



# Search for new physics in the dilepton channel with the CMS detector at the LHC

JINR Association of Young Scientists and Specialists Conference "Alushta-2022"

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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  $q\bar{q} \rightarrow \gamma/Z^0/Z' \rightarrow l^+l^-$  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);
- **U** 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).

 $\gamma^*/Z/Z'$ 

<u>New Physics (Z'/Z<sub>KK</sub>/G<sub>KK</sub>) contributions to SM processes</u>:
□ Spin-1 resonances (Extra gauge boson (Z'), DM...)
□ Spin-2 resonances (RS1 graviton...)
□ Non-resonant signals (Extra dimensions ADD...)

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



# CMS Detector and Collected Data

#### Large general-purpose particle physics detector

![](_page_2_Figure_2.jpeg)

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

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

#### CMS Integrated Luminosity, pp, $\sqrt{s}=$ 7, 8, 13 TeV

![](_page_2_Figure_6.jpeg)

# 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

$$\mathcal{L}(m|R_{\sigma}, M, \Gamma, w, \alpha, \beta, \kappa, \mu_{\rm B}) = \frac{\mu^{N} e^{-\mu}}{N!} \prod_{i=1}^{N} \left( \frac{\mu_{\rm S}(R_{\sigma})}{\mu} f_{\rm S}(m_{i}|M, \Gamma, w) + \frac{\mu_{\rm B}}{\mu} f_{\rm B}(m_{i}|\alpha, \beta, \kappa) \right) \quad \text{Background:}$$

• The expected cross section limits are expressed as the value of the function  $R_{\sigma}$ . The use of this ratio eliminates the uncertainty in the integrated luminosity and reduces the dependence on the experimental acceptance, trigger, and offline efficiencies

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

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

![](_page_3_Figure_6.jpeg)

# Heavy Resonances: Generalized Extra Gauge Bosons

The mass limits can be expanded at the other theoretical models: Grand Unified Theory (GUT) E6 or SO (10), SSM etc.

The cross section for charged lepton-pair production via a Z' vector boson can, in the narrow-width approximation (NWA), can be expressed in terms of the quantity  $c_u w_u + c_d w_d$   $o^{-1} E_{70}$ 

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

$$c_u = \frac{g'^2}{2} (g_V^{u2} + g_A^{u2}) \mathcal{B}(l^+ l^-),$$
  
$$c_d = \frac{g'^2}{2} (g_V^{d2} + g_A^{d2}) \mathcal{B}(l^+ l^-).$$

The parameters  $c_u$  and  $c_d$  contain information from the modeldependent 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

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.

![](_page_4_Figure_7.jpeg)

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# Heavy Resonances: Dark Matter

![](_page_5_Figure_1.jpeg)

SM

DM

SM

In the vector (axial-vector) mediator model, mediators with masses below 1.92 (4.64) TeV are excluded.

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#### Non-resonant signals: Extra dimensions

No significant deviations from standard model expectations are observed.

Arkani-Hamed, Dimopoulos, and Dvali ("ADD") model with large extra dimensions (n = 2..7)

![](_page_6_Figure_3.jpeg)

![](_page_6_Figure_4.jpeg)

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

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

#### 16-140 fb<sup>-1</sup> (13 TeV) CMS preliminary String resonance 0.5-7.9 1911.03947 (2) 137 fb<sup>-1</sup> 36 fb<sup>-1</sup> Zy resonance 035-4 1712.03143 (2µ + 1γ; 2e + 1γ; 2j + 1γ) Wy resonance 15-8 2106.10509 (1i+ 1v 137 fb<sup>-1</sup> 36 fb<sup>-1</sup> 072-3.25 1808.01257 (1j + 1y) Higgs y resonance Color Octect Scalar, $k_s^2 = 1/2$ 05-37 1911.03947 (2) 137 fb<sup>-1</sup> 137 fb<sup>-1</sup> Scalar Diquark 05-75 1911.03947 (2) $t\dot{t} + \phi$ , pseudoscalar (scalar), $g_{loo}^2 \times BR(\phi \rightarrow 2\ell) > = 0.03(0.004)$ 0.015-0.075 1911.04968 (31. ≥ 41) 137 fb $t\bar{t} + \phi$ , pseudoscalar (scalar), $g_{top}^{2} \times BR(\phi \rightarrow 2\ell) > = 0.03(0.04)$ 0.108-0.34 1911.04968 (31, ≥41) 137 fbquark compositeness (*ll*), $\eta_{\rm LLRR} = 1$ <24 2103.02708 (2/ 140 fb<sup>-1</sup> quark compositeness (ll), $n_{LIRE} = -1$ <36 2103.02708 (2/ 140 fb<sup>-1</sup> 77 fb<sup>-1</sup> xcited Lepton Contact Interaction 0.2-5.6 2001.04521 (2e+2j Excited Lepton Contact Interaction 02-57 2001.04521 (2u+2i 77 fbvector mediator (qq), $g_q = 0.25$ , $g_{cret} = 1$ , $m_g = 1$ GeV 0 35-07 1911.03761 (≥3i) 18 fb<sup>-1</sup> vector mediator ( $t\bar{t}$ ), $g_q = 0.1$ , $g_{iN} = 1$ , $g_t = 0.01$ , $m_g > 1$ TeV 0.2-1.92 2103.02708 (2e, 2µ) 140 fb-(axial-)vector mediator (qd), g<sub>1</sub> = 0.25, g<sub>1m</sub> = 1, m<sub>2</sub> = 1 GeV 0.5-2.8 1911.03947 (2j) <1.95 2107.13021 (≥1j+p\_T<sup>mim</sup>) 137 fb-(axial-) vector mediator ( $\chi\chi$ ), $g_q = 0.25$ , $g_{GM} = 1$ , $m_\chi = 1$ GeV 101 fb-(axial)-vector mediator $(\ell \bar{\ell}), g_q = 0.1, g_{DM} = 1, g_{\ell} = 0.1, m_g > m_{max}/2$ -4 64 2103.02708 (2e. 2u 140 fb<sup>-1</sup> 36 fb<sup>-1</sup> scalar mediator $(+t/t\bar{t})$ , $g_n = 1$ , $g_{DM} = 1$ , $m_r = 1$ GeV $1901.01553(0, 1l + \ge 2j + p_T^{min})$ scalar mediator (fermion portal), $\lambda_v = 1$ , $m_x = 1$ GeV 2107.13021 ( > 1j + p<sub>v</sub><sup>sin</sup>) 101 fb<sup>-1</sup> 101 fb<sup>-1</sup> pseudoscalar mediator (+j/V), g<sub>n</sub> = 1, g<sub>cre</sub> = 1, m<sub>s</sub> = 1 GeV <0.47 2107.13021 (≥1j+p<sub>T</sub><sup>nim</sup>) pseudoscalar mediator (+t/tt̂), $g_q = 1$ , $g_{cm} = 1$ , $m_g = 1$ GeV complex sc. med. (dark QCD), $m_{n_{R}} = 5$ GeV, $c\tau_{X_{R}} = 25$ mm < 0.3 1901.01553 (0, 1/ + ≥ 2i + p<sup>(that</sup>) 36 fb<sup>-1</sup> 1.54 1810.10069 (4) 16 fb-1 Z' mediator (dark QCD), $m_{min} = 20$ GeV, $r_{min} = 0.3$ , $\alpha_{min} = \alpha_{min}^{prode}$ 15 51 211211125/2i+ m<sup>rtm</sup> 138 fb-Baryonic Z', g<sub>4</sub> = 0.25, g<sub>cre</sub> = 1, m<sub>z</sub> = 1 GeV <1.6 1908.01713 (h + p<sub>T</sub><sup>miss</sup>) 36 fb<sup>-</sup> Z' - 2HDM, g<sub>z</sub> = 0.8, g<sub>cet</sub> = 1, tanß = 1, m<sub>z</sub> = 100 GeV 05-31 1908.01713 (h + p<sup>min</sup> 36 fb-Leptoquark mediator, $\beta = 1$ , B = 0.1, $\Delta_{r, DV} = 0.1$ , $800 < M_{LO} < 1500 \text{ GeV}$ 0.3-0.6 1811.10151 (1µ+1j+p;" 77 fb<sup>-1</sup> RPV stop to 4 guark 0.08-0.52 1808.03124 (2j; 4j) 36 fb-1 RPV squark to 4 quarks 0.1-0.72 1806.01058 (2j) 38 fb-RPV gluino to 4 quarks 01-141 1806.01058 (2) 38 fb<sup>-1</sup> RPV gluinos to 3 guarks <1.5 1810 10 092 (6i 36 fb-ADD (ii) HLZ, n= 3 <12 1803.08030 (2i) 36 fb<sup>-1</sup> 36 fb<sup>-1</sup> ADD ( $\gamma\gamma, tt$ ) HLZ, $n_{tt} = 3$ <9.1 1812.10443 (2y, 2f) ADD $G_{KK}$ emission, $n_{ED} = 2$ <10.8 2107.13021 ( > 1j + p."" 101 fb<sup>-1</sup> 36 fb<sup>-1</sup> <8.2 1803.08030(2j) ADD QBH (jj), $n_{\rm HD} = 6$ ADD OBH (eu), $n_{\rm PD} = 4$ <5.6 CMS-RAS-EX0-19-014 (en) 137 fb<sup>-1</sup> <5.2 CMS-PAS-EXO-19-014 (et) ADD QBH (er), $n_{\rm ED} = 4$ 137 fb-ADD OBH ( $\mu \tau$ ), $n_{\rm ED} = 4$ <5 CMS-PAS-EXO-19-014 (ut 137 fb-RS $G_{KK}(H)$ , $k/\overline{M}_{P} = 0.1$ <4.78 2103.02708 (2/ 140 fb-RS $G_{cc}(w)$ , $k/\overline{M}_n = 0.1$ <4.1 1809.00327 (2y) 36 fb<sup>-1</sup> 137 fb<sup>-</sup> RS $G_{KK}(q\bar{q}, gg), k/\overline{M}_{Pl} = 0.1$ 0.5-2.6 1911 RS QBH (jj), $n_{ED} = 1$ non-rotating BH, $M_D = 4$ TeV, $n_{ED} = 6$ <5.9 1803.08030 (2i) 36 fb<sup>-1</sup> 36 fb<sup>-1</sup> <9.7 1805.06013 ( = 7i(l, y) 0.4-2.8 2202.06075 (# + m<sup>criss</sup> split-UED, µ ≥ 2 TeV 137 fb-3-brane WED $g_{ex}(\phi + g \rightarrow ggg)$ , $g_{evw} = 6$ , $g_{ew} = 3$ , $\varepsilon = 0.5$ , $m(\phi)/m(g_{ex}) = 0.1$ 2-4.3 2201.02140 (2j) 137 fbexcited light quark (qy), $f_5 = f = f' = 1$ , $\Lambda = m_q^*$ 1-5.5 1711.04652 (y + j) 36 fb<sup>-1</sup> excited b quark, $f_2 = f = f' = 1$ , $\Lambda = m_c^*$ 1-1 8 1711.04652 (y + i) 36 fb-0.5-6.3 1911.03947 (2j) excited light quark (qg), $\Lambda = m_q^*$ 137 fbexcited electron, $f_5 = f = f' = 1$ , $\Lambda = m$ , 0.25-3.9 1811.03052 (y + 2e) 36 fb<sup>-</sup> excited muon, $f_s = f = f' = 1$ , $\Lambda = m_{\mu}^*$ 0.25-3.8 1811.03052 (y + 2µ) 36 fbvMSM, $|V_{eff}|^2 = 1.0$ , $|V_{\mu ff}|^2 = 1.0$ 0.001-1.43 1802.02965; 1806.10905 (3ℓ(μ, e); ≥ 1j + 2ℓ(μ, e)) 36 fb<sup>-1</sup> vMSM, $|V_{ett}V_{utt}^*|^2/(|V_{ett}|^2 + |V_{utt}|^2) = 1.0$ 0.02-1.6 1806.10905 (≥1j+µ+e) 36 fb-Type-III seesaw heavy fermions, Flavor-democratic 01-0.98 2202.08676 (31, = 41) 137 fb<sup>-1</sup> Vector like taus, Doublet 01-1045 2202.08676 (31. > 41) 137 fb-Vector like taus, Singlet 0125-015 2202.08676 (31. ≥ 41 137 fbscalar LQ (pair prod.), coupling to $1^{st}$ gen. fermions, $\beta = 1$ <1.44 1811.01197 (2e+2j) 36 fb<sup>-1</sup> scalar LQ (pair prod.), coupling to 1<sup>st</sup> gen. fermions, $\beta = 0.5$ <127 1811.01197 (2e + 2j; e + 2j + p+ 36 fbscalar LQ (pair prod.), coupling to $2^{nd}$ gen. fermions, $\beta = 1$ <1.53 1808.05082 (2µ + 2j) 36 fbscalar LO (pair prod.), coupling to $2^{14}$ gen. fermions, B = 108-15 181110151 (lu+li+p-" 77 fbscalar LQ (pair prod.), coupling to 2<sup>nd</sup> gen. fermions, $\beta = 0.5$ <1.29 1808.05082 (2µ + 2j; µ + 2j + p<sup>++</sup><sub>1</sub>) 36 fb scalar LQ (pair prod.), coupling to $3^{rd}$ gen. fermions, $\beta = 1$ <1.02 1811.00806 (2x + 2i) 36 fb-1-1.6 2107.13021 (≥1j+p<sub>T</sub><sup>min</sup> calar LQ (single prod.), coupling to $1^{st}$ gen. fermions, $\beta = 0$ , $\lambda = 1$ 101 fbscalar LQ (single prod.), coupling to $3^{rd}$ gen. fermions, $\beta = 1, \lambda = 1$ <0.74 1806.03472 (2x + b) 36 fb<sup>-1</sup> Z<sub>2</sub>, narrow resonance 0.0115-0.075 1912.04776 (2u) 137 fb<sup>-1</sup> 137 fb<sup>-1</sup> o, narrow resonance 1912.04776 (**2**u 0.2-5.15 2103.02708 (2e, 2µ) SSM Z'(II) 140 fb<sup>-1</sup> 137 fb<sup>-1</sup> SSM Z'(qq) 05-29 1911.03947 (2) Z'(qq) Superstring Z'e 1905.10331 (1i. 1v 36 fb<sup>-1</sup> 02-46 2103.02708 (2e. 2u) 140 fb-LFV Z'. BR(eu) = 10% 0.2-5 CMS-PAS-EXO-19-014 (eu 137 fb<sup>-1</sup> 137 fb<sup>-1</sup> 0.2-4.3 CMS-PAS-EXO-19-014 (er) LFV Z', BR(er) = 10% LFV Z', $BR(\mu\tau) = 10\%$ 0.2-4.1 CMS-PAS-EXO-19-014 (µT 137 fb<sup>-1</sup> 78 fb<sup>-1</sup> Leptophobic Z' 1909.04114 (**2i**) SSM W'(TV) 0.4-4 1807.11421 (T + pC 36 fb<sup>-1</sup> 137 fb<sup>-1</sup> 55M W'(tv) 0.4-5.7 2202.06075 (£ + p\_T<sup>efm</sup>) SSM W'(qq) 0.5-36 1911.03947 (2j) 137 fb<sup>-1</sup> 36 fb<sup>-1</sup> LRS M $W_n(\mu N_n)$ , $M_{v_n} = 0.5 M_w$ <5 2112.03949 (2µ + 2j) LRS M $W_{R}(eN_{R})$ , $M_{N_{R}} = 0.5M_{W}$ <4.7 2112.03949 (2e + 2i) 36 fb-LRS M $W_R(\tau N_R)$ , $M_{N_R} = 0.5 M_W$ <3.5 1811.00806 (2T + 2j) 36 fb-1 Axialuon, Coloron, $cot\theta = 1$ 05-66 1911.03947 (2) 137 fb-

Overview of CMS EXO results

Cher

10.0

Moriond 2022

![](_page_8_Picture_0.jpeg)

CMS performed a wide program of search for particles and phenomena with all Run2 statistics 140 fb<sup>-1</sup>;

RUN1 and RUN2 data demonstrate triumph of Standard Model: many Exotica Models were tested in the channel with dileptons in the final states;

**Upper limits of new phenomena models are improved;** 

□ The next step: RUN3 - will start in 2022, expected integrated luminosity ~300 fb<sup>-1</sup> at √s=13.6 TeV!

# Thanks for your attention!

# Back up

![](_page_11_Figure_0.jpeg)

#### Randall and Sundrum (RS1) of extra dimensions

5-dimensional anti-de Sitter space where the elementary particles (except the graviton) are localized on a (3 + 1)-dimensional brane or branes.

The RS1 model attempts to address the hierarchy problem.

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

 $q\overline{q}, gg \rightarrow G_{KK} \rightarrow e^+e^-, \mu^+\mu^-, \gamma\gamma, jet + jet$ 

- Simplified model with a DM particle
- ✓ has sizeable interactions with SM fermions through an additional spin-1 high-mass particle mediating the SM-DM interaction
- $\checkmark$  only one DM particle exists, which is assumed to be a Dirac fermion
- $\checkmark$  two cases with different sets of benchmark coupling values
  - a vector mediator with small couplings to leptons
  - an axial-vector mediator with equal couplings to quarks and leptons
- While the DM particle is not probed directly, its mass indirectly modulates the sensitivity of the dilepton search: Drell-Yan type process (sensitive directly to  $m_{Med}$ ,  $g_{I}$ ,  $g_{q}$ )

#### 5 parameters:

- m<sub>DM</sub> DM mass
- m<sub>Med</sub> mediator mass
- g<sub>DM</sub> coupling of a mediator-DM-DM vertex
- g<sub>l</sub> coupling with leptons
- g<sub>q</sub> coupling with quarks

![](_page_12_Figure_13.jpeg)

![](_page_12_Picture_14.jpeg)

![](_page_12_Figure_15.jpeg)

# Открытые вопросы Стандартной модели

Недостатки и открытые вопросы стандартной модели:

- ✓ Проблема иерархии двух сильно отличающихся по величине энергетических масштабов – планковского (10<sup>19</sup> ГэВ) и электрослабого (10<sup>2</sup> ГэВ)
- Проблема иерархии фермионных масс (объяснение разницы масс разных поколений кварков и лептонов), масса нейтрино, объединение взаимодействий, включение гравитации
- Набор космологических и астрофизических проблем (инфляция, темная материя, СРнарушение в ранней Вселенной и пр.)
- ✓ А также: свободные параметры СМ, число поколений (почему 3?), конфайнмент etc.

![](_page_13_Figure_6.jpeg)

#### **Standard Model of Elementary Particles**

![](_page_13_Figure_8.jpeg)