Extra Dimension Signatures at ATLAS

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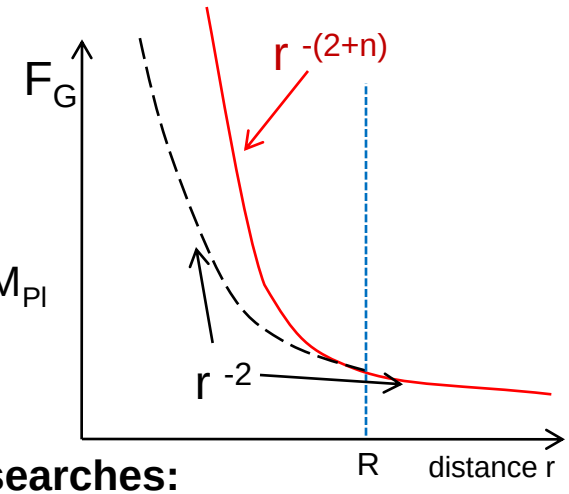
on behalf of the
ATLAS Collaboration

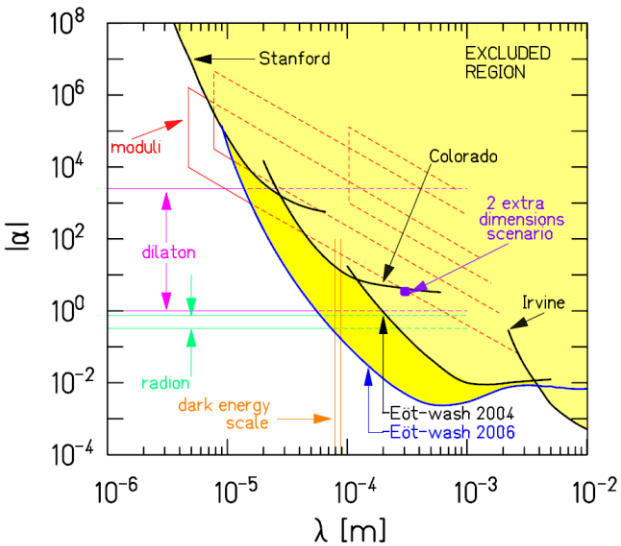
Implications of LHC results for TeV-scale physics, August/Sept 2011, CERN

Introduction

Motivation?

- Hierarchy problem – Gravity 10^{32} times weaker than weak force
  - Solution: n extra dimensions of size R, Planck Scale M_{Pl} misleading extrapolation from large distances
  - (Reduced) fundamental Planck Scale $M_D << M_{Pl}$





Providing a starting point for searches:

- strong constraints from electroweak precision data
  - M_D > 2 - 5 TeV
  - Can be circumvented by model
- Tevatron and LEP results
  - MD > 1.6 – 0.8 TeV (n = 2 - 6)
- Non-collider bounds
  - Direct measurements: e.g. n = 2 -> M_D > 3.2 TeV
  - Micro Black Holes in cosmic rays:
    - M_D > 1.0 – 1.4 TeV (n = 4 - 7)
  - Cosmological constraints, if M_D~TeV, n > 4
    - Model dependant

Before LHC results: M_D ~ 1 TeV quite possible, but low n disfavoured

Three Main Classes

ADD Arkani-Hamed, Dimoupoulos, Dvali	RS model Randall-Sundrum	UED Universal Extra Dimensions
Characteristics		
• n extra dimensions only accessible to gravity • Eliminates Hierarchy Problem	• Gravitons in single ED with special metric (“warped”) • Naturally solves hierarchy problem	• All fields propagate in EDs, but KK–number is conserved • Eliminates Hierarchy Problem
Kaluza-Klein (KK) spectra		

• Modes with energy spacing < 1GeV
• Cant be resolved, continuum
	• “Particle in a box”
	• Distinct energy eigenvalues
		• Distinct energy eigenvalues
		• KK-number conservation ->
		  • Pair production
		  • Lightest mode stable

Searched at ATLAS include the following signal benchmarks		

• Graviton production/mono-jets	• RS-Graviton
	  -> dileptons,
	  -> diphotons
	• KK-gluon -> ttbar
		• KK-quark/gluon pair -> lightest KK pair + X-> diphoton+ETmiss + X

• Semi-classical black-holes, string-balls, ... * • Quantum “black holes”*	• Semi-classical black-holes, string-balls, ... * • Quantum “black holes” *	• Semi-classical black-holes, string-balls, ... * • Quantum “black holes” *

*ADD Monte Carlo generator used as benchmark

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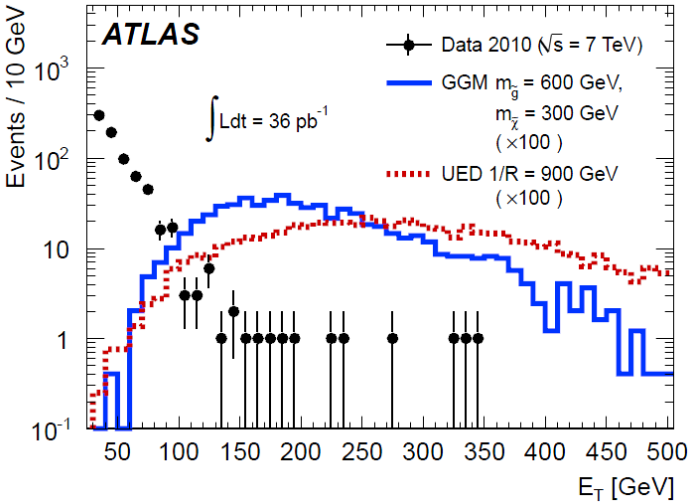
Extra dimensions/TeV Scale Gravity in ATLAS notes are:

Green: Main result Purple: Adapted result Red: Additional interpretation (analyses already presented)

*ADD Monte Carlo generator used as benchmark ★ data set >1/fb

UED: Diphoton + MET

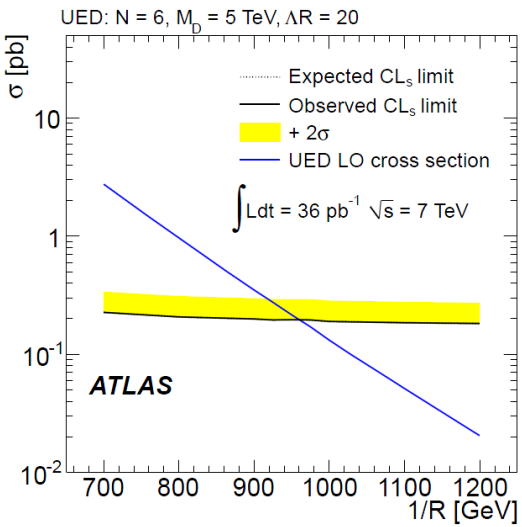
E_T^{miss} range [GeV]	Data events	Predicted background Total	Expected signal events UED
0 - 20	698	-	0.02 ± 0.01
20 - 75	63	61.4 ± 2.3	0.25 ± 0.02
75 - 125	1	0.38 ± 0.08	0.43 ± 0.02
> 125	0	0.10 ± 0.04	5.35 ± 0.11



Model (in addition to SUSY*)

- One UED embedded in larger space with N = 6 additional dimensions
- Lightest KK particle = γ*
  - Decays gravitationally to γ + Graviton
- Only 2010 results public at the moment

[arXiv:1107.0561]



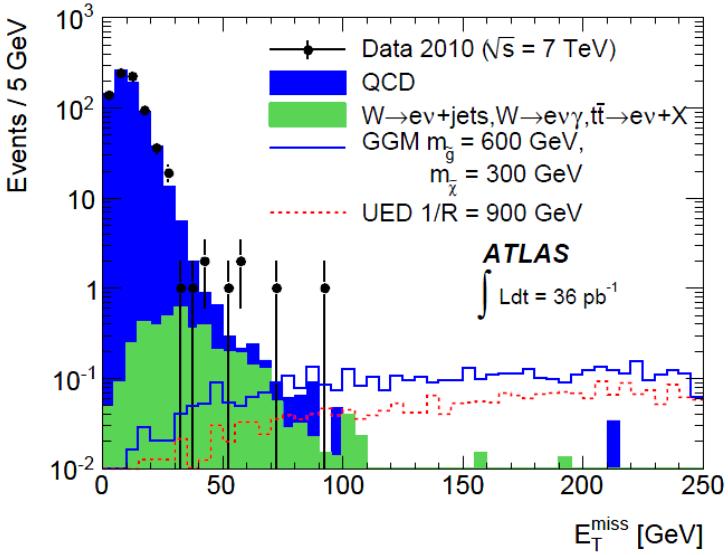
Observed 95% CLs limit

- **1/R > 961 GeV**

  (M_D = 5 TeV, ΛR = 20)

Tevatron (D0)

- 1/R > 477 GeV



* see working group 2

RS: Graviton Production

[ATLAS-CONF-2011-044] [arXiv:1108.1582]

Model

- Production and subsequent decay of RS graviton

Analyses:

Diphoton resonance search (2010 data only)

- Fully data driven background – fit of smooth parameterisation
- **RS Graviton mass m_G > 920 (545) GeV** at 95% CL, for coupling k/M_D = 0.1 (0.02)

Dilepton resonances

(2011 data, combined with search for Z')*

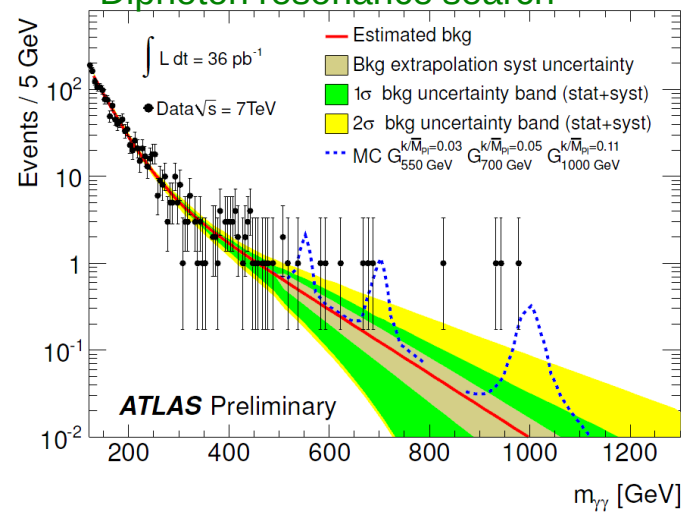
- μ and e channel combined
- Data consistent with Drell-Yan production
- **RS m_G > 1.63 TeV** at 95% CL (k/M_D = 0.1)

	RS Graviton			
Model/Coupling	0.01	0.03	0.05	0.1
Mass limit [TeV]	0.71	1.03	1.33	1.63

Tevatron:

RS m_G > 1.08 TeV at 95% CL (k/M_D = 0.1)

Diphoton resonance search



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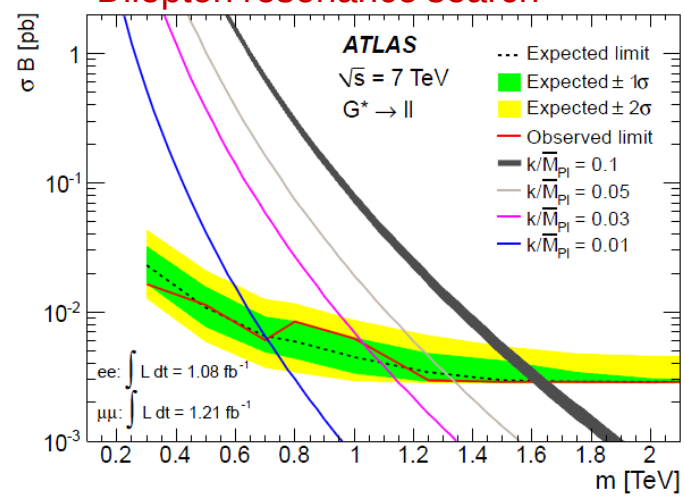
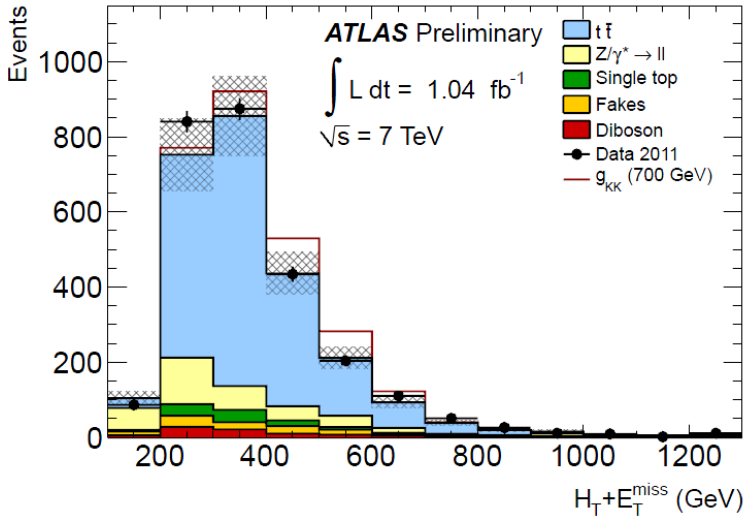
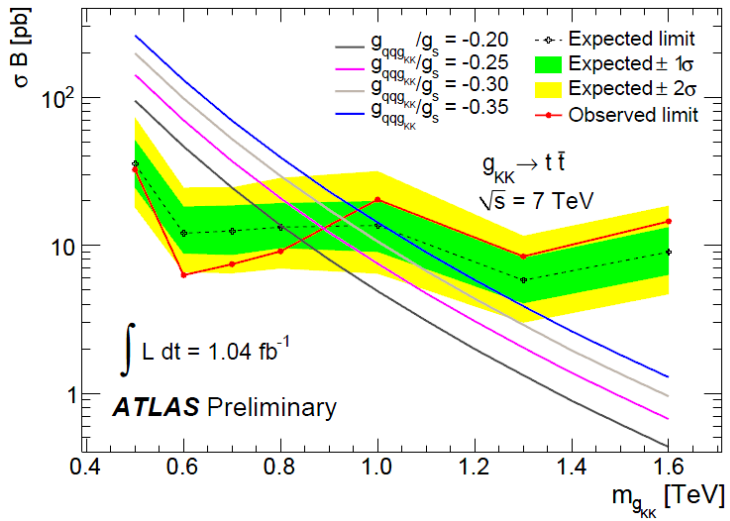


* see working group 3: New fermions and gauge interactions

RS: KK-gluon production

[ATLAS-CONF-2011-123]





Model

- Benchmark: KK-gluon decaying to ttbar in the dilepton channel

Analysis:

- Based on
  - HT: scalar sum of lepton and jet transverse momenta
  - ETmiss: scalar missing transverse momentum
- Limited by reconstruction of top decay (current analysis most sensitive up to 1 TeV)
- No evidence for new physics
- **95% CL limits depending on coupling strength** (default parameter 0.2):

	Mass Limit (TeV)	
$g_{qqg_{KK}}/g_s$	Expected	Observed
-0.20	0.80	0.84
-0.25	0.88	0.88
-0.30	0.95	0.92
-0.35	1.02	0.96

sign only important if interference taken into account

Quantum Black Holes

- Used as generic term for any quantum gravitational effect resulting in low multiplicity final states

Benchmark: BlackMax (ADD)

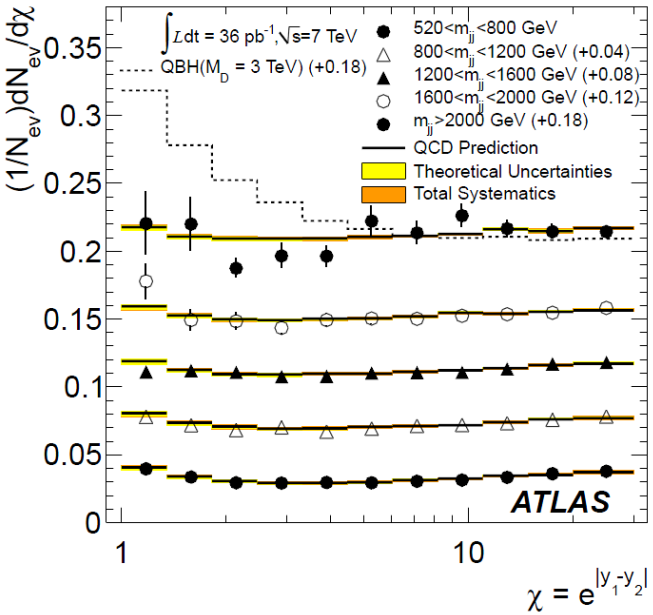
- Enhancement of central dijet cross-section above a production threshold $M_{th} = M_D$

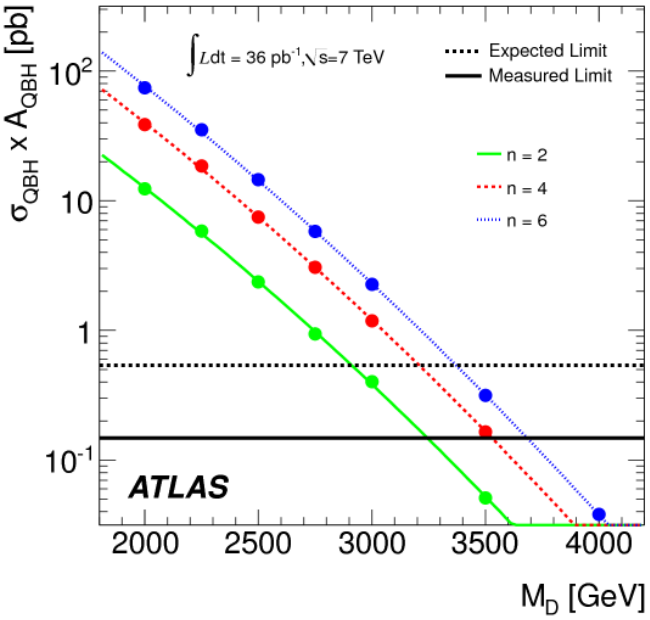
Analyses: (public results with 2010 data)

- Benchmark result from observed dijet mass m_{jj} distribution*:
  - **M_D > 3.67 TeV at 95% CL** (n = 6)

Number of Extra Dimensions	M_D Limit [TeV] Observed	Expected
2	3.20	3.18
3	3.38	3.35
4	3.51	3.48
5	3.60	3.58
6	3.67	3.64
7	3.73	3.71

- **Dijet angular distributions**
  - Less dependent on modelling
    - E.g. how does the production cross-section evolve in m_{jj}, sharp turnon, resonances, ...?
  - Use of highest mass bin m_{jj} > 2 TeV in distribution of $\chi = \exp(|y_1-y_2|) = (1+\cos\theta^*)/(1-\cos\theta^*)$ **





[arXiv:1103.3864]

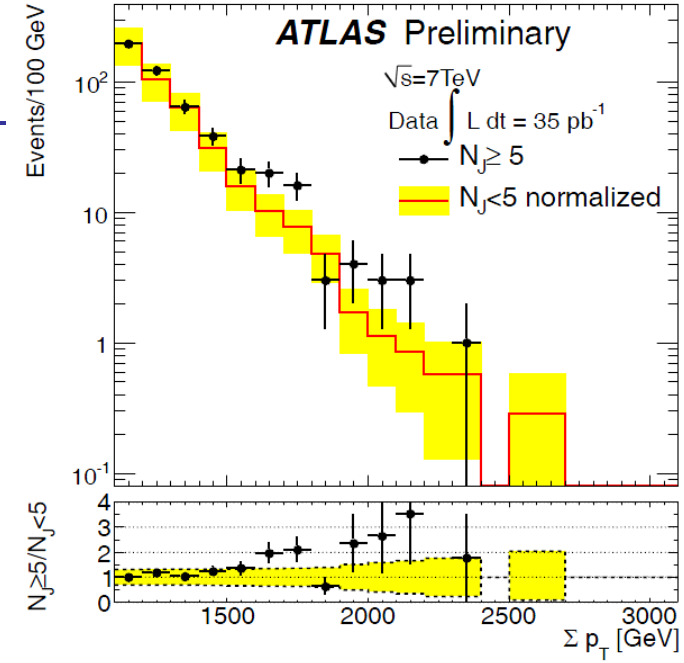
* see working group 3: New fermions and gauge interactions

** $y_{1,2}$: rapidities of two leading jets, θ*:cms scattering angle

Micro Black Holes

Use of semi-classical approximation

- Black hole decay via Hawking radiation
  - Democratic decay into high multiplicity of SM degrees of freedom
- **Only strictly valid for $M_{th} >> M_D$**
- Signal samples produced using BlackMax generator
  - σ x A results can be interpreted in different contexts



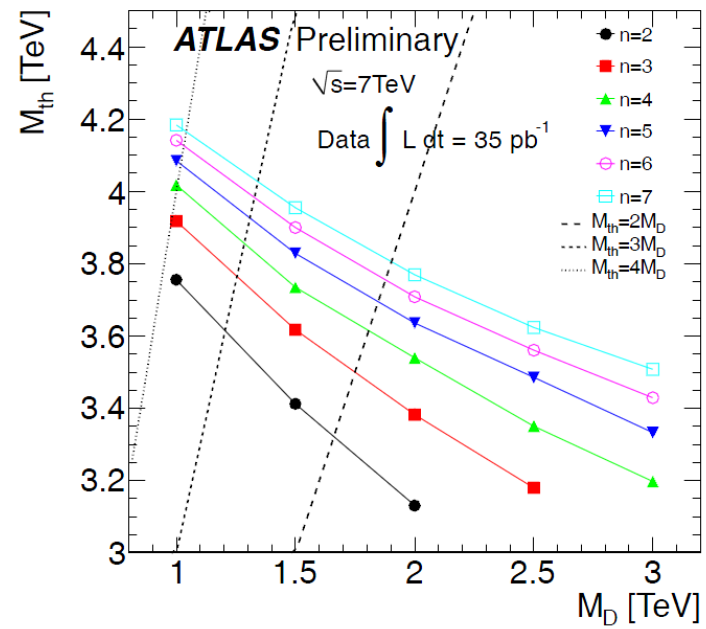
Analyses: (public results with 2010 data)

Multijets

- Data driven background estimate
  - 2-D control region
  - Verified using ALPGEN and Pythia
- No evidence for production of micro black holes
- **95% CL limit on σ x A of 0.29pb**
  - For events with $N_J \geq 5$ and $\sum p_T > 2$ TeV

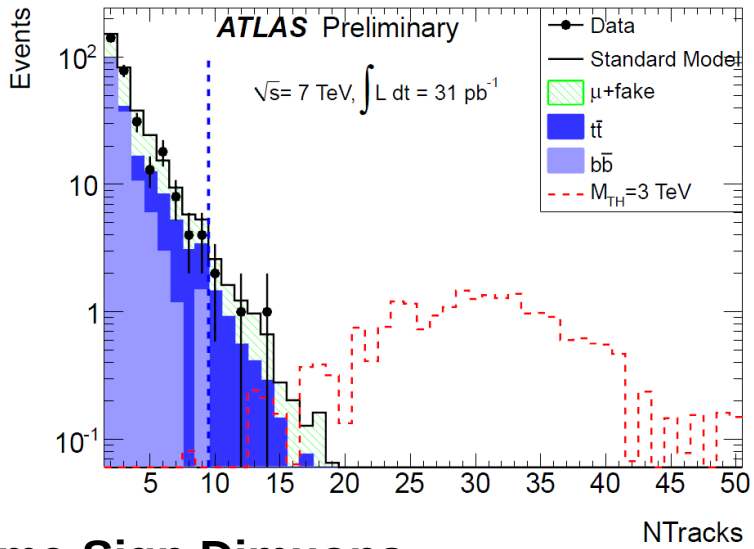
Benchmark:

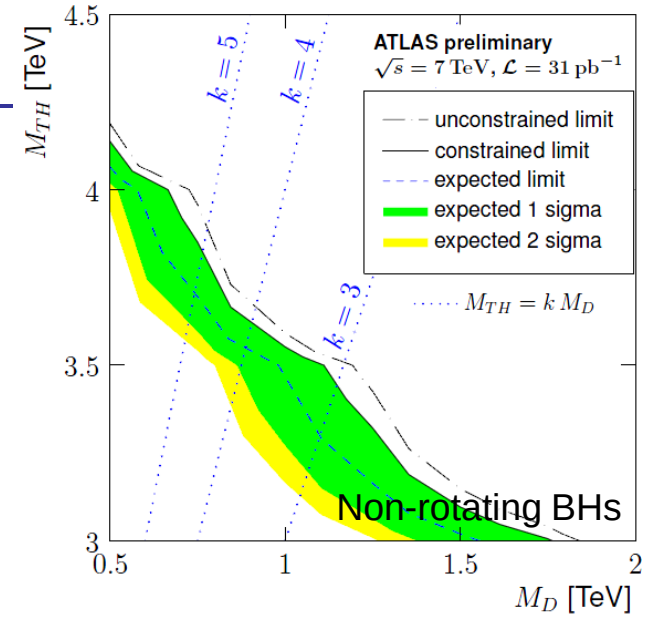
- ADD, n = 6, $M_{th} = 3\ M_D$
- **M_D > 1.37 TeV at 95% CL**

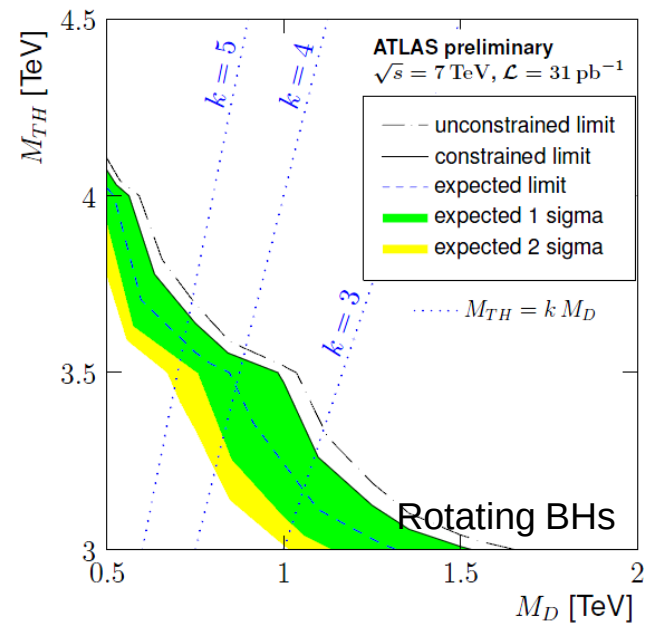


[ATLAS-CONF-2011-068]

Micro Black Holes





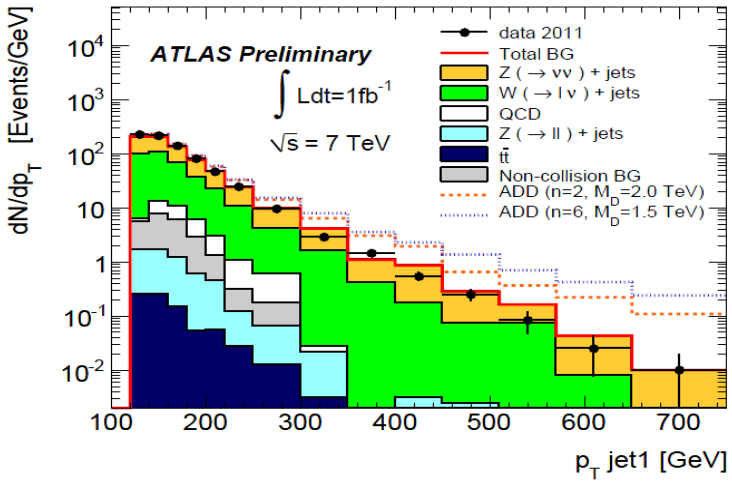


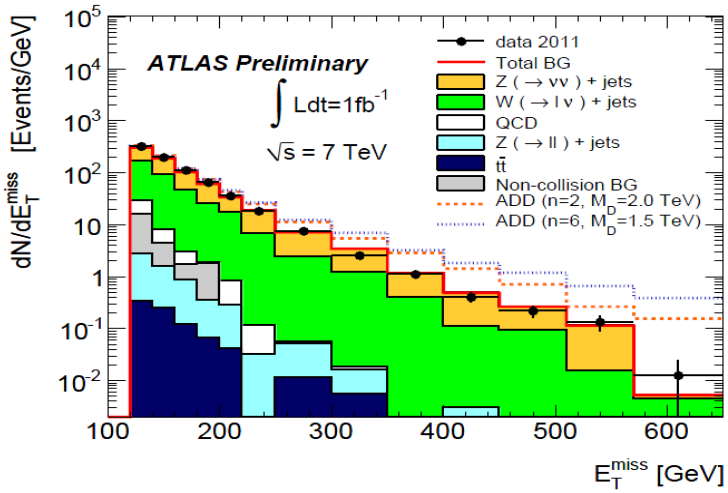
Same-Sign Dimuons

- Event selection
  - Two same-sign muon candidates, leading muon isolated
  - Signal region: Number of tracks > 9
- Data consistent with SM prediction
- **95% CL limit on σ x BR x A of 0.184 pb**
- Interpretation in context of non-rotating and rotating micro black holes
- Benchmark: ADD, n = 6, M_{th} = 3 M_D
  - **M_D > 1.20 TeV at 95% CL**

[ATLAS-CONF-2011-065]

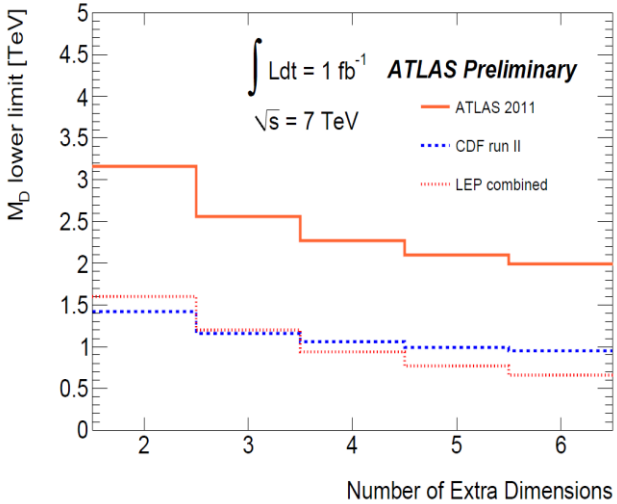
Monojet Search





- Event selection of signal region*
  - Leading jet pT > 250 GeV, ETmiss > 220 GeV
  - No additional jet with pT> 60 GeV or lepton/photon
- Background estimates data-driven or MC with data-driven normalization
- Event count in signal region consistent with SM prediction
- **95% CL limit on σ x BR x A of 0.11 pb**

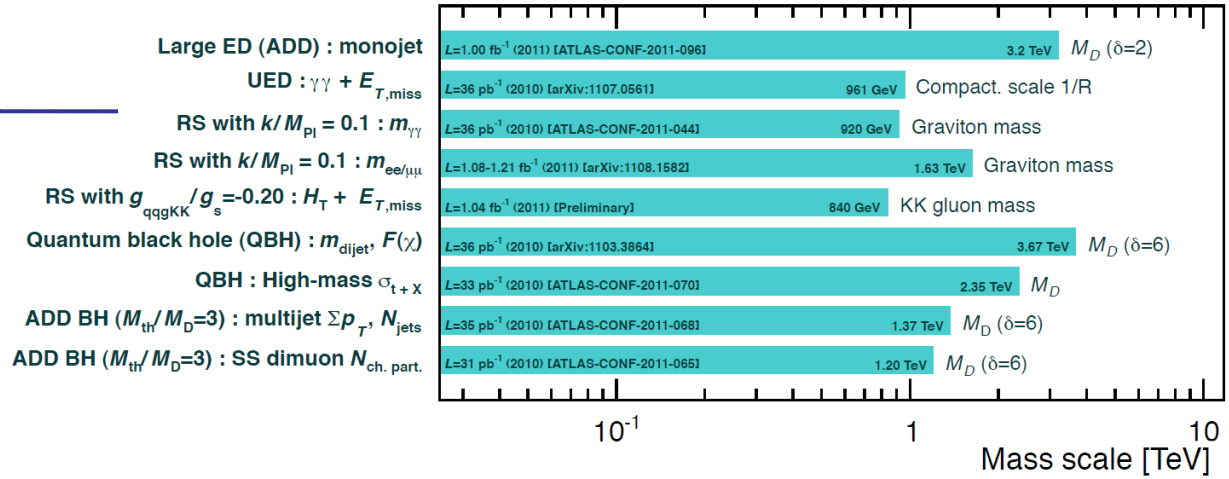
- Interpretation in context of ADD prompt graviton production
  - **M_D > 2.0 TeV at 95% CL, for n = 6**



[ATLAS-CONF-2011-096]

* The note provides all results for three signal regions, low to high pT/ETmiss. Given here is the one used for the final/benchmark results.

Conclusion



- LHC and ATLAS (+CMS ☺) are working well and very efficiently
  - Stringent limits on extra dimensions in many channels
    - Threshold for enhancement of dijet production > 3.2 TeV, for any n = 2..7 (with 2010 data)
      - M_D typically not expected significantly lower
    - Monojet limits on M_D from 2 to 3.2 TeV
    - Phase space for RS graviton production significantly narrowed
- **New physics, and specifically strong gravity/extra-dimensions were not around the corner ☹**
  - LHC no black-hole factory (none expected in 7 TeV LHC data anymore?)
- It might be time to rethink assumptions and explore different corners of the phase space
- A factor ~2 to ~50 more data available compared to the results presented

Thanks for your attention!