## THE ROYAL SOCIETY



# Pushing the precision frontier at the LHC

## Sarah Alam Malik University College London







## CMS measurement : 523 $\pm$ 16 MeV

First precise measurement of invisible Z decays at a hadron collider

# CMS measurement : 523 ±16 MeV

Source of systematic uncertainty	Uncertainty (%)
Muon identification efficiency (syst.)	2.1
Jet energy scale	1.8–1.9
Electron identification efficiency (syst.)	1.6
Electron identification efficiency (stat.)	1.0
Pileup	0.9–1.0
Electron trigger efficiency	0.7
$\tau_h$ veto efficiency	0.6–0.7
$p_{\rm T}^{\rm miss}$ trigger efficiency (jets plus $p_{\rm T}^{\rm miss}$ region)	>0.7
$p_{\rm T}^{\rm miss}$ trigger efficiency (Z/ $\gamma^* \rightarrow \mu\mu$ region)	0.6
Boson $p_{\rm T}$ dependence of QCD corrections	0.5
Jet energy resolution °	0.3–0.5
$p_{\rm T}^{\rm miss}$ trigger efficiency ( $\mu$ +jets region)	0.4
Muon identification efficiency (stat.)	0.3
Electron reconstruction efficiency (syst.)	0.3
Boson $p_{\rm T}$ dependence of EW corrections	0.3
PDFs	0.2
Renormalization/factorization scale	0.2
Electron reconstruction efficiency (stat.)	0.2
Overall	3.2

#### Z invisible decays at LEP collider

Large Electron Positron collider: Highest energy electron-positron collider ever built (1989 - 2000)



- LEP legacy: properties of the Z boson measured to <u>unprecedented</u> precision
- Direct and indirect measurement of Z boson invisible decays, indirect measurement used to deduce <u>three</u> species of light neutrinos



#### Z invisible decays at LEP collider

Large Electron Positron collider: Highest energy electron-positron collider ever built (1989 - 2000)



## LEP combined direct measurement : 503 $\pm$ 16 MeV

# CMS measurement : 523 $\pm$ 16 MeV LEP combined measurement : 503 $\pm$ 16 MeV

# CMS measurement : 523 $\pm$ 16 MeV LEP combined measurement : 503 $\pm$ 16 MeV

## Standard Model : 501.44 $\pm$ 0.04 MeV

# CMS measurement : 523 $\pm$ 16 MeV LEP combined measurement : 503 $\pm$ 16 MeV

## Standard Model : 501.44 $\pm$ 0.04 MeV

CMS result : Single most precise direct measurement in the world

## Dark matter and dark energy at the LHC: from the very big to the very small

Michaela Queitsch-Maitland University of Manchester



#### **Content of the Universe**





#### Top quark









Mass [GeV/c<sup>2</sup>]

**Gold atom** 





![](_page_21_Picture_0.jpeg)

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PUBLISHED: May 23, 2019

Constraints on mediator-based dark matter and scalar dark energy models using  $\sqrt{s}=13$  TeV pp collision data collected by the ATLAS detector

![](_page_21_Picture_4.jpeg)

The ATLAS collaboration

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ABSTRACT: Constraints on selected mediator-based dark matter models and a scalar dark energy model using up to 7 Hr $^{-1}$ , 92 = 13 KeV pp collision data collected by the ATLAS detector at the LHC during 2015–2016 are summarised in this paper. The results of performed assexhes in a variety of Hm states are interpreted in terms of a set of spin-1 and spin-0 simple-mediator dark matter simplified models and a second set of models involving an extended Higgs sector pulse and ditional vector or peusob-scalar mediator. The searches considered in this paper constrain spin-1 leptopholic and hypophilic mediators, embedded in extended Higgs sector pulse mediator are low  $\zeta = 5$  ReV pp collision data eucle of the interpretation of the result. The results are also interpreted for the first time in terms of light scalar particles that could contribute to the accelerating expansion of the universe (dark energy).

KEYWORDS: Dark matter, Hadron-Hadron scattering (experiments)

ARXIV EPRINT: 1903.01400

OPEN ACCESS, Copyright CERN, for the benefit of the ATLAS Collaboration. Article funded by SCOAP<sup>3</sup>. https://doi.org/10.1007/JHEP05(2019)142

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![](_page_22_Picture_0.jpeg)

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KEYWORDS: Dark matter, Hadron-Hadron scattering (experiments)

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![](_page_22_Figure_9.jpeg)

https://doi.org/10.1007/JHEP05(2019)142

![](_page_22_Figure_11.jpeg)

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												Searches for		NOLAN	EUROS AUGUSAS ALS	18-18-00 <sup>7</sup>	ark couplings in pp o	ollisions		Abread to Carrier	Search foi between A	r thavour-change in the top quart TLAS	ing new	- 44	CER (SC)
ATL	AS SUSY Sear	ches* -	95%	CL Lov	ver Limit	6						ATLAS Preliminary	nome		String resonance		CMS preliminary	overview of CN	15 EXO results		05-79 191	11 11 19 14 7 (2)	16	140 fb <sup>-1</sup>  13 TeV	eV) ] 137 fb'
March	odel	Sig	nature	∫£ dt [fb⁻	1	Mass	limit					Reference	Frans	į	Zymestiance Wymestiance Higgs ymestiance Geor Octool Scalar, ký = 1/2	6	7 7 7 7		_	035-4 17 032-235 1999 (119 05-27 1991)	12.03143 ( <b>2p + 3y; 2e + 3y</b> ) <b>3.5-8</b> 20 7 ( <b>3j + 3y</b> ) 8 9947 ( <b>2</b> j)	12)+341 100:10:000 (3)+341			36 fb <sup>-1</sup> 137 fb <sup>-1</sup> 36 fb <sup>-1</sup> 137 fb <sup>-1</sup>
$\tilde{q}\tilde{q}, \tilde{q}$	$\rightarrow q \tilde{t}_1^0$	0 e, µ 2 mono-jet 1	2-6 jets // 1-3 jets //	miss 139 miss 139 7 139				1.0 0.9	1	1.85	m(ž <sup>0</sup> )<400 GeV m(ž)-m(ž <sup>0</sup> )=5 GeV	2010.14293 2102.10874	tector		$ \begin{array}{l} \mbox{Scalar Diquark} \\ \mbox{$\vec{\pi}$+$\phi$, provides: star (scalar), $g^1_{\mu\nu}$ $\times$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$	= 0.03(0.004) # = 0.03(0.004) #	8 8 8 9 1011.04968134, #40	238-034 2911.00968 ( <b>3</b> 8, 1	41)		03-73 1911	11947 (2g)			137 fb <sup>-1</sup> 137 fb <sup>-1</sup> 137 fb <sup>-1</sup>
88, 8	$\rightarrow q\bar{q}\bar{\chi}_{1}^{0}$	0 <i>e</i> ,µ 2	2-6 jets 1	<sup>miss</sup> 139	Ř Ř			Forbidden	1.15	2.3 5-1.95	$m(\tilde{t}_1^0)=0 \text{ GeV}$ $m(\tilde{t}_1^0)=1000 \text{ GeV}$	2010.14293 2010.14293	ation	Contract	quark compositioness IM. quark = 1 quark compositioness IM. quark = -1 Excited Lepton Contact Interaction	Kun Kun W					02-56 2001 04521 (2e+	- 2)	<24 2103.02708 (21) 438 210	3.02708 (24)	140 fb <sup>-1</sup> 140 fb <sup>-1</sup> 77 fb <sup>-1</sup>
88, 8 88, 8	$\rightarrow q\bar{q}WX_1^{\alpha}$ $\rightarrow q\bar{q}(\ell\ell)\bar{X}_1^{\alpha}$	1 e,μ 2 ee,μμ	2 jets /	139 7 139	8 8					2.2	m(21)<600 GeV m(21)<700 GeV	2101.01629 CERN-EP-2022-014			Weter mediator (pd), g <sub>1</sub> = 0.25, g <sub>20</sub> = 1, m <sub>1</sub> = 1 vector mediator (pd), g <sub>1</sub> = 0.25, g <sub>20</sub> = 1, m <sub>1</sub> = 1	и IGeV и Lei,>ITeV и	*	0.1	-07 2011.007411 # 30	2-1 82 2003 02 708 (2+, 2p)	02-52 ANTIH-SETTIN	+4			18 fb <sup>-1</sup> 140 fb <sup>-1</sup>
88.8	$\rightarrow q\bar{q}\bar{w}Z\bar{r}_{1}$ $\rightarrow t\bar{t}\bar{x}_{1}^{0}$	SS e,μ 0-1 e,μ	6 jets 3 h l	7 139 139 <sup>miss</sup> 79.8	ž ž			1	.15	2.25	m(t) <600 GeV m(t)-m(t)=200 GeV m(t)<200 GeV	1909.08457 ATLAS-CONF-2018-041	ANIS		(anal-herctor mediator (pd), g <sub>1</sub> = 0.25, g <sub>20</sub> = 1, (anal-herctor mediator (gg), g <sub>1</sub> = 0.25, g <sub>20</sub> = 1, (anal-herctor mediator (g), g <sub>2</sub> = 0.1, g <sub>20</sub> = 1, (anal-herctor mediator (g), g <sub>2</sub> = 0.1, g <sub>20</sub> = 1,	Lm,=10eV # Lm,=10eV # A=01.m,>m,,0 #			1	05-28 201102047 (2) <1.95 210712021 ( a kj + p(**) 02-4.6	a 2103.02709 (2+, 2y)				137 fb <sup>-1</sup> 101 fb <sup>-1</sup> 140 fb <sup>-1</sup>
h.h.		SS e.µ	6 jets	139 nis 139	Ř L				1.25		m(g)-m(t <sup>0</sup> )=300 GeV	1909.08457	"ATI	Card Man	$\label{eq:constant} \begin{array}{c} \mbox{transmit} \left\{ V_{1}(x_{1},y_{2},m,z_{2},y_{2},m,z,m,z) \\ \mbox{transmit} \left\{ V_{1}(x_{1},y_{2},m,z) \\ \mbox{transmit} \left\{ V_{2}(x_{1},y_{2},m,z) \right \\ transmi$	1 GeV # m,=1 GeV # m,=1 GeV #	л — лл	+0.47 2207 +0.3 190101553-00, 87 + m	-1.5 3021 ( # 1( + p(*)) 2( + p(*))	2307.13623(#3)+#7**)					101 fb <sup>-1</sup> 101 fb <sup>-1</sup> 36 fb <sup>-1</sup>
D b.b.	$\bar{h}_1 \rightarrow h \bar{\chi}_1^0 \rightarrow h h \bar{\chi}_1^0$	0 e. µ	6 <i>b</i> 1	7 139	b <sub>1</sub> Forbi	'den		0.68	.23-1.35	$\Delta m(\hat{x}_{1}^{0}, \hat{x}_{1}^{0})$	$10 \text{ GeV} < \Delta m(\tilde{b}_1, \tilde{k}_1^2) < 20 \text{ GeV}$ = 130 GeV, $m(\tilde{k}_1^2) = 100 \text{ GeV}$	2101.12527 1908.03122			complex ac. med. (dark QCD), $m_{min} = 5$ GeV, $c_m = 2$ 2 mediator (dark QCD), $m_{min} = 20$ GeV, $c_m = 0$ Baryonic 27, $g_{\mu} = 0.25$ , $g_{\mu\nu} = 1$ , $m_{\mu} = 1$ GeV 2 $Z = 2450$ M, $g_{\mu\nu} = 0.8$ , $g_{\mu\nu} = 1$ , and $\theta = 1$ , $m_{\mu} = 100$	τ <sub>hc</sub> = 25 mm # 0.3. a <sub>cere</sub> = a <sup>men</sup> <sub>tere</sub> # # 20.0eV #		_	<154 <16	1810 10099 (4) 1908 02713 (h + p(**) 0.5-13 2008 02723 (	<b>-51</b> 2112 11125 (2) + p7*	"			16 fb <sup>-1</sup> 138 fb <sup>-1</sup> 36 fb <sup>-1</sup>
iii.	$1 \rightarrow t \tilde{t}_1^0$	2τ 0-1 e,μ	2 b // ≥ 1 jet //	miss 139 7 139	b <sub>1</sub> ī <sub>1</sub>			0.13-0.85	1.25	$\Delta m(k_2^0, k$	$\tilde{\chi}_{1}^{0}$ ]=130 GeV, m( $\tilde{\ell}_{1}^{0}$ )=0 GeV m( $\tilde{\ell}_{1}^{0}$ )=1 GeV	2103.08189 2004.14060,2012.03799			Leptoquark mediator, $\beta = 1$ , $\delta = 0.1$ , $\delta_{e, pre} = 0$ . RPV stap to 6 quarks	1, 800 < M <sub>10</sub> < 1500 GeV W	-	0.3+05 0.05+0.52	181110151(3p+3j+p(**)) 08:03124(3p;4p)			-			36 fb <sup>-1</sup>
hin hin	$1 \rightarrow W b \tilde{V}_1^0$ $1 \rightarrow \tilde{\tau}_1 b v, \tilde{\tau}_1 \rightarrow \tau \tilde{G}$ $r_0^0$	1 e,μ 3 1-2 τ 2	jets/1 b I jets/1 b I	7 139 7 139 7 139	ī1 ī1		Forbidden 0	Forbidden	1.4		m( $\hat{t}_1^0$ )=500 GeV m( $\hat{t}_1$ )=800 GeV	2012.03799 2108.07665		ŝ	Rev oparies to 4 quarks RPV glaine to 4 quarks RPV glaines to 3 quarks	K K K	а я я	01	01-141 1 415	806.03.058.02ji 1810.10.092.04ji					38 fb <sup>-1</sup> 36 fb <sup>-1</sup>
5 hh.	$1 \rightarrow c K_1 / c c, c \rightarrow c K_1$ $\ldots c 0 = c 0 \dots c m c 0$	0 е. µ п 1.2 е. µ	nono-jet I	7 36.1 7 139	č 1,		0.55	0.85	1 10		m(t <sub>1</sub> )=0 GeV m(t <sub>1</sub> ,t)-m(t <sub>1</sub> )=5 GeV	1805.01649 2102.10874 2006.05880			ADD (p) H,Z, n <sub>10</sub> = 3 ADD (n <sub>2</sub> , M H,Z, n <sub>10</sub> = 3 ADD Gas emission, n <sub>2</sub> = 2 ADD Gas emission, n <sub>2</sub> = 2	* * *	7 7				-91	<pre>x12 1803 08030 (2)) 1812 10443 (2y, 20 x103 2107 13121 ( a 1j + p) 000 080 (2)</pre>			36 fb <sup>-1</sup> 36 fb <sup>-1</sup> 101 fb <sup>-1</sup>
111. 1212,	$1 \rightarrow \infty_2, \alpha_2 \rightarrow z_2/\alpha_1$ $1 \rightarrow \tilde{t}_1 + Z$	3 e,µ	16 1	miss 139	12 28.28		Forbidden	0.86		m( $\tilde{k}_{1}^{0}$ )=360	0 GeV, m(f <sub>1</sub> )-m( $\tilde{k}_{1}^{0}$ )= 40 GeV	2006.05880			ACD C014 (apl, no. +4 ACD C014 (apl, no. +4 ACD C014 (apl, no. +4 ACD C014 (apl, no. +4	ŝ					456 045-945-040-04-452 045-945-040-045-045-045-045-045-045-045-045-0	-014 (ep) 4 (et) (pt)			137 fb <sup>-1</sup> 137 fb <sup>-1</sup> 137 fb <sup>-1</sup>
X1X2 0*0*	via WZ	ee, µµ	≥ljet /	miss 139	$\frac{\chi_{1}^{-}/\chi_{2}^{-}}{\tilde{\chi}_{1}^{\pm}/\tilde{\chi}_{2}^{0}} = 0.20$		0.42	0.96		m(k	$m(\tilde{k}_1^n)=0$ , wino-bino $\tilde{k}_1^n)=m(\tilde{k}_1^n)=5$ GeV, wino-bino $m(\tilde{k}_1^n)=0$ mino bino	2106.01676, 2108.07586 1911.12606	20 11	1	8 Guilli ANG = 0.1 8 Guilli ANG = 0.1 8 Guilli ANG = 0.1 8 Guilli ANG = 0.1	* * *	я я я			41 1 65-26 19110343 (2)	78 2003 02 708 (2r) 809 00 327 (2y)				140 m <sup>-1</sup> 36 m <sup>-1</sup> 137 m <sup>-1</sup>
11/1 11/2 11/2 11/2	via Wh	Multiple (/jets 2 e, µ	1	7 139 7 139 miss 139	$\hat{\chi}_{1}^{\pm}/\hat{\chi}_{2}^{0}$ Forbidden $\hat{\chi}_{1}^{\pm}$		0.44	1.0	5		m(t <sup>2</sup> )=70 GeV, wino-bino m(t <sup>2</sup> )=70 GeV, wino-bino m(t <sup>2</sup> ,9)=0.5(m(t <sup>4</sup> )+m(t <sup>2</sup> ))	2004.10894, 2108.07586 1908.08215	in		$\label{eq:second} \begin{array}{l} \mbox{non-relating } B(-M_{c}=4\mbox{ TeV}, n_{\rm ini}=6\mbox{ split-LED}, \mu \simeq 2\mbox{ TeV} \\ \mbox{3.6 same INED} \mbox{g}_{\rm in}(\phi+\phi=gpg)(, g_{\rm ini}=6, g_{\rm ini}=6 \end{array}$	и и 30 3, г = 0.5, мартицац = 0.1 марти	2 20 21			84-28 2202.00075.01+ 2-4.3	97""1  2201.02.140 ( <b>2</b> g)	9.7 1805.06013 ( <b>2</b> .7)7. yli			36 fb <sup>-1</sup> 137 fb <sup>-1</sup> 137 fb <sup>-1</sup>
11, 1 1, 1	$\rightarrow \tau \tilde{\chi}_{1}^{0}$ 	2 T 2 e, µ	0 jets /	miss 139 miss 139	† (†L. † <sub>R.L</sub> ) 7	0.16-0.3 0.	12-0.39	0.7			$m(\tilde{t}_1^0)=0$ $m(\tilde{t}_1^0)=0$	1911.05660 1908.08215	ecay	3	excited light quark $\log t, \delta_i = f - f' = 1, \Lambda = m_i^2$ excited b gash, $\delta_i = f - f' = 1, \Lambda = m_i^2$ excited light quark light $\Lambda = m_i^2$	5	R			1711 04652 ( <b>y</b> + J)	1-5.5 1711.04652.1y+j	ai.			36 fb <sup>-1</sup> 36 fb <sup>-1</sup> 117 fb <sup>-1</sup>
ĤĤ,	$\bar{H} \rightarrow h\bar{G}/Z\bar{G}$	0 e, µ	≥ 1 jot 1 ≥ 3 b 1 0 inte 1	mins 36.1 fails 120	1 Ĥ 0.13	0.256	0.55	0.29-0.88			$m(\ell) \cdot m(\ell_1^{\circ}) = 10 \text{ GeV}$ $BR(\tilde{\ell}_1^{\circ} \rightarrow h\tilde{G}) = 1$ $DR(\tilde{\ell}_1^{\circ} \rightarrow h\tilde{G}) = 1$	1911.12606 1806.04030 2100.11694		8	excited electron, $f_1 = f = f = 1, A = m_1^2$ excited moon, $f_2 = f = f = 1, A = m_2^2$	ж ж	я я			025-3.9 141 025-3.8 141	11.03.052 ( <b>y + 2</b> e) 1.03052 ( <b>y + 2</b> e)				
		$0 e, \mu \ge 2$	large jets I	7 139 7 139	n İl		0.55	0.45-0.93			$BP(\tilde{x}_1^0 \rightarrow ZG)=1$ $BP(\tilde{x}_1^0 \rightarrow ZG)=1$	2108.07586		ş	WOR, [Car] = 1.0, [Car] = 1.0 WER, [Car], [Var], [Var] + [Car] = 1.0 Type II sease heavy femion, Tavar demon Vector like taus, Doublet	ndc R	л л л		01-1045 2202 065351	act covers, secent covers (ablg, eg. a by e a 1000 (1000) ( a bj + y + e) . a 4/) ht, a 4/)	NA 40				36 fb <sup>-1</sup> 36 fb <sup>-1</sup> 137 fb <sup>-1</sup> 137 fb <sup>-1</sup>
Direc	$t \tilde{x}_{1}^{*} \tilde{x}_{1}^{-}$ prod., long-lived $\tilde{x}_{1}^{*}$	Disapp. trk	1 jet 2	miss 139	$\frac{\tilde{x}_{1k}^{\pm}}{\tilde{x}_{1}^{\pm}}$ 0.3	1	(	0.66			Pure Wino Pure higgsino	2201.02472 2201.02472			Vector like taus, Singlet scalar 10 (pair prod.), coupling to 1" gen. form scalar 10 (pair prod.), coupling to 1" gen. form	nins, J=1 m	# 0125+035 2202.0917	5 (3t, a.4t)	<14 : <1.11	1011.01.107 (2e+2)) 11.107 (2e+2))					
Meta 22 2	e ğ H-hadron stable ğ R-hadron, ğ→qqΫ <sup>0</sup>	pixel dE/dx pixel dE/dx	E	miss 139 miss 139 miss 130				0.7		2.05	m( $\tilde{t}_1^0$ )=100 GeV	CERN-EP-2022-029 CERN-EP-2022-029 2011-07812	20.4	-	scalar 10 (pair prod.), coupling to 2 <sup>rd</sup> pen. New scalar 10 (pair prod.), coupling to 2 <sup>rd</sup> pen. New scalar 10 (pair prod.), coupling to 2 <sup>rd</sup> pen. New	miors, β = 1 # miors, β = 1 # miors, β = 0.5 #	а а а а а		<153 08-15 <129 368	$\begin{array}{c} 1808.05082(2\mu+2j)\\ 1811.10.151(2\mu+2j+\mu \zeta^{***})\\ 05082(2\mu+2j;\mu+2j+\mu \zeta^{***}) \end{array}$					36 fb <sup>-1</sup> 37 fb <sup>-1</sup> 36 fb <sup>-1</sup>
d	10	pixel dE/dx	1	7 139 7 139	Ť	0.34 0.3	5	0.7			$\tau(\vec{\ell}) = 0.1 \text{ ns}$ $\tau(\vec{\ell}) = 10 \text{ ns}$	2011.07812 CERN-EP-2022-029	8 8	3	Scalar LD (pair prof.), coupling to 3" gen. fem scalar LD (single prof.), coupling to 3" gen. fem scalar LD (single prof.), coupling to 3" gen. fem	mions, $\beta = 1$ w ermions, $\beta = 0, 3 = 1$ w ermions, $\beta = 1, 3 = 1$ w	2 X X		<1.02 1011.00006.02 3+1.0 +0.74 1000.03.072 (2v+b)	x+3) 2007.13022.(m3)+97**)					36 fb <sup>-1</sup> 101 fb <sup>-1</sup> 36 fb <sup>-1</sup>
<i>R</i> † <i>R</i> † <i>P</i> † <i>P</i> †	$ \tilde{\chi}_{1}^{0}, \tilde{\chi}_{1}^{\pm} \rightarrow Z \ell \rightarrow \ell \ell \ell$ $ \tilde{\chi}_{-}^{0} \rightarrow WW/Z \ell \ell \ell m$	3 e, µ 4 e, µ	0 jets /	139 miss 139	$\tilde{\chi}_{1}^{*}/\tilde{\chi}_{1}^{0}$ (BR(Zr)=1, $\tilde{\chi}_{1}^{*}/\tilde{\chi}_{1}^{0}$ ( $lm \neq 0, ln$ )	R[Ze]=1]	0.6	25 1.05	1.55		Pure Wino	2011.10543 2103.11684			Za, name resonance Za, name resonance SSN 2100	2	R 02115-0.075 2012:04776(2p) R 011-02 1	512 04 TT 6 (240		52. 	-5 25 2003 02 708 (2+, 2p)				137 fb <sup>-1</sup> 137 fb <sup>-1</sup> 140 fb <sup>-1</sup>
88.8 II. I-	$\rightarrow qq \tilde{\chi}_{1}^{0}, \tilde{\chi}_{1}^{0} \rightarrow qq q$ $s \tilde{\chi}_{1}^{0}, \tilde{\chi}_{1}^{0} \rightarrow tbs$	4-5 M	large jets Aultiple	36.1 36.1	ğ [m(ℓ <sup>0</sup> <sub>1</sub> )=200 GeV, Î [ℓ <sup>n</sup> <sub>131</sub> =2e-4, 1e-2]	1100 GeV]	0.55	1.05	1.3	1.9	Large $J_{112}^{\prime\prime}$ m( $\tilde{\lambda}_1^0$ )=200 GeV, bino-like	1804.03568 ATLAS-CONF-2018-003		1	21401 Superstring 2, UFV.2, RR(n) = 10%		и и и и и и и и и и и и и и и и и и и	1 <sub>V</sub> i		03-23 1111111111111	2113 12 708 (2+, 2y) 2-5 CH5-FAS-EX0-19-012	~			36 fb <sup>-1</sup> 140 fb <sup>-1</sup> 137 fb <sup>-1</sup>
$\tilde{t}_1, \tilde{t}$ $\tilde{t}_1\tilde{t}_1,$	$b\tilde{\chi}_{1}^{\pm}, \tilde{\chi}_{1}^{\pm} \rightarrow bbs$ $_{1} \rightarrow bs$	2 j	$\geq 4b$ ets + 2 b	139 36.7	$\tilde{I} = [qq, bi]$		Forbidden 0.42 0.6	0.95			m(τ <sub>1</sub> )=500 GeV	2010.01015 1710.07171		or Game Lo	LEV Z, BR(er) = 10% UV Z, BR(ar) = 10% Laptopholic Z'			0.65-0.85 2202.04	134 (2)	03-63 03-61 0	CHE-PRE-EXD 19-014 (pm) MS-PRE-EXD 19-014 (pm)				137 fb <sup>-1</sup> 137 fb <sup>-1</sup> 78 fb <sup>-1</sup>
1(1), 5* (5	$1 \rightarrow q\ell$ $0 \neq 0$ $(h = \delta^+, hh)$	2 e,μ 1 μ	2 b DV	36.1 136	$\frac{\hat{I}_1}{\hat{I}_1}$ [10-10< $\hat{J}'_{204}$ <1 $z^0$	-8, 3e-10< X <sub>231</sub> <3	e-9)	1.0	0.4-1.45		$BR(\vec{r}_1 \rightarrow br/b\mu) > 20\%$ $BR(\vec{r}_1 \rightarrow q\mu) = 100\%, cost) = 1$	1710.05544 2003.11956			2 55N 87161 55N 87161 55N 87161 185M W(((A)), Ma, = 0.5Mm,	ŝ	л Я Я Я	1		03-38 10110	84-52 2202.06075.0 + 2467 (2) -5 2112.00929 (2) + 2)	97"1			137 fb <sup>-1</sup> 137 fb <sup>-1</sup> 36 fb <sup>-1</sup>
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	OPEN ACCESS, Copyri for the benefit of the J Article funded by SCC	ight CERN, ATLAS Collabo DAP <sup>3</sup> .	eration.	htt	ps://doi.org/10.10	17/JHEP05(20)	9)142			unur E				a da a da a da a da a da a da a da a da	doubly cha tate sign are room 2.5 soar are room 2.5 soar 3.5 soar 3.5 soa 3.5 soa 3.5 soa 3.5 soa 3.5 soa 3.5 soa 3.5 soa 3.5 soa 3.5 soa 3.5 soa 3.5 soa 3.5 soa 3.5 soa 3.5 soa 3.5 soa 3.5 so	is study uses proton-proto- mass energy of 13 TeV, o nificant signal is observed set on the ratio of branc port to the $Z_{ch}^{i+} \rightarrow (Z_{c}^{i+}$ theses in the rapidity ran is to 25 GeV/c. The result result or $\Delta_{c}^{i} K \rightarrow A_{c}^{i} K$ is standard deviations are - Tables in energy.	oton collision data collected with the LHCs detects corresponding to a total integrated minimoity o well in the invariant-mass range of 3.4.3.8 GeV/ $\epsilon^{-1}$ , exclusing fractions multiplied by the production cross $\Xi_{1}^{+} \rightarrow \mu \kappa^{-1} \sigma^{-1}$ decay for different $\Xi_{2}^{-1}$ mass and gate from 2.0 to 4.5 and the transverse momentum links from this search are combined with a previous $K^{+}\sigma^{-1}$ decay mode, yielding a maximum bound $K^{+}\sigma^{-1}$ decay on $(3.25)MM/\epsilon^{0}$ , including system	or at a centre- f & dfb <sup>-1</sup> . No Upper limits section with d lifetime hy- m range from sly published significance of titic uncertain-	and a second sec					and	A State State
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