ATLAS EXPERIMENT

Search for contact interactions and large extra dimensions in the dilepton channel using proton-proton collisions at √s = 8 TeV with the ATLAS detector

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Abstract

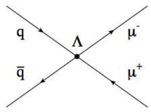
A search is conducted for non-resonant new phenomena in dielectron and dimuon final states, originating from either contact interactions or large extra spatial dimensions [1].
The full LHC 2012 proton-proton collision dataset recorded by the ATLAS detector is used, corresponding to 20 fb^{-1} at √s = 8 TeV.
The invariant mass spectrum is used as a discriminating variable alongside forward-backward asymmetry where relevant to increase the search sensitivity.
A Bayesian approach is used to set lower limits on the new physics parameters of interest at the 95% credibility level.

Theory

Contact Interactions

A contact interaction (CI) could be caused by

- quark-lepton compositeness or
- any new interaction with a massive mediator.



CI Lagrangian [2]:

$$\mathcal{L} = \frac{g^2}{\Lambda^2}\left[\eta_{LL}\left(\bar{q}_L\gamma_\mu q_L\right)\left(\ell_L\gamma^\mu\ell_L\right) + \eta_{RR}\left(\bar{q}_R\gamma_\mu q_R\right)\left(\ell_R\gamma^\mu\ell_R\right) + \eta_{LR}\left(\bar{q}_L\gamma_\mu q_L\right)\left(\ell_R\gamma^\mu\ell_R\right) + \eta_{RL}\left(\bar{q}_R\gamma_\mu q_R\right)\left(\bar{\ell}_L\gamma^\mu\ell_L\right)\right],$$

where: energy scale Λ corresponds to the binding energy between fermion constituents
η_{ij} defines the chiral structure of the interaction where i and j are L or R (left or right)
Sign of η dictates if interference is constructive (-) or destructive (+).

CI cross-section:
$$\sigma_{\rm tot} = \sigma_{\rm DY} - \eta_{ij}\frac{F_{\rm I}}{\Lambda^2} + \frac{F_{\rm C}}{\Lambda^4}\,.$$

has a Drell-Yan (DY) component, interference (F_I) and pure CI (F_C) terms.

Large Extra Dimensions (ADD)

Introduced to explain the vast hierarchy between the electroweak and Planck scales.
Arkani-Hamed, Dimopoulos, and Dvali (ADD) postulated *n* additional large flat spatial dimensions of size R compactified on an n-dimensional torus [3].
The fundamental Planck scale M_D and the observed M_{Pl}, related by $M_{Pl}^2 \sim M_D^{n+2}R^n$.
Only the gravitons propagate into the extra dimensions.

Cross-section:
$$\sigma_{\rm tot} = \sigma_{\rm DY} + \mathcal{F}\frac{F_{\rm int}}{M_S^4} + \mathcal{F}^2\frac{F_G}{M_S^8},$$

has DY, interference and pure Graviton terms.
The interaction strength is characterized by $\mathcal{F}/M_S^4$, where $\mathcal{F}$ depends on formalism:
Giudice–Rattazzi–Wells (GRW) [4], Hewett [5] and Han–Lykken–Zhang (HLZ) [6].

$$\mathcal{F} = 1, \quad (\text{GRW}) \qquad \mathcal{F} = \log\left(\frac{M_S^2}{s}\right) \text{ for } n=2, \quad (\text{HLZ})$$
$$\mathcal{F} = \frac{2\lambda}{\pi} = \frac{\pm 2}{\pi}, \quad (\text{Hewett}) \qquad \mathcal{F} = \frac{2}{n-2} \text{ for } n>2. \quad (\text{HLZ})$$

Dielectron & Dimuon Analyses

Event Selection

Dielectron
$|\eta| < 2.47$ (excluding 1.37 – 1.52)
$p_T > 40$ GeV (leading) and 30 GeV (sub-leading)

Dimuon
$|\eta| < 2.5$
$p_T > 25$ GeV
$|z_0| < 1$mm wrt PV
$|d_0| < 0.2$ mm wrt PV

ee/μμ highest lepton p_T pair
opposite signs & invariant mass ($M_{ee}/M_{\mu\mu}$) > 80 GeV

Main Backgrounds

- Drell-Yan
- Top
- Multi-Jet & W+Jets*,
- Di-Boson
- Photon-Induced processes

- Simulated using Monte-Carlo and reconstructed using Geant4
- Except *, estimated by data-driven method (non negligible for electron channel)
- MC is normalized to data $M_{ee}/M_{\mu\mu}$ in region 80-120 GeV

Search Regions

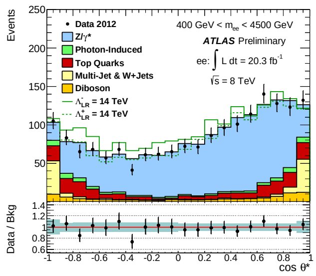
Contact Interactions

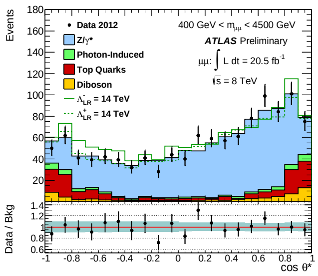
Discriminating variables: $M_{ee}/M_{\mu\mu}$ & Forward/Backward CosTheta*
Search Region: 6 mass bins: in range 400-4500 GeV

CosTheta*

The dilepton decay angle, θ*, defined in the Collins–Soper frame [7].
θ*: angle between the outgoing lepton and the incoming quark direction in the dilepton rest frame.
Then the initial quark direction is chosen to be the dilepton boost direction.

$$\cos\theta^* = \frac{p_z(\ell^+\ell^-)}{|p_z(\ell^+\ell^-)|}\frac{2(p_1^+p_2^- - p_1^-p_2^+)}{m(\ell^+\ell^-)\sqrt{m(\ell^+\ell^-)^2 + p_T(\ell^+\ell^-)^2}}\,.$$

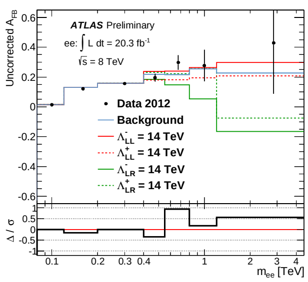


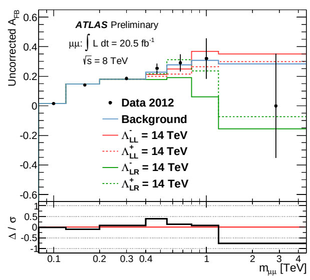


Forward-Backward Asymmetry

$$A_{\rm FB} = \frac{N_{\rm F} - N_{\rm B}}{N_{\rm F} + N_{\rm B}}\,.$$

where N_F : Cosθ* > 0 and N_B : Cosθ* < 0

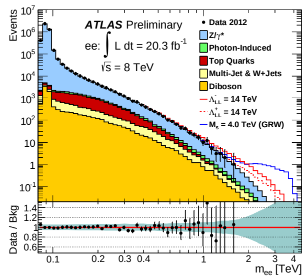


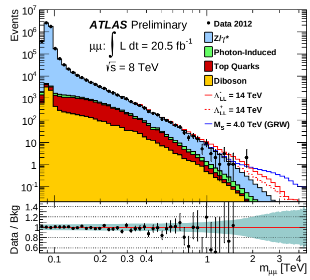


Large Extra Dimensions

Discriminating variables: $M_{ee}/M_{\mu\mu}$
Search Region: 1 mass bin in range1900-4500 GeV

Invariant Mass $M_{ee}/M_{\mu\mu}$





Systematic Uncertainties

Mass-dependent systematic uncertainties can affect the shape of the discriminating variables.
For CI search: these are as a function of invariant mass for forward and backward events.

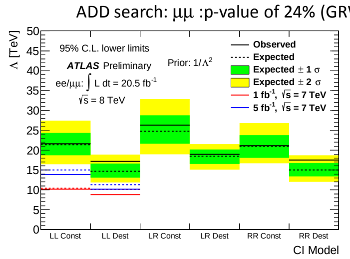
At relevant invariant masses of 1 (2) TeV:

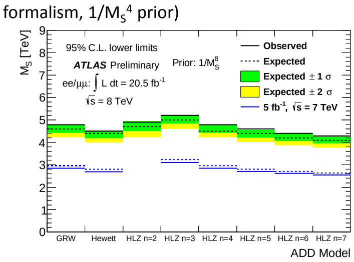
Source	Dielectrons		Dimuons	
	Signal	Background	Signal	Background
Normalization	4.0% (4.0%)	N/A	4.0% (4.0%)	N/A
PDF Variation	< 0.1% (0.2%)	5.0% (11.0%)	< 0.1% (< 0.1%)	5.0% (12.0%)
PDF Choice	N/A	1.0% (7.0%)	N/A	1.0% (6.0%)
α_S	N/A	1.0% (3.0%)	N/A	1.0% (3.0%)
EW Corrections	N/A	1.0% (2.0%)	N/A	1.0% (3.0%)
Photon-Induced	N/A	7.0% (12.0%)	N/A	6.5% (9.5%)
Efficiency	1.0% (2.0%)	1.0% (2.0%)	3.0% (6.0%)	3.0% (6.0%)
Scale/Resolution	1.2% (2.4%)	1.2% (2.4%)	1.0% (4.0%)	1.0% (4.0%)
Multi-Jet & W+Jets	N/A	3.0% (5.0%)	N/A	N/A
Beam Energy	1.0% (3.0%)	1.0% (3.0%)	1.0% (3.0%)	2.0% (3.0%)
Charge Misidentification	1.2% (2.0%)	1.2% (2.0%)	—	—
MC Statistics	3.0% (3.0%)	0.5% (0.5%)	3.0% (3.0%)	0.5% (0.5%)
Total	5.5% (6.9%)	9.5% (19.4%)	6.0% (9.3%)	9.2% (18.7%)

Results

- A Bayesian approach is used using a uniform positive prior as a function of the parameter of interest to quantify any observed excess.
- In the absence of signal, 95% Credibility Level lower exclusion limits are set on these parameters.

Most significant deviation from the expected background:
CI search: μμ : p-value of 8% (LL model, destructive interference, $1/\Lambda^2$ prior)
ADD search: μμ :p-value of 24% (GRW formalism, $1/M_S^4$ prior)





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