Sensitivity of the ATLAS Experiment to Extra Dimensions

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Extra Dimensions

- Nordström 1914; Kaluza 1921 and Klein 1926 *("KK")*
- Hierarchy problem: $M_{EW}/M_{Pl} \sim 10^{-17}$
- Could be resolved by existence of ED:
  Effective gravity scale lowered from $M_{Pl} \sim 10^{19}$ GeV to $\sim$ 1 TeV

Many models/scenarios exist. We focus on those with the most promising observations:

Large ED

- Gravitons propagate in bulk
- Virtual graviton exchange
- Direct graviton production
- Black holes

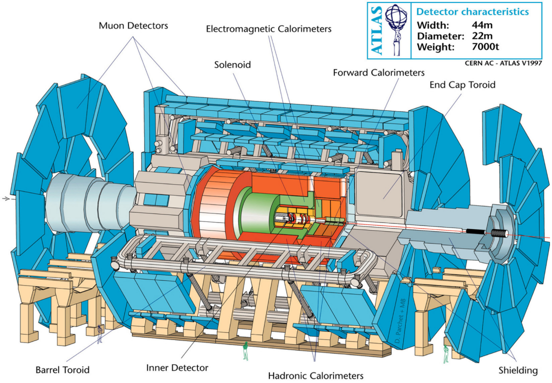
Warped ED

- Gravitons propagate in bulk
- Graviton resonances
- Radions
- Black holes

Universal ED

- In particular: 1/TeV scale ED
- Bosons can propagate in bulk
- KK pair production
- Resonances from KK excitations

The ATLAS Experiment



Muon Spectrometer

- $|\eta| < 2.7$, $B = 4$ T
- drift tubes, CSCs, RPCs and TGCs
- 6 GeV $< p_T < 2$ TeV
- $\sigma(m_{Z\to\mu\mu}) =$2.5 GeV

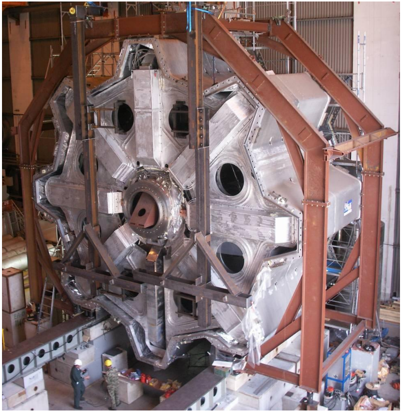
Tracking

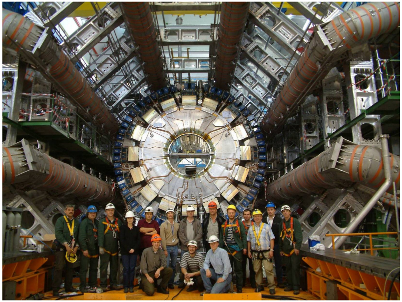
- $|\eta| < 2.5$, $B = 2$ T
- Si pixels + strips, transition radiation tracker
- 15 μm vertex res.

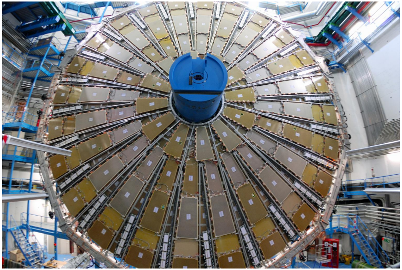
Calorimetry

- $|\eta| < 3.2$
- EM: Pb-LAr, 20 MeV – 2 TeV, $\sigma(E)/E = 10\%/\sqrt{E} \oplus 0.4\ GeV/E \oplus 0.7\%$
- Hadronic: Fe/scintillator (barrel), Cu/W-LAr (fwd), jet-E resolution 8%

- Installation in progress
- Close beampipe late summer 2007
- 900 GeV collisions by end of 2007
- 14 TeV collisions by summer 2008
- 1-4 fb^{-1} by end of 2008







Large Extra Dimensions

Extra Dimensions in ATLAS

Ivo Gough Eschrich

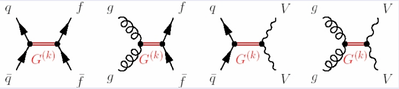
Introduction
ATLAS
LED
RS
UED
BH
Summary

Arkani-Hamed, Dimopolous, Dvali, PLB 429:263 (1998)

- Mass scale M_S of gravity in (4+n)D: $M_{\rm Pl}^2 \sim M_S^{n+2} R^n$; $R \gg 1/\text{TeV}$
- SM particles restricted to 4D brane

Virtual graviton exchange

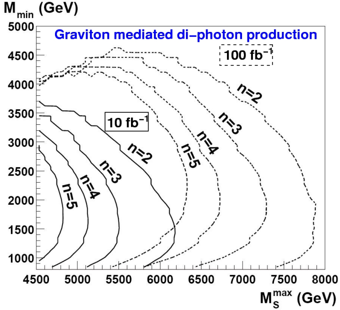
- Observe tower of KK gravitons
- Mass splitting $\sim 1/R$: continuum of graviton states

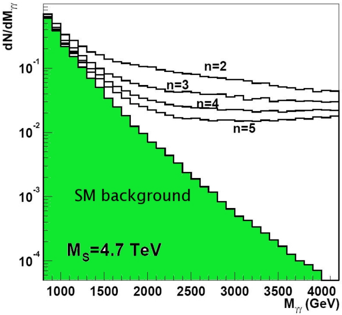


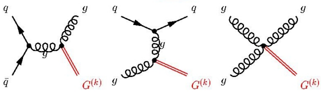
$G^* \to \gamma\gamma, \to e^- e^-$

- 5σ sensitivity at 100 fb^{-1} for $M_S = 6.3 \ldots 7.9$ TeV ($n = 5 \ldots 2$)

Kabachenko et al., ATL-PHYS-2001-012



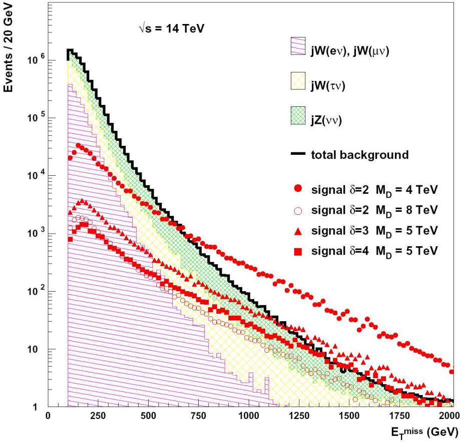




Direct graviton production

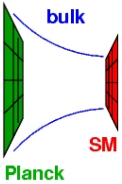
- Jet + missing E_T signature
- Can probe ED up to $M_D = 6 - 9$ TeV for $100\,\text{fb}^{-1}$

Vacavant & Hinchliffe, JPG 27(2001) 1839



Warped Extra Dimensions

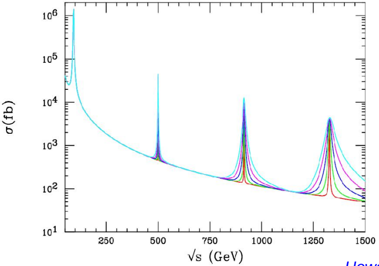
- Randall-Sundrum 'Type I' scenario
  Randall, Sundrum, PRL 83:3370 (1999)
- Brane metric scales with location in bulk
- Hierarchy problem solved by warp factor
- KK graviton resonances well separated

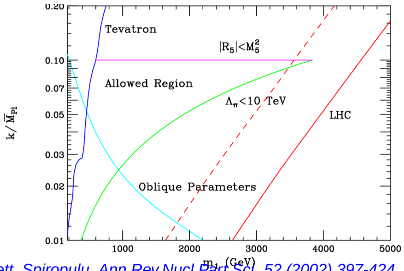


$$ds^2 = e^{-2ky}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2$$

Scale $\Lambda = \bar{M}_{\rm Pl} e^{-kr_c\pi}$

for $\Lambda \sim 1$ TeV $kr_c \sim 12$
KK masses $m_n = x_n(k/\bar{M}_{\rm Pl})\Lambda$





Hewett, Spiropulu, Ann.Rev.Nucl.Part.Sci. 52 (2002) 397-424

RS1 Scenario at ATLAS

- Golden mode: $G^* \to e^+e^-$
  - Drell-Yan dominated background
  - Excellent mass resolution

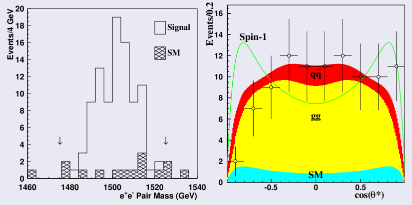
Assuming $k/\bar{M}_{\mathrm{Pl}} = 0.01$ and 100 fb^{-1}:

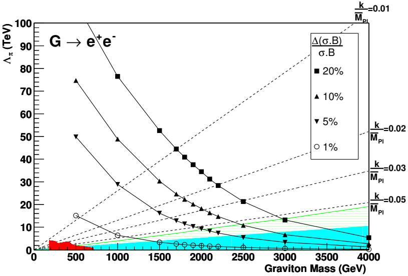
- Resonance mass reach 2.08 TeV
- Spin 2 can be determined to 90% CL up to 1.72 TeV
- $\sigma(pp \to G^*) \cdot \mathcal{B}(G^* \to e^+e^-)$ with 10% stat. err. up to 1.4 TeV
- Also looking at $(k/\bar{M}_{\mathrm{Pl}}) > 0.01$
- Other modes studied as well ($G^* \to \mu\mu, q\bar{q}, WW, ZZ, ..$)

Allanach et al., JHEP 09(2000)019

and JHEP 12(2002)039

1.5 TeV Resonance Mass





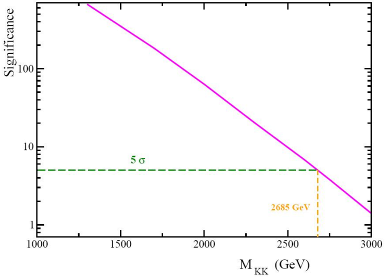
Universal Extra Dimensions: $KK \rightarrow$ Di-Jets

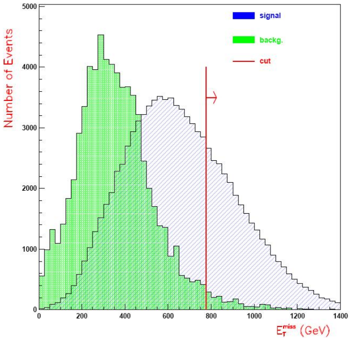
- SM particles can propagate in small (TeV^{-1} size) ED
- Small ED can be embedded in large ED
- KK particles produced in pairs

Di-jet signals

- $KK \rightarrow GG + jj$: two jets and large missing energy
- Assume $m_{\mathrm{KK}} = 1.3$ TeV and 100 fb^{-1}
- Require 2 jets of $p_T > 250$ (150) GeV; missing $E_T > 775$ GeV
- 5σ discovery reach for $m_{\mathrm{KK}} < 2.68$ TeV

Beauchemin + Azuelos, ATL-PHYS-PUB-2005-003



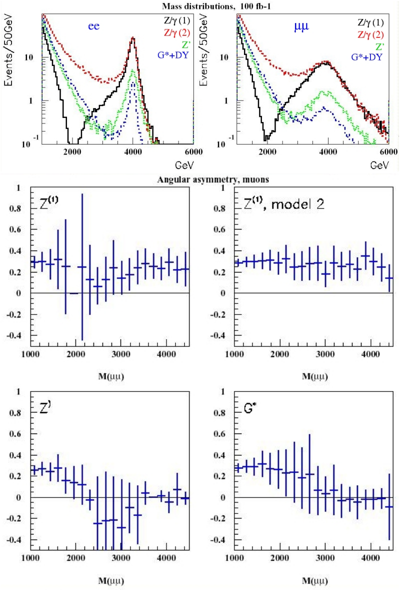


KK Excitations of Gauge Bosons

- TeV^{-1} scale ED accessible to bosons
- Fermions confined to 4D brane
- KK excitations of W, Z studied for 1 ED
- Compactification scale $M_c \geq 4$ TeV from EW data
- Masses $M_n^2 = (nM_c)^2 + M_0^2$

ATLAS Reach for $Z, W \to \ell\ell$

- Z resonance for $M_c < 5.8$ TeV (100 fb^{-1}, peak in $M_{\ell\ell}$)
- Distinguish from Z', G^* by forward-backward asymmetry
- If no peak observed: study $M_{\ell\ell}$ dist for $M_c < 13.5$ TeV (300 fb^{-1})



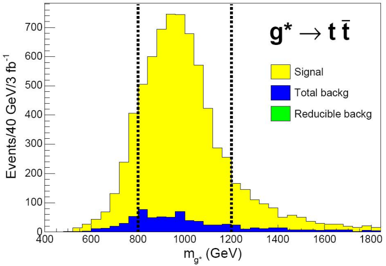
Azuelos, Polesello, Eur Phys J C 39s2, 1 (2004)

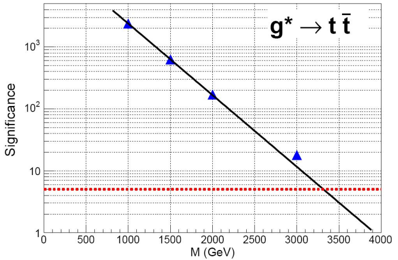
UED: KK Gluon Decays to Heavy Quarks

$g^* \to b\bar{b}, t\bar{t}$

- KK excitations of gluon
- only hadronic decays
- here: focus on decays to heavy quarks
- excess of di-jet events
- Decays to *b*-quarks difficult to see
- *t*-quark channel may yield signal for $m_{g^*} < 3.3$ TeV

March et al., ATL-PHYS-PUB-2006-002





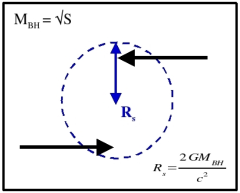
Micro Black Holes

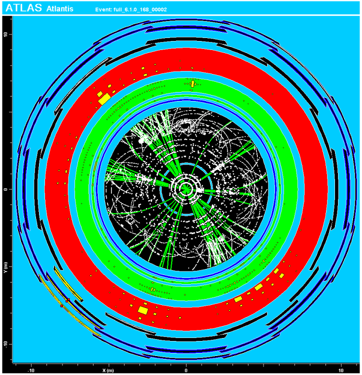
- Here studied: LED scenario with $M_{\rm Pl} \sim 1$ TeV, $M_{BH} \gg M_{\rm Pl}$, $M_{BH} \gg T_H$
- Decay by Hawking radiation to 'democratic' spectrum of SM particles:

q, g	ℓ	Z^0, W	ν, G	H^0	γ
72%	11%	8%	6%	2%	1%

Giddings & Thomas, PRD65:056010(2002)

- High-multiplicity, high Σp_T spherical events with significant missing p_T





BH parameters

- Schwarzschild radius R_S
- Mass $M_{BH} = \sqrt{s}$
- Hawking Temperature T_H

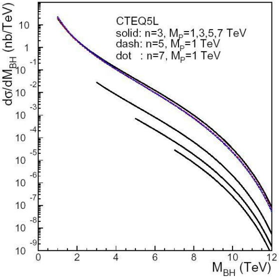
Micro Black Hole Production

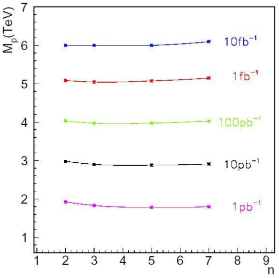
- Cross section
  $\sigma(pp \to BH) = F_{ab} \pi R_S^2$
  Dimopoulos & Landsberg, PRL87:161602 (2001)
- F_{ab} for partons a, b depends on PDF.
- Schwarzschild radius in $(4+n)$ dimensions:

$$R_S = \frac{1}{\sqrt{\pi} M_{\mathrm{Pl}}} \left[\frac{M_{BH}}{M_{\mathrm{Pl}}} \left(\frac{8\Gamma(\frac{n+3}{2})}{n+2} \right) \right]^{\frac{2}{1+n}}$$

5σ Discovery Reach

- $M_{\mathrm{Pl}} < 5$ TeV: $1\,\mathrm{fb}^{-1}$
  (...by Xmas 2008?)
- $M_{\mathrm{Pl}} < 4$ TeV: $100\,\mathrm{pb}^{-1}$
  (...Labor Day?)





Tanaka et al., Eur. Phys. J. C 41s2, 19 (2005)

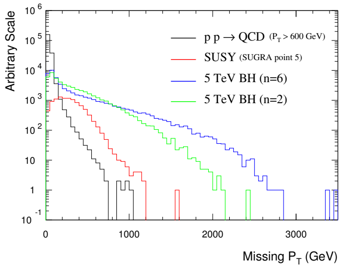
Determining ED Parameters from BH Events

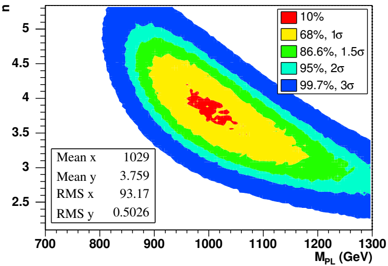
- Number n of extra dimensions
- Planck mass M_{Pl}

Test Model: n=4; M_{BH}=7 TeV

- Assume production cross section known to 20%
- $T_H = 340 \pm 30$ GeV
- $\sigma(M_{\mathrm{Pl}})/M_{\mathrm{Pl}} = 15\%$
- $\sigma(n) = 0.75$

Harris et al., JHEP05(2005)053





Conclusions

ATLAS is well suited to discover extra dimension signatures if within LHC reach.

- With 100 fb^{-1} of data, should be able to see
  - Evidence for gravitons if LED scenario is true...
  - Graviton resonance if RS scenario is true...
  - KK excitations if 1/TeV scenario is true...

  ...and Planck mass and number of dimensions just happen to be in accessible range!
- If micro black holes can be produced, the rate could be very high
  - BH events should be obvious once detector response is understood
  - Candidate for “Day 1” discovery, about 2 years from now..