



LHC Searches for Exotic Phenomena



Çiğdem İşsever University of Oxford

Lincoln College



On the behalf of the ATLAS, CMS, LHCb Experiments ICFA 2017 Seminar Ottawa, Canada

Credits: Martino Borsato (Universidade de Santiago de Compostela), Koji Terashi (ICEPP, U of Tokyo), Steven Worm (U of Birmingham), Shahram Rahatlou (U of Rom)

What Characterizes Exotics Searches?

No unified parameter phase space No precise model to guide us **Standard Model:** Supersymmetry Searches: Predicted Higgs boson $\widetilde{t_{i}}\widetilde{t_{1}} \text{ production}, \widetilde{t_{1}} \rightarrow \text{ b f f' } \widetilde{\chi}_{1}^{0} / \widetilde{t_{1}} \rightarrow \text{ c } \widetilde{\chi}_{1}^{0} / \widetilde{t_{1}} \rightarrow \text{ W b } \widetilde{\chi}_{1}^{0} / \widetilde{t_{1}} \rightarrow \text{ t } \widetilde{\chi}_{1}^{0} \qquad \begin{array}{c} \text{Status: May 2017} \\ \hline \text{revised September 2017} \\ \hline \end{array}$ $\mathsf{m}_{\widetilde{\chi}_i^0}\left[\mathsf{GeV}\right]$ \$2000 **ATLAS** Preliminary CMS Preliminary 700 √s=13 TeV S/B Weighted Data $\tilde{t}_1 \rightarrow t \tilde{\chi}_1^0 / \tilde{t}_1 \rightarrow W b \tilde{\chi}_1^0$ 0L 36.1 fb⁻¹ [CONF-2017-020] ເງັ້1800 is = 7 TeV, L = 5.1 fb $\begin{array}{c} \overbrace{t}^{0} \overbrace{t} \rightarrow t \hspace{0.1cm} \widetilde{\chi}_{1}^{0} \hspace{0.1cm} / \hspace{0.1cm} \widetilde{t}_{1} \hspace{0.1cm} \rightarrow \hspace{0.1cm} W \hspace{0.1cm} b \hspace{0.1cm} \widetilde{\chi}_{1}^{0} \hspace{0.1cm} / \hspace{0.1cm} \widetilde{t}_{1} \hspace{0.1cm} \rightarrow \hspace{0.1cm} b \hspace{0.1cm} f \hspace{0.1cm} f \hspace{0.1cm} \widetilde{\chi}_{1}^{0} \\ \overbrace{t}^{0} \atop 1 \rightarrow t \hspace{0.1cm} \widetilde{\chi}_{1}^{0} \hspace{0.1cm} / \hspace{0.1cm} \widetilde{t}_{1} \hspace{0.1cm} \rightarrow \hspace{0.1cm} W \hspace{0.1cm} b \hspace{0.1cm} \widetilde{\chi}_{1}^{0} \hspace{0.1cm} / \hspace{0.1cm} \widetilde{t}_{1} \hspace{0.1cm} \rightarrow \hspace{0.1cm} b \hspace{0.1cm} f \hspace{0.1cm} f \hspace{0.1cm} \widetilde{\chi}_{1}^{0} \\ \end{array}$ 1L 36.1 fb⁻¹ [CONF-2017-037] Bkg Fit Component is = 8 TeV, L = 5.3 fb⁻¹ 61600 600 2L 36.1 fb⁻¹ [CONF-2017-034] Monojet 3.2 fb⁻¹ [1604.07773] 51400 s=8 TeV. 20 fb Run 1 [1506.08616] 500 All limits at 95% CL Observed limit 400 300 200 200 0 120 140 100 m_{yy} (GeV) Phys. Lett. B 716 (2012) 1-29 300 400 700 800 900 1000 m_{t̃} [GeV] Phys. Lett. B 716 (2012) 30-61

Exotics Searches

Cover wide range of final states

Cover vast range of models

Largely model independent

- Look for resonances
- Look for any disagreement



The Role of Models in "most" Exotics Searches



Toscanelli's model of the geography of the Atlantic Ocean, which directly influenced Columbus's plans

C. Issever, University of Oxford

The Role of Models in "most" Exotics Searches



Columbus' Voyages

ATLAS Exotics Searches* - 95% CL Exclusion

Status: July 2015

ATLAS Preliminary

 $\int \mathcal{L} dt = (4.7 - 20.3) \text{ fb}^{-1}$

 $\sqrt{s} = 7, 8 \text{ TeV}$

	Model	<i>ℓ</i> , γ	Jets	E_{T}^{miss}	∫£ dt[ft	⁻¹] Limit	Reference
Extra dimensions	ADD $G_{KK} + g/q$ ADD non-resonant $\ell\ell$ ADD QBH $\rightarrow \ell q$ ADD QBH high γ_{trk} ADD BH high Σ_{pr} ADD BH high multijet RS1 $G_{KK} \rightarrow \ell\ell$ Bulk RS $G_{KK} \rightarrow ZZ \rightarrow qq\ell$ Bulk RS $G_{KK} \rightarrow WW \rightarrow qq$ Bulk RS $g_{KK} \rightarrow t\bar{t}$ 2UED / RPP	$\sum_{\substack{2e,\mu\\1e,\mu\\2\mu(SS)}}^{-2e,\mu}$	$ \sum_{j=1}^{2} \frac{1}{j} = \frac$	Yes - - - - Yes /2j Yes j Yes	20.3 20.3 20.3 20.3 20.3 20.3 20.3 20.3	Mp 5.25 TeV n = 2 Ms 5.25 TeV n = 3 HLZ Mth 5.2 TeV n = 6 Mth 5.2 TeV n = 6 Mth 5.2 TeV n = 6 Mth 4.7 TeV n = 6 Mth 5.8 TeV n = 6, Mp = 3 TeV, non-rot BH Mth 5.8 TeV n = 6, Mp = 3 TeV, non-rot BH Mth 5.8 TeV n = 6, Mp = 3 TeV, non-rot BH Mth 5.8 TeV n = 6, Mp = 3 TeV, non-rot BH Mth 5.8 TeV n = 6, Mp = 3 TeV, non-rot BH KK mass 2.66 TeV k/Mp; = 0.1 GKK mass 740 GeV k/Mp; = 0.1 V'mass 760 GeV k/Mp; = 1.0 KK mass 500-720 GeV k/Mp; = 1.0 KK mass 960 GeV BR = 0.925	1502.01518 1407.2410 1311.2006 1407.1376 1308.4075 1405.4254 1503.08988 1405.4123 1504.05511 1409.6190 1503.04677 1506.0028 1505.07018 1504.04605
Gauge bosons	$\begin{array}{c} \operatorname{SSM} Z' \to \ell\ell \\ \operatorname{SSM} Z' \to \tau\tau \\ \operatorname{SSM} W' \to \ellv \\ \operatorname{EGM} W' \to \\ \operatorname{EGM} W' \to \\ \operatorname{EGM} W' \to \\ \operatorname{HVT} W' \to vt_{D} \\ \operatorname{LRSM} W'_R \to t_{D} \\ \operatorname{LRSM} W'_R \to t_{D} \end{array}$	2 e, μ 2 τ 1 e, μ Gauge 1 e, μ 1 e, μ 0 e, μ	- BO 2 b, 0-1 j ≥ 1 b, 1	- Yes SON Tes Yes	20.3 19.5 20.3 S 20.3 20.3 20.3 20.3	Z' mass 2.9 TeV Z' mass 2.02 TeV W' mass 3.24 TeV W' mass 1.52 TeV W' mass 1.59 TeV W' mass 1.51 TeV W' mass 1.47 TeV W' mass 1.92 TeV W' mass 1.76 TeV	1405.4123 1502.07177 1407.7494 1406.4456 1409.6190 1506.00962 1503.08089 1410.4103 1408.0886
C	Cl qqqq Cl qqℓℓ Cl uutt	intera	ctio	ns	17.3 20.3	Λ 12.0 TeV $\eta_{LL} = -1$ Λ 21.6 TeV $\eta_{LL} = -1$ 4.3 TeV $ C_{LL} = 1$ $\eta_{LL} = -1$	1504.00357 1407.2410 1504.04605
MD	EFT D5 operator (Dirac) EFT D9 operator (Dirac)	0 e, μ 0 e, μ	≥ 1 J,	Dar	k M	974 GeV at 90% CL for m(x) < 100 GeV 2.4 TeV at 90% CL for m(x) < 100 GeV	1502.01518 1309.4017
ΓØ	Scalar LO Scalar LO Scalar LO	-Quark	(S j ≥3	– – j Yes	20.3 20.3 20.3	LQ mass 1.05 TeV $\beta = 1$ LQ mass 1.0 TeV $\beta = 1$ LQ mass 640 GeV $\beta = 0$	Preliminary Preliminary Preliminary
Heavy quarks	$ \begin{array}{l} VLQ \ TT \ \rightarrow \ Ht + X \\ VLQ \ YY \ \rightarrow \ Wb + X \\ VLQ \ BB \ \rightarrow \ Hb + X \\ VLQ \ BB \ \rightarrow \ Hb + X \\ VLQ \ BB \ \rightarrow \ Zb + X \\ T_{5/3} \ \rightarrow \ Wt \end{array} $	Heavy	>2h >3 Qu	arks	20.3).3).3).3 20.3	T mass 855 GeV Y mass 770 GeV B mass 735 GeV B mass 735 GeV B mass 755 GeV B in (B,Y) doublet B in (B,Y) doublet B mass 755 GeV B in (B,Y) doublet B in (B,Y) doublet	1505.04306 1505.04306 1505.04306 1409.5500 1503.05425
Excited fermions	Excited quark $q^* \rightarrow q_*$ Excited quark $q^* \rightarrow$ Excited quark $b^* \rightarrow$ Excited lepton $\ell^* \rightarrow$ Excited lepton $v^* \rightarrow q_*$	cited F	- ern	nior	20.3 IS 20.3	q* mass 3.5 TeV only u* and d*, A = m(q*) q* mass 4.09 TeV only u* and d*, A = m(q*) b* mass 870 GeV left-handed coupling t* mass 2.2 TeV A = 2.2 TeV v* mass 1.6 TeV A = 1.6 TeV	1309.3230 1407.1376 1301.1583 1308.1364 1411.2921
Other	LSTC $a_T \rightarrow W\gamma$ LRSM Majorana v Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$ Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$ Monotop (non-res prod) Multi-charged particles Magnetic monopoles	1 e,μ, 1 γ Othe	er	Yes - Yes 	20.3 20.3 20.3 20.3 20.3 20.3 20.3 7.0	a_T mass 960 GeV N ⁰ mass 2.0 TeV H ^{±±} mass 551 GeV H ^{±±} mass 400 GeV spin-1 invisible particle mass 657 GeV multi-charged particle mass 785 GeV monopole mass 1.34 TeV	1407.8150 1506.06020 1412.0237 1411.2921 1410.5404 1504.04188 Preliminary
	√s = 7 TeV	√s = 8 TeV				10 ⁻¹ 1 ¹⁰ Mass scale [TeV]	

A	FLAS Exotics	Search	ies* -	95%	6 CL	Exclusion				ATLA	S Preliminar
Sta	atus: July 2015						1	TeV ∫	10		\sqrt{s} = 7, 8 TeV
	Model	<i>ℓ</i> , γ	Jets	E_T^miss	∫£ dt[f	b ⁻¹]	Limit		TO		Reference
	ADD $G_{KK} + g/q$	-	≥1j	Yes	20.3	Mp		5.25 TeV		n = 2	1502.01518
	ADD non-resonant $\ell\ell$	2e, µ	-	-	20.3	Ms		4.7 TeV		n = 3 HLZ	1407.2410
	ADD QBH $\rightarrow \ell q$	1 e,μ	1 j	-	20.3	M _{th}		5.2 TeV		<i>n</i> = 6	1311.2006
Su	ADD QBH	-	2 j	-	20.3	M _{th}		5.82 Te	/	<i>n</i> = 6	1407.1376
si	ADD BH high N _{trk}	2 μ (SS)	-	-	20.3	M _{th}		4.7 TeV	_	$n = 6, M_D = 3$ TeV, non-rot BH	1308.4075
üé	ADD BH high $\sum p_T$					M _{th}		5.8 Te	4	$n = 6, M_D = 3$ TeV, non-rot BH	1405.4254
Ē	ADD BH nigh multijet	xtra Di	mer	ารโด	ns	M _{th}		5.8 TeV	4	$n = 6, M_D = 3$ TeV, non-rot BH	1503.08988
g	$RS1 G_{KK} \rightarrow \ell\ell$.5.0		G _{KK} mass		2.68 lev		$k/M_{Pl} = 0.1$	1405.4123
tra	$RS1 G_{KK} \rightarrow \gamma \gamma$		01/11		00.0	G _{KK} mass	740.0-14	2.66 lev		$k/M_{Pl} = 0.1$	1504.05511
Щ	Bulk RS $G_{KK} \rightarrow ZZ \rightarrow qqq$	$z = z = \mu$	2]/1]	- Vee	20.3	G _{KK} mass	740 GeV			$k/M_{Pl} = 1.0$	1409.6190
	Bulk RS $G_{KK} \rightarrow VVV \rightarrow qq$	ητν τε,μ	2] / 1 J	Yes	20.3	vv mass	760 GeV			$k/M_{Pl} = 1.0$	1503.04677
	Bulk RS $G_{KK} \rightarrow HH \rightarrow DD$	DD –	40	1/21 1/20	19.5	G _{KK} mass	500-720 Gev	0.0.7-1/		$K/M_{Pl} = 1.0$	1506.00285
	DUIK HO $g_{KK} \rightarrow tt$	2 e u (SS)	210,210)>1b>1	1 i Voc	20.3	KK mass	960 Col	2.2 100		DH = 0.925	1503.07018
	20ED/RPP	2 ε, μ (00)	/ 210, 2.	rj tes	20.3		900 Gev				1504.04605
~	$SSM Z' \to \ell\ell$	2 e, μ	-	-	20.3	Z' mass		2.9 TeV			1405.4123
ŝ	SSM $Z' \rightarrow \tau \tau$	27	-	-	19.5	Z' mass		2.02 TeV			1502.07177
SC	SSM $W' \rightarrow V_V$	l.e. µ	-	Yes	20.3	W' mass		3.24 TeV			1407.7494
ă		Caura		~ ~ ~	a	vv mass		50 TeV			1406.4456
ge		Gauge	5 RO	SOL	S ²	vv mass	1.9	5 ToW			1506 00062
ari		U			2	W mass	1.0			$\sigma_{ij} = 1$	1500.00902
G	$ RSM W' \to t\bar{b}$	1 e µ	2h 0-1	i Voc	20.0	W/ mass		1 92 TeV		$s_V - 1$	1410 4103
	$LBSM W' \rightarrow tb$	0 e u	>1b1	J 103	20.3	W' mass		1 76 TeV			1408 0886
		0.01	, ,	•	20.0						
7		intora	ctio	nc	17.3	٨			12.0 1	$\eta_{LL} = -1$	1504.00357
0		intera		115	20.3	Λ		4.3 TeV		21.6 IEV $\eta_{LL} = -1$	1407.2410
~		0			I. N./						
۲ ۵	EFT D5 operator (Dirac)	0 e,μ 0 e,μ		Dar	K IVI	latter	974 Ge\	2.4 ToV		at 90% CL for $m(\chi) < 100 \text{ GeV}$	1502.01518
		υ ε,μ	10,					2.4 164			1303.4017
a	Scalar LQ			-	20.3	LQ mass	1.05 Te			$\beta = 1$	Preliminary
Ц	Scalar LQ Lepto)-Quari	KS 🗄	-	20.3	LQ mass	1.0 Te			B = 1	Preliminary
	Scalar LQ	-	≥3	j Yes	20.3	LQ mass	640 GeV			3 = 0	Preliminary
	$VLQ TT \rightarrow Ht + X$	1 <i>e u</i>	>2h>1	3 i Voc	20.3	T mass	855 GeV			T in (T,B) doublet	1505.04306
Şξ	$VLQ\; YY \to Wb + X$		~).3	Y mass	770 GeV			Y in (B,Y) doublet	1505.04306
lea Jai	$VLQ \ BB \to Hb + X$	Heavy	/ ()U	ark	S).3	B mass	735 GeV			sospin singlet	1505.04306
<u>г</u> 6	$VLQ BB \to Zb + X$,	~~.).3	B mass	755 GeV			B in (B,Y) doublet	1409.5500
	$T_{5/3} \rightarrow Wt$	ι e, μ	210,23	oj Yes	20.3	T _{5/3} mass	840 GeV				1503.05425
- s	Excited quark $q^* \rightarrow q\gamma$	1 v	1 i	-	20.3	q* mass		3.5 TeV		only u^* and d^* , $\Lambda = m(q^*)$	1309.3230
ğS	Excited quark $q^* \rightarrow$		_			q* mass		4.09 TeV		only u^* and d^* , $\Lambda = m(q^*)$	1407.1376
j E	Excited quark $b^* \rightarrow$	xcited	Fern	nior	15	b* mass	870 GeV			eft-handed coupling	1301.1583
த் ப	Excited lepton $\ell^* \rightarrow$					ℓ* mass		2.2 TeV		\ = 2.2 TeV	1308.1364
	Excited lepton $v^* \rightarrow v v v$, $v z$	<u>. σe, μ, τ</u>	-	-	20.3	v* mass		I.6 TeV		\ = 1.6 TeV	1411.2921
	LSTC $a_T \rightarrow W\gamma$	1 e, μ, 1 γ		Yes	20.3	a _T mass	960 GeV				1407.8150
	LRSM Majorana v			_	20.3	N ⁰ mass		2.0 TeV		$m(W_R) = 2.4$ TeV, no mixing	1506.06020
~	Higgs triplet $H^{\pm\pm} \rightarrow \ell \ell$	O+h	or	-	20.3	H ^{±±} mass	551 GeV			DY production, BR($H_L^{\pm\pm} \rightarrow \ell \ell$)=1	1412.0237
he	Higgs triplet $H^{\pm\pm} \rightarrow \ell \tau$	Ull	er	-	20.3	H ^{±±} mass	400 GeV			DY production, BR($H_L^{\pm\pm} \rightarrow \ell \tau$)=1	1411.2921
ð	Monotop (non-res prod))	Yes	20.3	spin-1 invisible particle mass	657 GeV			anon-res = 0.2	1410.5404
	Multi-charged particles	-	-	-	20.3	multi-charged particle mass	785 GeV			DY production, $ q = 5e$	1504.04188
	Magnetic monopoles	-	-	-	7.0	monopole mass	1.3	3 TeV		DY production, $ g = 1g_D$, spin 1/2	Preliminary
	√s – 7 TeV	√s = 8 TeV						· · · · · ·			
	43 - 1 104	13-0104				10-1		1	10) Mass scale [TeV]	

*Only a selection of the available mass limits on new states or phenomena is shown.

A	FLAS Exotics	s Search	es* -	95%	6 CL	Exclusion				ATLA	S Preliminary
Sta	atus: July 2015						1	TeV ∮	10		\sqrt{s} = 7, 8 TeV
	Model	<i>ℓ</i> , γ	Jets	\mathbf{E}_{T}^{miss}	∫£ dt[f	b ⁻¹]	Limit		TO		Reference
	ADD $G_{KK} + g/q$	-	≥ 1 j	Yes	20.3	MD		5.25 TeV		n = 2	1502.01518
	ADD non-resonant $\ell\ell$	2e, µ	_	-	20.3	Ms		4.7 TeV		n = 3 HLZ	1407.2410
~	ADD QBH $\rightarrow \ell q$	1 e, µ	1)	-	20.3	M _{th}		5.2 TeV		n = 6	1311.2006
Ĕ	ADD QBH	-	2]	-	20.3	M _{th}		5.82 TeV		n = 6	1407.1376
Sic	ADD BH high N _{trk}	2 µ (55)	-	-	20.3	M _{th}		4.7 TeV		$n = 6$, $M_D = 3$ leV, non-rot BH	1308.4075
en	ADD BH high multiist					M _{th}		5.8 Tev		$h = 0, M_D = 3$ TeV, non-rot BH	1405.4254
<u>,</u> E	RS1 Curren M	xtra Di	mer	ารเด	ns	Mith		5.8 TeV			1405 4100
g	$RS1 G_{KK} \rightarrow ii =$					G _{KK} mass		2.00 TeV		$k/M_{Pl} = 0.1$	1504 05511
dra U	Bulk BS $G_{WK} \rightarrow YY$	ff 2 e u	2i/1.l	_	20.3	G _{KK} mass	740 GoV	2.00 100		$k/M_{Pl} = 0.1$	1409 6190
ш	Bulk BS $G_{KK} \rightarrow ZZ \rightarrow QQ$	αlv 1eu	2j/10	Voc	20.3	W/ mass	740 GeV			$\frac{k}{M} = 1.0$	1503 04677
	Bulk BS $G_{KK} \rightarrow HH \rightarrow b\bar{b}$	φ <i>τ</i> γ τ ς, μ	4h	-	19.5	Gree mass	500-720 GeV			$k/M_{\rm Pl} = 1.0$	1506.00285
	Bulk BS $g_{VV} \rightarrow t\bar{t}$	1 е. ц	> 1 b. > 1.	J/2i Yes	20.3	g _{KK} mass	500-120 CCV	2.2 TeV		BB = 0.925	1505.07018
	2UED / RPP	2 e. μ (SS)	≥ 1 b. ≥ 1	li Yes	20.3	KK mass	960 GeV				1504.04605
	201071	0		,							
6	$SSM Z' \to \ell\ell$	2 e, µ	-	-	20.3	Z' mass		2.9 TeV			1405.4123
ğ	SSM $Z' \rightarrow \tau \tau$	27	-		19.5	Z' mass		2.02 TeV			1407 7404
SC	SSIM $W' \rightarrow Q'$	1 e. u	-	tes	20.3	W mass		3.24 TeV			1407.7494
ğ				con		W mass		50 ToV			1400.4400
ge		Jauge		SOL	S	W' mass	1 9	5 TeV			1506.00962
au	HVT $W' \rightarrow w = + c v d t$		2.0	THS.	cu 3	W' mass	1.0	7 TeV		$g_{\mathcal{M}} = 1$	1503 08089
G	LRSM $W'_{-} \rightarrow t\overline{b}$	1 е. µ	2 b. 0-1	i Yes	20.3	W' mass		1.92 TeV		5v -	1410.4103
	LRSM $W'_{a} \rightarrow t\overline{b}$	0 e.μ	≥1b,1	J –	20.3	W' mass		1.76 TeV			1408.0886
			_ ,		17.0						
5		intora	ctio	nc	17.3	<u>۸</u>			12.0 1	$\eta_{LL} = -1$	1504.00357
0		intera	CUO	115	20.3	Λ		4.2 ToV		21.6 IeV $\eta_{L} = -1$	1407.2410
	Gluutt							4.5 167		C[[] = 1	1504.04605
S	EFT D5 operator (Dirac)	0 e,μ	≥	Dar	kМ	atter	974 Ge\			at 90% CL for m(/ < 100 GeV	1502.01518
	EFT D9 operator (Dirac)	0 e, µ	1 J,	Dui				2.4 TeV		at 90% CL $f = n(\chi) < 100 \text{ GeV}$	1309.4017
~	Scalar LQ	_	li	-	20.3	LQ mass	1.05 Te			$\beta = 1$	Preliminary
9	Scalar LQ	∿-Ouarl	/ C	-	20.3	LQ mass	1.0 Te			$\beta = 1$	Preliminary
	Scalar LQ	Quan	S ≥3	j Yes	20.3	LQ mass	640 GeV			$\beta = 0$	Preliminary
		1.0.4	>26 >3		00.0	Tmass	OFF Call			Lin (T.B.) doublet	1505 04000
<u>2 S</u>	V = V = W + X				1.3	V mass	770 CoV			(in (B,X) doublet	1505.04306
e te	$V \cup BB \rightarrow Hb + X$	Hony	(\cap)	ark	C 12	T mass	770 GeV			sospin singlet	1505.04306
f f	$V \downarrow Q BB \rightarrow Zb + X$	ILCavy	Qu	air)	B mass	755 GeV			B in (B,Y) doublet	1409.5500
	$T_{5/3} \rightarrow Wt$	ι <i>e</i> ,μ	210,23	V Yes	20.3	T _{5/3} mass	840 GeV				1503.05425
	Evelted events at a sur				00.0	•		0.5.7.14			1000.0000
p Su Su	Excited quark $q^* \rightarrow q_Y$	1 2	11	-	20.3	q* mass		3.5 TeV		pnly u^* and d^* , $\Lambda = m(q^*)$	1309.3230
Щ.	Excited quark $h^* \rightarrow$	vaitad I	Form	ninr	20	q mass	970 CoV	4.09 Tev		off banded coupling	1407.1376
XE	Excited lepton $\ell^* \rightarrow$	xcited i	геп		15	D mass	670 Gev	2.2 ToV			1209 1264
ш ф	Excited lepton $v^* \rightarrow t_{VV} - v_{v}$		_	_	(11-2)	t mass		2.2 IOV		1 - 2.2 lev 1 - 1.6 TeV	1411 2921
		Δ σ σ, μ, ι			20.0	y mass		1.0 164		1-1.0 164	1411.2321
	LSTC $a_T \rightarrow W\gamma$	1 e, μ, 1 γ	-	Yes	20.3	a _T mass	960 GeV				1407.8150
	LHSM Majorana v			-	20.3	N ⁰ mass		2.0 TeV		$n(W_R) = 2.4$ TeV, no mixing	1506.06020
5	Higgs triplet $H^{\pm\pm} \rightarrow \ell \ell$	Oth	or	-	20.3	H ^{±±} mass	551 GeV			PY production, BH($H_L^{\pm\pm} \rightarrow \ell \ell$)=1	1412.0237
the	Higgs triplet $H^{\pm\pm} \rightarrow \ell \tau$	Oth			20.3	H ^{±±} mass	400 GeV			production, BH($H_L^{++} \rightarrow \ell \tau$)=1	1411.2921
0	Multi-obargod particles)	Yes	20.3	spin-1 invisible particle mass	657 GeV			Pron-res = 0.2	1410.5404
	Magnetic monopolog	-	-	_	20.3	monopole mass	785 GeV	ToW		Production, q = 5e	1504.04188 Preliminary
	magnetic monopoles	_	-	_	7.0		1.			r_{BD} , production, $ \mathbf{g} = 1 \mathbf{g}_D$, split $1/2$	Freinniary
	√s = 7 TeV	√s = 8 TeV				40-1		1	4/		
						10 -		I	10	' Mass scale [TeV]	

*Only a selection of the available mass limits on new states or phenomena is shown.

Α	FLAS Exotics	Searche	s* - 9	95%	CL	Exclusion					ATLA	S Preliminar
Sta	atus: July 2015						1	TeV	∫ ,	10		$\sqrt{s} = 7, 8 \text{ Te}$
	Model	ℓ,γ	Jets E	miss T	∫£ dt[fb	-1]	Limit			TO		Reference
sions	ADD $G_{KK} + g/q$ ADD non-resonant $\ell\ell$ ADD QBH $\rightarrow \ell q$ ADD QBH ADD BH high N_{trk}	2e,μ 1 e,μ 2μ (SS)	≥1j - 1j 2j	Yes _ _ _	20.3 20.3 20.3 20.3 20.3	MD Ms Mth Mth Mth		5.: 4.7 .7 .7	7 TeV feV .2 TeV 5.82 TeV 7 TeV		n = 2 n = 3 HLZ n = 6 n = 6 $n = 6$, $M_D = 3 \text{ TeV}$, non-rot BH	1502.01518 1407.2410 1311.2006 1407.1376 1308.4075
Extra dimens	ADD BH high $\sum p_T$ ADD BH high multijet RS1 $G_{KK} \rightarrow \ell \ell$ BS1 $G_{KK} \rightarrow \ell \ell$ Bulk RS $G_{KK} \rightarrow ZZ \rightarrow qq\ell \ell$ Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\ell v$ Bulk RS $G_{KK} \rightarrow HH \rightarrow b\bar{b}b\bar{b}$ Bulk RS $g_{KK} \rightarrow t\bar{t}$	tra Din $\frac{2 e, \mu}{1 e, \mu}$	$ \begin{array}{c} \text{nens} \\ \text{2} \\ \text{j/1} \\ \text{j/1} \\ \text{4} \\ \text{b} \\ \text{1} \\ \text{b}, \geq 1 \\ \text{j/2} \\$	- Yes Yes	20.3 20.3 19.5 20.3	Mth Mth Gкк mass Gкк mass W' mass Gкк mass Gкк mass gкк mass gкк mass	740 GeV 760 GeV 500-720 GeV	2.68 TeV 2.66 TeV 2.2 TeV	5.8 TeV 5.8 TeV		$ \begin{split} &n=6, M_D=3 \text{TeV}, \text{non-rot BH} \\ &n=6, M_D=3 \text{TeV}, \text{non-rot BH} \\ &k/\overline{M}_{Pl}=0.1 \\ &k/\overline{M}_{Pl}=0.1 \\ &k/\overline{M}_{Pl}=1.0 \\ &k/\overline{M}_{Pl}=1.0 \\ &k/\overline{M}_{Pl}=1.0 \\ &BR=0.925 \end{split} $	1405.4254 1503.08988 1405.4123 1504.05511 1409.6190 1503.04677 1506.00285 1505.07018
Gauge bosons	$\begin{array}{c} \text{SSM } Z' \rightarrow \ell\ell \\ \text{SSM } Z' \rightarrow \ell\tau \\ \text{SSM } Z' \rightarrow \tau\tau \\ \text{EGM } W' \rightarrow t \\ \text{LRSM } W'_{\mathcal{B}} \rightarrow t \\ \text{D} \end{array}$	2 e,μ (SS) 2 2 e,μ 2 τ 1 e,μ Gauge 1 e,μ 1 e,μ 2 t 2 t 2 t 2 t 2 t 2 t 2 t 2 t 2 t 2 t	Bos(2 b, 0-1 j	Yes Yes Ons Yes	20.3 19.5 20.3 5 3 5 20.3 20.3	KK mass Z' mass Z' mass W' mass W' mass W' mass W' mass W' mass	960 Gev 1.3	2.9 Te 2.02 TeV 3.24 * V 59 TeV 5 9 TeV 5 7 teV 7 TeV 1.92 TeV			$g_V = 1$	1405.4123 1405.4123 1502.07177 1407.7494 1406.4456 1409.6190 1506.00962 1503.08089 1410.4103
Ū	$\begin{array}{c} \text{LRSM } W_R^{\prime} \rightarrow tb \\ \text{Cl } qqqq \\ \text{Cl } qq\ell\ell \\ \text{Cl } uutt \end{array} \qquad	nterac	tion	S	20.3 17.3 20.3			1.76 TeV 4.1	TeV	2.0 1	$ \begin{array}{c} \eta_{LL} = -1 \\ \textbf{21.6 TeV} \\ \zeta_{LL} = 1 \end{array} $	1408.0886 1504.00357 1407.2410 1504.04605
DM	EFT D5 operator (Dirac) EFT D9 operator (Dirac)	0e,μ 0e,μ 1	≥ D	ark	(Ma	atter	974 GeV	2.4 TeV			at 90% CL for $m(\chi) < 100 \text{ GeV}$ at 90% CL for $m(\chi) < 100 \text{ GeV}$	1502.01518 1309.4017
ΓQ	Scalar LQ Scalar LQ Scalar LQ	Quarks	S ¦j ≥3j	– – Yes	20.3 20.3 20.3	LQ mass LQ mass LQ mass	1.05 To 1.0 Te 640 GeV				$ \begin{array}{l} \beta = 1 \\ \beta = 1 \\ \beta = 0 \end{array} $	Preliminary Preliminary Preliminary
quarks	$VLQ TT \rightarrow Ht + X$ $VLQ YY \rightarrow Wb + X$ $VLQ BB \rightarrow Hb + X$ $VLQ BB \rightarrow Zb + X$ $T_{5/3} \rightarrow Wt$	leu Heavy (2h > 3i Qua	rks	20.3).3).3).3 20.3	T mass Y mass B mass B mass T _{5/3} mass	855 GeV 770 GeV 735 GeV 755 GeV 840 GeV				T in (T,B) doublet Y in (B,Y) doublet sospin singlet B in (B,Y) doublet	1505.04306 1505.04306 1505.04306 1409.5500 1503.05425
fermions	Excited quark $q^* \rightarrow q_Y$ Excited quark $q^* \rightarrow e_Y$ Excited quark $b^* \rightarrow e_Y$ Excited lepton $t^* \rightarrow e_Y$, y_Z	cited Fe	ermi	ion	20.3 S	q* mass q* mass b* mass f* mass y* mass	870 GeV	3.5 TeV 4.09 Te 2.2 TeV .6 TeV	ēΥ		pnly u^* and d^* , $\Lambda = m(q^*)$ pnly u^* and d^* , $\Lambda = m(q^*)$ eff-handed coupling $\Lambda = 2.2 \text{ TeV}$ $\Lambda = 1.6 \text{ TeV}$	1309.3230 1407.1376 1301.1583 1308.1364 1411.2921
Other	LSTC $a_T \rightarrow W\gamma$ LRSM Majorana ν Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$ Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$ Monotop (non-res prod) Multi observed particular	^{1 e,μ, 1 γ} Othe	r	Yes - - Yes	20.3 20.3 20.3 20.3 20.3 20.3	a _T mass N ⁰ mass H ^{±±} mass H ^{±±} mass spin-1 invisible particle mass milli-charged particle mass	960 GeV 551 GeV 400 GeV 657 GeV 785 GeV	2.0 TeV			$n(W_R) = 2.4$ TeV, no mixing DY production, BR $(H_L^{\pm\pm} \rightarrow \ell \ell) = 1$ DY production, BR $(H_L^{\pm} \rightarrow \ell r) = 1$ $\mu_{non-res} = 0.2$ DY production, $ a = 5e$	1407.8150 1506.06020 1412.0237 1411.2921 1410.5404 1504.04188

*Only a selection of the available mass limits on new states or phenomena is shown.

A٦	LAS Exotics	s Search	1es* - 9	95%	6 CL	Upper Exclu	sion Lim ^{···}			ATL	4S Preliminary
Sta	tus: July 2017						1	TeV	$\int \mathcal{L} = 1$	0 TeV	\sqrt{s} = 8, 13 TeV
	Model	<i>ℓ</i> ,γ	Jets†	E ^{miss} T	∫£ dt[fb	-1]	Limit				Reference
CIDIC	ADD $G_{KK} + g/q$ ADD non-resonant $\gamma\gamma$	0 e, μ 2 γ	1 – 4 j –	Yes –	36.1 36.7	M _D			7 5 TeV 8.6 TeV	n = 2 n = 3 HLZ NLO n = 6	ATLAS-CONF-2017-060 CERN-EP-2017-132 1703.09217
	ADD BH high $\sum p_T$ ADD BH multijet RS1 $G_{KK} \rightarrow \gamma\gamma$	Extra D	imen	sic	9 NS 36.7	M _{th} M _{th} G _{KK} mass		4.1 TeV	8.2 TeV 9.55 TeV	$m = 6$, $M_D = 3$ TeV, rot BH $p = 6$, $M_D = 3$ TeV, rot BH $\sqrt{M_{Pl}} = 0.1$	1606.02265 1512.02586 CERN-EP-2017-132
LY	Bulk RS $G_{KK} \rightarrow WW \rightarrow a$ 2UED / RPP	gqℓv 1e,μ 1e,μ	1 J ≥ 2 b, ≥ 3 j	Yes Yes	36.1 13.2	G _{KK} mass KK mass		1.75 TeV 1.6 TeV		$egin{aligned} & \overline{M}_{Pl} = 1.0 \ & ext{er}\left(1,1 ight), \mathcal{B}ig(A^{(1,1)} o ttig) = 1 \end{aligned}$	ATLAS-CONF-2017-051 ATLAS-CONF-2016-104
210	$\begin{array}{l} \text{SSM } Z' \to \ell\ell \\ \text{SSM } Z' \to \tau\tau \\ \text{Leptophobic } Z' \to bb \end{array}$	2 e, μ 2 τ -	- - 2 h	- -	36.1 36.1 3.2	Z' mass Z' mass Z' mass		4.5 T 2.4 TeV 5 TeV	/		ATLAS-CONF-2017-027 ATLAS-CONF-2017-050 1603.08791
adda -	Leptophobi SSM $W' -$ HVT $V' \rightarrow$ HVT $V' \rightarrow WH/ZH$ mode		e Bos	on	S 1 7 36.1	Z' mass W' mass V' mass V' mass		2.0 TeV 5.* 3.5 TeV 2.93 TeV	TeV	$\begin{bmatrix} m = 3\%\\ g = 3\\ g = 3 \end{bmatrix}$	ATLAS-CONF-2016-014 1706.04786 CERN-EP-2017-147 ATLAS-CONF-2017-055
5	LRSM $W'_R \to tb$ LRSM $W'_R \to tb$	1 e, μ 0 e, μ	2 b, 0-1 j ≥ 1 b, 1 J	Yes –	20.3 20.3	W' mass W' mass		1.92 TeV 1.76 TeV			1410.4103 1408.0886
5	CI gqqq CI ll qq CI uutt	/ intera	actio	าร	37.0 36.1 20.3	Λ Λ Λ		4.9	v ($\begin{array}{c c} \textbf{21.8 TeV} & \eta_{LL} \\ & \textbf{40.1 TeV} \\ \eta_{LL} \\ \eta_{LL} \\ \eta_{RR} = 1 \end{array}$	1703.09217 ATLAS-CONF-2017-027 1504.04605
	Axial-vector mediator (Dirac Vector mediator (Dirac DM $VV_{\chi\chi}$ EFT (Dirac DM)	ic DM) 0 e, μ) 0 e, μ, 1 g 0 e, μ	$\begin{array}{cc} 1-4\\ \gamma & \leq 1 \\ 1 \\ J, \leq 1 \end{array}$	Dai	rk N	latter	1.2 700 GeV	5 TeV •V		=0.25, g_{χ} =1.0, $m(\chi) < 400$ deV g_q =0.20, $g_{\chi\gamma} < 480$ GeV $m(\chi) < 150$ GeV	ATLAS-CONF-2017-060 1704.03848 1608.02372
y 1	Scalar LC Scalar LC Scalar LC	o-Quar	ks ^j ₂₃j	– – Yes	3.2 3.2 20.3	LQ mass LQ mass LQ mass	1.1 T 1.05 Te 640 GeV			$ \begin{aligned} \beta &= 1 \\ \beta &= 1 \\ \beta &= 0 \end{aligned} $	1605.06035 1605.06035 1508.04735
	$\begin{array}{l} VLQ \ TT Ht + X \\ VLQ \ TT Zt + X \end{array}$	0 or 1 e, j	$\mu \geq 2 \text{ b}, \geq 3 \text{ j}$	Yes	13.2 1	T mass T mass	1.2 1.16	V V		$egin{aligned} \mathcal{B}(T o Ht) &= 1 \ \mathcal{B}(T o Zt) &= 1 \end{aligned}$	ATLAS-CONF-2016-104 1705.10751
-	$VLQ TT \rightarrow Wb + X$ $VLQ BB \rightarrow Hb + X$ $VLQ BB \rightarrow Zb + X$	Heav	y Qua	ark	S 3	T mass B mass B mass	1.3 700 GeV 790 GeV	3 TeV		$\mathcal{B}(T \to Wb) = 1$ $\mathcal{B}(B \to Hb) = 1$ $\mathcal{B}(B \to Zb) = 1$	CERN-EP-2017-094 1505.04306 1409.5500
	$VLQ BB \rightarrow Wt + X$ $VLQ QQ \rightarrow WqWq$	1 e,μ 1 e,μ	$\geq 1 \text{ b}, \geq 1 \text{ J/2}$ $\geq 4 \text{ j}$	i Yes Yes	36.1 20.3	B mass Q mass	1.25 690 GeV	5 eV		$\mathcal{B}(B \to Wt) = 1$	CERN-EP-2017-094 1509.04261
mions	Excited quark $q^* \rightarrow qg$ Excited quark q^* Excited quark b^*	cited F	^{2j}	on	37.0 7 3	q* mass q* mass b* mass		5.3 2.3 TeV	6.0 TeV 3 TeV	only u^* and d^* , $\Lambda = m(q^*)$ only u^* and d^* , $\Lambda = m(q^*)$	1703.09127 CERN-EP-2017-148 ATLAS-CONF-2016-060
fer	Excited lepton ℓ^*	З <i>е</i> , <i>µ</i> , <i>т</i>	-	-	20.3	le mass le mass v* mass		3.0 TeV		$\Lambda = 3.0 \text{ TeV}$ $\Lambda = 1.6 \text{ TeV}$	1411.2921 1411.2921
	LRSM Majorana ν Higgs triplet $H^{\pm\pm} \rightarrow \ell \ell$ Higgs triplet $H^{\pm\pm} \rightarrow \ell \tau$	2 e, µ	2 j	-	20.3 36.1 20.3	N ⁰ mass H ^{±±} mass H ^{±±} mass	870 GeV	2.0 TeV		$m(W_R) = 2.4$ TeV, no mixing DY production DY production, $\mathcal{B}(H_i^{\pm\pm} \rightarrow \ell \tau) = 1$	1506.06020 ATLAS-CONF-2017-053 1411.2921
Othe	Monotop (non-res prod) Multi-charged particles Magnetic monopoles		er	Yes - -	20.3 20.3 7.0	spin-1 invisible particle mass multi-charged particle mass monopole mass	657 GeV 785 GeV 1.3	3 TeV		$a_{non-res} = 0.2$ DY production, $ q = 5e$ DY production, $ g = 1g_D$, spin 1/2	1410.5404 1504.04188 1509.08059
		√s = 8 TeV	√s = 13	TeV		10 ⁻¹	Ciăden	n İssever	1	Mass scale [TeV]	1

†Small-radius (large-radius) jets are denoted by the letter j (J).

10

At the beginning of our journey

~ 35 fb⁻¹ data analysed 1% of what LHC + HL-LHC will deliver

Two new windows to probe nature...

Top-quark (1995, Tevatron) Higgs boson (2012, LHC)

Our "gravitational waves"....

Comment about the selection of results



Focus on one topic

ATLAS Public Exotics Results are <u>HERE</u> CMS Public Exotics Results are <u>HERE</u> LHCb Public Exotics Results are <u>HERE</u>



Dark Matter Searches at the LHC



VAN ALBADA ET AL.

Strong Evidence...









15

What we know about Dark Matter



Strong astrophysical evidence for the existence of dark matter

What we know about Dark Matter

- Massive
- Non-relativistic (slow)
- Long lived (old)
- No electric or colour charge
- Very weakly interacting with ordinary matter
- Subject to gravity interactions

Dark Matter (DM) interaction with ordinary matter (SM)



Experimental detection of Dark Matter



"break it": indirect detection

Experimental detection of Dark Matter



Experimental detection of Dark Matter

"make it": Collider Production





 g_q and g_x coupling strengths



 g_q and g_x coupling strengths

Empty detector



 g_{α} and g_{χ} coupling strengths

Empty detector + something



 g_q and g_x coupling strengths

Empty detector + something



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Simplified Model



Simplified Model





Simplified Model



Charge	Q-0101 S-Channel										
Lorentz	Scalar $g_q \frac{\phi}{\sqrt{2}} \sum_f y_f \bar{f} f$	Vector $g_q \sum_q V_\mu \bar{q} \gamma^\mu q$									
structure	Pseudoscalar $g_q rac{iA}{\sqrt{2}} \sum_f y_f ar{f} \gamma^5 f$	Axial-vector $g_q \sum_q A_\mu \bar{q} \gamma^\mu \gamma^5 q$									
Coupling	∝ mass	∝ charge									





ATLAS

- $E_T^{miss} > 250 \text{ GeV}, \Delta \phi(\text{jet}, p_T^{miss}) > 0.4$
- Jet $p_T > 250$ GeV, $|\eta| < 2.4$
- $N_{jets} \le 4$

CMS

- $E_T^{miss} > 250 \text{ GeV}$
- Jet $p_T > 100$ GeV, $|\eta| < 2.5$

Mono-jet

Axial-vector mediator



For vector and axial-vector interactions:

- Mediator mass excluded up to 1.6 1.8 TeV
- DM mass excluded up to 400 700 GeV

Mono-Higgs



Higgs / γ E_T^{miss}

Mono-Higgs

CMS-PAS-EXO-16-054



Mediator masses excluded up to 0.8 TeV for m(DM) = 1 GeVfor baryonic Z' model

Mono-Mania!





Di-jet searches

- Look for resonance above fit
- Analysis limited by trigger
 - 1-jet trigger E_T ~ 380 GeV
 - Implies m(jj) > 1.1.
 TeV
- Dedicated analysis used for lower-mass searches

Strong limits on DM mediator



High-mass dijet searches



Mediator masses excluded between 1.5 TeV and 3.5 TeV Couplings excluded between 0.07 and 0.28

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Low-mass di-jet searches

Search for low-mass particles using ISR boost





New Techniques

- Large-R jet
- Jet substructure
- Data-driven bkg

ATLAS and CMS Low-mass di-jet searches

CMS-PAS-EXO-17-001



Mediator masses down to 50 GeV explored!

DM Mediator Search @ LHCb



arXiv:1710.02867

DM Mediator Search @ LHCb

Dark Photon Searches: A'



No significant excess found First limit on dark photons for m(A') > 10 GeV Already competitive for m(A') < 0.5 GeV

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arXiv:1710.02867

Comparison with Non-Collider Searches



Relevant Scales for DM Searches

Direct Detection Indirect Detection Collider DM momentum 10 TeV I MeV 10 MeV 100 MeV 1 GeV 10 GeV 100 GeV I TeV transfer particle W, Z, h, t??? b π p, n e mass 3- or 4-EFT w/ non-ren. nuclear response functions flavour QCD DM interactions theory EFT non-pert. EFT Heavy DM EFT + w/ NR nucleons 5-flavour QCD Comparisons across scales not straight forward!!

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[Haisch, Bishara]

LHC DM Working Group



Comparison with Direct Detection

Spin-dependent DM-neutron cross section vs m_{DM}



For these model assumptions:

Collider searches have ~3 orders better sensitivity for σ_{SD} (DM-nucleon)

Comparison with Direct Detection

Spin-independent DM-nucleon cross section vs m_{DM}



For these model assumptions:

Collider searches are sensitive at low DM for σ_{SI} (DM-nucleon)

Summary

Searches for Exotic searches in general

- We have explored O(10 GeV) to 10 TeV mass/energy scales
- Only 1% of the LHC data analysed --- we are at the beginning
- New probes: Top quark and Higgs boson

Dark Matter Searches are thriving at the LHC

- For vector and axial vector interactions
 - Dark Matter masses up 400 GeV 700 GeV (mono-jet) excluded
 - Mediator mass up to 1.6 1.8 TeV (mono-jet) excluded
 - Mediator mass up to 1.2 TeV (mono-photon) excluded
 - Mediator mass up to 0.7 TeV (mono-Z) excluded
 - LHCb Dark Photon limits m(A)>10 GeV

LHC DM searches complement non-collider DM searches

m_{DM} < O(10 GeV)

Where to go from here?

- Direct searches \rightarrow more and more systematic limited
 - Better experimental techniques will be developed
 - Better theoretical uncertainties needed
 - Constrain backgrounds via measurements
 - Look at low mass AND high mass
- Indirect searches (measurements) rising

My thoughts on colliders for the future:

- Precision Higgs and top collider (e-e+ collider)
 - Will give us direction where to look
- DM Collider

Backup Slides



Mono-X & Mediator Searches

- Picture changes with choice of couplings
 - Strong constraints from di-lepton search if g_l>0
 - Dijet and mono-X constraints weakened when g_q = 0.25 →0.1

CMS DM Summary



Mono-photon





- Photon $E_T > 150$ GeV, $|\eta| < 2.37$
- $E_{\rm T}^{\rm miss} / \sqrt{\sum E_{\rm T}} > 8.5 \ {\rm GeV}^{1/2}$
- $\Delta \phi$ (photon, E_T^{miss}) > 0.4
- $N_{jets}(p_T>30~\text{GeV}, |\eta|<4.5)\leq 1$

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Mono-photon





For vector and axial-vector interactions:

- Mediator mass excluded up to 1.2 TeV
- DM mass excluded up to 340 480 GeV

Mono-Higgs



Z' (A) mass excluded up to 2.6 (0.6) TeV for Z'-2HDM model

b

CMS angular di-jet search

CMS-PAS-EXO-16-046



Mediator masses excluded between 2.5 TeV and 5.0 TeV

Era of Boosted Techniques

- Search for heavy new particles m >> 1TeV
- Final state consist of particles of m ~ O(100 GeV)

OR

Search for light particles + something they recoil against

→ Final state objects are heavily boosted!

For example $H \rightarrow b\overline{b}$

distance of decay products: $\Delta R \sim \frac{2m}{p_T}$

$p_T > 250 \text{ GeV}$ b-quark pair within $\Delta R < 1$



Jet substructure: N-subjettiness $oldsymbol{ au}_{21}$



arxiv:1011.2268

 τ_N : pT-weighted distance between constituents and N axes

How compatible jet with having N axis

small τ_{2}/τ_{1} : more two- than one-prong like

b-quark Identifikation (ID) – wichtig für 2H Prozesse



Standard b-quark ID: beinträchtig durch Kollimation bei hohen transversal Impulsen

New advanced $H \rightarrow bb$ taggers Zürich **Higgs-tagging**

(13 TeV)

CMS-PAS-BTV-15-002

0.8 0.9

Fagging officianov (U shb)



- input related to observables from SV and tracks associated to each τ -axis (27 total)
- Factor ~2 higher rejecting rate compared to standard b-tag methods

0.1 0.2 0.3 0.4 0.5 0.6 0.7

CMS Simulation Preliminary

double-b-tag

---- Subjet CSVv2

Fatjet CSVv2

AK8

Mistagging efficiency

10-2

 10^{-3}



AK8 jet double b tagger

0.05

Ā

Neue b-quark ID: Centre of Mass (COM)



Neue b-quark ID Effizienzen

ATL-PHYS-PUB-2017-010



Neue b-quark ID: Variable Radii



