**Searches for effects of TeV-scale gravity in the 2010 ATLAS data**

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**Extra Dimensions and TeV-Scale Gravity**

- One of problems in the Standard Model is hierarchy problem that there is large difference between the Planck scale ($M_P \sim 10^{16}$GeV) and electroweak scale ($M_W \sim 100$GeV).
- Theories of extra dimensions introduce “TeV-Scale Fundamental Planck Scale”, $M_0$, as a solution of the problem.
- Only the gravitational field can propagate into all dimensions. Hence, the gravitational field measured in four space-time dimension is reduced in strength from fundamental gravitational field and $M_0$ could be as small as the electroweak scale.
- The ADD model, proposed by Arkani-Hamed, Dimopoulos, and Dvali, is an extra dimensions model with large flat extra dimensions. Lower limits on $M_0$ are set as ~1 TeV by collider experiments.

**Black Hole Search**

- Black holes are produced when half of the impact parameter of the two collision partons is less than horizon radius of black hole with mass, $M_{BH}$, equal to center of mass energy of proton-proton collision.
- The mass of black hole has a continuous distribution from $M_{TH}$ (> MD) to center of mass energy of proton-proton collision.
- Events with third jet with $p_T > 15$GeV are vetoed.
- $\Delta \phi$ of them < 1.3
- Add graviton doesn't interact with the detector
  - Missing energy in association with a jet is main signal.
  - Event selection:
    - Leading jet: $p_T > 200$GeV, $|\eta| < 2.4$, isolated
    - Second leading jet: $p_T > 100$GeV, $|\eta| < 2.4$, same charge with leading $\mu$
    - Number of tracks $\geq 10$
    - Main backgrounds are $\mu +$ fake (di(boson+jets)), ttbar, bbbar
      - $\mu +$ fake: Track faking muon rate is estimated in $W+$tracks sample in data
    - ttbar and bbbar are estimated with MC (A normalization factor for bbbar is estimated from bbbar enriched control region)
  - Background events: 332 ± 30
  - Observed events: 297 ± 40.1

**Multijet Final State**

- The Standard Model background rate is low for same sign dimuon events.
- Event selection:
  - Leading $\mu$: $p_T > 20$GeV, $|\eta| < 2.4$, isolated
  - Second leading $\mu$: $p_T > 10$GeV, $|\eta| < 2.4$
  - Number of tracks $\geq 10$
  - Main backgrounds are $\mu +$ fake (di(boson+jets)), ttbar, bbbar
  - $\mu +$ fake: Track faking muon rate is estimated in $W+$tracks sample in data
  - ttbar and bbbar are estimated with MC (A normalization factor for bbbar is estimated from bbbar enriched control region)
- Background events: 7
- Observed events: 5

**Same-Sign Dimuon Final State**

- Decays from particle to black holes are dominated by gluons and quarks because of their large number of degrees of freedom for color.
- Multijet final state is main signal of black hole events.
- Selection high $p_T$, $p_T > 500$GeV, $|\eta| < 2.8$
- Number of Jets ($N_J$): 5
- Scalar sum of jets in events ($\Sigma p_T$): $> 2$TeV
- Main background is QCD multijet. Shapes of $\Sigma p_T$ distributions of QCD show little dependences on $N_J$
  - The distribution for $N_J \geq 5$ can be assumed to have same distribution of $N_J < 5$
- Under a background-only hypothesis
  - Background events: 332
  - Observed events: 297

**Quantum Black Hole in Dijet**

- Quantum black holes is a scenario in which black holes decay into two-body final state.
- Event selection:
  - Leading jet: $p_T > 150$GeV, $|\eta| < 2.5$, Second leading jet: $p_T > 30$GeV, $|\eta| < 2.5$
  - $\Delta \eta$ of them < 1.3
  - Events with third jet with $p_T > 15$GeV are vetoed
- Add graviton doesn't interact with the detector
  - Missing energy in association with a jet is main signal.
  - Event selection:
    - Leading jet: $p_T > 250$GeV, $|\eta| < 2.0$
    - Second leading jet: $p_T < 60$GeV and $|\eta| < 4.5$
    - Missing $E_T > 220$GeV
    - $\Delta \phi$ (second jet, missing $E_T$): > 0.5
  - Background events: 40.1 ± 2.9(stat) ± 4.5(syst)
  - Observed events: 39

**ADD Graviton in Monojet**

- Quantum black holes is a scenario in which black holes decay into two-body final state.
- Event selection:
  - Leading jet: $p_T > 250$GeV, $|\eta| < 2.0$
  - Second leading jet: $p_T < 60$GeV and $|\eta| < 4.5$
  - Missing $E_T > 220$GeV
  - $\Delta \phi$ (second jet, missing $E_T$): > 0.5
  - Background events: 40.1 ± 2.9(stat) ± 4.5(syst)
  - Observed events: 39

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Ref: The ATLAS Collaboration, Search for Microscopic Black Holes in Multi-Jet Final States with the ATLAS Detector at $\sqrt{s} = 7$ TeV, ATLAS-CONF-2011-068

Ref: The ATLAS Collaboration, Search for strong gravity effects in same-sign dimuon final states, ATLAS-CONF-2011-065


Ref: arXiv:hep-ex/0410004


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**Missing $E_T$ distribution**

**Leading jet $p_T$ distribution**

**Limits on black hole production for rotating black hole**

**Dijet invariant mass distribution**

**Limits on the cross section × acceptance for ADD graviton**

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