Search for Z^* boson at ATLAS detector

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on behalf of ATLAS collaboration

1. Theoretical backgrounds
2. Properties of Z^*
3. 2011 ATLAS experimental results
4. Conclusions and outlook

‘Why not?’ motivation

$$\mathcal{L}_{\psi^*} = \frac{g}{\Lambda} \bar{\psi}^* \sigma^{\mu\nu} \psi \cdot (\partial_\mu Z_\nu - \partial_\nu Z_\mu)$$

Searches for excited fermions ψ^* have been performed at LEP, HERA, Tevatron, and LHC
(e.g., ATLAS-CONF-2012-008)

ψ^* - why not Z^* ?

$$\mathcal{L}_{Z^*} = \frac{g}{\Lambda} \bar{\psi} \sigma^{\mu\nu} \psi \cdot (\partial_\mu Z_\nu^* - \partial_\nu Z_\mu^*)$$

M.V. Chizhov, V.A. Bednyakov, and J.A. Budagov, Proposal for chiral bosons search at LHC via their unique new signature, *Phys. Atom. Nucl.* **71** (2008) 2096; arXiv:0801.4235

Theoretical backgrounds

Hierarchy problem motivated theories

One of the theoretical motivations for beyond the Standard Model physics around TeV energies (LHC) is provided by the Hierarchy Problem - an inexplicable ultraviolet stability of the weak interaction scale.

Weak mass scale $M_{W,Z}=10^2\text{GeV}$ versus the Planck scale $M_P=10^{19}\text{GeV}$

Introduction of new spin-1 bosons with the internal quantum numbers identical to the Standard Model Higgs doublet can help to solve by the hierarchy problem.

$$\begin{pmatrix} H^+ \\ H^0 \end{pmatrix} \leftrightarrow \begin{pmatrix} W_\mu^{*+} \\ Z_\mu^* \end{pmatrix}$$

Hierarchy problem motivated theories

The common feature of these models is the existence of the $SU(3)_W$ gauge extension of the weak $SU(2)_W$ group, which is broken down to the latter at some energy scale around TeV.

In such theory - there exists the electroweak doublet vectors (Z^*, W^*) which possesses only anomalous couplings.

$$\begin{aligned}\mathcal{L}_{(Z^*W^*)} = & \frac{g_d}{\Lambda} (\bar{u}_L \bar{d}_L) \sigma^{\mu\nu} d_R \cdot \left[\partial_\mu \begin{pmatrix} W_\nu^{*+} \\ Z_\nu^* \end{pmatrix} - \partial_\nu \begin{pmatrix} W_\mu^{*+} \\ Z_\mu^* \end{pmatrix} \right] \\ & + \frac{g_u}{\Lambda} (\bar{u}_L \bar{d}_L) \sigma^{\mu\nu} u_R \cdot \left[\partial_\mu \begin{pmatrix} \bar{Z}_\nu^* \\ -W_\nu^{*-} \end{pmatrix} - \partial_\nu \begin{pmatrix} \bar{Z}_\mu^* \\ -W_\mu^{*-} \end{pmatrix} \right] + \text{h.c.}\end{aligned}$$

M. Chizhov and G. Dvali "Origin and Phenomenology of Weak-Doublet Spin-1 Bosons", Phys.Lett. **B703** (2011) 593-598; arXiv:0908.0924

Theories, where W,Z are not elementary

Some theories suggest that SM weak bosons are not elementary

(e.g., H.Fritzsch “Composite Weak Bosons at the LHC”, arxiv:1203.5600)

Thus - weak dynamics could be similar to hadron dynamics

In this sense the most interesting is axial-vector b_1 meson, which has only anomalous interaction with the tensor current $\partial_\nu (\bar{q} \sigma_{\mu\nu} \gamma_5 q)$

It could be an analogue of Z^* in weak field theory.

Properties of Z^*

Several models predict new high mass neutral resonances that could decay into dilepton pairs (Z' , G^* , Z^* , Technicolor, Kaluza-Klein, etc.)

Properties of Z^*

Unique angular distribution of Z^*

$$\mathcal{L}_{Z^*} = \frac{g}{\Lambda} \bar{\psi} \sigma^{\mu\nu} \psi \cdot (\partial_\mu Z_\nu^* - \partial_\nu Z_\mu^*)$$

In case discovered, Z^* can be easily distinguished from other types of resonances

ATLAS experimental results

Search for Z^* in di-lepton channel was performed at ATLAS detector in 2010, 2011 and is going in 2012

ATLAS experiment

Signal process and it's major backgrounds

Signal	Z/γ^*	ZZ, WZ, WW	$t\bar{t}$	QCD

Event display of the selected event with the highest dimuon invariant mass in 2011 data. Muons are indicated via solid blue lines. The invariant mass of the pair is 1252 GeV.

Data/Standard Model expectation comparison

Dimuon channel

$m_{\mu^+\mu^-}$ [GeV]	110 - 200	200 - 400	400 - 800	800 - 1200	1200 - 3000
Z/γ^*	21246 ± 1200	2095 ± 230	173 ± 15	7.7 ± 0.8	0.98 ± 0.16
$t\bar{t}$	863 ± 100	268 ± 50	18 ± 11	0.32 ± 0.07	0.019 ± 0.007
Diboson	289 ± 32	97 ± 24	11.8 ± 2.7	0.59 ± 0.26	0.087 ± 0.016
Total	22405 ± 1200	2463 ± 240	203 ± 19	8.7 ± 0.9	1.09 ± 0.16
Data	21945	2294	197	10	2

Data/Standard Model expectation comparison

Dielectron channel

$m_{e^+e^-} [\text{GeV}]$	110 - 200	200 - 400	400 - 800	800 - 1200	1200 - 3000
Z/γ^*	26700 ± 700	2960 ± 80	265 ± 13	12.1 ± 0.9	1.47 ± 0.18
$t\bar{t}$	1300 ± 60	408 ± 24	26.5 ± 2.8	0.41 ± 0.17	0.034 ± 0.034
Diboson	415 ± 12	146 ± 5	16.2 ± 0.9	0.88 ± 0.05	0.101 ± 0.011
QCD and $W + \text{jets}$	1890 ± 320	510 ± 120	50 ± 31	2.0 ± 1.8	0.26 ± 0.31
Total	30300 ± 800	4030 ± 140	357 ± 34	15.4 ± 2.0	1.86 ± 0.35
Data	29816	4026	358	17	3

Control plots

Dielectron channel

Dimuon channel

Data/Standard Model expectation comparison

Dielectron channel

$M_{Z^*} > 2.10 \text{ TeV}$

Dimuon channel

$M_{Z^*} > 1.97 \text{ TeV}$

In the absence of a signal, upper limits on the number of events produced by the decay of a new resonance Z^* are determined at the 95% CL (confidence level).

The expected exclusion limits are determined using simulated pseudoexperiments containing only Standard Model processes by evaluating the 95% CL upper limits for each pseudoexperiment for each fixed value of the resonance pole mass M_{Z^*} .

Data/Standard Model expectation comparison

Combination of two channels

Upper limit on Z^* mass in 2011

$M_{Z^*} > 2.20 \text{ TeV}$

Conclusions and outlook

2012 analysis

Transition to the proton-proton center of mass energy of 8TeV at LHC led to increase of theoretical signal cross sections.

In case of successful 2012 data taking campaign (plans are to record $\sim 25\text{fb}^{-1}$ of data) the dilepton mass range investigated will be broaden up significantly.

Relative increase of Z^* production cross section at 8TeV compared to 7TeV collisions, depending on the Z^* mass. Relative increase at 2.5TeV is ~ 3.0 .

Conclusions and outlook

2012 analysis

Due to Z^* unique angular distribution, the additional selection, suppressing SM backgrounds can be introduced.

Additional cut for final leptons
 $|\eta_1 - \eta_2| > 0.9$ is expected to bring 10-15% increase of the signal over SM background statistics.

Conclusions

- ATLAS detector 2011 data showed good agreement with SM expectation in dilepton channel
- In the absence of a signal – new upper limits were set on a number of theoretical models.
- $M_{Z^*} > 2.20 \text{ GeV}$.
- Improvements on analysis are implemented for 2012

Backup slides

Event selection

Dielectron channel

$E_T > 25 \text{ GeV}$

$|\eta| < 2.47$, excluding crack $1.37 < |\eta| < 1.52$

Cuts on shower shape and track matching

A hit in the first layer of the pixel detector is required if to suppress background from photon conversions

Higher E_T must be isolated requiring
 $\Sigma E_T (\Delta R < 0.2) < 7 \text{ GeV}$ – to suppress QCD background

Dimuon channel

$p_T > 25 \text{ GeV}$

$|\eta| < 2.5$

Muons with combined ID+MS tracks

Muons with opposite charge

Both muons must be isolated
 $\Sigma p_T (\Delta R < 0.3) / p_T < 0.05$

	$Z'_{\text{SSM}} \rightarrow e^+e^-$	$Z'_{\text{SSM}} \rightarrow \mu^+\mu^-$	$Z'_{\text{SSM}} \rightarrow \ell^+\ell^-$
Observed limit [TeV]	2.08	1.99	2.22
Expected limit [TeV]	2.13	2.00	2.25

$k/\overline{M}_{\text{Pl}}$	0.01	0.03	0.05	0.1	0.12	0.14	0.17	0.2
Observed limit [TeV]	0.92	1.49	1.72	2.16	2.23	2.32	2.42	2.51
Expected limit [TeV]	1.02	1.53	1.81	2.17	2.25	2.33	2.44	2.53