## Searches for Exotics: Heavy resonances with the ATLAS detector

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#### Introduction

- Heavy resonance discoveries have played a very significant role in the development of particle physics
- Examples:  $J/\psi$ , Upsilon, W, Z
- Most theories beyond the SM predict such new resonances
- We look for heavy resonances at the Large Hadron Collider!
- This talk:

• <i>jj</i>	• $\mathcal{W}\mathcal{W} \to \ell \mathcal{V}\ell \mathcal{V}$
• l+l-	• $ZW$ , $ZZ \rightarrow llqq$
• γγ	• ττ

• lv • tt, tj

References shown on the conclusion slide



## Introduction

- Searches are signature-based, but interpreted in terms of theories beyond the Standard Model, used as benchmarks
- W' and Z': Additional gauge bosons
  - Sequential Standard Model (SSM)
    - Not well-motivated, but simplest
  - Grand Unified Theories



- Extra dimensions
  - Randall-Sundrum models: G\*, G\*
  - TeV<sup>-1</sup> Kaluza-Klein models: g<sub>κκ</sub>, Z<sub>κκ</sub> ...
  - ADD models



- Other solutions to the hierarchy problem: Technicolour, chiral bosons (W\*, Z\*)
- Excited fermions, Colour-octet scalars, String resonances, Quantum black holes...
- Effective four-fermion contact interactions with scale  $\Lambda$



 $\mathcal{X} \rightarrow jj$ 



m<sub>ii</sub> = 4.69 TeV

# Dijet resonances – $\sqrt{s}$ = 8 TeV

- Invariant mass spectrum from the two highest-p<sub>T</sub> central jets
- Data-driven background estimate: spectrum fit using

$$f(x) = p_1 (1 - x)^{p_2} x^{p_3 + p_4 \ln}$$
$$x \equiv m_{jj} / \sqrt{s}$$

x

- No significant excess
  - Bin-by-bin significance
  - Global *p* > 0.5



## Dijet resonances – $\sqrt{s}$ = 8 TeV

- fit] / fit

data

- Invariant mass spectrum from the two highest-p<sub>τ</sub> central jets
- Data-driven background estimate: spectrum fit using  $f(x) = p_1(1-x)^{p_2}x^{p_3+p_4\ln x},$

 $x \equiv m_{jj}/\sqrt{s}$ 

- No significant excess, global p > 0.5
- Limits on q\*: M > 3.84 TeV
- Model-independent limits
- Angular analysis and limits on further models using data taken in 2011 at  $\sqrt{s} = 7$  TeV [see appendix]



 $\mathcal{X} \rightarrow \ell^+ \ell^-$ 



Run Number: 190975, Event Number: 26669226 Date: 2011-10-13, 23:34:58 CET

Muon: blue Electron:black Cells:Tiles, EMC



1

Persint



= 1.66 TeV m ee

#### **Dilepton resonances**

- Main experimental challenges
  - Muon channel

 $\frac{\sigma(p_T)}{p_T} = S_1 + \frac{S_2 \cdot p_T}{p_T}$ 

BO

δz

BI

- Momentum measured as track curvature
- Very-high momentum  $\rightarrow$  Very straight tracks!
- Use only the best-aligned chambers: S<sub>2</sub> < 0.25/TeV</li>

$$\frac{\sigma(E)}{E} = \frac{k_1}{\sqrt{E}} + \frac{k_2}{\sqrt{E}}$$

- Electron channel
  - The EM calorimeter provides a good energy measurement:  $k_2 < 2\%$
  - Main challenge is particle identification: need stringent cuts to distinguish high-energy electrons from QCD jets and converted photons
  - Data-driven strategies to estimate what remains after these cuts

## Dilepton resonances – $\sqrt{s}$ = 8 TeV





Backgrounds:

Z/γ\*, dibosons, ttbar, W+jets (simulated) QCD multijets (data-driven)

- Normalization to the Z peak: 80-110 GeV
- Good agreement with the Standard Model with *p*-values: 9% (ee) and 69% (μμ)
- Limits on further models using data taken in 2011 at  $\sqrt{s} = 7$  TeV [see appendix]

 $\mathcal{X} \rightarrow \gamma \gamma$ 



# Diphoton resonances $-\sqrt{s} = 7 \text{ TeV}$

- Tight photon selection:
  - Shower width and energy distribution in the EM Calorimeter
  - Isolation requirement
- Ambient energy correction
  - Removes contributions from the underlying event and pile-up
- Backgrounds: SM γγ (simulated);
   γj, jγ and jj (data-driven)
- Good agreement with the SM, with *p*-value 86%
- Combined with the dilepton analysis results at  $\sqrt{s} = 7$  TeV
- $G^* \rightarrow ee/\mu\mu/\gamma\gamma$ : M > 2.23 TeV, for k/ $\overline{M}_{_{Pl}} = 0.1$



 $\mathcal{X} \rightarrow \ell \nu$ 

### Lepton + neutrino resonances – $\sqrt{s}$ = 7 TeV

- Exactly one very-high-energy electron or muon, with high missing transverse momentum (E<sub>τ</sub><sup>miss</sup>)
- Same lepton selection as in the dilepton analysis
- Looking for an excess in the m<sub>T</sub> distribution:  $m_T = \sqrt{2p_T E_T^{\text{miss}}(1 \cos \varphi_{\ell \nu})}$
- Backgrounds:
  - Mainly W, but also Z/γ\* where one lepton is not reconstructed, dibosons, ttbar, single top (all simulated); QCD mulitjets (from data)



W' and W\*



## Lepton + neutrino resonances – $\sqrt{s}$ = 7 TeV



 $X \rightarrow VV$ 

#### Resonances $\rightarrow$ WW $\rightarrow$ lvlv $-\sqrt{s} = 7$ TeV

- Exactly two oppositely-charged high-p\_ leptons, and large  $E_{\rm T}^{\rm miss}$
- Suppress Z/γ\*: m<sub>µ</sub> > 106 GeV
- b-tag veto to reject ttbar events
- Cross-check Z/γ\* and ttbar background estimates using control regions
- Background fits for  $m_{\tau}^{WW} > 300 \text{ GeV}$





#### Resonances $\rightarrow$ WW $\rightarrow$ IvIv $-\sqrt{s} = 7$ TeV

- Exactly two oppositely-charged high- $p_{T}$  leptons, and large  $E_{T}^{miss}$
- Suppress Z/γ\*: m<sub>µ</sub> > 106 GeV
- b-tag veto to reject ttbar events
- Cross-check Z/γ\* and ttbar background estimates using control regions
- Background fits for  $m_{\tau}^{WW} > 300 \text{ GeV}$

- Sensitive to high-mass resonances
- No significant excess
- Looking for RS G\* and G\* bulk
- G\*: M > 1.23 TeV, for  $k/\overline{M}_{_{Pl}} = 0.1$

• 
$$G^*_{\text{bulk}}$$
: M > 0.84 TeV, for k/ $\overline{M}_{Pl}$  = 0.1



#### Resonances $\rightarrow$ ZW or ZZ $\rightarrow$ Ilqq, $\sqrt{s} = 8$ TeV

- Looking for an excess in the mass spectrum
- For very high-mass resonances, the W/Z are very boosted and hadronic decays merge into a single large jet
- Leptons from Z decay: 66 < m<sub>\_</sub> < 116 GeV

Ldt =  $7.2 \text{ fb}^{-1}$ 

**Resolved Signal Region** 

Merged Signal Region

ATLAS Preliminary

vs = 8TeV

1.2<sub>P</sub>

0.8

0.6

0.4

0.2

Acceptance



#### Resonances $\rightarrow$ ZW or ZZ $\rightarrow$ IIqq, $\sqrt{s}$ = 8 TeV

- Background fit function:
  - $p_0 \cdot \frac{(1-x)^{p_1}}{x^{p_2+p_3} \cdot \ln(x)},$  $x = m_{\ell\ell jj} / \sqrt{s}$  or  $m_{\ell\ell j} / \sqrt{s}$
- No significant excess
- G\*<sub>bulk</sub>: M > 0.88 TeV, for  $k/\overline{M}_{_{Pl}} = 1.0$

 $\sigma(\mathsf{pp} o \mathsf{G}^*) imes \mathsf{BR}(\,\mathsf{G}^* o \mathsf{ZZ}$  ) [pb] 01

10-2

400

600

800



3000

2×10<sup>3</sup>

m(llj) [GeV]

3rd generation searches

## Ditau resonances – $\sqrt{s}$ = 7 TeV

- New gauge bosons in theories beyond the SM may couple preferentially to 3<sup>rd</sup> generation fermions
- Hadronic tau decay identification
  - Boosted Decision Trees to discriminate against QCD jets
  - Using shower shape and tracking identification
- Backgrounds:
  - $Z/\gamma^*$ , Dibosons, ttbar, single top (simulated)
  - W+jets & QCD multijets (data-driven)
- Search performed by counting events above threshold in  $m_{_{\rm T}}^{_{tot}}$

$$m_{\rm T}^{\rm tot} = \sqrt{2p_{\rm T1}p_{\rm T2}C + 2E_{\rm T}^{\rm miss}p_{\rm T1}C_1 + 2E_{\rm T}^{\rm miss}p_{\rm T2}C_2}$$





#### Ditau resonances – $\sqrt{s}$ = 7 TeV

• Results with 2011 data at  $\sqrt{s}$  = 7 TeV, from 4 search channels



# Ditop resonances – Fully hadronic – $\sqrt{s} = 7$ TeV

- New physics may be related to the heavy top mass
- Hadronic top-tagging allows a search for resonances decaying to top quark pairs in the fully hadronic channel
- Two top-tagging algorithms with complementary results
- Data-driven QCD multijet background estimate



#### TopTemplateTagger



"alliets" 46%

µ+jets 15%

τ+jets 15%



## Ditop resonances – Fully hadronic – $\sqrt{s}$ = 7 TeV

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- Hadronic top-tagging allows a search for resonances decaying to top quark pairs in the fully hadronic channel
- Two top-tagging algorithms with complementary results
- Data-driven QCD multijet background estimate

 $g_{_{KK}}$  excluded for [0.70, 1.62] TeV; Z' in appendix



**Top Pair Branching Fractions** 

e+jets 15%

τ+τ 1%

"dileptons'

"alljets" 46%

µ+jets 15%

"lepton+jets"

τ+jets 15%

## Ditop resonances – Semi-leptonic – $\sqrt{s}$ = 7 TeV

- Semi-leptonic channel: evb+jjb or µvb+jjb
- Resolved selection: assign jets to either top quark using a  $\chi^2$  algorithm
- Boosted selection: one b-tag and one fat jet





## Top + jet resonances – $\sqrt{s}$ = 7 TeV

- Semi-leptonic ttbar selection, with at least one additional jet (at least 5 jets in total)
- Likelihood test to assign jets to either top quark
- The additional jets forming the highest top-jet and highest antitop-jet invariant mass are considered





# Top + jet resonances – $\sqrt{s} = 7$ TeV

- Semi-leptonic ttbar selection, with at least one additional jet (at least 5 jets in total)
- Likelihood test to assign jets to either top quark

**Colour-singlet limits** 

The additional jets forming the highest top-jet and highest antitop-jet invariant mass are considered





#### **Colour-triplet limits**

#### Conclusion

- We have searched for heavy resonances in the ATLAS experiment
- Looking forward to analyze the full 2012 dataset: > 20 fb<sup>-1</sup> !
- For more information:

~	Dijet	ATLAS-CONF-2012-148	
Te/	Dilepton	ATLAS-CONF-2012-129	
Ø	DijetATLAS-CONF-2012-14DileptonATLAS-CONF-2012-14ZW or ZZ $\rightarrow$ llqqATLAS-CONF-2012-15Dijet1210.1718Dilepton (resonant)1209.2535Dilepton (non-resonant)1211.1150Diphoton1210.8389Lepton + Neutrino1209.4446Ditau1210.6604WW $\rightarrow$ lvlv1208.2880Ditop, semi-leptonicATLAS-CONF-2012-13Ditop, fully hadronic1211.2202Top + Jet1209.6593	ATLAS-CONF-2012-150	
	Dijet	1210.1718	Submitted to JHEP
	Dilepton (resonant)	1209.2535	Accepted by JHEP
[eV	Dilepton (non-resonant)	1211.1150	Submitted to Phys. Rev. D
	Diphoton	1210.8389	Submitted to Phys. Lett. B
	Lepton + Neutrino	1209.4446	Submitted to EPJC
ן א_ו	Ditau	1210.6604	Submitted to Phys. Lett. B
٢	$WW \rightarrow IvIv$	1208.2880	Submitted to Phys. Lett. B
	Ditop, semi-leptonic	ATLAS-CONF-2012-136	
	Ditop, fully hadronic	1211.2202	Submitted to JHEP
	Top + Jet	1209.6593	Submitted to PRD Rapid C.



	Lorgo ED (ADD) : monoiet + E			
	Large ED (ADD) : monophoton + E	L=4.7 fb , 7 TeV [1210.4491]	4.37 lev	M <sub>D</sub> (0-2)
\$	Large ED (ADD) : diphoton & dilepton $m$	L=4.6 fb , 7 lev [1209.4625]	1.93 TEV MD (0-2)	M (HIZ S=3 NLO) ATLAS
uo	UED : diphoton + $E_{-}$	L=4.9 fb <sup>-1</sup> 7 TeV [1211.1130]	1 41 Tay Compact scale	Preliminary
Sli	$S^{1}/Z$ ED : dilepton m	L=4.0 fb , 7 feV [A1LAS-CONF-2012-072]	4 71 TeV	M ~ B <sup>-1</sup>
er	BS1 : diphoton & dilepton, m	1 =4.7-5.0 fb <sup>-1</sup> 7 TeV [1210.8380]	2 23 TeV Graviton	mass $(k/M_{-} = 0.1)$
im	RS1 : ZZ resonance m	$l = 1.0 \text{ fb}^{-1}$ 7 TeV [1203.0718]	845 GeV Graviton mass (k/Mar =	0.1)
0	RS1 : WW resonance. m	$I = 4.7 \text{ fb}^{-1}$ 7 TeV [1208.0810]	1 23 TeV Graviton mass (k)	$M_{\rm ev} = 0.1$ ) $Ldt = (1.0 - 13.0)  {\rm fb}^{-1}$
tro	RS g $\rightarrow$ tt (BR=0.925) : tt $\rightarrow$ I+jets, m	L=4.7 fb <sup>-1</sup> , 7 TeV [ATLAS-CONF-2012-136]	1.9 TeV g., mass	j ( , ,
Ě	ADD BH $(M_{TH}/M_{D}=3)$ : SS dimuon, $N_{sb, port}$	L=1.3 fb <sup>-1</sup> , 7 TeV [1111.0080]	1.25 TeV M <sub>D</sub> (δ=6)	(s = 7, 8 TeV
	ADD BH $(M_{TH}/M_{D}=3)$ : leptons + jets, $\Sigma p_{T}$	L=1.0 fb <sup>-1</sup> , 7 TeV [1204.4646]	1.5 TeV M <sub>D</sub> (δ=6)	
	Quantum black hole : dijet, F (m)	L=4.7 fb <sup>-1</sup> , 7 TeV [1210.1718]	4.11 TeV	M <sub>ρ</sub> (δ=6)
	qqqq contact interaction : $\hat{\chi}(m_{\perp})$	L=4.8 fb <sup>-1</sup> , 7 TeV [ATLAS-CONF-2012-038]		7.8 TeV Λ
G	qqll CI : ee & μμ, mื	L=4.9-5.0 fb <sup>-1</sup> , 7 TeV [1211.1150]		13.9 TeV A (constructive int.)
	uutt CI : SS dilepton + jets + E <sub>7.miss</sub>	L=1.0 fb <sup>-1</sup> , 7 TeV [1202.5520]	1.7 TeV A	
	Z' (SSM) : m <sub>ee/uu</sub>	L=5.9-6.1 fb <sup>-1</sup> , 8 TeV [ATLAS-CONF-2012-129	e) 2.49 TeV Z' mass	
	Z' (SSM) : m <sub>ee</sub>	L=4.7 fb <sup>-1</sup> , 7 TeV [1210.6604]	1.4 TeV Z' mass	
1	W' (SSM) : m <sub>T,e/µ</sub>	L=4.7 fb <sup>-1</sup> , 7 TeV [1209.4446]	2.55 TeV W' mas	s
_	W' ( $\rightarrow$ tq, g <sub>R</sub> =1) : $m_{tq}$	L=4.7 fb <sup>-1</sup> , 7 TeV [1209.6593]	430 GeV W' mass	
	$W'_R (\rightarrow tb, SSM) : m_{tb}$	L=1.0 fb <sup>-1</sup> , 7 TeV [1205.1016]	1.13 TeV W' mass	
	W* : <i>m</i> <sub>T.e/µ</sub>	L=4.7 fb <sup>-1</sup> , 7 TeV [1209.4446]	2.42 TeV W* mas	S
$\alpha$	Scalar LQ pair (β=1) : kin. vars. in eejj, evjj	L=1.0 fb <sup>-1</sup> , 7 TeV [1112.4828]	660 Gev 1° gen. LQ mass	
ΓC	Scalar LQ pair (β=1) : kin. vars. in μμjj, μvjj	L=1.0 fb <sup>-1</sup> , 7 TeV [1203.3172]	685 Gev 2" gen. LQ mass	
	Scalar LQ pair (β=1) : kin. vars. in ττjj, τvjj	L=4.7 fb <sup>-1</sup> , 7 TeV [Preliminary]	538 GeV 3" gen. LQ mass	
ks	4 <sup>th</sup> generation : t't'→ WbWb	L=4.7 fb <sup>-1</sup> , 7 TeV [1210.5468]	656 GeV t' mass	
ar	4 generation : D D (1 $_{5/3}$ ) $\rightarrow$ VVIVVI Now quark b' : b'b' $\rightarrow$ Zb+X m	L=4.7 fb", 7 TeV [ATLAS-CONF-2012-130]	670 GeV D (1 5/3) mass	
nb	Top partner: TT $\rightarrow$ tt + A A (dilepton M <sup>Zb</sup> )	L=2.0 fb <sup>-1</sup> , 7 TeV [1204.1265]	400 GeV b' mass	
×	Top partiel : $TT \rightarrow tt + A_0A_0$ (dilepton, $M_1$ )	L=4.7 fb <sup>-</sup> , 7 TeV [1209.4186]	483 GeV T mass (m(A) < 100 GeV)	1/2
Ve	Vector-like quark : NC m	L=4.6 fb , 7 TeV [ATLAS-CONF-2012-137]	1.12 lev VLQ mass (charge	$-1/3$ , coupling $\kappa_{q0} = \sqrt{m_Q}$
	Excited quarks : v-let resonance. m	L=4.6 fb , 7 TeV [ATLAS-CONF-2012-137]	1.08 TeV VLQ mass (charge .	$k_{qQ} = V/m_Q$
m.	Excited quarks : dijet resonance m	L=2.1 fb , / lev [1112.3560]	2.46 TeV Q IIIdS	* mass
μĘ	Excited lepton : I-y resonance, m	L=13.0 fb <sup>-1</sup> 8 TeV (ATLAS-CONE-2012-146)	2.2 TeV  * mass (/	$\Lambda = m(l^*)$
	Techni-hadrons (LSTC) ; dilepton, m	L=13.0 10 + 0 10 (1209 2535)	850 GeV 0 /0 mass (m(0 /0))-	$m(\pi) = M$
Teo	chni-hadrons (LSTC) : WZ resonance (vIII), m	$l = 1.0 \text{ fb}^{-1}$ 7 TeV (1204 1648)	<b>483 GeV</b> 0 mass $(m(0) = m(\pi_{-}) + m_{w}, m_{-}$	$(a_1) = 1.1m(o_1)$
5	Major neutr (LRSM no mixing) 2-lep + jets	L=2.1 fb <sup>-1</sup> , 7 TeV [1203.5420]	1.5  TeV N mass (m(W)	$(\Delta_{T}) = 2 \text{ TeV}$
he	W <sub>o</sub> (LRSM, no mixing) : 2-lep + jets	L=2.1 fb <sup>-1</sup> , 7 TeV [1203.5420]	2.4 TeV We mas	s (m(N) < 1.4 TeV)
õ	$H^{\pm}$ (DY prod., BR( $H^{\pm} \rightarrow \parallel$ )=1) : SS ee (µµ), m	L=4.7 fb <sup>-1</sup> , 7 TeV [1210.5070]	409 Gev H <sup>±±</sup> mass (limit at 398 GeV for μμ)	)
	H <sup>±</sup> (DY prod., BR(H <sup>±</sup> →eμ)=1) : SS eμ, m	L=4.7 fb <sup>-1</sup> , 7 TeV [1210.5070] 3	75 GeV H <sup>±±</sup> mass	
	Color octet scalar : dijet resonance, m	L=4.8 fb <sup>-1</sup> , 7 TeV [1210.1718]	1.86 TeV Scalar reso	nance mass
	<b>.</b>			
		10 <sup>-1</sup>	1	10 10
			·	Mass seals (T-)/
				wass scale [TeV]

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

- There are a lot more results from the ATLAS Exotics group!
- Other talks here by Andrée Robichaud-Véronneau and John Leslie Almond

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#### **BONUS SLIDES**

## Dilepton resonances – $\sqrt{s}$ = 7 TeV

Events





Backgrounds:

Z/γ\*, dibosons, ttbar (simulated) W+jets & QCD multijets (data-driven)

- Normalization to the Z peak: 70-110 GeV
- Good agreement with the Standard Model
   with *p*-values: 36% (ee) and 68% (μμ)

Model	$Z'_\psi$	$Z'_{ m N}$	$Z'_\eta$	$Z'_{ m I}$	$Z_{ m S}'$	$Z'_{\chi}$
Observed limit [TeV]	1.79	1.79	1.87	1.86	1.91	1.97
Expected limit [TeV]	1.87	1.87	1.92	1.91	1.95	2.00

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#### Dilepton resonances $-\sqrt{s} = 7$ TeV



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## Dilepton resonances – $\sqrt{s} = 7 \text{ TeV}$



#### Non-resonant dilepton and diphoton searches – $\sqrt{s}$ = 7 TeV

- Searches looking for an excess of events in the high-invariant-mass tail
- Contact interactions (Ilqq): Λ > 13.9 TeV for constructive interference, 1/Λ<sup>2</sup> prior
- ADD M<sub>s</sub> > [2.8, 4.2] TeV, depending on n<sub>ED</sub> and the choice of model and prior

Channel	Prior	Expect	Expected limit [TeV]			Observed limit [TeV]			
		Constr.	Des	Destr.		Constr.		tr.	
ee	$1/\Lambda^2$	13.8	10.4		12.1		9.5		
	$1/\Lambda^4$	12.5	9.8	9.8		11.4			
$\mu\mu$	$1/\Lambda^2$	12.7	9.9	)	12.9		9.6		
	$1/\Lambda^4$	11.6	9.1	9.1		11.7		)	
$ee + \mu\mu$	$1/\Lambda^2$	15.0	11.	$\begin{array}{c} 11.3 \\ 10.5 \end{array}$		13.9		10.2	
	$1/\Lambda^4$	13.8	10.			12.9		9.8	
Channel	Prior	GRW	Hewett			HLZ			
				n=3	n=4	n=5	n=6	n=7	
ee	$1/M_{ m S}^4$	2.95	2.63	3.51	2.95	2.66	2.48	2.34	
	$1/M_{ m S}^8$	2.82	2.67	3.08	2.82	2.68	2.59	2.52	
$\mu\mu$	$1/M_{ m S}^4$	3.07	2.74	3.65	3.07	2.77	2.58	2.44	
	$1/M_{ m S}^8$	2.82	2.67	3.08	2.82	2.68	2.59	2.52	
$ee + \mu\mu$	$1/M_{ m S}^4$	3.27	2.92	3.88	3.27	2.95	2.75	2.60	
	$1/M_{ m S}^8$	3.09	2.92	3.37	3.09	2.94	2.84	2.76	
$ee + \mu\mu$	$1/M_{ m S}^4$	3.51	3.14	4.18	3.51	3.17	2.95	2.79	
$+ \gamma \gamma$	$1/M_{ m S}^8$	3.39	3.20	3.69	3.39	3.22	<b>3</b> .11	3.02	

Dilepton distributions: number of events above m<sup>min</sup>



## Dijet resonances – $\sqrt{s}$ = 7 TeV

• Limits on further models, with 2011 data taken at  $\sqrt{s} = 7$  TeV



## Dijet angular analysis $-\sqrt{s} = 7$ TeV

• Angular analysis, with 2011 data at  $\sqrt{s} = 7$  TeV

 $y \equiv \frac{1}{2} \ln(\frac{E+p_z}{E-p_z}), y^* = \frac{1}{2}(y_1 - y_2)$ : Jet rapidity difference

$$\chi \equiv \exp(|y_1 - y_2|) = \exp(2|y^*|)$$

$$F_{\chi}(m_{jj}) \equiv rac{\mathrm{d}N_{\mathrm{central}}/\mathrm{d}m_{jj}}{\mathrm{d}N_{\mathrm{total}}/\mathrm{d}m_{jj}}, \ N_{\mathrm{central}} : |y^*| < 0.6$$











m<sub>ii</sub> [GeV]

## Dijet angular analysis – $\sqrt{s}$ = 7 TeV

- Angular analysis, with 2011 data at  $\sqrt{s}$  = 7 TeV
  - Data are consistent with QCD NLO simulation
  - Quantum black holes:  $M_D > 4.11$  TeV, for  $n_{ED} = 6$
  - Contact interactions: Λ > 7.6 TeV







m<sub>jj</sub> [GeV]

## Ditop resonances – Fully hadronic – $\sqrt{s}$ = 7 TeV

**Top Pair Branching Fractions** 

e+jets 15%

"alliets" 46%

µ+jets 15%

"lepton+jets"

τ+jets 15%

- New physics may be related to the heavy top mass
- Hadronic top-tagging allows a search for resonances decaying to top quark pairs in the fully hadronic channel
- Two top-tagging algorithms with complementary results
- Data-driven QCD multijet background estimate
- Leptophobic Z' excluded for [0.70, 1.00] TeV and [1.28, 1.32] TeV "dileptons"

