





7/Jan/2013, Cracow Epiphany Conference

# **Exotics Searches at ATLAS**

• After the discovery of Higgs-like particle, there are still some problems in the Standard Model

 $\rightarrow$  hierarchy problem, dark matter/energy, etc...

- There could be SUSY or other Exotics
- A lot of scenarios are being searched for in a lot of signatures



- More than 40 papers were published/submitted based on 7 TeV data of 2011
- 6 primary results are already available with 8 TeV data of 2012

# **New Phenomena in Dijet Mass**

#### ATLAS-CONF-2012-148, 8TeV, 13fb<sup>-1</sup>

- Search for excess in m<sub>ii</sub> distribution
- High p<sub>T</sub> 2jets event
- Fit m<sub>jj</sub> distribution with:  $f(x) = p_1(1-x)^{p_2}x^{p_3+p_4\ln x}$ where  $x = m_{jj}/\sqrt{s}$





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## **New Phenomena in Dijet Mass**



• Excited Quark Production: •  $\rightarrow M_{q^*} > 3.84 \text{ TeV}$ 



- Model Independent oxA limit
  - $\rightarrow$  Obtained by using simple Gaussian peaks with different width
- More models were searched for in 2011 study: <u>arXiv:1210.1718</u>
  - $\rightarrow$  Axigluon, Quantum Blackhole, RS Graviton
  - $\rightarrow$  Angular distribution of dijet was also studied in the same paper

## **New Phenomena in Dijet Mass**



Highest  $m_{ii}$  event:  $m_{ii}$  = 4.69TeV, Jet  $p_T$  = 2.29TeV, 2.19TeV

## **New Phenomena in Dilepton Mass**



$$m_{\mu\mu} = 1258 \text{GeV}$$
  
 $p_{T_{\mu}} = 289, 274 \text{ GeV}$ 

### ATLAS-CONF-2012-129, 8TeV, 6.1fb<sup>-1</sup>

- Search for high-mass dilepton resonances
- ee channel:
  - $\rightarrow$  E<sub>T</sub>>40, 30 GeV
  - $\rightarrow$  A × eff. (Z'(2TeV))=70%
- μμ channel
  - $\rightarrow\,p_T\,{>}25GeV$ , opposite sign
  - $\rightarrow$  A × eff. (Z'(2TeV))=39%
- Backgrounds
  - $\rightarrow$  Drell-Yan
  - $\rightarrow$  QCD multijet
  - $\rightarrow$  ttbar
  - $\rightarrow$  W+jets
  - $\rightarrow$  Diboson
- MC based except for QCD
  - → QCD distribution for m<sub>ee</sub> was obtained in looser ID electron control region

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### **New Phenomena in Dilepton Mass**



#### Uncertainties

Source	Dielectrons		Dimuons	
	Signal	Background	Signal	Background
Normalization	5%	NA	5%	NA
PDF / $\alpha_s$ / $\alpha_{em}$ / scale	NA	20%	NA	20%
Electroweak corrections	NA	4.5%	NA	4.5%
Efficiency	< 3%	< 3%	6%	6%
Dijet and $W$ + jets background	NA	21%	NA	< 3%
Total	5%	30%	8%	21%



	$Z'_{\rm SSM} \rightarrow e^+ e^-$	$Z'_{\rm SSM} \rightarrow \mu^+ \mu^-$	$Z'_{\rm SSM} \rightarrow \ell^+ \ell^-$
Observed mass limit [TeV]	2.39	2.19	2.49
Expected mass limit [TeV]	2.39	2.17	2.49

Model	$Z'_{\psi}$	$Z'_{\rm N}$	$Z'_{\eta}$	$Z'_I$	$Z'_{\rm S}$	$Z'_{\chi}$
Observed mass limit [TeV]	2.09	2.10	2.15	2.14	2.18	2.24
Expected mass limit [TeV]	2.07	2.08	2.14	2.13	2.17	2.23

### ATLAS-CONF-2012-150, 8TeV, 7.2fb<sup>-1</sup>

- Search for a resonance in the di-boson mass spectrum (Iljj final state)
- Z boson is highly boosted at high mass region
  - $\rightarrow$  Z boson hadronic decay products fall within the same jet
- Event selection
  - $\rightarrow$  ee or  $\mu\mu$  event
  - ightarrow 66 < m\_{||} < 116 GeV
  - → Resolved (Low mass) region ( $m_{IIjj}$  <1TeV) →  $p_{T_II}$  > 50GeV,  $\Delta \phi_{ij}$  < 1.6, 65 <  $m_{ij}$  < 115GeV
  - → Merged (High mass) region ( $m_{IIj}$ >1TeV) →  $p_{T |I|}$ > 200GeV,  $p_{T |I|}$ > 200GeV,  $m_i$ > 40GeV
  - → Regions were divided based on the sensitivity





### **Background estimation**

- Control region: inverted m<sub>ii</sub> or m<sub>i</sub> cut
- Fit  $m_{\text{IIJj}}$  or  $m_{\text{IIJj}}$  with the function:  $f(x) = p_1(1-x)^{p_2}x^{p_3+p_4\ln x}$ where  $x = m_{\text{IIJ}(j)}/\sqrt{s}$

### Uncertainties:

- Fit uncertainties:
  - $\rightarrow$  <5% for m<sub>IIII</sub> distribution
  - $\rightarrow$  10-40% for m<sub>IIj</sub> distribution
- Signal acceptance (lepton efficiency, jet energy scale/resolution, PDF, ISR/FSR, luminosity)
  - → **11-15%**



### **Background estimation**

- Control region: inverted m<sub>ij</sub> or m<sub>j</sub> cut
- Fit  $m_{\text{IIJj}}$  or  $m_{\text{IIJj}}$  with the function:  $f(x) = p_1(1-x)^{p_2}x^{p_3+p_4\ln x}$ where  $x = m_{\text{IIJ}(j)}/\sqrt{s}$

### Uncertainties:

- Fit uncertainties:
  - $\rightarrow$  <5% for m<sub>IIII</sub> distribution
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- Signal acceptance (lepton efficiency, jet energy scale/resolution, PDF, ISR/FSR, luminosity)
  - → **11-15%**







95% CL upper limits on  $\sigma B(G^* \rightarrow ZZ)$ m<sub>IIII</sub> (m<sub>III</sub>) was used for m<sub>G\*</sub> < (>) 1 TeV

Lower limit on the mass of the bulk RS Graviton for  $\kappa/M_{pl} = 1.0$ :  $m_{G^*} > 850$  GeV



Muons: ( $p_T = 439.7 \text{ GeV}, \eta = -0.833, \phi = 2.81$ ), ( $p_T = 207.5 \text{ GeV}, \eta = -0.903, \phi = 3.10$ ) Leading jet  $p_T = 718.9 \text{ GeV}, \eta = 1.947, \phi = -0.474, m = 46.0 \text{ GeV},$ sub-leading jet  $p_T = 232.6 \text{ GeV}, p_{T_u\mu} = 641.3 \text{ GeV}, m_{\mu\mu} = 89.7 \text{GeV}, m_{\mu\mu} = 2.93 \text{ TeV}$ 

# **Excited Lepton Search**



- Search for  $q\bar{q} \to l^*\bar{l}(l^* \to l\gamma)$ ,  $\bar{q}$
- $e^+e^-\gamma$  and  $\mu^+\mu^-\gamma$  final state
- Dominant background
  - $\rightarrow$  Drell-Yan:
  - Z+γ and Z+jets (fake photon)

Z+jets can be suppressed by tight photon requirement

- Selection:
  - $\rightarrow$  e channel:p<sub>T\_e1</sub>> 40GeV, p<sub>T\_e2</sub> > 35GeV
  - $\rightarrow \mu \text{ channel:p}_{T_{\mu 1,2}} > 25 GeV$
  - $\rightarrow$  p<sub>T y</sub> > 30GeV, isolated from leptons
  - $\rightarrow m_{\parallel} > 100 GeV$
- Background estimation
  - $\rightarrow$  Based on Monte Carlo
  - → Z+jets scale factor was estimated from 70<m<sub>II</sub><110GeV (correct  $\gamma$  fake ratio)
  - $\rightarrow$  For m<sub>II</sub>>250GeV, Z+ $\gamma$ /jet distributions were extrapolated from low m<sub>II</sub> region using fitting



## **Excited Lepton Search**



#### Uncertainties for m<sub>I\*</sub>=200GeV

Source	<i>e</i> *		$\mu^*$			
	Signal Background		Signal	Background		
Extrapolation	NA	5%	NA 6%			
Theory	NA	6%	6% NA			
Luminosity	4%	4%	4%	4%		
Efficiency	4%	4%	4%	4%		
Total	6%	10%	6% 10%			
Uncertainties for m <sub>I*</sub> =2TeV						
Source		e*		μ*		
	Signal	Background	Signal	Background		
Extrapolation	NA	39%	NA	40%		
Theory	NA	8%	NA	8%		
Luminosity	4%	4%	4%	4%		
Efficiency	6%	4%	6%	5%		
Total	7%	40%	7%	41%		

- Excited Electron  $\rightarrow \sigma B < 0.6 \text{ fb for } m_{e^*} > 0.8 \text{ TeV}$  $\rightarrow m_{e^*} > 2.2 \text{ TeV for } \Lambda = m_{e^*}$
- Excited Muon  $\rightarrow \sigma B < 0.7 \text{ fb for } m_{e^*} > 0.8 \text{ TeV}$  $\rightarrow m_{\mu^*} > 2.2 \text{ TeV for } \Lambda = m_{\mu^*}$

# <u>Mono-jet Search</u>

### ATLAS-CONF-2012-147, 8TeV, 10fb<sup>-1</sup>

- Searched for new phenomena in monoict uniccipal E event
  - jet + missing E<sub>T</sub> event
    - $\rightarrow$  ADD Graviton, squark/gluino+Gravitino
    - $\rightarrow$  Weakly Interacting Massive Particles (WIMP)
- Event selection
  - $\rightarrow$  missE\_T>120GeV, Leading Jet p\_T>120GeV
  - $\rightarrow$  I $\Delta\phi$ (missE<sub>T</sub>,2nd Jet)I>0.5
  - $\rightarrow$  3rd Jet p<sub>T</sub> < 30 GeV
  - $\rightarrow$  Lepton veto
  - $\rightarrow$  4 Signal regions (SR1,2,3,4):

missE<sub>T</sub>, Leading Jet  $p_T > (120, 220, 350, 500)$  GeV

- Backgrounds
  - $\rightarrow$  Z(vv)+jets (dominant): Data driven
  - $\rightarrow$  W/Z+jets: data driven
  - $\rightarrow$  QCD multijet: data driven
  - $\rightarrow$  Non-collision: data driven
  - $\rightarrow$  Top, Dibosons: MC based



ADD Graviton (LED) squark/gluino+Gravitino



WIMP production



### EW background estimation

- Control region:  $W(I_V)$ +jets/Z(II)+jets
  - $\rightarrow$  e.g.) W(µv)+jets: 1µ, 40<m<sub>T</sub><100 GeV
- Apply transfer factors (MC base)

 $\rightarrow$  e.g.) Estimation Z(vv)+jets from W(uv)+jets

 $N(Z(\rightarrow \nu\bar{\nu}) + jets)_{SR} = (N_{W\rightarrow\mu\nu,CR}^{data} - N_{W,CR}^{BG}) \times \frac{N^{MC}(Z(\rightarrow\nu\bar{\nu}+jets)_{SR})}{N_{W\rightarrow\mu\nu,CR}^{MC}} + \frac{N^{MC}(Z(\rightarrow\nu\bar{\nu}+jets)_{SR})}{N_{W\rightarrow\mu\nu,CR}^{MC}} + \frac{N^{MC}(Z(\rightarrow\nu\bar{\nu}+jets)_{SR})}{N_{W\rightarrow\mu\nu,CR}^{MC}} + \frac{N^{MC}(Z(\rightarrow\nu\bar{\nu}+jets)_{SR})}{N_{W\rightarrow\mu\nu,CR}^{MC}} + \frac{N^{MC}(Z(\rightarrow\nu\bar{\nu}+jets)_{SR})}{N_{W\rightarrow\mu\nu,CR}} + \frac{N^{MC}(Z(\rightarrow\nu\bar{\nu}+jets)_{SR})}{N_{W\rightarrow\mu\nu,CR}} + \frac{N^{MC}(Z(\rightarrow\nu\bar{\nu}+jets)_{SR})}{N_{W\rightarrow\mu\nu,CR}} + \frac{N^{MC}(Z(\rightarrow\nu\bar{\nu}+jets)_{SR})}{N_{W,CR}} + \frac$ 



 $m_{T}$  distribution in SR1 but 1µ required instead of lepton veto



### Multijet background estimation

- Main source is misreconstruction of the energy
- **Control region** 
  - $\rightarrow$  Dijet (for single-jets data):  $|\Delta \phi(\text{missE}_{\tau}, 2\text{nd Jet})|$ < 0.5
  - $\rightarrow$  3-jets (for two-jets data): require 3rd jet, I  $\Delta \phi$ (missE<sub>T</sub>,3rd Jet)I<0.5
- Extrapolate  $p_T$  distribution to below jet  $p_T$  threshold (30GeV)

## Mono-jet Search



Similar search in mono-photon is available in arXiv:1209.4625 (7TeV)

## **New Results with 7 TeV data**





- A lot of signatures are being studied for the new physics search
  →No new physics indication has been found...
- More 8 TeV results will be coming soon!
- There will be more exciting challenges with 13-14 TeV run in 2015!



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

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults



ATLAS Exotics Searches\* - 95% CL Lower Limits (Status: HCP 2012)

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	Large ED (ADD) : monojet + $E_{T,miss}$	L=4.7 fb <sup>-1</sup> , 7 TeV [1210.4491]	4	<b>.37 TeV</b> <i>M</i> <sub>D</sub> (δ=2)	
	Large ED (ADD) : monophoton + $E_{T \text{ miss}}$	L=4.6 fb <sup>-1</sup> , 7 TeV [1209.4625]	1.93 TeV M <sub>D</sub>	(δ=2)	
SL	Large ED (ADD) : diphoton & dilepton, m	L=4.7 fb <sup>-1</sup> , 7 TeV [1211.1150]	4.	18 τεν Μ <sub>S</sub> (HLZ δ=3, NLO)	AILAS
10	UED : diphoton + $E_{T,\text{miss}}$	L=4.8 fb <sup>-1</sup> , 7 TeV [ATLAS-CONF-2012-072]	1.41 TeV Compac	t. scale R <sup>-1</sup>	Preliminary
ns	$S^{1}/Z_{2}$ ED : dilepton, $m_{\mu}$	L=4.9-5.0 fb <sup>-1</sup> , 7 TeV [1209.2535]		4.71 ТеV М <sub>КК</sub> ~ R <sup>-1</sup>	
he	RS1 : diphoton & dilepton, m	L=4.7-5.0 fb <sup>-1</sup> , 7 TeV [1210.8389]	2.23 TeV G	raviton mass $(k/M_{Pl} = 0.1)$	
lin	RS1 : ZZ resonance, m	L=1.0 fb <sup>-1</sup> , 7 TeV [1203.0718]	845 Gev Graviton mass (	$k/M_{\rm Pl} = 0.1$ )	
m	RS1 : WW resonance, $m_{T,byly}$	L=4.7 fb <sup>-1</sup> , 7 TeV [1208.2880]	1.23 TeV Graviton m	hass $(k/M_{\rm Pl} = 0.1)$ Ldi	$t = (1.0 - 13.0) \text{ fb}^{-1}$
<i>ktr</i>	RS g <sub>KK</sub> $\rightarrow$ 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 9 <sub>кк</sub>	mass J	
Ш	ADD BH ( $M_{TH}/M_{D}=3$ ) : SS dimuon, $N_{ch, part}$	L=1.3 fb <sup>-1</sup> , 7 TeV [1111.0080]	1.25 TeV M <sub>D</sub> (δ=6)		s = 7,8 lev
	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, $F_{y}(m_{ij})$	L=4.7 fb <sup>-1</sup> , 7 TeV [1210.1718]	4.1	<b>11 TeV</b> $M_D(\delta=6)$	
	qqqq contact interaction : $\chi(m_{ij})$	L=4.8 fb <sup>-1</sup> , 7 TeV [ATLAS-CONF-2012-038]		7.8 TeV Λ	
C	qqll CI : ee & μμ, m_	L=4.9-5.0 fb <sup>-1</sup> , 7 TeV [1211.1150]		13.9 TeV Λ (C	onstructive int.)
	uutt CI : SS dilepton + jets + $E_{T.miss}$	L=1.0 fb <sup>-1</sup> , 7 TeV [1202.5520]	1.7 TeV Λ		
	Z' (SSM) : <i>m</i> <sub>ee/uu</sub>	L=5.9-6.1 fb <sup>-1</sup> , 8 TeV [ATLAS-CONF-2012-129]	2.49 TeV	Z' mass	
	Z' (SSM) : <i>m</i> <sub>TT</sub>	L=4.7 fb <sup>-1</sup> , 7 TeV [1210.6604]	1.4 TeV Z' mass		
2	W' (SSM) : m <sub>T e/u</sub>	L=4.7 fb <sup>-1</sup> , 7 TeV [1209.4446]	2.55 TeV	W' mass	
~	W' ( $\rightarrow$ tq, g <sub>p</sub> =1) : $m_{tq}$	L=4.7 fb <sup>-1</sup> , 7 TeV [1209.6593] 43	0 GeV W' mass		
	$W'_{R} (\rightarrow tb, SSM) : m_{tb}^{T}$	L=1.0 fb <sup>-1</sup> , 7 TeV [1205.1016]	1.13 TeV W' mass		
	W* : <i>m</i> <sub>T.e/u</sub>	L=4.7 fb <sup>-1</sup> , 7 TeV [1209.4446]	2.42 TeV	N* mass	
~	Scalar LQ pair ( $\beta$ =1) : kin. vars. in eejj, evjj	L=1.0 fb <sup>-1</sup> , 7 TeV [1112.4828]	660 Gev 1 <sup>st</sup> gen. LQ mass		
L L	Scalar LQ pair ( $\beta$ =1) : kin. vars. in µµjj, µvjj	L=1.0 fb <sup>-1</sup> , 7 TeV [1203.3172]	685 GeV 2 <sup>nd</sup> gen. LQ mass		
	Scalar LQ pair (β=1) : kin. vars. in ττjj, τνjj	L=4.7 fb <sup>-1</sup> , 7 TeV [Preliminary]	538 GeV 3 <sup>rd</sup> gen. LQ mass		
S	4 <sup>th</sup> generation : t't'→ WbWb	L=4.7 fb <sup>-1</sup> , 7 TeV [1210.5468]	656 GeV t' mass		
ark	$4^{tn}$ generation : b'b'( $T_{5/3}T_{5/3}$ ) $\rightarrow$ WtWt	L=4.7 fb <sup>-1</sup> , 7 TeV [ATLAS-CONF-2012-130]	670 Gev b' (T <sub>5/3</sub> ) mass		
ļn	New quark b' : b' $\ddot{b} \rightarrow Zb+X, m_{zb}$	L=2.0 fb <sup>-1</sup> , 7 TeV [1204.1265] 400	GeV b' mass		
7	Top partner : TT $\rightarrow$ tt + A <sub>0</sub> A <sub>0</sub> (dilepton, M <sub>T2</sub> )	L=4.7 fb <sup>-1</sup> , 7 TeV [1209.4186]	<b>483 GeV</b> T mass $(m(A_0) < 100 \text{ Ge})$	eV)	
lev	Vector-like quark : CC, $m_{lvq}$	L=4.6 fb <sup>-1</sup> , 7 TeV [ATLAS-CONF-2012-137]	1.12 TeV VLQ mass (	charge -1/3, coupling $\kappa_{qQ} = v$	/m <sub>o</sub> )
<	Vector-like quark : NC,m <sub>llq</sub>	L=4.6 fb <sup>-1</sup> , 7 TeV [ATLAS-CONF-2012-137]	1.08 TeV VLQ mass (	charge 2/3, coupling $\kappa_{qQ} = v/r$	n <sub>o</sub> )
it. n.	Excited quarks : γ-jet resonance, m	L=2.1 fb <sup>-1</sup> , 7 TeV [1112.3580]	2.46 TeV	q* mass	
N LE	Excited quarks : dijet resonance, $\ddot{m}_{ii}$	L=13.0 fb <sup>-1</sup> , 8 TeV [ATLAS-CONF-2012-148]	3.84	tev q* mass	
ЩК	Excited lepton : I-γ resonance, m	L=13.0 fb <sup>-1</sup> , 8 TeV [ATLAS-CONF-2012-146]	2.2 TeV <sup> *</sup>	mass $(\Lambda = m(I^*))$	
_	Techni-hadrons (LSTC) : dilepton,mee/µµ	L=4.9-5.0 fb <sup>-1</sup> , 7 TeV [1209.2535]	<mark>850 GeV</mark> ρ <sub>_</sub> /ω <sub>τ</sub> mass ( <i>m</i> (	$\sigma_{\rm T}/\omega_{\rm T}) - m(\pi_{\rm T}) = M_{\rm W})$	
Te	echni-hadrons (LSTC) : WZ resonance (/III), m	L=1.0 fb <sup>-1</sup> , 7 TeV [1204.1648]	<b>483 GeV</b> $\rho_{T}$ mass $(m(\rho_{T}) = m(\pi_{T}) - m(\pi_{T})$	$m_{W}, m(a_{T}) = 1.1 m(\rho_{T})$	
er	Major. neutr. (LRSM, no mixing) : 2-lep + jets	L=2.1 fb <sup>-1</sup> , 7 TeV [1203.5420]	1.5 TeV N mass	$(m(W_B) = 2 \text{ TeV})$	
th	W <sub>R</sub> (LRSM, no mixing) : 2-lep + jets	L=2.1 fb <sup>-1</sup> , 7 TeV [1203.5420]	2.4 TeV	$N_R$ mass ( $m(N) < 1.4$ TeV)	
0	$H_{L}^{\pm\pm}$ (DY prod., BR( $H_{L}^{\pm\pm} \rightarrow II$ )=1) : SS ee ( $\mu\mu$ ), $m_{\mu}$	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 <sup>"</sup> <sub>eu</sub>	L=4.7 fb <sup>-1</sup> , 7 TeV [1210.5070] 375 (	aev H <sup>±±</sup> mass		
	Color octet scalar : dijet resonance, $m_{ii}$	L=4.8 fb <sup>-1</sup> , 7 TeV [1210.1718]	1.86 TeV Scal	ar resonance mass	
		10 <sup>-1</sup>	1	10	10 <sup>2</sup>
		10	•		
* Only	a coloction of the queilable mass limits or your states -	a phonomono a phone		Ma	ass scale [IeV]
Only	a selection of the available mass limits on new states of https://	/twiki.cern.ch/twiki/bin/vi	ew/AtlasPublic/Exotics	PublicResults	



# **Dijet: Angular Distribution**

#### arXiv:1210.1718, 7TeV, 4.8fb<sup>-1</sup>



# Mono-jet Search



#### <u>arXive:1210.4491</u>, 7TeV, 4.7fb<sup>-1</sup>





#### arXiv:1209.4625, 7TeV, 4.6fb<sup>-1</sup>









Photon  $p_T = 218 \text{GeV}$ Missint $E_T = 218 \text{GeV}$ 





