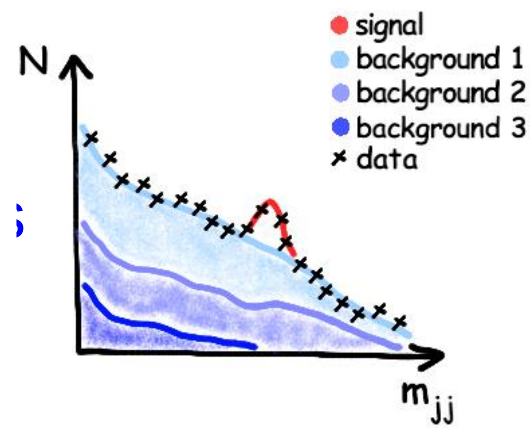
New Physics ($Z'/Z_{KK}/G_{KK}$) contributions to SM processes

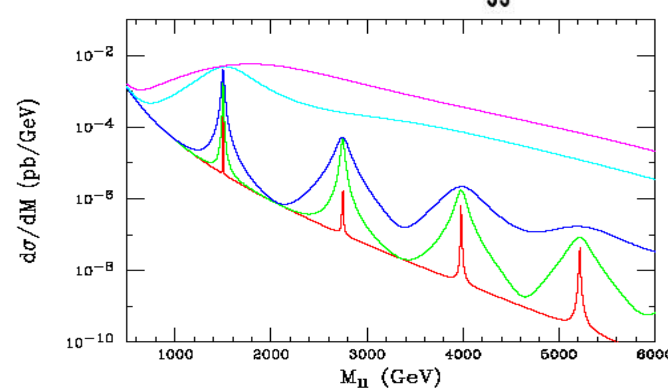
- ❑ Spin-1 resonances
  - ✓ Extra gauge boson (Z′) from Extended gauge models (LRMs and GUT-inspired models)
  - ✓ Dark Matter Mediators
  - ✓ KK excitations of SM gauge bosons (Z^0) in TeV^{-1} model of flat extra dimensions
- ❑ Spin-2 resonances
  - ✓ Kaluza-Klein graviton excitations (RS1 graviton) from Randall-Sundrum model of AdS_5 extra dimens
- ❑ Rare Higgs Decays ($H \to \mu\mu$)

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



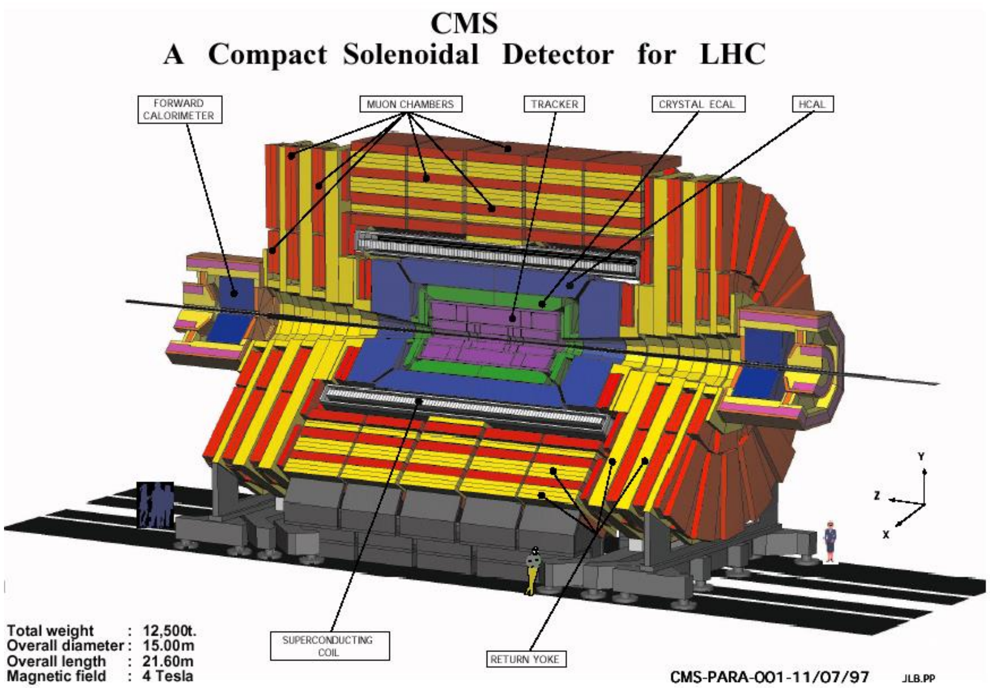
Well separated mass spectrum





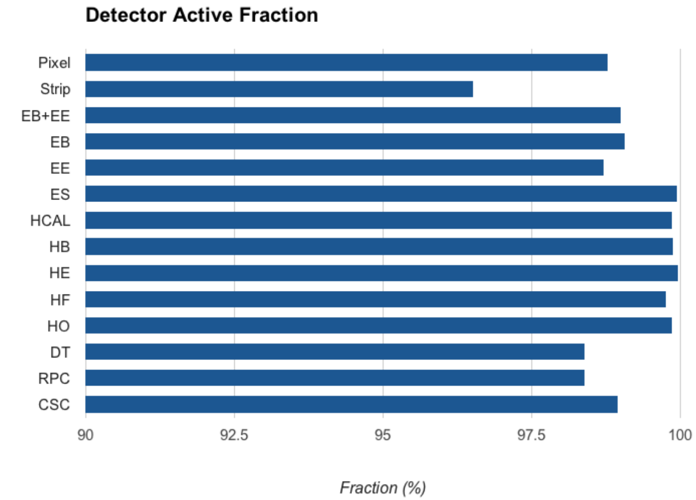
CMS Detector and Collected Data

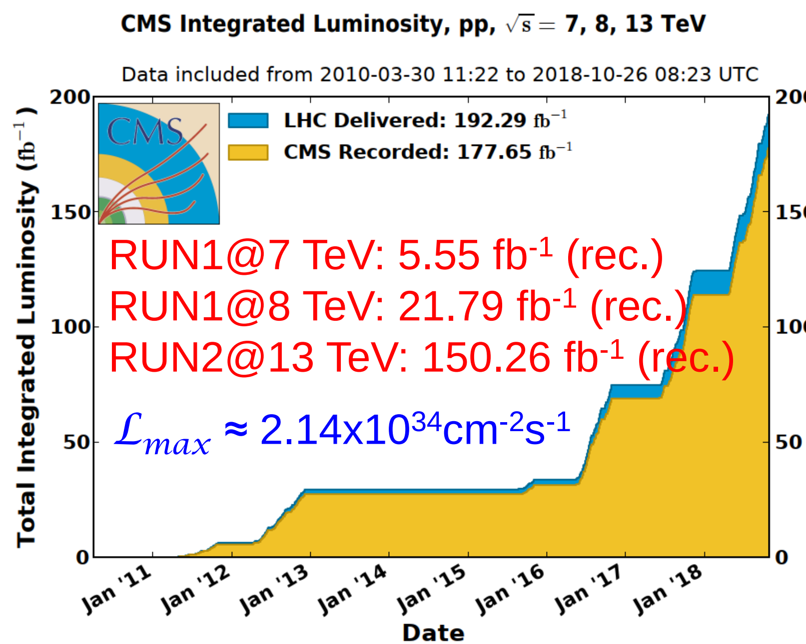
Large general-purpose particle physics detector



Total weight	***12 500 t***
Overall diameter	***15.00 m***
Overall length	***21.6 m***
Magnetic field	***3.8 Tesla***

Detector subsystems are designed to measure: the energy and momentum of photons, electrons, muons, jets, missing ET up to a few TeV





RUN1@7 TeV: 5.55 fb^{-1} (rec.)

RUN1@8 TeV: 21.79 fb^{-1} (rec.)

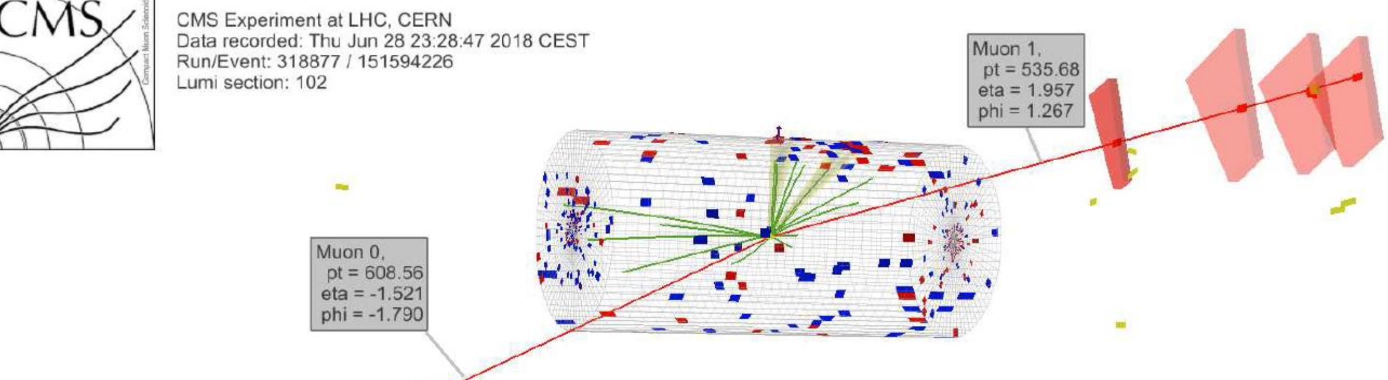
RUN2@13 TeV: 150.26 fb^{-1} (rec.)

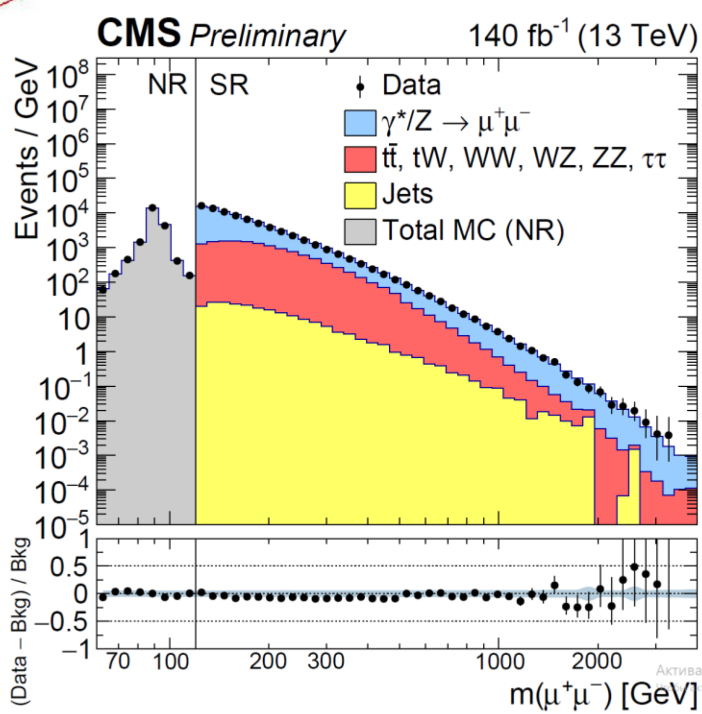
$\mathcal{L}_{max} \approx 2.14 \times 10^{34} cm^{-2}s^{-1}$

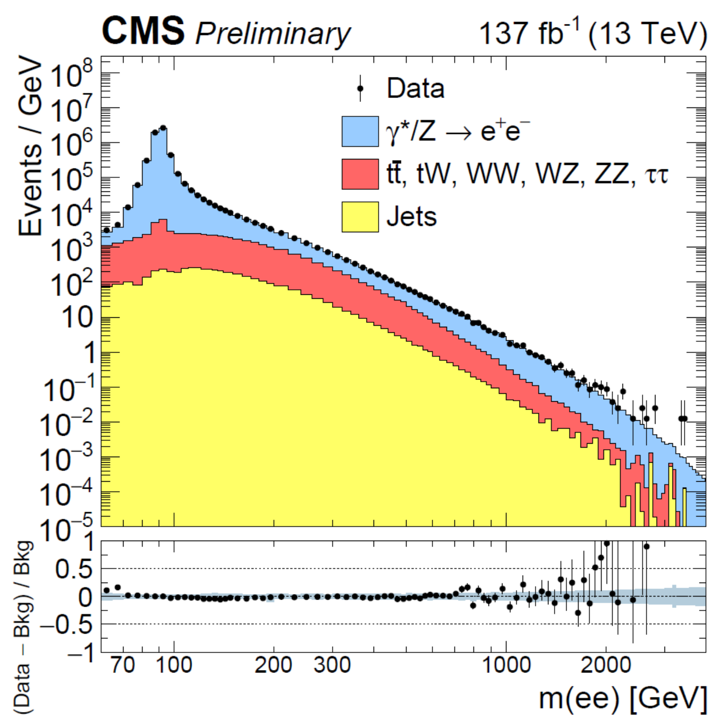
Dilepton Mass Spectra

$$M = 3.3\ \text{TeV}$$

$$\text{Muons:}\ p_T = 610,\ 540\ \text{GeV},\ \ \eta = -1.52,\ +1.96$$







Heavy Resonances: Z′ and RS1 Limits

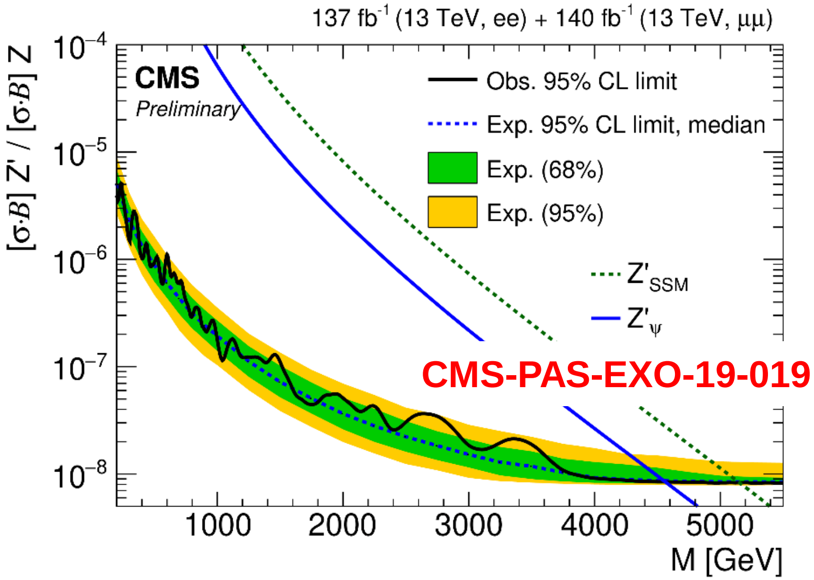
The likelihood function is based on probability density functions (pdf) that describe the signal and background contributions to the invariant mass spectra

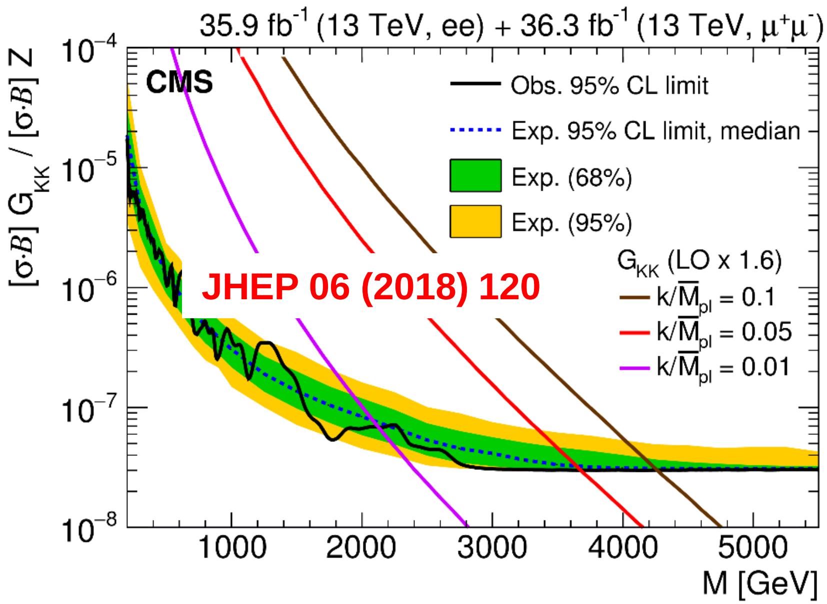
$$\mathcal{L}(m|R_\sigma, M, \Gamma, w, \alpha, \beta, \kappa, \mu_B) = \frac{\mu^N e^{-\mu}}{N!} \prod_{i=1}^{N} \left(\frac{\mu_S(R_\sigma)}{\mu} f_S(m_i|M, \Gamma, w) + \frac{\mu_B}{\mu} f_B(m_i|\alpha, \beta, \kappa) \right)$$

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

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 corresponding 95% CL limits are set
- for the Z_{SSM}, mass limit is 5.15 TeV
- for the Z_ψ, mass limit is 4.56 TeV
- for G_{KK}, mass limit is 2.10 TeV (c=0.01)
- for G_{KK}, mass limit is 4.25 TeV (c=0.1)

The mass limits can be expanded at the other theoretical models.

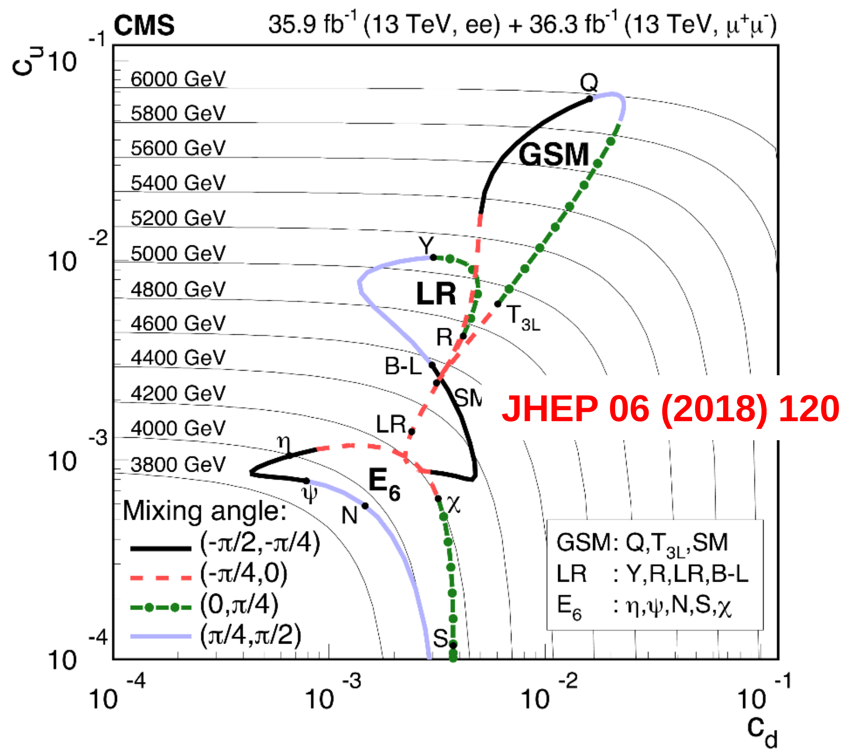
The cross section for charged lepton-pair production via a Z′ vector boson can, in the narrow-width approximation (NWA), be expressed in terms of the quantity $c_u w_u + c_d w_d$

$$\sigma_{l^+l^-} = \frac{\pi}{48s}[c_u w_u(s, M_V^2) + c_d w_d(s, M_V^2)],$$

$$c_u = \frac{g'^2}{2}(g_V^{u2} + g_A^{u2})\mathcal{B}(l^+l^-),$$

$$c_d = \frac{g'^2}{2}(g_V^{d2} + g_A^{d2})\mathcal{B}(l^+l^-).$$

The parameters c_u and c_d contain information from the model-dependent Z′ couplings to fermions in the annihilation of charge 2/3 and charge −1/3 quarks; w_u and w_d contain the information about PDFs



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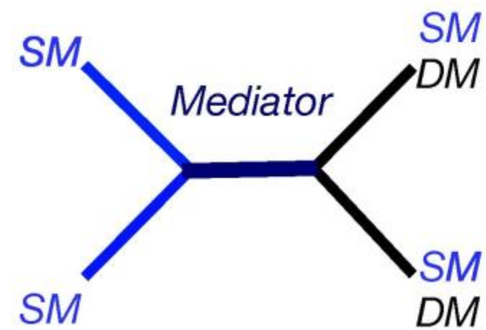
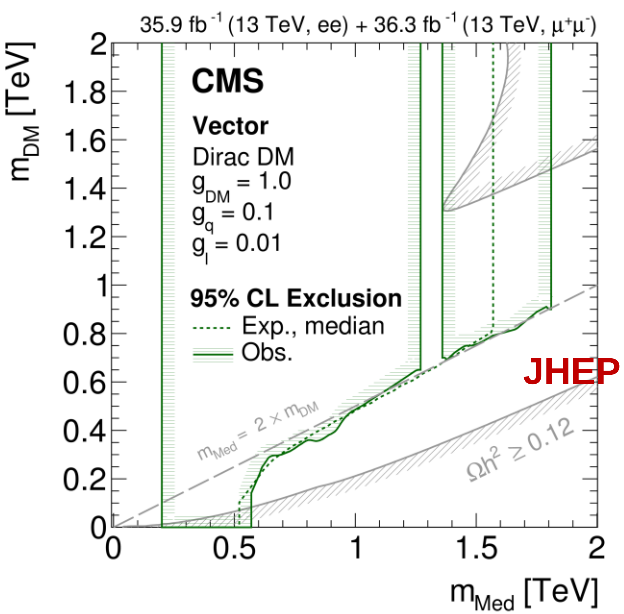
The limits on the Z′ mass are shown as lines in the (c_d,c_u) plane intersected by curves showing (c_d,c_u) as a function of a mixing parameter for various models.

Heavy Resonances: Dark Matter

The results are also interpreted in the context of a simplified model with a DM particle that has sizeable interactions with SM fermions through an additional spin-1 high-mass particle mediating the SM-DM interaction

- ✓ vector mediator with small couplings to leptons: g_q=0.1, g_{DM}=1.0, g_l=0.01
- ✓ axial-vector mediator with equal couplings to quark and leptons: g_{DM} =1.0, g_q=g_l=0.1 (recommendation of **CERN-LPCC-2017-01)**





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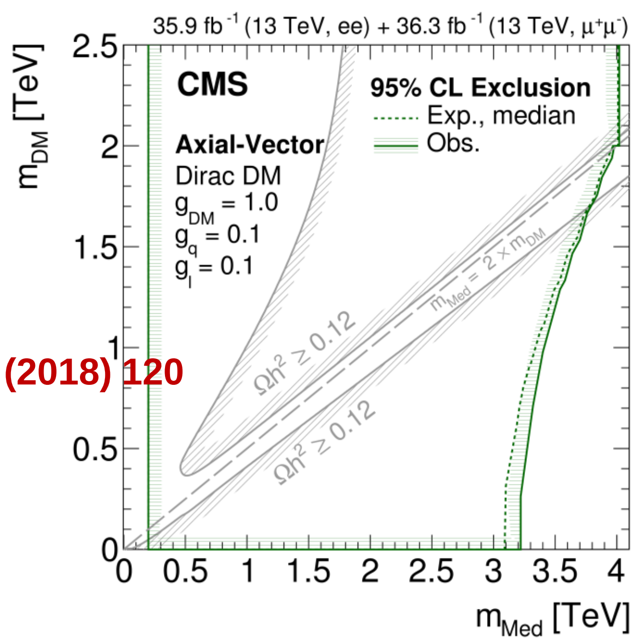
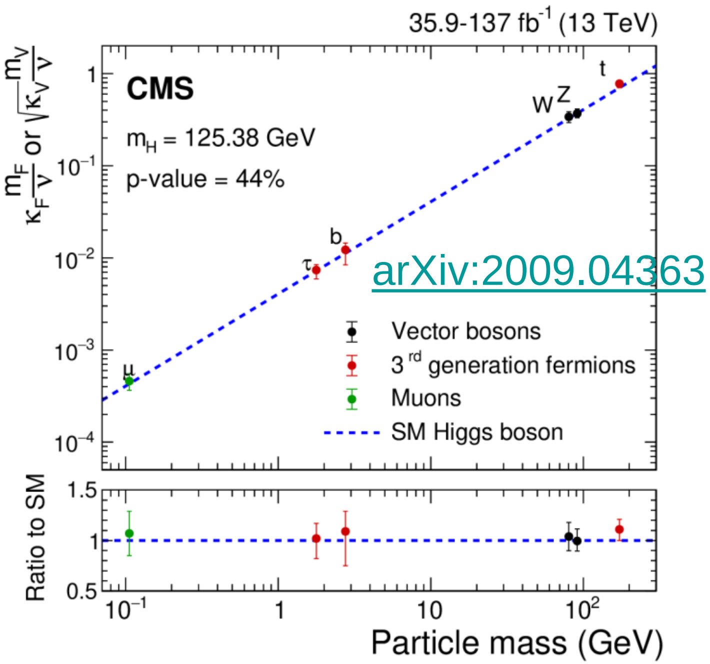


In the axial-vector (vector) mediator model, the limit on the mediator mass reaches up to 3-4 (1.8) TeV, depending on the mass of the DM particle

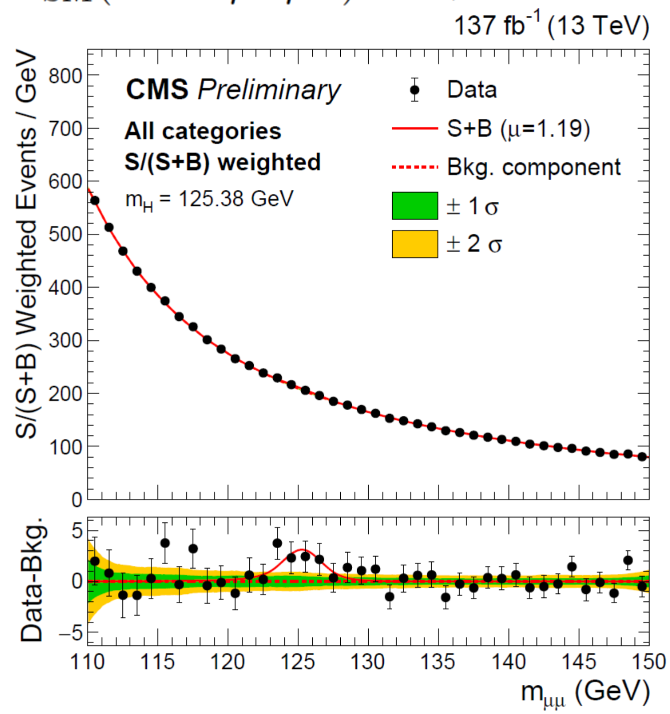
The current results of RUN1 and RUN2 demonstrate full compatibility of the Higgs bosons with SM expectations. At the same time, there are rare processes involving Higgs, which have not yet been observed or studied poorly.

$$\mathcal{B}_{\mathrm{SM}}(H \to e^+e^-) \approx 0{,}09 \cdot 10^{-5}\,\%$$

$$\mathcal{B}_{\mathrm{SM}}(H \to \mu^+\mu^-) = 0{,}022\,\%$$

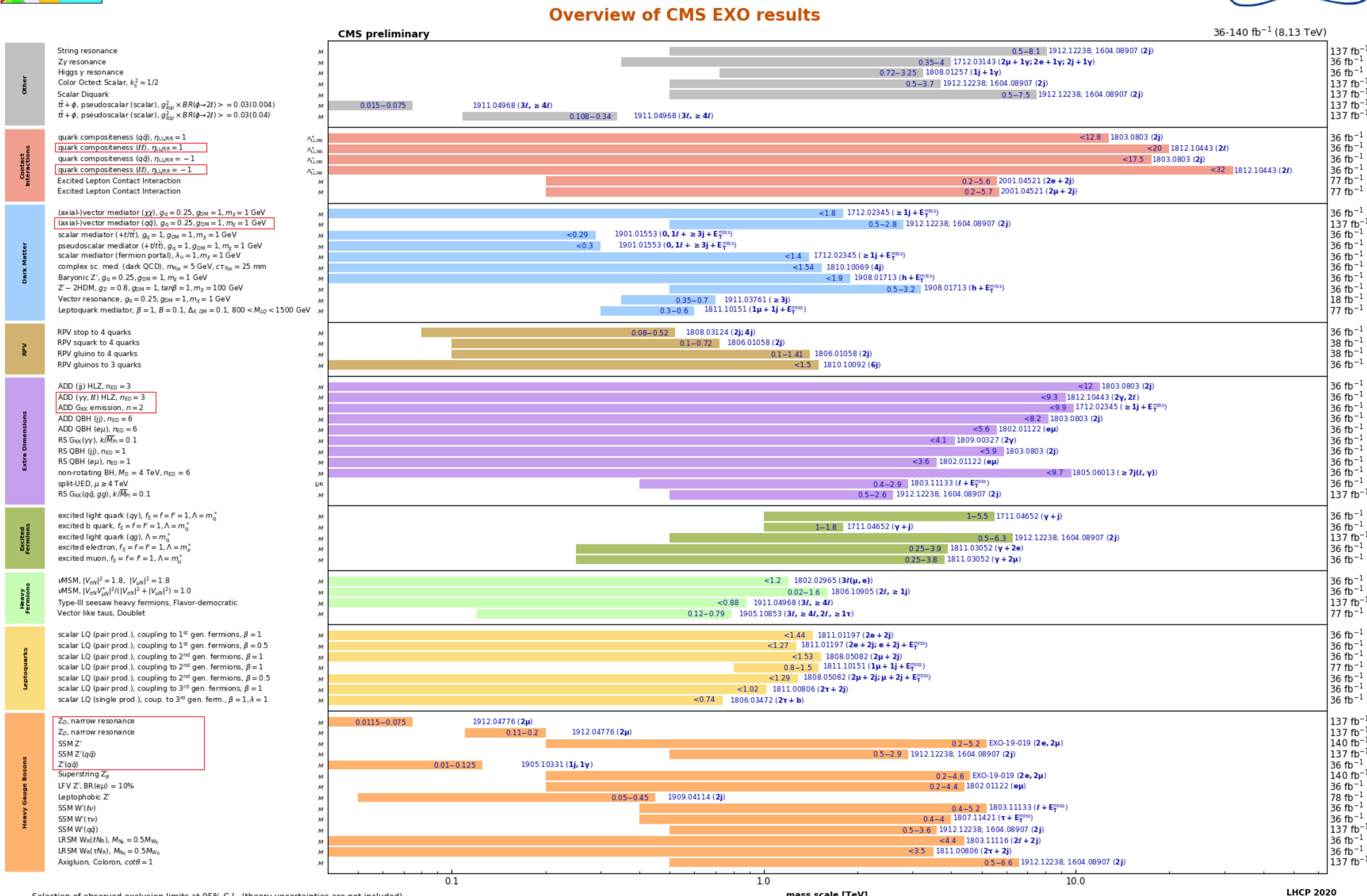


arXiv:2009.04363



CMS&ATLAS - first evidence of the Higgs boson interacting with the muon!
An excess of events is observed in data with a significance of 3.0 standard deviations, against SM expectation Higgs in 2.5.

Overview of CMS Exotica (95% C.L.)



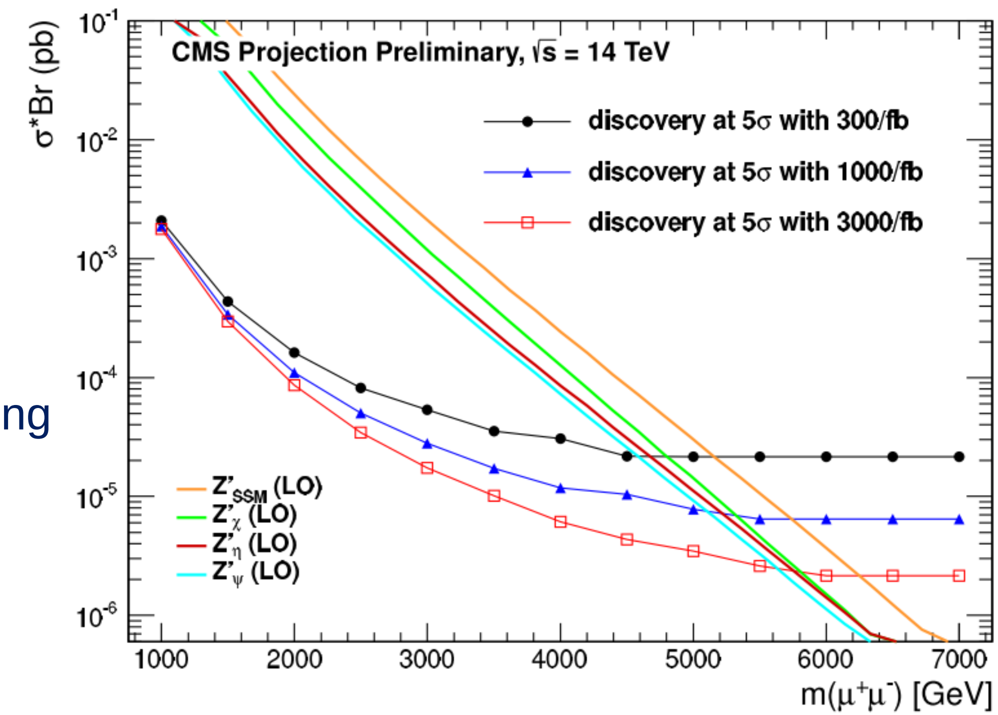
http://cms-results.web.cern.ch/cms-results/public-results/publications/

Conclusions

CMS performed a wide program of search for particles and phenomena

RUN1 and RUN2 data demonstrate triumph of Standard Model (many Exotica Models were tested in the channel with dileptons in the final states and new limits are derived)

- for the Z_{SSM} mass limit is 5.15 TeV;
- for the Z_{ψ} mass limit is 4.56 TeV;
- for G_{KK} mass limits are 2.10 TeV (c=0.01) and 4.25 TeV (c=0.1);
- for Dark matter (axial-)vector mediator model reaches up to 3-4 (1.8) TeV;
- first evidence of the Higgs boson interacting with the muon.



RUN3 will starts in 2021, expected integrated luminosity ~300 fb^{-1}

arXiv:1307.7135

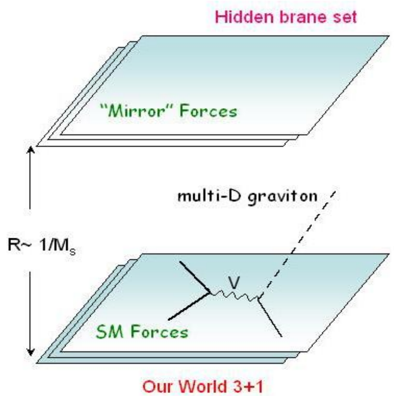
Thank you for your attention

Back up slides

Extra dimensions scenarios

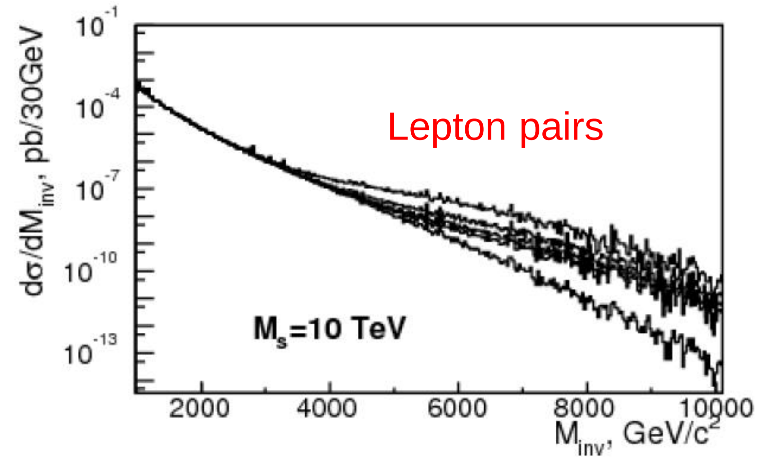
reducing of fundamental gravity scale to M_D ~ TeV. SM fields are on 3D-brane, gravity “feels” extra dimensions.

Arkani-Hamed–Dimopoulos–Dvali model (ADD)

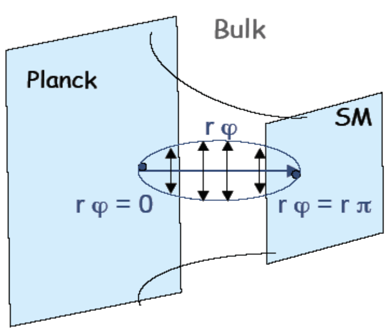


Евклидово пр-во плоских ДПИ (n = 2..7)

$$M_{\rm Pl}^2 = V_n M_D^{n+2} = (2\pi R)^n M_D^{n+2}$$

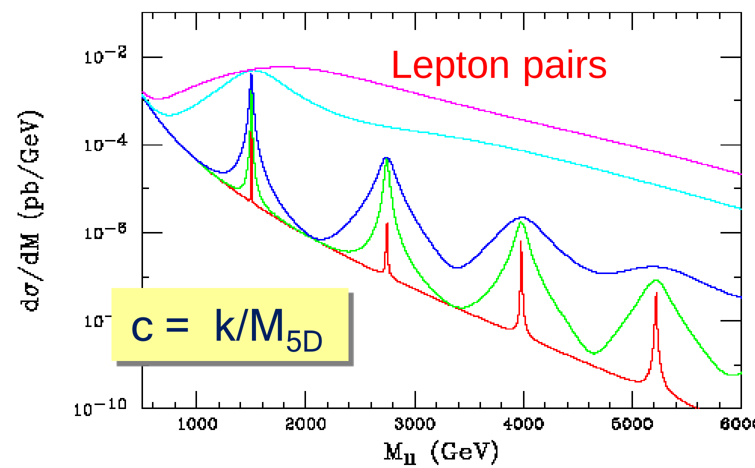


RS1 (Randall-Sundrum) model



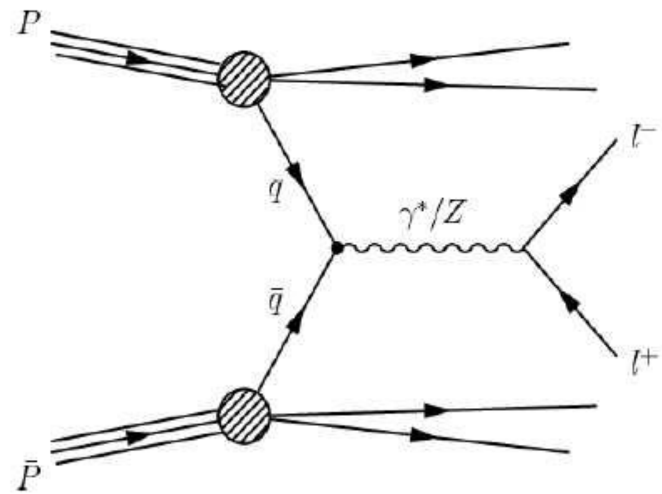
5-dimensional anti de Sitter space AdS5 with curvature k

KK gravitons contribute to SM processes (in particular, Drell-Yan)



Motivation to Study Dimuons at CMS

Many major discoveries were made before LHC in dimuon channel (J/ψ, , Z, ...) — rather clean channel for finding new narrow resonances (often unexpected).

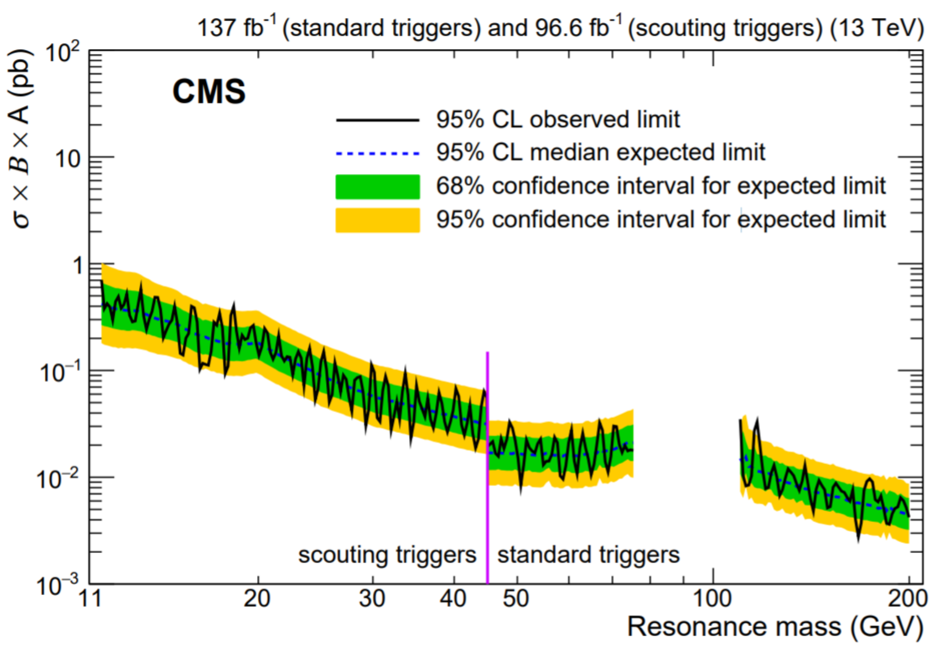


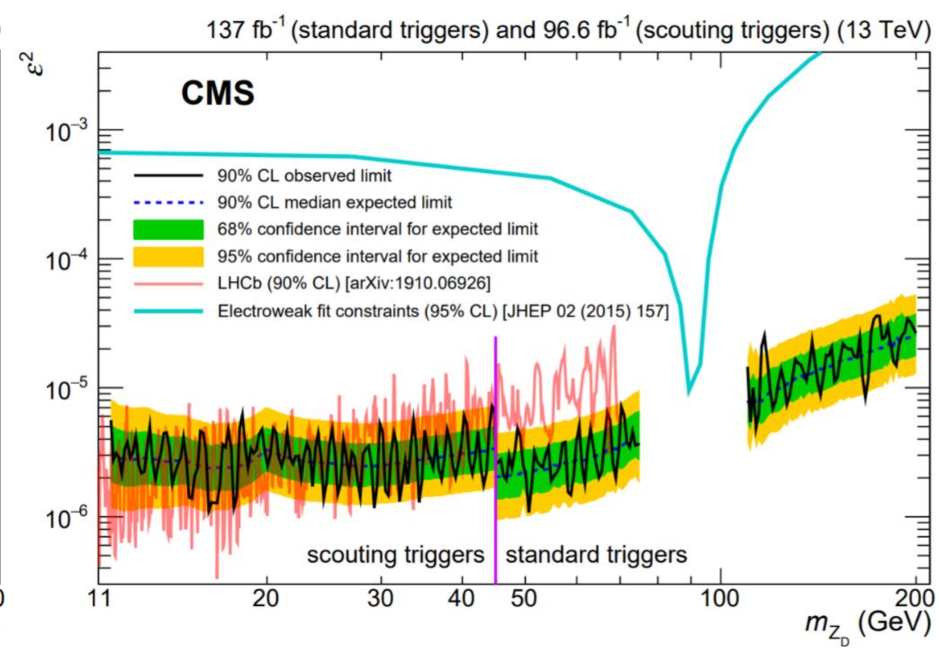
<u>Why study dimuons at CMS?</u>

- ❑ Important Standard model benchmark channel Theoretical cross section calculated up to NNLO allowing tests of pQCD;
- ❑ Many theoretical models predict contribution of New Physics in dimuon channel;
- ❑ Used to constrain PDFs;
- ❑ Simple experimental signature (muon channel) - two oppositely charged, well spatially isolated muon;
- ❑ Physics Processes produced in association with Z boson, $H \to ZZ$, $B \to \mu\mu$ discovery, 5 σ discovery of $H \to b\bar{b}$ used also $Z \to \mu\mu$.

Search for a narrow resonance lighter than 200 GeV

Result of search for a narrow resonance decaying to a pair of muons in the 45–75 and 110–200 GeV resonance mass ranges.
Expected and observed 95% CL upper limits on the product of the signal cross section (σ), branching fraction to a pair of muons (B), and acceptance (A) as a function of the mass of a narrow resonance (left plot).
Expected and observed 90% CL upper limits on ϵ^2 as a function of the Z_D mass (right plot).





Results obtained using scouting data.
No significant resonant peaks are observed.

CMS PAS EXO-19-018