



HELMHOLTZ **RESEARCH FOR GRAND CHALLENGES** 

# EXOTIC SEARCHES IN CMS



Jeremi Niedziela (DESY) for CMS Collaboration

## ) JTI INF

### Searches for BSM particles decaying to Higgs, top and Gauge bosons (B2G)

- <u>B2G-21-055</u> <u>B2G-20-010</u>



Exotica (EXO)

- a pair of muons EXO-21-005

• Search for W' bosons decaying to a top and a bottom quark in leptonic final states <u>B2G-20-012</u>

• Search for a heavy resonance decaying into a top quark and a W boson in the lepton+jets final state

• Search for prompt production of a GeV scale resonance decaying to

 Search for dark matter particles produced in W+W- events with transverse momentum imbalance EXO-21-012





## 

#### Why search for new physics at LHC?

- dark Matter,
- dark Energy,
- baryon asymmetry in the Universe,
- origin of neutrino masses,
- gravity and quantum mechanics,
- fine-tuning of the Higgs mass,
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And what could explain it? lepton jets unparticles hidden valley leptoquarks black holes extra dimensions massive gravitons stopped particles W'/Z' bosons dark photons excited quarks extra scalars dark Higgs emerging jets excited leptons supersymmetry sterile neutrinos contact interactions 4<sup>th</sup> generation quarks trackless jets technicolor



## INTRODUCTION

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And what could explain it?

#### This talk

Presented results (unless stated otherwise):

- proton-proton collisions at  $\sqrt{s} = 13$  TeV,
- full LHC Run 2 data,
- luminosity: **138 fb**<sup>-1</sup>.



### W'SEARCH

- target: multi-TeV mass range (2-6 TeV considered)
   → completing previous searches (< 3 TeV)</li>
- top quark  $\rightarrow$  distinct signature
- different width (1, 10, 20, 30%) and chirality assumptions
  - → interpretations for wide range of models



#### Analysis details

- backgrounds: W+jets, QCD, tt, single top
- signal/control regions: number of b-tagged top/W' jets





### W' search











#### find b-jet originating from top



### W' search













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## W' search

B2G-20-012









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B2G-20-012



#### Results

- ABCD-like method with m<sub>jetW</sub>, vs. m<sub>top</sub>,
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- ABCD-like method with m<sub>jetW</sub>, vs. m<sub>top</sub>,
- good agreement in the Control Region,
- small excess at 3.4-4.4 TeV (local: 2.6 $\sigma$ , global: 2.0 $\sigma$ ) in one of the  $\mu$  SR
  - best described by right-handed, narrow width signal hypothesis,









#### Analysis details & Results

- backgrounds: tt, QCD, W+jets, single top, VV,
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- good agreement in Control Regions,
- no significant excess observed,
- depending on the signal hypothesis and final states, excited b-quarks excluded up to 3.0-3.2 TeV.





### HEAVY TVV RESONANCE

### B2G-20-010



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### LOW-MASS DIMUONS

- final state: 2 opposite sign muons
- extension of high-mass searches
  - mass range: 1.1-2.6 GeV and 4.2-7.9 GeV
- example theoretical scenarios
  - dark photons  $Z_D$ , with kinetic mixing  $\varepsilon$
  - two Higgs doublet models with extra scalar a (2HDM+S)



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#### Analysis details

- dedicated scouting trigger stream
  - muon pT as low as 3 GeV
  - storing reduced event information

#### Scouting trigger

- at HLT:  $\geq 2 \text{ muons } p_T > 3 \text{ GeV}$ ,
- $\approx$ 4-8 kB/event (standard event size  $\approx$ 1 MB),
- 2 kHz event rate (standard dimuon triggers: 0.45 kHz),
- integrated luminosity: **96.6 fb**<sup>-1</sup>,





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### Offline analysis

- $p_T > 4$  GeV,  $|\eta| < 1.9$  (assure optimal dimuon mass resolution),
- **muons identified** with a MVA technique, based on:
  - tracks quality,
  - isolation,
  - vertex information.





### Signal extraction & background estimation

Fit to dimuon m<sub>inv</sub> distribution:

- signal: double Crystal Ball + Gaussian, parameters from known resonances,
- background: empirical functions (e.g. polynomial times exponential).



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- the largest excess at 2.41 GeV (local:  $3.24\sigma$ , global:  $1.27\sigma$ ),
  - $\rightarrow$  side note: 3.1 $\sigma$  LHCb excess at 2.42 GeV,



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- limits derived for dark photons and 2HDM+S.





W-

 $\mathbb{W}^+$ 

- models with dark Higgs s, Z' boson and DM candidates  $\chi$
- $m_s > 160 \text{ GeV} \rightarrow \text{decays to WW dominant}$
- di-leptonic & semi-leptonic channels

Analysis details

- luminosity: 137 fb<sup>-1</sup> (2016-2018)
- backgrounds: WW, Z→µµ, W+jets, tW, tt
- signal/control regions: e.g. same sign vs. opposite sign leptons





#### Analysis details

- di-leptonic channel:
  - main variable:  $m_T$  of trailing lepton  $\oplus p_T^{miss}$  system,
  - ▶ 2D fit to m<sub>II</sub> vs. m<sub>T</sub>Imin,pTmiss,
- semi-leptonic channel:  $\bullet$ 
  - BDT based on 13 most discriminative variables (e.g.  $p_T^{ij}$ ,  $\Delta \eta_{I,ij}$ ,  $p_T^{miss}$ ).

EXO-21-012





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  - BDT based on 13 most discriminative variables (e.g.  $p_{T^{jj}}$ ,  $\Delta \eta_{I,jj}$ ,  $p_{T^{miss}}$ ).

#### Results

- simultaneous fit to both channels,
- no significant excess,
- limits derived on  $m_s$  vs.  $m_{Z'}$  for different  $m_x$  assumptions,
- for  $m_x = 200$  GeV, these are the most stringent limits.





# INMARY

#### W' search

- small excess (< 3σ) at 3.4-4.4 TeV,
- best described by RH narrow width W'.

#### Heavy tW resonance

- consistent with SM,
- excited **b-quarks excluded** up to 3.0 3.2 TeV.

#### Low-mass dimuon scouting

- small excess at 2.41 GeV (local  $3\sigma$ ), consistent with the LHCb excess at 2.42 GeV, limits on dark photons and 2HDM+S.

### Dark Higgs boson

- consistent with SM,
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String resonance	CMS preliminary		March 2
	N		0.5_7.0 TeV 1911 030/7 (2i)
Zy resonance	M		0.35-4 TeV 1712.03143 (2µ + 1y; 2e + 1y; 2j + 1y)
y resonance	M		15-8 TeV 2106.10509 (1i + 1v)
ggs y resonance	M .		072-325 TeV 1808.01257 (1i + 1v)
or Octect Scalar, $k^2 = 1/2$			0.5 - 3.7  TeV 1911 03947 (2i)
ar Diguark			0.5-7.5 TeV 1911 03947 (2i)
$\phi$ , pseudoscalar (scalar), $q_{l}^2 \times BR(\phi \rightarrow 2l) > = 0.03(0.004)$		0.015 - 0.075  TeV 1911 04968 (31. > 41)	And and the second of the literature of the lite
, pseudoscalar (scalar), $a_1^2 \times BR(\phi \rightarrow 2l) > = 0.03(0.04)$		0.108_0.34 TeV/ 1011.04.068 (3/. > 4/)	
Z/v + X	M .	0.100-0.34 (EV 1911.04 900 (St, 2 4t)	1.6 TeV CMS-PAS-EXO-19-009 (pp + 11, pp + v)
		0.0-	the second
k compositeness ( <i>l.l</i> ), η <sub>LLRR</sub> = 1	tim 1		<24 TeV 2103.02708 (21)
k compositeness ( $ll$ ), $\eta_{LL,RR} = -1$	ũn l		<36 TeV 2103.02 708
ted Lepton Contact Interaction	м		0.2-5.6 TeV 2001.04521 (2e + 2j)
ited Lepton Contact Interaction	м		0.2-5.7 TeV 2001.04521 ( <b>2µ + 2</b> j)
$a_{\rm respective} = 0.25  a_{\rm res} = 1  m_{\rm res} = 1  GeV$			- 21
or mediator (qq), $g_q = 0.25$ , $g_{DM} = 1$ , $m_\chi = 1$ GeV	M	0.35-0.7 TeV 1911.03 /01 ( 2	≥ 3j)
so mediator $(\alpha), g_q = 0.1, g_{DN} = 1, g_l = 0.01, m_\chi > 1 \text{ TeV}$	M		0.2-1.92 (ev 2105.02706) (2e, 2µ)
al-)vector mediator (qq), $g_q = 0.25$ , $g_{DM} = 1$ , $m_\chi = 1$ GeV	M .		$(3-2.8 \ [ev] \ 1911.03947 \ (2))$
all vector mediator $(\chi_{\chi}), g_q = 0.25, g_{QM} = 1, m_{\chi} = 1.000$	M		<1.55 lev 210/.15021 (21) + PT /
$g_{I}$ vector mediator $(t_{I}, g_{q} = 0.1, g_{DN} = 1, g_{I} = 0.1, m_{\chi} > m_{med}/2$	M	<0.20 TeV/ 1001 01552 /0.1/ + > 2i + p <sup>mbay</sup>	0.2-4.04 TeV 2103.02700 (28, 2µ)
ar mediator $(f_1, a_1), g_q = 1, g_{DM} = 1, m_g = 1$ GeV	M	(0.25  (eV 130101335) (eV 14  (eV 13010335) (e	111
ar mediator (ter, $g_q = 1, g_{DM} = 1, m_x = 1$ GeV ar mediator (fermion portal), $\lambda_v = 1, m_z = 1$ GeV		0.03-0.4 (64 210) 10032 (0) 21 + 223 + 97	5 TeV 2107 13021 (>1i+ n <sup>mi=</sup> )
udoscalar mediator (+ <i>i</i> /V), $q_n = 1$ , $q_{DM} = 1$ , $m_r = 1$ GeV		<0.47 TeV 2107 13021 (>1i+ p <sup>min</sup>	
udoscalar mediator $(+t/tt)$ , $a_{-} = 1$ , $a_{rat} = 1$ , $m_{-} = 1$ GeV	M	$<0.3 \text{ TeV} (1901.01553 (0.1) + \ge 2i + p_{\text{m}}^{\text{min}})$	
eudoscalar mediator ( $t\bar{t}$ ), $q_n = 1$ , $q_{nM} = 1$ , $m_r = 1$ GeV	M	$0.05 - 0.42 \text{ TeV} 2107.10892 (0, 1l + \ge 2j + r)$	rrinn)
mplex sc. med. (dark QCD), $m_{n_{RH}} = 5 \text{ GeV}$ , $c\tau_{X_{RH}} = 25 \text{ mm}$	м	<1	54 TeV 1810.10069 (4j)
ryonic Z', $g_q = 0.25$ , $g_{CM} = 1$ , $m_\chi = 1$ GeV	М		<1.6 TeV 1908.01713 (h + p <sub>T</sub> <sup>miss</sup> )
mediator (dark QCD), $m_{dark} = 20$ GeV, $r_{inv} = 0.3$ , $\alpha_{dark} = \alpha_{dark}^{peak}$	М		1.5-5.1 TeV 2112.11125 (2j + p <sub>T</sub> <sup>min</sup> )
- 2HDM, g <sub>Z</sub> = 0.8, g <sub>DM</sub> = 1, tanβ = 1, m <sub>g</sub> = 100 GeV	м		0.5-3.1 TeV 1908.01713 (h + p <sub>T</sub> <sup>miss</sup> )
sptoquark mediator, $\beta = 1$ , $B = 0.1$ , $\Delta_{x, DM} = 0.1$ , 800 < $M_{LQ}$ < 1500 GeV	м	0.3-0.6 TeV 1811.10151 (1µ+	$1j + p_T^{rrism}$ )
xion-like particle, f <sup>-1</sup> = 1.2 TeV <sup>-1</sup>	м		0.5-2 TeV CMS-PAS-EXO-21-007 (pp + yy)
elastic dark matter model, $y = 10^{-6}$ , $a_0 = 0.1$	M	0.003-0.08 TeV CMS-PAS-EXO-20-010 (2 displaced µ + p <sub>T</sub> <sup>mba</sup> )	
elastic dark matter model, $y = 10^{-7}$ , $\alpha_0 = 0.1$	м	0.02-0.08 TeV CMS-PAS-EXO-20-010 (2 displaced μ + p <sub>T</sub> <sup>mina</sup> )	
rk Higgs model, $g_q = 0.25$ , $g_{DM} = 1$ , $\theta = 0.01$ , $m_\chi = 200$ GeV, $m_{Z'} = 700$ GeV	м	0.16-0.352 TeV CMS-PAS-EXO-21-012 (1/ + 2j + p	$T_{\tau}^{mha}$ , $2\ell + p_{\tau}^{mha}$
PV stop to 4 quarks	M	0.08-0.52 TeV 1808.03124 (2j; 4j)	
V squark to 4 quarks	M	0.1-0.72 TeV 1806.01058 (7	2j)
V gluino to 4 quarks	M	0.1-141	TeV 1806.01 058 (Zj)
v giulnos to 3 quarks	M	<1	
D (ii) HIZ n = 3			<12 TeV 1902 09 020 (21)
$DD (vv, ll) HLZ, n_{m} = 3$			<9.1 TeV 1812 10.443 (2v. 2/)
DD $G_{KK}$ emission, $n_{ED} = 2$	M		<10.8 TeV 2107.13021 (≥ 1i + p <sup>+(m)</sup> )
DD QBH (jj), $n_{ED} = 6$	M		<8.2 TeV 1803,08030 (2j)
DD QBH ( $e\mu$ ), $n_{ED} = 4$	М		<5.6 TeV 2205.06709 (eµ)
DD QBH (et), $n_{ED} = 4$	M		<5.2 TeV 2205.06709 (et)
DD QBH ( $\mu \tau$ ), $n_{eo} = 4$	М		<5 TeV 2205.06709 (µt)
DD QBH ( $\gamma j$ ), $n_{eD} = 6$	М		2-7.5 TeV CMS-PAS-EXO-20-012 (γ + j)
$S G_{KK}(U), k/\overline{M_{P}} = 0.1$	M		<4.78 TeV 2103.02708 (21)
$S G_{KK}(\gamma\gamma), k/\overline{M}_{PI} = 0.1$	M		<4.1 TeV 1809.00327 (2γ)
IS $G_{KK}(q\bar{q}, gg), k \overline{M}_{Pl} = 0.1$	м		0.5-2.6 TeV 1911.03947 (2j)
$5 \text{ QBH (jj)}, n_{\text{ED}} = 1$	м		<5.9 TeV 1803.08030 (2j)
$5 \text{ QBH } (\gamma j), n_{eD} = 1$	M		2-5.2 TeV CMS-PAS-EXO-20-012 (y + j)
on-rotating BH, $M_D = 4$ TeV, $n_{eD} = 6$	м		<9.7 TeV 1805.06013 (≥7j( <i>l</i> , γ))
-brane WED $g_{\kappa\kappa}(\phi + g \rightarrow ggg)$ , $g_{\sigma m} = 0$ , $g_{\sigma w} = 3$ , $\varepsilon = 0.5$ , $m(\phi)/m(g_{\kappa\kappa}) = 0.1$	g <sub>loc</sub> )		2-4.3 TeV 2201.02140 (2j)
pirt-UED, μ≥2 TeV	1/R		$0.4 - 2.8 \text{ TeV} 2202.06075 (l + p_T^{max})$
wheel links much family A and			0.5 5.7 T-V 1011 02047 (2i)
$\mathcal{X}$ (red light duark ( $n$ ) $n = m$	IT		0.0-0.3 TeV 1911.03947 (2)/
voited light quark (qg), $\Lambda = m_q$ voited light quark (qy), $f_r = f = f' = 1$ , $\Lambda = m^*$	171		1-0 16V CHO-FAG-EAC/2V-V12 (V + J)
crited light quark (qg), $h = m_q$ crited light quark (qq), $f_s = f = f' = 1$ , $h = m_q^*$ crited b quark, $f_s = f = f' = 1$ , $h = m_s^*$	N		1_2.2.7 TeV (MS-PAS-EXO-20-012 (v + i)
cited light quark (qg), $\Lambda = m_q$ cited light quark (qq), $f_s = f = f' = 1$ , $\Lambda = m_q^*$ cited b quark, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ cited electron, $f_s = f = f' = 1$ , $\Lambda = m^*$	M		1-2.2 TeV CMS-PAS-EXO-20-012 (γ + j) 0.25-3.9 TeV [1811.03052 (ν + 2e)
cited light quark (qg), $\Lambda = m_q$ cited light quark (qq), $f_s = f = f' = 1$ , $\Lambda = m_q^*$ cited b quark, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ cited electron, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ cited muon, $f_s = f = f' = 1$ , $\Lambda = m_u^*$	M M		1-2.2 TeV CMS-PAS-EXO-20-012 (γ + j) 0.25-3.9 TeV 1811.03052 (γ + 2e) 0.25-3.8 TeV 1811.03052 (γ + 2μ)
cited light quark (qg), $\Lambda = m_q$ cited light quark (qg), $f_s = f = f' = 1$ , $\Lambda = m_q^*$ cited b quark, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ cited electron, $f_s = f = f' = 1$ , $\Lambda = m_a^*$ cited muon, $f_s = f = f' = 1$ , $\Lambda = m_\mu^*$	M M M		1-2.2 TeV CMS-PAS-EXO-20-012 (γ + j) 0.25-3.9 TeV 1811.03052 (γ + 2e) 0.25-3.8 TeV 1811.03052 (γ + 2μ)
cited light quark (qg), $\Lambda = m_q$ cited light quark (qq), $f_s = f = f' = 1$ , $\Lambda = m_q^*$ cited b quark, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ cited electron, $f_s = f = f' = 1$ , $\Lambda = m_{\mu}^*$ cited muon, $f_s = f = f' = 1$ , $\Lambda = m_{\mu}^*$ ISM, $ V_{ell} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$	M M M	0.001–1.24 TeV	1-2.2 TeV CMS-PAS-EXO-20-012 (γ + j) 0.25-3.9 TeV 1811.03 052 (γ + 2e) 0.25-3.8 TeV 1811.03 052 (γ + 2μ) γ 1802.02965; 1806.10905 (3μ; ≥ 1j + 2μ)
cited light quark (qg), $N = m_q$ cited light quark (qq), $f_s = f = f' = 1$ , $\Lambda = m_q^*$ cited b quark, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ cited electron, $f_s = f = f' = 1$ , $\Lambda = m_\mu^*$ cited muon, $f_s = f = f' = 1$ , $\Lambda = m_\mu^*$ ISM, $ V_{eV} ^2 = 1.0$ , $ V_{\mu V} ^2 = 1.0$ ISM, $ V_{eV} ^2 = 1.0$ , $ V_{\mu V} ^2 = 1.0$	M M M M	0.001-1.24 TeV 0.001-1.43	1-2.2 TeV CMS-PAS-EXO-20-012 (γ + j) 0.25-3.9 TeV 1811.03052 (γ + 2e) 0.25-3.8 TeV 1811.03052 (γ + 2μ) V 1802.02965; 1806.10905 (3μ; ≥ 1j + 2μ) 8 TeV 1802.02965; 1806.10905 (3e; ≥ 1j + 2e)
The sector of t	M M M M M	0.001-1.24 Te 0.001-1.43 0.02-	$\frac{1-2.2 \text{ TeV} \text{ CMS-PAS-EXO-20-012 } (\mathbf{y} + \mathbf{j})}{0.25-3.9 \text{ TeV} 1811.03052 } (\mathbf{y} + 2\mathbf{e})}$ $\frac{0.25-3.8 \text{ TeV} 1811.03052 } (\mathbf{y} + 2\mathbf{\mu})}{1811.03052 } (\mathbf{y} + 2\mathbf{\mu})}$ $\frac{1802.02965; 1806.10905 } (3\boldsymbol{\mu}; \ge 1\mathbf{j} + 2\boldsymbol{\mu})}{3 \text{ TeV} 1802.02965; 1806.10905 } (3\mathbf{e}; \ge 1\mathbf{j} + 2\mathbf{e})}$ $\frac{1.6 \text{ TeV} 1806.10905 } (\ge 1\mathbf{j} + \boldsymbol{\mu} + \mathbf{e})}{1805.00905 } (\ge 1\mathbf{j} + \mathbf{\mu} + \mathbf{e})}$
The dilight quark (qg), $h = m_q$ Sited light quark (qq), $f_s = f = f' = 1$ , $h = m_q^*$ Sited electron, $f_s = f = f' = 1$ , $h = m_q^*$ Sited electron, $f_s = f = f' = 1$ , $h = m_q^*$ Sited muon, $f_s = f = f' = 1$ , $h = m_{\mu}^*$ SM, $ V_{all} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ SM, $ V_{all} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ SM, $ V_{all} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ SM, $ V_{all} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ SM, $ V_{all} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ SM, $ V_{all} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$	M M M M M M M	0.001-1.24 Te 0.001-1.24 Te 0.001-1.43 0.02- 0.1-0.98 TeV 2202	$\begin{array}{c} 1-2.2 \ \text{TeV} \ \text{CMS-PAS-EXO-20-012} \ (\textbf{y}+\textbf{j}) \\ 0.25-3.9 \ \text{TeV} \ 1811.03052 \ (\textbf{y}+2\textbf{e}) \\ 0.25-3.8 \ \text{TeV} \ 1811.03052 \ (\textbf{y}+2\textbf{\mu}) \end{array}$
cred light quark (qg), $N = m_q$ cited light quark (qq), $f_s = f = f' = 1$ , $\Lambda = m_q^*$ cited b quark, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ cited electron, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ cited muon, $f_s = f = f' = 1$ , $\Lambda = m_\mu^*$ (SM, $ V_{ell} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ (SM, $ V_{ell} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ (SM, $ V_{ell}V_{\mu ll}^* ^2/( V_{ell} ^2 +  V_{\mu ll} ^2) = 1.0$ (SM, $ V_{ell}V_{\mu ll}^* ^2/( V_{ell} ^2 +  V_{\mu ll} ^2) = 1.0$ (SM, $ V_{ell}V_{\mu ll}^* ^2/( V_{ell} ^2 +  V_{\mu ll} ^2) = 1.0$ (SM, $ V_{ell}V_{\mu ll}^* ^2/( V_{ell} ^2 +  V_{\mu ll} ^2) = 1.0$	M M M M M M M	0.001-1.24 Te 0.001-1.43 0.02- 0.1-0.98 TeV 2202 0.1-1.045 TeV 2202	$\begin{array}{c} 1-2.2 \ \text{TeV} \ \text{CMS-PAS-EXO-20-012} \ (\mathbf{\gamma}+\mathbf{j}) \\ 0.25-3.9 \ \text{TeV} \ 1811.03052 \ (\mathbf{\gamma}+2\mathbf{e}) \\ 0.25-3.8 \ \text{TeV} \ 1811.03052 \ (\mathbf{\gamma}+2\mathbf{\mu}) \end{array}$ $\begin{array}{c} \mathbf{\gamma} \ 1802.02965; \ 1806.10905 \ (\mathbf{3\mu}; \ \geq 1\mathbf{j}+2\mathbf{\mu}) \\ 3 \ \text{TeV} \ 1802.02965; \ 1806.10905 \ (\mathbf{3e}; \ \geq 1\mathbf{j}+2\mathbf{e}) \\ \mathbf{1.6 \ \text{TeV}} \ 1806.10905 \ (\geq 1\mathbf{j}+\mathbf{\mu}+\mathbf{e}) \\ 0.86676 \ (\mathbf{3l}, \ \geq 4l, 1\tau+3l, 2\tau+2l, 3\tau+1l, 1\tau+2l, 2\tau+1l) \\ 02.08676 \ (\mathbf{3l}, \ \geq 4l, 1\tau+3l, 2\tau+2l, 3\tau+1l, 1\tau+2l, 2\tau+1l) \end{array}$
The origin (quark (qg), $N = m_q$ cited light quark (qq), $f_s = f = f' = 1$ , $\Lambda = m_q^*$ cited b quark, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ cited electron, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ cited muon, $f_s = f = f' = 1$ , $\Lambda = m_\mu^*$ SM, $ V_{ell} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ SM, $ V_{ell}V_{\mu ll} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ SM, $ V_{ell}V_{\mu ll} ^2/( V_{ell} ^2 +  V_{\mu ll} ^2) = 1.0$ SM, $ V_{ell}V_{\mu ll}^* ^2/( V_{ell} ^2 +  V_{\mu ll} ^2) = 1.0$ Se-III seesaw heavy fermions, Flavor-democratic ctor like taus, Doublet ctor like taus, Singlet	M M M M M M M M M M	0.001-1.24 Te 0.001-1.43 0.02- 0.1-0.98 TeV 2202 0.1-1.045 TeV 2202 0.125-0.15 TeV 2202.08676 (3 <i>t</i> , ≥ 4 <i>t</i> , 1 <b>τ</b> + 3 <i>t</i> , 2 <b>τ</b> + 2 <i>t</i> , 3 <b>τ</b> + 1 <i>t</i> , 1 <b>τ</b> + 2 <i>t</i> , 3	$\begin{array}{c} 1-2.2 \ \text{TeV} \ \text{CMS-PAS-EXO-20-012} \ (\mathbf{\gamma}+\mathbf{j}) \\ 0.25-3.9 \ \text{TeV} \ 1811.03052 \ (\mathbf{\gamma}+2\mathbf{e}) \\ 0.25-3.8 \ \text{TeV} \ 1811.03052 \ (\mathbf{\gamma}+2\mathbf{\mu}) \end{array}$
inted light quark (qg), $N = M_q$ inted light quark (qq), $f_s = f = f' = 1$ , $\Lambda = m_q^*$ inted light quark, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ inted electron, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ inted muon, $f_s = f = f' = 1$ , $\Lambda = m_\mu^*$ SM, $ V_{eV} ^2 = 1.0$ , $ V_{\mu V} ^2 = 1.0$ SM, $ V_{eV} _{\mu N}^2 = 1.0$ , $ V_{\mu N} ^2 = 1.0$ SM, $ V_{eV} _{\mu N}^{*} ^2 / ( V_{eV} ^2 +  V_{\mu N} ^2) = 1.0$ e-III seesaw heavy fermions, Flavor-democratic thor like taus, Doublet thor like taus, Singlet	M M M M M M M M M M	0.001-1.24 Te 0.001-1.45 0.02- 0.1-0.98 TeV 2202 0.1-1.045 TeV 2202 0.1-1.045 TeV 2202 0.125-0.15 TeV 2202.08676 (31, ≥41, 1T + 31, 2T + 21, 3T + 11, 1T + 21, 3T 0.0115 0.075 TeV 1012.04 375 (2m)	$\frac{1-2.2 \text{ TeV} (\text{CMS-PAS-EXO-20-012 } (\mathbf{y} + \mathbf{j})}{0.25-3.9 \text{ TeV} 1811.03052 } (\mathbf{y} + 2\mathbf{e})}{0.25-3.8 \text{ TeV} 1811.03052 } (\mathbf{y} + 2\mathbf{e})}$ $\frac{1}{0.25-3.8 \text{ TeV} 1811.03052 } (\mathbf{y} + 2\mathbf{\mu})}{0.25-3.8 \text{ TeV} 1802.02965; 1806.10905 } (3\mathbf{\mu}; \ge 1\mathbf{j} + 2\mathbf{\mu})}$ $\frac{1}{0.25-3.8 \text{ TeV} 1802.02965; 1806.10905 } (3\mathbf{\mu}; \ge 1\mathbf{j} + 2\mathbf{\mu})}{0.25-3.8 \text{ TeV} 1802.02965; 1806.10905 } (3\mathbf{e}; \ge 1\mathbf{j} + 2\mathbf{e})}$ $\frac{1}{0.16 \text{ TeV} 1806.10905 } (\ge 1\mathbf{j} + \mathbf{\mu} + \mathbf{e})}{0.08676 } (3t, \ge 4t, 1\mathbf{\tau} + 3t, 2\mathbf{\tau} + 2t, 3\mathbf{\tau} + 1t, 1\mathbf{\tau} + 2t, 2\mathbf{\tau} + 1t)}$ $\frac{1}{0.208676 } (3t, \ge 4t, 1\mathbf{\tau} + 3t, 2\mathbf{\tau} + 2t, 3\mathbf{\tau} + 1t, 1\mathbf{\tau} + 2t, 2\mathbf{\tau} + 1t)}{2\mathbf{\tau} + 1t}$
inted light quark (qg), $N = M_q$ iited light quark (qg), $R = f = f' = 1$ , $\Lambda = m_q^*$ iited b quark, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ iited electron, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ iited muon, $f_s = f = f' = 1$ , $\Lambda = m_{\mu}^*$ $SM$ , $ V_{eV} ^2 = 1.0$ , $ V_{\mu V} ^2 = 1.0$ $SM$ , $ V_{eV} ^2 = 1.0$ , $ V_{\mu V} ^2 = 1.0$ $SM$ , $ V_{eV} _{\mu V_{\mu V}}^{\nu} ^2/( V_{eV} ^2 +  V_{\mu V} ^2) = 1.0$ e-III seesaw heavy fermions, Flavor-democratic tor like taus, Doublet tor like taus, Singlet narrow resonance, $\varepsilon^2 = 8 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 4 \times 10^{-2}$ (90% C.L.)	M M M M M M M M M M M M	0.001-124 Te 0.001-1.4 0.02- 0.1-0.98 TeV 2202 0.1-1.045 TeV 2202 0.1-1.045 TeV 2202 0.125-0.15 TeV 2202.08676 (3ℓ, ≥ 4ℓ, 1τ + 3ℓ, 2τ + 2ℓ, 3τ + 1ℓ, 1τ + 2ℓ, 3 0.0115-0.075 TeV 1912.04776 (2μ) 0.0115-0.075 TeV 1912.04776 (2μ)	$\frac{1-2.2 \text{ TeV} (\text{CMS-PAS-EXO-20-012 } (\mathbf{y} + \mathbf{j})}{0.25-3.9 \text{ TeV} 1811.03052 } (\mathbf{y} + 2\mathbf{e})} \\ 0.25-3.8 \text{ TeV} 1811.03052 } (\mathbf{y} + 2\mathbf{\mu})}$ $\frac{1811.03052 } (\mathbf{y} + 2\mathbf{\mu})}{1811.03052 } (\mathbf{y} + 2\mathbf{\mu})}$ $\frac{1802.02965; 1806.10905 } (3\mathbf{\mu}; \ge 1\mathbf{j} + 2\mathbf{\mu})}{3 \text{ TeV} 1802.02965; 1806.10905 } (3\mathbf{e}; \ge 1\mathbf{j} + 2\mathbf{e})} \\ \frac{1.6 \text{ TeV} 1806.10905 } (\ge 1\mathbf{j} + \mathbf{\mu} + \mathbf{e})}{.08676 } (3t, \ge 4t, 1\tau + 3t, 2\tau + 2t, 3\tau + 1t, 1\tau + 2t, 2\tau + 1t)} \\ \frac{1.02.08676 } (3t, \ge 4t, 1\tau + 3t, 2\tau + 2t, 3\tau + 1t, 1\tau + 2t, 2\tau + 1t)}{2\tau + 1t}$
International quark (qg), $\Lambda = m_q$ inter light quark (qg), $f_s = f = f' = 1$ , $\Lambda = m_q^*$ inter light quark, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ inter light quark, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ inter light quark, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ inter light quark (qg), $ V_{\mu\nu} ^2 = 1.0$ inter light quark (qg), $ V_{\mu\nu} ^2$	M M M M M M M M M M M M M M M M M M M	0.001-1.24 Te 0.001-1.4 0.02- 0.1-0.98 TeV 2202 0.1-1.045 TeV 2202 0.1-1.045 TeV 2202 0.125-0.15 TeV 2202.08676 (3 <i>t</i> , ≥ 4 <i>t</i> , 1 <b>τ</b> + 3 <i>t</i> , 2 <b>τ</b> + 2 <i>t</i> , 3 <b>τ</b> + 1 <i>t</i> , 1 <b>τ</b> + 2 <i>t</i> , 3 0.0115-0.075 TeV 1912.04 776 (2μ) 0.11-0.2 TeV 1912.04776 (2μ)	$\frac{1-2.2 \text{ TeV} (CMS-PAS-EXO-20-012 (y + j))}{0.25-3.9 \text{ TeV} [1811.03052 (y + 2e)]}$ $\frac{0.25-3.8 \text{ TeV} [1811.03052 (y + 2\mu)]}{1.03052 (y + 2\mu)}$ $\frac{1802.02965; 1806.10905 (3\mu; \ge 1j + 2\mu)}{3 \text{ TeV} [1802.02965; 1806.10905 (3e; \ge 1j + 2e)]}$ $\frac{1.6 \text{ TeV} [1806.10905 (\ge 1j + \mu + e)]}{0.08676 (3t, \ge 4t, 1\tau + 3t, 2\tau + 2t, 3\tau + 1t, 1\tau + 2t, 2\tau + 1t)]}$ $\frac{20.08676 (3t, \ge 4t, 1\tau + 3t, 2\tau + 2t, 3\tau + 1t, 1\tau + 2t, 2\tau + 1t)}{2\tau + 1t}$
The light quark (qg), $N = m_q$ ited light quark (qq), $f_s = f = f' = 1$ , $\Lambda = m_q^*$ ited light quark ( $f_s = f = f' = 1$ , $\Lambda = m_q^*$ ited electron, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ ited muon, $f_s = f = f' = 1$ , $\Lambda = m_{\mu}^*$ iM, $ V_{ell} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ iM, $ V_{ell} _{l}^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ iM, $ V_{ell} _{l}^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ iM, $ V_{ell} _{l}^2  V_{ell} _{l}^2 +  V_{\mu ll} ^2) = 1.0$ at ll seesaw heavy fermions, Flavor-democratic ior like taus, Doublet ior like taus, Singlet narrow resonance, $\varepsilon^2 = 8 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 7 \times 10^{-7}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.)	M M M M M M M M M M M M M M M M M M M	0.001-1.24 Te 0.001-1.43 0.02- 0.1-0.98 TeV 2202 0.1-0.98 TeV 2202 0.1-1.045 TeV 2202 0.125-0.15 TeV 2202.08676 (3t, ≥ 4t, 1τ + 3t, 2τ + 2t, 3τ + 1t, 1τ + 2t, 3τ 0.0115-0.075 TeV 1912.04 776 (2μ) 0.11-0.2 TeV 1912.04 776 (2μ) VS-EXO-21-005 (2μ)	$\frac{1-2.2 \text{ TeV} \text{ CMS-PAS-EXO-20-012 } (\mathbf{y} + \mathbf{j})}{0.25-3.9 \text{ TeV} 1811.03052 } (\mathbf{y} + 2\mathbf{e})}{0.25-3.8 \text{ TeV} 1811.03052 } (\mathbf{y} + 2\mathbf{e})}$ $\frac{1802.02965; 1806.10905 (3\boldsymbol{\mu}; \ge 1\mathbf{j} + 2\boldsymbol{\mu})}{3 \text{ TeV} 1802.02965; 1806.10905 } (3\boldsymbol{e}; \ge 1\mathbf{j} + 2\mathbf{e})}{1.6 \text{ TeV} 1806.10905 } (\ge 1\mathbf{j} + \boldsymbol{\mu} + \mathbf{e})}$ $\frac{1.6 \text{ TeV} 1806.10905 }{0.8676 } (3t, \ge 4t, 1\tau + 3t, 2\tau + 2t, 3\tau + 1t, 1\tau + 2t, 2\tau + 1t)}{22.08676 } (3t, \ge 4t, 1\tau + 3t, 2\tau + 2t, 3\tau + 1t, 1\tau + 2t, 2\tau + 1t)}$
The light quark (qg), $N = m_q$ ited light quark (qq), $f_s = f = f' = 1$ , $N = m_q^*$ ited light quark ( $f_s = f = f' = 1$ , $N = m_q^*$ ited electron, $f_s = f = f' = 1$ , $N = m_q^*$ ited muon, $f_s = f = f' = 1$ , $N = m_{\mu}^*$ SM, $ V_{eN} ^2 = 1.0$ , $ V_{\mu N} ^2 = 1.0$ SM, $ V_{eN} ^2 = 1.0$ , $ V_{\mu N} ^2 = 1.0$ SM, $ V_{eN} _{\mu N}^{P} ^2/( V_{eN} ^2 +  V_{\mu N} ^2) = 1.0$ e-III seesaw heavy fermions, Flavor-democratic tor like taus, Doublet tor like taus, Singlet narrow resonance, $\varepsilon^2 = 8 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 7 \times 10^{-7}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.)	M M M M M M M M M M M M M M M M M M M	0.001-124 Te 0.001-124 Te 0.001-1.4: 0.02- 0.1-0.98 TeV 2202 0.1-0.98 TeV 2202 0.1-1.045 TeV 2202 0.125-0.15 TeV 2202.08676 ( <b>3</b> <i>t</i> , ≥ 4 <i>t</i> , <b>1τ</b> + 3 <i>t</i> , <b>2τ</b> + 2 <i>t</i> , <b>3τ</b> + 1 <i>t</i> , <b>1τ</b> + 2 <i>t</i> , <b>3</b> 0.0115-0.075 TeV 1912.04 776 ( <b>2</b> μ) 0.11-0.2 TeV 1912.04776 ( <b>2</b> μ) AS-EXO-21-005 ( <b>2</b> μ)	$\frac{1-2.2 \text{ TeV} (CMS-PAS-EXO-20-012 (y + j))}{0.25-3.9 \text{ TeV} [1811.03052 (y + 2e))}$ $\frac{0.25-3.8 \text{ TeV} [1811.03052 (y + 2\mu)]}{0.25-3.8 \text{ TeV} [1811.03052 (y + 2\mu)]}$ $1000000000000000000000000000000000000$
Ited light quark (qg), $h = m_q$ ited light quark (qq), $f_s = f = f' = 1$ , $h = m_q^*$ ited light quark, $f_s = f = f' = 1$ , $h = m_q^*$ ited electron, $f_s = f = f' = 1$ , $h = m_q^*$ ited muon, $f_s = f = f' = 1$ , $h = m_{\mu}^*$ $\delta M$ , $ V_{ell} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ $\delta M$ , $ V_{ell} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ $\delta M$ , $ V_{ell} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ $\delta M$ , $ V_{ell} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ $\delta M$ , $ V_{ell} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ $\delta M$ , $ V_{ell} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ $\delta M$ , $ V_{ell} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ $\delta M$ , $ V_{ell} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ $\delta M$ , $ V_{ell} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ $\delta M$ , $ V_{ell} ^2 = 1.0$ , $ V_{ell} ^2 = 1.0$ narrow resonance, $\varepsilon^2 = 8 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) $\Lambda Z'(Ul)$ $\Lambda Z'(q\bar{q})$	M M M M M M M M M M M M M M M M M M M	0.001–1.24 Te 0.001–1.4: 0.02– 0.1–0.98 TeV 2202 0.1–0.98 TeV 2202 0.1–1.045 TeV 2202 0.125–0.15 TeV 2202.08676 ( <b>3</b> <i>t</i> , ≥ 4 <i>t</i> , 1 <b>τ</b> + 3 <i>t</i> , 2 <b>τ</b> + 2 <i>t</i> , 3 <b>τ</b> + 1 <i>t</i> , 1 <b>τ</b> + 2 <i>t</i> , 5 0.0115–0.075 TeV 1912.04 776 (2μ) 0.11–0.2 TeV 1912.04776 (2μ) AS-EXO-21-005 ( <b>2</b> μ)	$\frac{1-2.2 \text{ TeV} (\text{CMS-PAS-EXO-20-012 } (\mathbf{y} + \mathbf{j})}{0.25-3.9 \text{ TeV} 1811.03052 } (\mathbf{y} + 2\mathbf{e})}{0.25-3.8 \text{ TeV} 1811.03052 } (\mathbf{y} + 2\mathbf{e})}$ $\frac{1}{0.25-3.8 \text{ TeV} 1811.03052 } (\mathbf{y} + 2\mathbf{\mu})}{(\mathbf{y} + 2\mathbf{\mu})^{3}}$ $\frac{1}{2} \text{ TeV} 1802.02965; 1806.10905 } (3\boldsymbol{\mu}; \geq 1\mathbf{j} + 2\boldsymbol{\mu})}{3 \text{ TeV} 1802.02965; 1806.10905 } (3\boldsymbol{e}; \geq 1\mathbf{j} + 2\mathbf{e})}$ $\frac{1.6 \text{ TeV} 1806.10905 } (\geq 1\mathbf{j} + \boldsymbol{\mu} + \mathbf{e})}{1.08676 } (3t, \geq 4t, 1\tau + 3t, 2\tau + 2t, 3\tau + 1t, 1\tau + 2t, 2\tau + 1t)}$ $\frac{1.22 \text{ TeV} 1802.02965; 1806.10905 } (3t, \geq 4t, 1\tau + 3t, 2\tau + 2t, 3\tau + 1t, 1\tau + 2t, 2\tau + 1t)}{22 \text{ TeV} 1802.02965 } (3t, \geq 4t, 1\tau + 3t, 2\tau + 2t, 3\tau + 1t, 1\tau + 2t, 2\tau + 1t)}$ $\frac{1.22 \text{ TeV} (2103.02708 } (2\mathbf{e}, 2\mathbf{\mu})}{0.5-2.9 \text{ TeV} 1911.03947 } (2\mathbf{j})}$
inted light quark (qg), $N = m_q$ iited light quark (qq), $f_s = f = f' = 1$ , $\Lambda = m_q^*$ iited lo quark, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ iited electron, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ iited muon, $f_s = f = f' = 1$ , $\Lambda = m_{\mu}^*$ SM, $ V_{eN} ^2 = 1.0$ , $ V_{\mu N} ^2 = 1.0$ SM, $ V_{eN}V_{\mu N}^* ^2/( V_{eN} ^2 +  V_{\mu N} ^2) = 1.0$ e-III seesaw heavy fermions, Flavor-democratic tor like taus, Doublet tor like taus, Singlet narrow resonance, $\varepsilon^2 = 8 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 7 \times 10^{-7}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) N Z'(U) M Z'(U)	M M M M M M M M M M M M M M M M M M M	0.001-124 Te 0.001-1.4 0.02- 0.1-0.98 TeV 2202 0.1-1.045 TeV 2202.08676 (3 <i>t</i> , ≥ 4 <i>t</i> , 1 <b>τ</b> + 3 <i>t</i> , 2 <b>τ</b> + 2 <i>t</i> , 3 <b>τ</b> + 1 <i>t</i> , 1 <b>τ</b> + 2 <i>t</i> , 3 0.0115-0.075 TeV 1912.04 776 (2μ) 0.11-0.2 TeV 1912.04776 (2μ) 4S-EXO-21-005 (2μ) 0.01-0.125 TeV 1905.10331 (1j, 1γ)	$\frac{1-2.2 \text{ TeV} (\text{CMS-PAS-EXO-20-012 } (\mathbf{y} + \mathbf{j})}{0.25-3.9 \text{ TeV} 1811.03052 } (\mathbf{y} + 2\mathbf{e})}{0.25-3.8 \text{ TeV} 1811.03052 } (\mathbf{y} + 2\mathbf{\mu})}$ <b>V</b> 1802.02965; 1806.10905 (3 <b>µ</b> ; <b>≥</b> 1 <b>j</b> + 2 <b>µ</b> ) <b>3</b> TeV 1802.02965; 1806.10905 (3 <b>e</b> ; <b>≥</b> 1 <b>j</b> + 2 <b>e</b> ) -1.6 TeV 1806.10905 ( <b>≥</b> 1 <b>j</b> + <b>µ</b> + <b>e</b> ) -0.86676 (3 <i>t</i> , <b>≥</b> 4 <i>t</i> , 1 <b>τ</b> + 3 <i>t</i> , 2 <b>τ</b> + 2 <i>t</i> , 3 <b>τ</b> + 1 <i>t</i> , 1 <b>τ</b> + 2 <i>t</i> , 2 <b>τ</b> + 1 <i>t</i> ) -0.208676 (3 <i>t</i> , <b>≥</b> 4 <i>t</i> , 1 <b>τ</b> + 3 <i>t</i> , 2 <b>τ</b> + 2 <i>t</i> , 3 <b>τ</b> + 1 <i>t</i> , 1 <b>τ</b> + 2 <i>t</i> , 2 <b>τ</b> + 1 <i>t</i> ) -2.08676 (3 <i>t</i> , <b>≥</b> 4 <i>t</i> , 1 <b>τ</b> + 3 <i>t</i> , 2 <b>τ</b> + 2 <i>t</i> , 3 <b>τ</b> + 1 <i>t</i> , 1 <b>τ</b> + 2 <i>t</i> , 2 <b>τ</b> + 1 <i>t</i> ) -0.2-5.15 TeV 2103.02708 (2 <b>e</b> , 2 <b>µ</b> ) 0.5-2.9 TeV 1911.03947 (2 <b>j</b> )
ited light quark (qg), $h = m_q$ ited light quark (qq), $f_s = f = f' = 1, h = m_q^*$ ited b quark, $f_s = f = f' = 1, h = m_q^*$ ited electron, $f_s = f = f' = 1, h = m_q^*$ ited muon, $f_s = f = f' = 1, h = m_\mu^*$ $SM,  V_{ell} ^2 = 1.0,  V_{\mu ell} ^2 = 1.0$ $SM,  V_{ell} ^2 = 1.0,  V_{\mu ell} ^2 = 1.0$ $SM,  V_{ell} ^2 / ( V_{ell} ^2 +  V_{\mu ell} ^2) = 1.0$ e-III seesaw heavy fermions, Flavor-democratic tor like taus, Doublet tor like taus, Singlet narrow resonance, $\varepsilon^2 = 8 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 7 \times 10^{-7}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) Z'(U) Z'(U)	M M M M M M M M M M M M M M M M M M M	0.001-1.24 Te 0.001-1.4 0.002- 0.1-0.98 TeV 2202 0.1-1.045 TeV 2202 0.125-0.15 TeV 2202.08676 (3 <i>t</i> , ≥ 4 <i>t</i> , 1τ + 3 <i>t</i> , 2τ + 2 <i>t</i> , 3τ + 1 <i>t</i> , 1τ + 2 <i>t</i> , 3 0.0115-0.075 TeV 1912.04776 (2μ) 0.11-0.2 TeV 1912.04776 (2μ) 0.11-0.2 TeV 1912.04776 (2μ)	$\frac{1-2.2 \text{ TeV} (\text{CMS-PAS-EXO-20-012 } (\mathbf{y} + \mathbf{j})}{0.25-3.9 \text{ TeV} 1811.03 052 } (\mathbf{y} + 2\mathbf{e})}$ $0.25-3.8 \text{ TeV} 1811.03 052 } (\mathbf{y} + 2\mathbf{\mu})$ $\frac{1}{9} 1802.02965; 1806.10905 } (3\mathbf{\mu}; \ge 1\mathbf{j} + 2\mathbf{\mu})$ $\frac{1}{9} 1802.02965; 1806.10905 } (3\mathbf{e}; \ge 1\mathbf{j} + 2\mathbf{e})$ $\frac{1}{1.6 \text{ TeV} 1806.10905 } (\ge 1\mathbf{j} + \mathbf{\mu} + \mathbf{e})}{0.08676 } (3t, \ge 4t, 1\mathbf{r} + 3t, 2\mathbf{r} + 2t, 3\mathbf{r} + 1t, 1\mathbf{r} + 2t, 2\mathbf{r} + 1t)}$ $\frac{0.2-5.15 \text{ TeV}}{27 + 1t} 2103.02708 } (2\mathbf{e}, 2\mathbf{\mu})$ $\frac{0.2-4.6 \text{ TeV}}{2103.02708 } (2\mathbf{e}, 2\mathbf{\mu})$
ited right quark (qg), $N = m_q$ ited light quark (qg), $f_s = f = f' = 1$ , $\Lambda = m_q^*$ ited b quark, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ ited electron, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ ited muon, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ $5M$ , $ V_{ell} ^2 = 1.0$ , $ V_{\mu ell} ^2 = 1.0$ $5M$ , $ V_{ell} ^2 = 1.0$ , $ V_{\mu ell} ^2 = 1.0$ $5M$ , $ V_{ell} ^2/( V_{ell} ^2 +  V_{\mu ell} ^2) = 1.0$ e-III seesaw heavy fermions, Flavor-democratic tor like taus, Doublet tor like taus, Singlet narrow resonance, $\varepsilon^2 = 8 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 7 \times 10^{-7}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) N Z'(H) A Z'(H) $A Z'(q\bar{q})$ $q\bar{q}$ ) perstring $Z'_{q}$ , $'Z'$ , BR(e $\mu$ ) = 10%	M M M M M M M M M M M M M M M M M M M	0.001-1.24 Te 0.001-1.4 0.001-1.4 0.02- 0.1-0.98 TeV 2202 0.1-1.045 TeV 2202 0.125-0.15 TeV 2202.08676 (3 <i>t</i> , ≥ 4 <i>t</i> , 1τ + 3 <i>t</i> , 2τ + 2 <i>t</i> , 3τ + 1 <i>t</i> , 1τ + 2 <i>t</i> , 0.0115-0.075 TeV 1912.04776 (2μ) 0.11-0.2 TeV 1912.04776 (2μ) AS-EXO-21-005 (2μ) 0.01-0.125 TeV 1905.10331 (1j, 1γ)	$1-2.2 \text{ TeV} (MS-PAS-EXO-20-012 (y + j))$ $0.25-3.9 \text{ TeV} [1811.03 052 (y + 2e))$ $0.25-3.8 \text{ TeV} [1811.03 052 (y + 2\mu))$ $1802.02965; 1806.10905 (3\mu; \ge 1j + 2\mu)$ $3 \text{ TeV} [1802.02965; 1806.10905 (3e; \ge 1j + 2e))$ $1.6 \text{ TeV} [1806.10905 (\ge 1j + \mu + e)]$ $0.8676 (3t, \ge 4t, 1\tau + 3t, 2\tau + 2t, 3\tau + 1t, 1\tau + 2t, 2\tau + 1t)$ $20.08676 (3t, \ge 4t, 1\tau + 3t, 2\tau + 2t, 3\tau + 1t, 1\tau + 2t, 2\tau + 1t)$ $2\tau + 1t)$ $0.2-5.15 \text{ TeV} [2103.02708 (2e, 2\mu)]$ $0.2-4.6 \text{ TeV} [2103.02708 (2e, 2\mu)]$ $0.2-5 \text{ TeV} [2103.02708 (2e, 2\mu)]$
ted light quark (qg), $N = m_q$ ited light quark (qq), $f_s = f = f' = 1$ , $\Lambda = m_q^*$ ited light quark, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ ited electron, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ ited muon, $f_s = f = f' = 1$ , $\Lambda = m_{\mu}^*$ $M$ , $ V_{ell} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ $M$ , $ V_{ell} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ $M$ , $ V_{ell}V_{\mu ll}^* ^2/( V_{ell} ^2 +  V_{\mu ll} ^2) = 1.0$ e-III seesaw heavy fermions, Flavor-democratic for like taus, Doublet tor like taus, Singlet narrow resonance, $\varepsilon^2 = 8 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 7 \times 10^{-7}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.)  Z'(H)  $ Z'(q\bar{q}) $ $\bar{q} $ erstring $Z'_{ip}$ $Z'$ , BR( $e\mu$ ) = 10% $Z'$ , BR( $e\mu$ ) = 10%	M M M M M M M M M M M M M M M M M M M	0.001-1.24 Te 0.001-1.4 0.02- 0.1-0.98 TeV 2202 0.1-0.98 TeV 2202 0.1-1.045 TeV 2202 0.125-0.15 TeV 2202.08676 (3 <i>t</i> , ≥ 4 <i>t</i> , 1τ + 3 <i>t</i> , 2τ + 2 <i>t</i> , 3τ + 1 <i>t</i> , 1τ + 2 <i>t</i> , 0.0115-0.075 TeV 1912.04776 (2μ) 0.11-0.2 TeV 1912.04776 (2μ) AS-EXO-21-005 (2μ) 0.01-0.125 TeV 1905.10331 (1j, 1γ)	$1-2.2 \text{ TeV} (\text{CMS-PAS-EXO-20-012 } (\mathbf{y} + \mathbf{j}) \\ 0.25-3.9 \text{ TeV}   1811.03.052 } (\mathbf{y} + 2\mathbf{e}) \\ 0.25-3.8 \text{ TeV}   1811.03.052 } (\mathbf{y} + 2\mathbf{\mu}) \\ 1802.02965; 1806.10905 } (3\mathbf{\mu}; \ge 1\mathbf{j} + 2\mathbf{\mu}) \\ 3 \text{ TeV}   1802.02965; 1806.10905 } (3\mathbf{e}; \ge 1\mathbf{j} + 2\mathbf{e}) \\ -1.6 \text{ TeV}   1806.10905 } (\ge 1\mathbf{j} + \mathbf{\mu} + \mathbf{e}) \\ .08676 (3t, \ge 4t, 1\mathbf{r} + 3t, 2\mathbf{r} + 2t, 3\mathbf{r} + 1t, 1\mathbf{r} + 2t, 2\mathbf{r} + 1t) \\ .02.08676 (3t, \ge 4t, 1\mathbf{r} + 3t, 2\mathbf{r} + 2t, 3\mathbf{r} + 1t, 1\mathbf{r} + 2t, 2\mathbf{r} + 1t) \\ 2\mathbf{r} + 1t ) \\ 0.5-2.9 \text{ TeV}   1911.03.947 (2\mathbf{j}) \\ 0.2-4.6 \text{ TeV}   2103.02.708 (2\mathbf{e}, 2\mathbf{\mu}) \\ 0.2-5 \text{ TeV}   2205.06.709 (\mathbf{e}\mathbf{\mu}) \\ 0.2-4.3 \text{ TeV}   2.2.4.3 \text{ TeV}   2.4.3 \text{ TeV}   2.4.3 \text{ TeV}   2.4.3 \text{ TeV}$
The dright quark (qg), $N = m_q$ ited light quark (qg), $f_s = f = f' = 1$ , $N = m_q^*$ ited loguark, $f_s = f = f' = 1$ , $N = m_q^*$ ited electron, $f_s = f = f' = 1$ , $N = m_q^*$ ited muon, $f_s = f = f' = 1$ , $N = m_q^*$ SM, $ V_{ell} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ SM, $ V_{ell} V_{ell} ^2 = 1.0$ , $ V_{\mu ll} ^2 = 1.0$ SM, $ V_{ell}V_{\mu ll}^{\prime \prime} ^2/( V_{ell} ^2 +  V_{\mu ll} ^2) = 1.0$ e-III seesaw heavy fermions, Flavor-democratic tor like taus, Doublet tor like taus, Singlet narrow resonance, $\varepsilon^2 = 8 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 7 \times 10^{-7}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) AZ'(U) $AZ'(Q\bar{q})$ $N\bar{q}$ ) perstring $Z'_{\psi}$ $(Z', BR(e\mu) = 10\%$ $(Z', BR(\mu\tau) = 10\%)$	M M M M M M M M M M M M M M M M M M M	0.001-1.24 Te 0.001-1.24 Te 0.001-1.43 0.02- 0.1-0.98 TeV 2202 0.1-0.98 TeV 2202 0.1-0.45 TeV 2202 0.125-0.15 TeV 2202.08676 (3 <i>t</i> , ≥ 4 <i>t</i> , 1 <b>τ</b> + 3 <i>t</i> , 2 <b>τ</b> + 2 <i>t</i> , 3 <b>τ</b> + 1 <i>t</i> , 1 <b>τ</b> + 2 <i>t</i> , 0.0115-0.075 TeV 1912.04776 (2μ) 0.11-0.2 TeV 1912.04776 (2μ) AS-EXO-21-005 (2μ) 0.01-0.125 TeV 1905.10331 (1j, 1γ)	$1-2.2 \text{ TeV} (CMS-PAS-EXO-20-012 (y + j))$ $0.25-3.9 \text{ TeV} [1811.03 052 (y + 2e))$ $0.25-3.8 \text{ TeV} [1811.03 052 (y + 2\mu)]$ $y [1802.02965; 1806.10905 (3\mu; \ge 1j + 2\mu)]$ $8 \text{ TeV} [1802.02965; 1806.10905 (3e; \ge 1j + 2e)]$ $1.6 \text{ TeV} [1806.10905 (\ge 1j + \mu + e)]$ $0.8676 (3t, \ge 4t, 1\tau + 3t, 2\tau + 2t, 3\tau + 1t, 1\tau + 2t, 2\tau + 1t)]$ $20.8676 (3t, \ge 4t, 1\tau + 3t, 2\tau + 2t, 3\tau + 1t, 1\tau + 2t, 2\tau + 1t)]$ $2\tau + 1t)$ $0.2-5.15 \text{ TeV} [2103.02708 (2e, 2\mu)]$ $0.5-2.9 \text{ TeV} [1911.03947 (2j)]$ $0.2-4.6 \text{ TeV} [2103.02708 (2e, 2\mu)]$ $0.2-5. \text{ TeV} [2205.06709 (e\mu)]$ $0.2-4.1 \text{ TeV} [2205.06709 (\mu\tau)]$
The dright quark (qg), $h = m_q$ Sited light quark (qq), $f_s = f = f' = 1, h = m_q^*$ Sited electron, $f_s = f = f' = 1, h = m_q^*$ Sited electron, $f_s = f = f' = 1, h = m_q^*$ Sited muon, $f_s = f = f' = 1, h = m_q^*$ SM, $ V_{av} ^2 = 1.0,  V_{\mu v} ^2 = 1.0$ SM, $ V_{av} V_{\mu v}^* ^2/( V_{av} ^2 +  V_{\mu v} ^2) = 1.0$ e-III seesaw heavy fermions, Flavor-democratic thor like taus, Doublet thor like taus, Singlet narrow resonance, $\varepsilon^2 = 8 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 4 \times 10^{-5}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) (M Z'( $ll$ ) M Z'( $pl$ ) = 10% (Z', BR( $e_T$ ) = 10% M V'( $tv$ )	M M M M M M M M M M M M M M M M M M M	0.001–1.24 Te 0.001–1.4 0.02- 0.1–0.98 TeV 202- 0.1–0.98 TeV 202- 0.125–0.15 TeV 2020.8676 (3 <i>t</i> , ≥ 4 <i>t</i> , 1τ + 3 <i>t</i> , 2τ + 2 <i>t</i> , 3τ + 1 <i>t</i> , 1τ + 2 <i>t</i> , 0.0115–0.075 TeV 1912.04776 (2μ) 0.11–0.2 TeV 1912.04776 (2μ) AS-EXO-21-005 (2μ) 0.01–0.125 TeV 1905.10331 (1j, 1γ)	$1-22 \text{ TeV} (MS-PAS-EXO-20-012 (y + j))$ $0.25-3.9 \text{ TeV} [1811.03052 (y + 2e))$ $0.25-3.8 \text{ TeV} [1811.03052 (y + 2\mu)]$ $y [1802.02965; 1806.10905 (3\mu; \ge 1j + 2\mu)]$ $8 \text{ TeV} [1802.02965; 1806.10905 (3e; \ge 1j + 2e)]$ $1.6 \text{ TeV} [1806.10905 (\ge 1j + \mu + e)]$ $0.8676 (3l, \ge 4l, 1\tau + 3l, 2\tau + 2l, 3\tau + 1l, 1\tau + 2l, 2\tau + 1l)$ $20.8676 (3l, \ge 4l, 1\tau + 3l, 2\tau + 2l, 3\tau + 1l, 1\tau + 2l, 2\tau + 1l)$ $2\tau + 1l)$ $0.2-5.15 \text{ TeV} [2103.02708 (2e, 2\mu)]$ $0.2-4.6 \text{ TeV} [2103.02708 (2e, 2\mu)]$ $0.2-4.6 \text{ TeV} [2103.02708 (2e, 2\mu)]$ $0.2-4.3 \text{ TeV} [2205.06709 (e\mu)]$ $0.2-4.1 \text{ TeV} [2205.06709 (e\tau)]$ $0.4-5.7 \text{ TeV} [2202.06075 (l + p_{\tau}^{rtm})]$
The dright quark (qg), $N = m_q$ ited light quark (qg), $f_s = f = f' = 1, \Lambda = m_q^*$ ited light quark $f_s = f = f' = 1, \Lambda = m_q^*$ ited electron, $f_s = f = f' = 1, \Lambda = m_q^*$ ited muon, $f_s = f = f' = 1, \Lambda = m_{\mu}^*$ SM, $ V_{en} ^2 = 1.0,  V_{\mu n} ^2 = 1.0$ SM, $ V_{en} ^2 = 1.0,  V_{\mu n} ^2 = 1.0$ SM, $ V_{en} V_{\mu n}^* ^2/( V_{en} ^2 +  V_{\mu n} ^2) = 1.0$ e-III seesaw heavy fermions, Flavor-democratic tor like taus, Doublet tor like taus, Singlet narrow resonance, $\varepsilon^2 = 8 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 7 \times 10^{-7}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) (2', Ul) $AZ'(Q\bar{q})$ $AZ'(Q\bar{q})$ $AZ'(Q\bar{q})$ AZ'(D) AZ'(LV) AZ	M M M M M M M M M M M M M M M M M M M	0.001-1.24 Te 0.001-1.24 Te 0.001-1.45 0.02- 0.1-0.98 TeV 2202 0.1-1.045 TeV 2202 0.1-1.045 TeV 2202 0.125-0.15 TeV 2202.08676 (3 <i>t</i> , ≥ 4 <i>t</i> , 1τ + 3 <i>t</i> , 2τ + 2 <i>t</i> , 3τ + 1 <i>t</i> , 1τ + 2 <i>t</i> , 0.0115-0.075 TeV 1912.04776 (2μ) 0.11-0.2 TeV 1912.04776 (2μ) AS-EXO-21-005 (2μ) 0.01-0.125 TeV 1905.10331 (1j, 1γ) 0.05-0.45 TeV 1909.04114 (2j)	$1-22 \text{ TeV} (MS-PAS-EXO-20-012 (y + j))$ $0.25-3.9 \text{ TeV} [1811.03052 (y + 2e))$ $0.25-3.8 \text{ TeV} [1811.03052 (y + 2\mu))$ $1.61 \text{ TeV} [1802.02965; 1806.10905 (3\mu; \ge 1j + 2e))$ $1.6 \text{ TeV} [1802.02965; 1806.10905 (3e; \ge 1j + 2e))$ $1.6 \text{ TeV} [1806.10905 (\ge 1j + \mu + e)]$ $0.8676 (3l, \ge 4l, 1\tau + 3l, 2\tau + 2l, 3\tau + 1l, 1\tau + 2l, 2\tau + 1l)$ $2.08676 (3l, \ge 4l, 1\tau + 3l, 2\tau + 2l, 3\tau + 1l, 1\tau + 2l, 2\tau + 1l)$ $2\tau + 1l)$ $0.2-5.15 \text{ TeV} [2103.02708 (2e, 2\mu)]$ $0.5-2.9 \text{ TeV} [1911.03947 (2j)]$ $0.2-4.6 \text{ TeV} [2103.02708 (2e, 2\mu)]$ $0.2-4.3 \text{ TeV} [2205.06709 (e\mu)]$ $0.2-4.1 \text{ TeV} [2205.06709 (\mu\tau)]$ $0.4-5.7 \text{ TeV} [2202.06075 (l + p_{\tau}^{\text{rten}})]$
The light quark (qg), $N = m_q$ ited light quark (qq), $f_s = f = f' = 1$ , $\Lambda = m_q^*$ ited b quark, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ ited electron, $f_s = f = f' = 1$ , $\Lambda = m_q^*$ ited muon, $f_s = f = f' = 1$ , $\Lambda = f' = 1$	M M M M M M M M M M M M M M M M M M M	0.001-1.24 Te 0.001-1.4 0.001-1.4 0.02- 0.1-0.98 TeV 2202 0.1-0.98 TeV 2202 0.1-0.98 TeV 2202 0.1-0.075 TeV 1912.04 776 (2μ) 0.11-0.2 TeV 1912.04776 (2μ) AS-EXO-21-005 (2μ) 0.01-0.125 TeV 1905.10331 (1j, 1γ) 0.01-0.125 TeV 1905.10331 (1j, 1γ) 0.05-0.45 TeV 1909.04114 (2j)	$\frac{1-22 \text{ TeV} (\text{CMS-PAS-EXO-20-012 } (\mathbf{y} + \mathbf{j})}{0.25-3.9 \text{ TeV}} 1811.03052 (\mathbf{y} + 2\mathbf{e})} \\ 0.25-3.8 \text{ TeV}} 1811.03052 (\mathbf{y} + 2\mathbf{\mu})}$ $\frac{1802.02965; 1806.10905 (3\mathbf{\mu}; \ge 1\mathbf{j} + 2\mathbf{\mu})}{8\text{ TeV}} 1802.02965; 1806.10905 (3\mathbf{e}; \ge 1\mathbf{j} + 2\mathbf{e})} \\ 1.6 \text{ TeV}} 1806.10905 (3\mathbf{e}; \ge 1\mathbf{j} + 2\mathbf{e}) \\ 1.6 \text{ TeV}} 1806.10905 (3\mathbf{i}; \ge 1\mathbf{j} + 2\mathbf{i}, 3\mathbf{r} + 1\mathbf{i}, 1\mathbf{r} + 2\mathbf{i}, 2\mathbf{r} + 1\mathbf{i})} \\ 208676 (3\mathbf{i}, \ge 4\mathbf{i}, 1\mathbf{r} + 3\mathbf{i}, 2\mathbf{r} + 2\mathbf{i}, 3\mathbf{r} + 1\mathbf{i}, 1\mathbf{r} + 2\mathbf{i}, 2\mathbf{r} + 1\mathbf{i})} \\ 2\mathbf{r} + 1\mathbf{i}) \\ \frac{0.2-5.15 \text{ TeV}}{0.5-2.9 \text{ TeV}} 1911.03947 (2\mathbf{j})} \\ 0.2-4.6 \text{ TeV}} 2103.02708 (2\mathbf{e}, 2\mathbf{\mu}) \\ 0.2-5.5 \text{ TeV}} 2205.06709 (\mathbf{e}\mathbf{r}) \\ 0.2-4.1 \text{ TeV}} 2205.06709 (\mathbf{e}\mathbf{r}) \\ 0.2-4.1 \text{ TeV}} 2205.06709 (\mathbf{e}\mathbf{r}) \\ 0.2-5.7 \text{ TeV}} 1911.03947 (2\mathbf{j}) \\ \end{array}$
creating interval ( <i>qg</i> ), $h = m_q$ cited light quark ( <i>qg</i> ), $h = f = f' = 1, h = m_q^*$ cited b quark, $f_S = f = f' = 1, h = m_q^*$ cited electron, $f_S = f = f' = 1, h = m_{\mu}^*$ SM, $ V_{ell} ^2 = 1.0,  V_{ell} ^2 = 1.0$ SM, $ V_{ell} ^2 = 1.0,  V_{ell} ^2 = 1.0$ SM, $ V_{ell} ^2 = 1.0,  V_{ell} ^2 +  V_{\mu n} ^2$ = 1.0 SM, $ V_{ell}V_{\mu n}^* ^2/( V_{ell} ^2 +  V_{\mu n} ^2) = 1.0$ ve-III seesaw heavy fermions, Flavor-democratic ttor like taus, Doublet ttor like taus, Singlet , narrow resonance, $\varepsilon^2 = 8 \times 10^{-6}$ (90% C.L.) , narrow resonance, $\varepsilon^2 = 7 \times 10^{-7}$ (90% C.L.) , narrow resonance, $\varepsilon^2 = 7 \times 10^{-7}$ (90% C.L.) , narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) M Z'( <i>U</i> ) M Z'( <i>U</i> ) M Z'( <i>q</i> $\ddot{q}$ ) $q\ddot{q}$ ) perstring $Z'_{\psi}$ / Z', BR(e $\mu$ ) = 10% / Z', BR(e $\mu$ ) = 10% / Z', BR( $\mu$ ) = 10% / W'( <i>t</i> $\nu$ ) hophobic Z' M W <sub>1</sub> ( $\mu$ M <sub>R</sub> ), $M_{H_R} = 0.5M_{W_R}$	M M M M M M M M M M M M M M M M M M M	0.001-124 Te 0.001-124 Te 0.001-124 Te 0.02- 0.1-0.98 TeV 2202 0.1-0.98 TeV 2202 0.1-0.98 TeV 2202 0.1-1.045 TeV 2202 0.125-0.15 TeV 2202.08676 (3 <i>I</i> , ≥ 4 <i>I</i> , 1 <b>x</b> + 3 <i>I</i> , 2 <b>x</b> + 2 <i>I</i> , 3 <b>x</b> + 1 <i>I</i> , 1 <b>x</b> + 2 <i>I</i> , 0.0115-0.075 TeV 1912.04776 (2µ) 0.011-0.2 TeV 1912.04776 (2µ) 0.01-0.125 TeV 1912.04776 (2µ) 0.01-0.125 TeV 1905.10331 (1j, 1γ) 0.05-0.45 TeV 1909.04114 (2j)	$\frac{1-22 \text{ TeV} (\text{MS-PAS-EXO-20-012 } (\mathbf{y} + \mathbf{j})}{0.25-3.9 \text{ TeV}} 1811.03052 (\mathbf{y} + 2\mathbf{e})} \\ 0.25-3.8 \text{ TeV}} 1811.03052 (\mathbf{y} + 2\mathbf{\mu})}$ $\frac{1}{9} 1802.02965; 1806.10905 (3\boldsymbol{\mu}; \ge 1\mathbf{j} + 2\boldsymbol{\mu})}{11.6 \text{ TeV}} 1806.10905 (3\boldsymbol{\mu}; \ge 1\mathbf{j} + 2\mathbf{e})} \\ \frac{1}{1.6 \text{ TeV}} 1806.0905 (3\boldsymbol{\mu}; \ge 1\mathbf{j} + 2\mathbf{e})}{11.6 \text{ TeV}} 1806.0905 (3\boldsymbol{\mu}; \ge 1\mathbf{j} + 2\mathbf{e})} \\ \frac{1}{1.6 \text{ TeV}} 1806.0905 (\ge 1\mathbf{j} + \boldsymbol{\mu} + \mathbf{e})}{10.8 676 (3\boldsymbol{\ell}, \ge 4\boldsymbol{\ell}, 1\mathbf{T} + 3\boldsymbol{\ell}, 2\mathbf{T} + 2\boldsymbol{\ell}, 3\mathbf{T} + 1\boldsymbol{\ell}, 1\mathbf{T} + 2\boldsymbol{\ell}, 2\mathbf{T} + 1\boldsymbol{\ell})} \\ 20.8 676 (3\boldsymbol{\ell}, \ge 4\boldsymbol{\ell}, 1\mathbf{T} + 3\boldsymbol{\ell}, 2\mathbf{T} + 2\boldsymbol{\ell}, 3\mathbf{T} + 1\boldsymbol{\ell}, 1\mathbf{T} + 2\boldsymbol{\ell}, 2\mathbf{T} + 1\boldsymbol{\ell})} \\ 20.8 676 (3\boldsymbol{\ell}, \ge 4\boldsymbol{\ell}, 1\mathbf{T} + 3\boldsymbol{\ell}, 2\mathbf{T} + 2\boldsymbol{\ell}, 3\mathbf{T} + 1\boldsymbol{\ell}, 1\mathbf{T} + 2\boldsymbol{\ell}, 2\mathbf{T} + 1\boldsymbol{\ell}) \\ 22.7 + 1\boldsymbol{\ell}) \\ \frac{0.2-5 \text{ TeV}}{0.5-2.9 \text{ TeV}} 1911.03947 (2\mathbf{j})} \\ 0.2-4.3 \text{ TeV}} 2205.06709 (\mathbf{e}\mathbf{T}) \\ 0.2-4.3 \text{ TeV}} 2205.06709 (\mathbf{e}\mathbf{T}) \\ 0.2-4.1 \text{ TeV}} 2205.06709 (\mathbf{e}\mathbf{T}) \\ 0.4-5.7 \text{ TeV}} 2202.06075 (\boldsymbol{\ell} + \mathbf{p}_{\mathbf{T}}^{\text{true}}) \\ \frac{0.5-3.6 \text{ TeV}}{0.2112.03947 (2\mathbf{j})} \\ \frac{0.5-3.6 \text{ TeV}}{0.2112.03947 (2\mathbf{j})} \\ \frac{0.5-3.6 \text{ TeV}}{0.2112.03947 (2\mathbf{j})} \\ \frac{0.5-3.6 \text{ TeV}}{0.2112.03949 (2\mathbf{\mu} + 2\mathbf{j})} \\ \end{array}$
cred right quark (qg), $h = m_q$ cited light quark (qy), $f_s = f = f' = 1, A = m_q^*$ cited b quark, $f_s = f = f' = 1, A = m_q^*$ cited electron, $f_s = f = f' = 1, A = m_\mu^*$ SM, $ V_{ev} ^2 = 1.0,  V_{ev} ^2 = 1.0$ SM, $ V_{ev} V_{\mu n} ^2 = 1.0,  V_{ev} ^2 = 1.0$ SM, $ V_{ev} V_{\mu n} ^2 / ( V_{ev} ^2 +  V_{\mu n} ^2) = 1.0$ ve-III seesaw heavy fermions, Flavor-democratic ctor like taus, Doublet tor like taus, Singlet , narrow resonance, $\varepsilon^2 = 8 \times 10^{-6}$ (90% C.L.) , narrow resonance, $\varepsilon^2 = 4 \times 10^{-3}$ (90% C.L.) , narrow resonance, $\varepsilon^2 = 7 \times 10^{-7}$ (90% C.L.) , narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) M Z'( $U$ ) M Z'( $U$ ) M Z'( $q\dot{q}$ ) q $\dot{q}$ ) perstring Z' <sub>0</sub> / Z', BR(e $\mu$ ) = 10% / Z', BR(e $\mu$ ) = 10% / Z', BR( $\mu$ ) = 10% / Z', BR( $\mu$ ) = 10% / W'( $t\nu$ ) xophobic Z' M W'( $t\nu$ ) M W <sub>1</sub> ( $\mu$ M <sub>R</sub> ), $M_{N_R} = 0.5M_{W_R}$ M W'( $t\nu$ )	M M M M M M M M M M M M M M M M M M M	0.001-124 Te 0.001-124 Te 0.001-1.4 0.02- 0.1-0.98 TeV 2202 0.1-1.045 TeV 2202 0.125-0.15 TeV 2202.08676 (3 <i>I</i> , ≥ 4 <i>I</i> , 1T + 3 <i>I</i> , 2T + 2 <i>I</i> , 3T + 1 <i>I</i> , 1T + 2 <i>I</i> , 0.0115-0.075 TeV 1912.04 776 (2µ) 0.011-0.2 TeV 1912.04776 (2µ) 0.01-0.125 TeV 1912.04776 (2µ) 0.01-0.125 TeV 1905.10331 (1j, 1γ) 0.05-0.45 TeV 1909.04114 (2j)	$\frac{1-2.2 \text{ TeV} (CMS-PAS-EXO-20-012 (y + j)}{0.25-3.9 \text{ TeV} 1811.03052 (y + 2e)}{0.25-3.8 \text{ TeV} 1811.03052 (y + 2e)}$ $\frac{1}{0.25-3.8 \text{ TeV} 1811.03052 (y + 2e)}{1.6 \text{ TeV} 1802.02965; 1806.10905 (3e; \geq 1j + 2e)}{1.6 \text{ TeV} 1802.02965; 1806.10905 (3e; \geq 1j + 2e)}{1.6 \text{ TeV} 1806.10905 (\geq 1j + \mu + e)}{0.86676 (3t, \geq 4t, 1\tau + 3t, 2\tau + 2t, 3\tau + 1t, 1\tau + 2t, 2\tau + 1t)}{22.08676 (3t, \geq 4t, 1\tau + 3t, 2\tau + 2t, 3\tau + 1t, 1\tau + 2t, 2\tau + 1t)}{22.7 + 1t})\frac{0.2-5.15 \text{ TeV} 2103.02708 (2e, 2\mu)}{0.5-2.9 \text{ TeV} 1911.03947 (2j)}\frac{0.2-4.6 \text{ TeV} 2103.02708 (2e, 2\mu)}{0.2-4.3 \text{ TeV} 2205.06709 (e\mu)}0.2-4.1 \text{ TeV} 2205.06709 (e\tau)0.4-5.7 \text{ TeV} 2202.06075 (t + p_{T}^{\text{sten}})\frac{0.5-3.6 \text{ TeV} 1911.03947 (2j)}{2122.03949 (2\mu + 2j)}0.5-4.8 \text{ TeV} 2122.12604 (\tau + p_{T}^{\text{sten}})$
In the origin quark (qg), $\Lambda = m_q^{-1}$ is cited light quark (qq), $f_s = f = f' = 1$ , $\Lambda = m_q^{+1}$ is cited b quark, $f_s = f = f' = 1$ , $\Lambda = m_q^{+1}$ is cited electron, $f_s = f = f' = 1$ , $\Lambda = m_q^{+1}$ (SM, $ V_{ell} ^2 = 1.0$ , $ V_{ell} ^2 = 1.0$ (SM, $ V_{ell} ^2 = 1.0$ , $ V_{ell} ^2 = 1.0$ (SM, $ V_{ell}V_{ell} ^2 / ( V_{ell} ^2 +  V_{ell} ^2) = 1.0$ pe-III seesaw heavy fermions, Flavor-democratic ctor like taus, Doublet ctor like taus, Singlet i, narrow resonance, $\varepsilon^2 = 8 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 4 \times 10^{-3}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i, narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) i,	M M M M M M M M M M M M M M M M M M M	AS-EXO-21-005 (2μ) 0.01-0.125 TeV 1905.10331 (1j, 1γ) 0.01-0.125 TeV 1905.10331 (1j, 1γ) 0.01-0.125 TeV 1905.10331 (1j, 1γ) 0.01-0.125 TeV 1905.10331 (1j, 1γ) 0.01-0.125 TeV 1905.10331 (1j, 1γ) 0.05-0.45 TeV 1909.04114 (2j)	$\frac{1-22 \text{ TeV} (CMS-PAS-EXO-20-012 (y + j)}{0.25-3.9 \text{ TeV} 1811.03052 (y + 2e)}{0.25-3.8 \text{ TeV} 1811.03052 (y + 2e)}$ $\frac{1}{0.25-3.8 \text{ TeV} 1811.03052 (y + 2\mu)}$ $\frac{1}{0.25-3.8 \text{ TeV} 1806.10905 (3\mu; \ge 1j + 2\mu)}{1.6 \text{ TeV} 1802.02965; 1806.10905 (3e; \ge 1j + 2e)}{1.6 \text{ TeV} 1802.02965; 1806.10905 (3e; \ge 1j + 2e)}{1.6 \text{ TeV} 1806.05065 (2e; ≥1j + 4e)}$ $\frac{0.8676 (3t, \ge 4t, 1\tau + 3t, 2\tau + 2t, 3\tau + 1t, 1\tau + 2t, 2\tau + 1t)}{22.08676 (3t, \ge 4t, 1\tau + 3t, 2\tau + 2t, 3\tau + 1t, 1\tau + 2t, 2\tau + 1t)}$ $\frac{0.2-5.15 \text{ TeV} 2103.02708 (2e, 2\mu)}{0.5-2.9 \text{ TeV} 1911.03947 (2j)}$ $\frac{0.2-4.6 \text{ TeV} 2103.02708 (2e, 2\mu)}{0.2-4.1 \text{ TeV} 2205.06709 (e\tau)}$ $\frac{0.2-4.1 \text{ TeV} 2205.06709 (e\tau)}{0.4-5.7 \text{ TeV} 2202.06075 (t + p_{T}^{min})}$ $\frac{0.5-3.6 \text{ TeV} 1911.03947 (2j)}{(5 \text{ TeV} 2112.03949 (2\mu + 2j))}$ $\frac{0.6-4.8 \text{ TeV} 2212.12604 (\tau + p_{T}^{min})}{(4.7 \text{ TeV} 2112.03949 (2e + 2j)}$
Creating the quark (qg), $N = m_q$ cited light quark (qy), $f_s = f = f' = 1, \Lambda = m_q^*$ cited b quark, $f_s = f = f' = 1, \Lambda = m_q^*$ cited electron, $f_s = f = f' = 1, \Lambda = m_q^*$ cited muon, $f_s = f = f' = 1, \Lambda = m_q^*$ ISM, $ V_{ev} ^2 = 1.0,  V_{ev} ^2 = 1.0$ ISM, $ V_{ev} V_{ev}^{\dagger} ^2  ( V_{ev} ^2 +  V_{ev} ^2) = 1.0$ se-III seesaw heavy fermions, Flavor-democratic thor like taus, Doublet thor like taus, Singlet , narrow resonance, $\varepsilon^2 = 8 \times 10^{-6}$ (90% C.L.) , narrow resonance, $\varepsilon^2 = 7 \times 10^{-7}$ (90% C.L.) , narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) , narrow resonance, $\varepsilon^2 = 3 \times 10^{-6}$ (90% C.L.) M Z'( $t$ ) M W( $t$ ) thore is the taus of tau	M M M M M M M M M M M M M M M M M M M	0.001-124 Te 0.001-124 Te 0.001-124 Te 0.001-124 Te 0.001-0.98 Te¥ 2002 0.1-0.098 Te¥ 2002 0.1-0.098 Te¥ 2002.08676 (3 <i>t</i> , ≥ 4 <i>t</i> , 1 <b>T</b> + 3 <i>t</i> , 2 <b>T</b> + 2 <i>t</i> , 3 <b>T</b> + 1 <i>t</i> , 1 <b>T</b> + 2 <i>t</i> , 0.0115-0.075 Te¥ 1912.04 776 (2µ) 0.11-0.2 Te¥ 1912.04 776 (2µ) 0.01-0.125 Te¥ 1912.04 776 (2µ) 0.01-0.125 Te¥ 1905.10331 (1j, 1γ) 0.05-0.45 Te¥ 1909.04114 (2j)	$\frac{1-2.2 \text{ TeV} (\text{CMS-PAS-EXO-20-012 } (\mathbf{y} + \mathbf{j})}{0.25-3.9 \text{ TeV} 1811.03052 } (\mathbf{y} + 2\mathbf{e})}{0.25-3.8 \text{ TeV} 1811.03052 } (\mathbf{y} + 2\mathbf{\mu})}$ $\frac{1802.02965; 1806.10905 (3\mathbf{\mu}; \ge 1\mathbf{j} + 2\mathbf{\mu})}{1802.02965; 1806.10905 (3\mathbf{e}; \ge 1\mathbf{j} + 2\mathbf{e})}$ $\frac{1.6 \text{ TeV} 1802.02965; 1806.10905 (3\mathbf{e}; \ge 1\mathbf{j} + 2\mathbf{e})}{1.6 \text{ TeV} 1802.02965; 1806.10905 (3\mathbf{e}; \ge 1\mathbf{j} + 2\mathbf{e})}$ $\frac{1.6 \text{ TeV} 1806.10905 (\ge 1\mathbf{j} + \mathbf{\mu} + \mathbf{e})}{0.8676 } (3t, \ge 4t, 1\mathbf{r} + 3t, 2\mathbf{r} + 2t, 3\mathbf{r} + 1t, 1\mathbf{r} + 2t, 2\mathbf{r} + 1t)}{22.08676 } (3t, \ge 4t, 1\mathbf{r} + 3t, 2\mathbf{r} + 2t, 3\mathbf{r} + 1t, 1\mathbf{r} + 2t, 2\mathbf{r} + 1t)}$ $\frac{0.2-5.15 \text{ TeV} 2103.02708 } (2\mathbf{e}, 2\mathbf{\mu})}{0.5-2.9 \text{ TeV} 1911.03947 } (2\mathbf{j})}$ $\frac{0.2-4.3 \text{ TeV} 2205.06709 } (\mathbf{e}\mathbf{r})}{0.2-4.1 \text{ TeV} 2205.06709 } (\mathbf{e}\mathbf{r})}$ $0.2-4.3 \text{ TeV} 2205.06709 } (\mathbf{e}\mathbf{r})$ $0.5-3.6 \text{ TeV} 1911.03947 } (2\mathbf{j})$ $\frac{0.5-3.6 \text{ TeV} 1911.03947 } (2\mathbf{j})}{(5-3.6 \text{ TeV} 2112.03949 } (2\mathbf{\mu} + 2\mathbf{j})}$ $0.6-4.8 \text{ TeV} 2212.12604 } (\mathbf{r} + \mathbf{p}_{\mathbf{r}}^{\text{rtw}})$ $\frac{4.7 \text{ TeV} 2112.03949 } (2\mathbf{r} + 2\mathbf{j})}{(3.5 \text{ TeV} 1811.00806 } (2\mathbf{r} + 2\mathbf{j})}$

Mass Scale [TeV]

### EXO Results

#### Trigger

- muons,
- electrons,
- photons  $\rightarrow$  helps for very high energy electrons
- jets  $\rightarrow +8\%$  efficiency,

### Selections

- isolation requirements  $(I_{mini}) \rightarrow$  reduce number of leptons from hadronic decays,
- events with additional  $e/\mu$  discarded  $\rightarrow$  reduce the background,
- $p_T^{miss} > 120 \text{ GeV} \rightarrow \text{suppress QCD background}$ ,
- AK4 jets:  $\geq$ 2 required (>300 GeV and >150 GeV):
  - for top quark and W' candidates,
  - jet ID with DeepJet to reduce light quark an gluon jets,
- AK8 jets:  $\geq$ 2 required:
  - for loose selection,
  - veto hadronic tops from SM backgrounds.

number of b-jets	jet <sub>top</sub> b-tagged	jetw <sup>,</sup> b-tagged	la			
0	X	X	F			
Signal-enriched regions						
1	$\checkmark$	Х				
1	Х	$\checkmark$	F			
≥2	$\checkmark$	$\checkmark$	F			

$$I_{\text{mini}} = \frac{\Sigma_I(R)}{p_T^{lep}}, \text{ with } R = \frac{10 \text{ GeV}}{\min(\max(p_T^{lep}, 50 \text{ GeV}), 200 \text{ GeV})}$$









#### **Regions definition**

- regions: depending on which selected W' and t jets are b-tagged,
- subregions based on:
  - $m_{SD,AK8}$  of the AK8 jet with smallest  $\Delta R(jet_{W'}, jet_{AK8})$ . Soft-drop declustering removes soft wide-angle radiation from a jet,
  - the mass of the reconstructed top quark m<sub>top</sub>.

#### Background estimation

- distribution of background extracted from data,
- overall shape and normalization found from control regions,
- simulation used to determine transfer functions to signal regions,
- function fitted:  $a \cdot \exp(b \cdot m_{W'}) + c \cdot m_{W'} + d$ ,
- statistical uncertainty of the fit propagated to the prediction,
- some regions used to estimate systematic effects (differences in m<sub>W</sub> spectra due to selections, or different background composition).

B2G-20-012









B2G-20-012











### B2G-20-012

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#### Trigger

- ≥1 muon,
- $\geq$  2 electron,
- photons



### Heavy tW search

B2G-20-010

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![](_page_45_Picture_9.jpeg)

![](_page_46_Figure_0.jpeg)

## Heavy tW search

B2G-20-010

![](_page_46_Figure_3.jpeg)

![](_page_46_Figure_4.jpeg)

![](_page_46_Figure_5.jpeg)

![](_page_46_Picture_8.jpeg)

W

![](_page_47_Figure_0.jpeg)

Data/Bkg

Data/Bkg

Data/Bkg.

![](_page_47_Picture_6.jpeg)

![](_page_48_Figure_0.jpeg)

![](_page_48_Figure_1.jpeg)

# Heavy tW search

### B2G-21-005

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![](_page_48_Picture_6.jpeg)

#### Signal/control regions

- dominant backgrounds: QCD & tt,
- QCD from data: ABCD method, several CRs, simultaneous maximum-likelihood fit with the SRs,
- tt determined from simulation:

  - W tagging requirement  $\rightarrow$  t tagging requirement on AK8 jets,
  - QCD background in tt CR small  $\rightarrow$  taken from simulation,
- minor backgrounds from W+jets, diboson, top + W  $\rightarrow$  shape from simulation, yields through nuisance paramaters in the fit.

![](_page_49_Picture_9.jpeg)

• tt-enriched CR used to constrain the uncertainties in the tt normalization and shape of the tt background in the m<sub>tw</sub> distribution,

![](_page_49_Picture_15.jpeg)

![](_page_49_Picture_16.jpeg)

![](_page_50_Figure_1.jpeg)

![](_page_50_Picture_4.jpeg)

![](_page_50_Picture_7.jpeg)

### OW-MASS DIMUON ٧G

![](_page_51_Figure_1.jpeg)

C	V
	ί

Effect	$m_{\mu\mu}$ < 2.6 GeV	$m_{\mu\mu} > 4.2 \text{ GeV}$
Integrated luminosity	2.3–2.5%	
Mass resolution	20%	
Trigger efficiency	1–20%	
Muon ID efficiency	4–9%	12–20%
Vertex selection	—	3%
Efficiency application	8%	4%
D meson normalization TFs	20–25%	—

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![](_page_51_Picture_6.jpeg)

![](_page_51_Figure_7.jpeg)

# INELASTIC DIV

#### Trigger

• triggering on MET (muons too soft)

### Backgrounds

- QCD (suppressed with Njets  $\leq$  2 requirement)
- top (suppressed by b-jets veto)
- W+jets

![](_page_52_Figure_7.jpeg)

### EXO-20-010

![](_page_52_Picture_11.jpeg)

![](_page_53_Figure_1.jpeg)

EXO-21-012

![](_page_53_Picture_5.jpeg)

![](_page_53_Picture_6.jpeg)

![](_page_53_Picture_7.jpeg)

![](_page_53_Picture_8.jpeg)

![](_page_53_Picture_9.jpeg)

![](_page_53_Picture_10.jpeg)

![](_page_53_Picture_11.jpeg)

![](_page_53_Picture_12.jpeg)

![](_page_54_Figure_1.jpeg)

![](_page_54_Picture_2.jpeg)

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### Signal/control regions

- normalization of background from observed CRs.
- main backgrounds:
  - WW & DY (di-leptonic channel),
  - W+jets (semi-leptonic channel),
  - tW & tt (both),
- one independent CR for each process:
  - tW and tt enriched region  $\rightarrow$  reversing requirement on the number of b-tagged jets,
  - W+W-  $\rightarrow$  reversing the  $\Delta R_{\parallel}$ :  $\Delta R_{\parallel} > 2.5$ ,
  - Drell-Yan  $\rightarrow$  inverting the m<sub>T</sub><sup>mll,pTmiss</sup>: m<sub>T</sub><sup>mll,pTmiss</sup> <50GeV,
  - W + jets  $\rightarrow$  inverting the m<sub>ii</sub>: m<sub>ii</sub> < 65 GeV or mjj > 105 GeV,
- yields in CRs fitted simultaneously with SRs, background normalizations float freely.

![](_page_55_Picture_13.jpeg)

### INELASTIC DM

- first search for inelastic DM at a hadron collider
  - $\geq 2$  DM states  $\chi_1 \& \chi_2 + \text{dark photon A' with } \epsilon$  mixing
- small  $\Delta = m_2 m_1 \in [10, 40\%] m_1$ :
  - long lived (easier to distinguish from backgrounds)
  - Iow selection efficiency (even 10-4 for low mass/large displacement)
  - large predicted **cross sections** (≈a few fb)
  - low  $p_T$ , low  $\Delta R$  muons
- pT<sup>miss</sup> collimated with displaced muons

![](_page_56_Figure_9.jpeg)

#### Analysis details

- backgrounds: QCD, single top, W+jets
- signal regions: depending on di-muon displacement
- control region: >2 jets
- cosmic muons rejected by  $\Delta R < 0.9$

![](_page_56_Picture_17.jpeg)

### Search for inelastic dark matter in events with two displaced muons and missing transverse momentum

![](_page_57_Figure_1.jpeg)

- muon system only,
- cosmic muons algorithm for track seeding,
- efficient for large displacement, up to a few meters,
- small displacement muons replaced by standard PF algorithm,
- signal regions defined by number of dSA muons replaced by PF muons.

#### Results

- ABCD method: min-d<sub>xy</sub> vs. relative isolation  $I_{PF}$  or  $\Delta \phi_{\mu\mu}^{MET}$ ,
- data consistent with the SM prediction,
- limits in interaction strength y vs. m<sub>1</sub>,
- sensitivity at  $m_1 = 30 \text{ GeV} \rightarrow m_{A'} = 90 \text{ GeV}$  increased due to kinetic mixing between A' and Z boson.

EXO-20-010

Specialized displaced standalone (dSA) muon reconstruction

![](_page_57_Figure_16.jpeg)

![](_page_57_Figure_19.jpeg)

![](_page_57_Figure_20.jpeg)

![](_page_57_Figure_21.jpeg)