The Abdus Salam
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Beyond the Standard Model: Results with the 7 TeV LHC Collision Data

19 - 23 September 2011

Search for Extra Dimensions at ATLAS

Sourabh Dube
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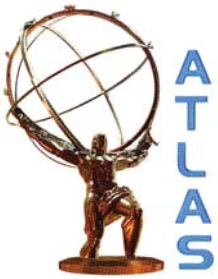
U.S.A.



Search for Extra Dimensions at ATLAS

Sourabh Dube
For the ATLAS collaboration
20th September, 2011

Beyond the Standard Model:

Results with the 7 TeV LHC Collision Data

Lawrence Berkeley
National Laboratory

ICTP, Trieste, Italy

Outline

- Motivation and Models of Extra Dimensions
- Graviton resonance searches
- Searches with Missing Energy
- Black hole searches

https://twiki.cern.ch/twiki/bin/view/AtlasPublic
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults

Motivation and Models

Extra dimension theories address the problem of unification of forces and the hierarchy problem - why is M_{Pl} so much greater than M_W?

In ED theories SM fields usually are localized to 4 spacetime dimensions, while gravity propagates in higher dimensions.

In the ADD (Arkani-Hamed, Dimopoulos, Dvali) family of models

- Large flat extra dimensions
- Gravity propagates into extra dimensions
- $M_{Pl}^2 \sim M_D^{2+n} R^n$, where M_D = true Planck mass,

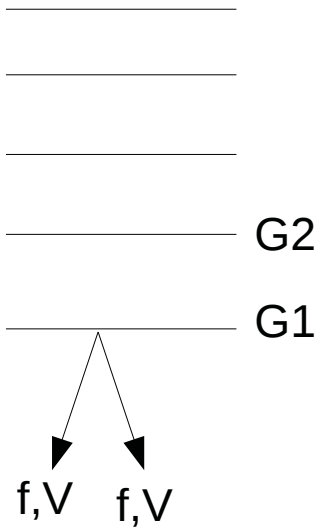
  n = number of extra dimensions, R = compactification radius
- Compactification of ED gives a Kaluza-Klein tower of closely-spaced massive Graviton states which do not decay.

Motivation and Models

Small extra dimensions

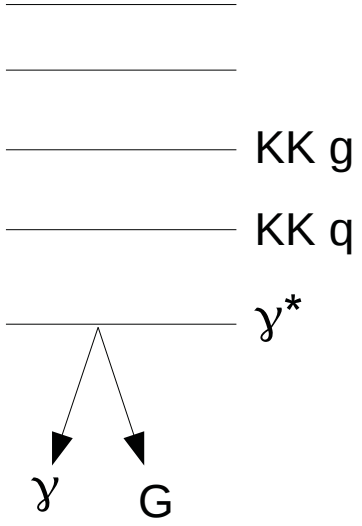
In the RS (Randall-Sundrum) family of models

- One highly curved extra dimension
- In minimal RS models, G propagating in bulk gives rise to KK tower of ~TeV separated massive graviton states
- G's (spin 2) have $k/\overline{M}_{Pl}$ coupling to SM fields
- M_G, mass of lightest graviton, in the TeV range for hierarchy solution.



Modified UED models

- SM fields can propagate in the extra dimensions
- KK excitations for each SM particle
- Lightest KK particle being γ^*.
- At LHC, produce KK quarks/gluons cascade decay to γ^*, followed by $\gamma^* \rightarrow \gamma + G$ (no KK-parity)



Searches for Graviton Decay

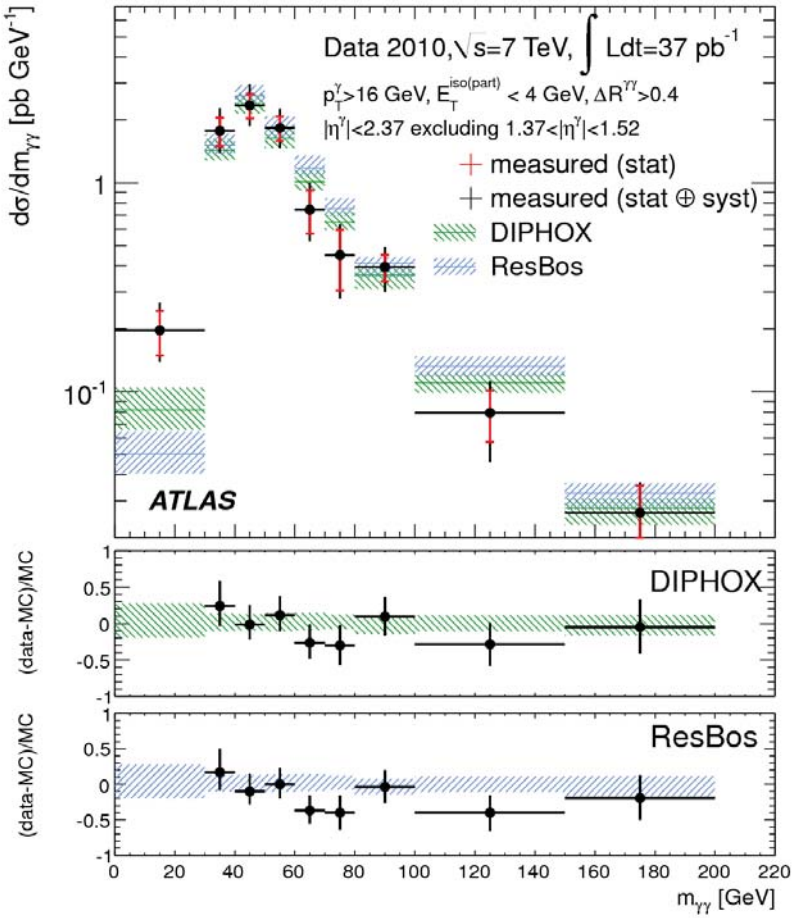
RS models

- Graviton decay to diphotons
- Graviton decay to dileptons

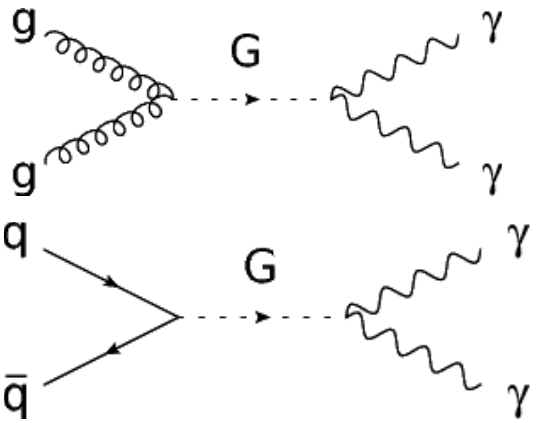
Graviton : diphoton

ATLAS has measured diphoton cross section, finds good agreement with SM.

http://arxiv.org/abs/1107.0581



- RS models predict excited KK modes of G
- Search for narrow heavy resonance in diphoton invariant mass distribution



Graviton : diphoton

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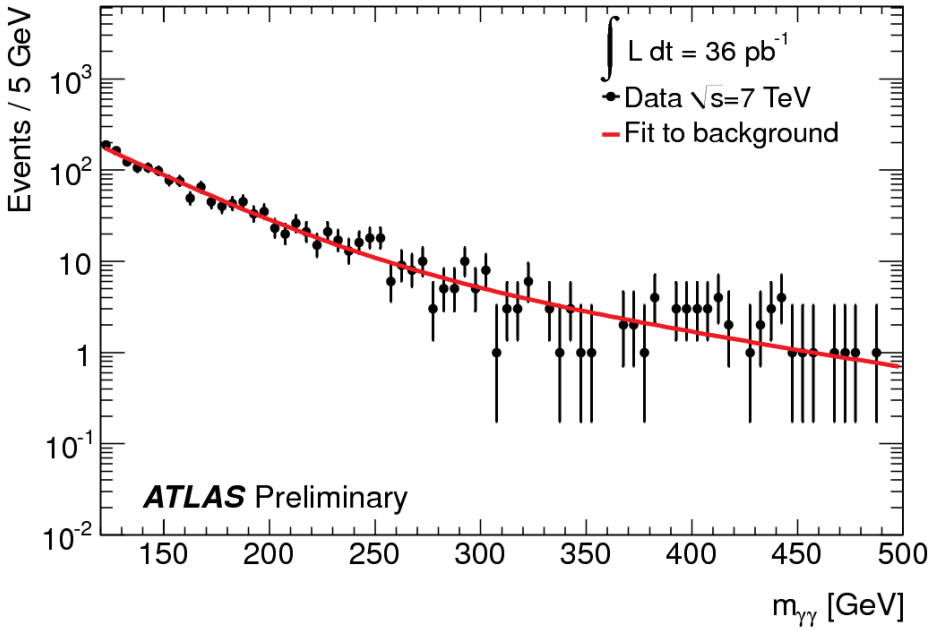
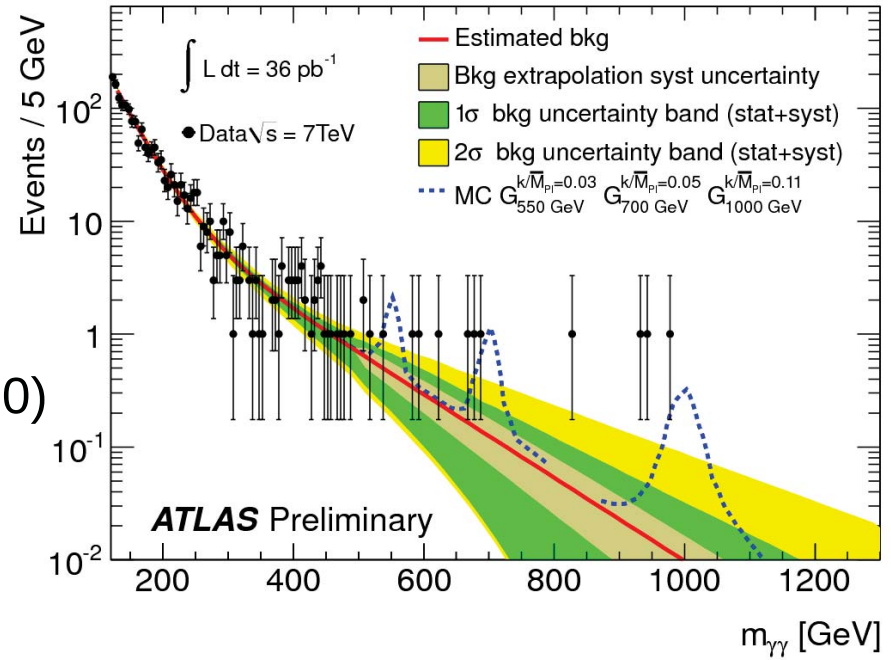


Analysis -

Data: 2010 , 36 pb^{-1}
Photon E_T > 25, 25 GeV

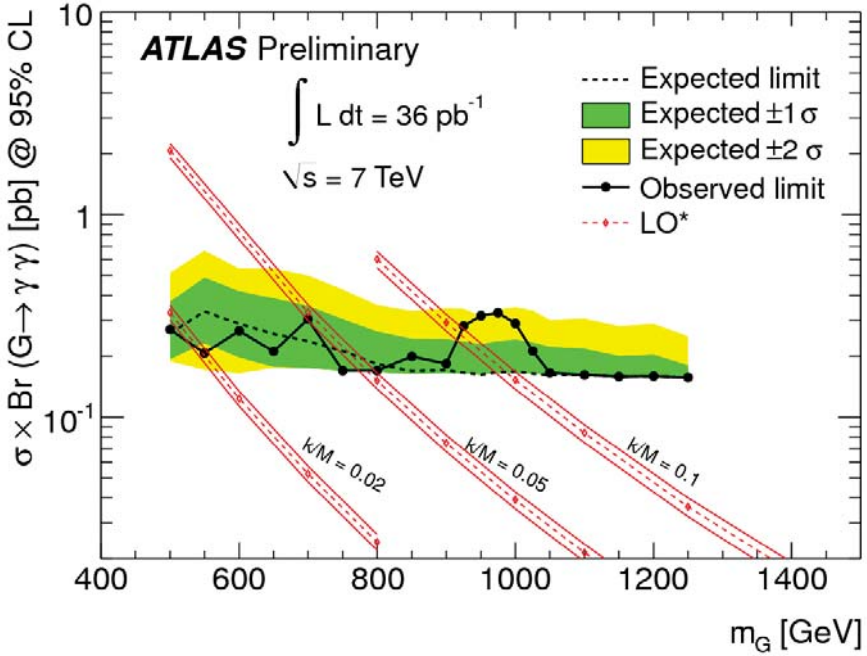
Backgrounds : irreducible SM diphoton, QCD γ+jet, dijet.

Fit $\gamma\gamma$ invariant mass ($120 < M_{\gamma\gamma}[\text{GeV}] < 500$) with sum of two exponentials to get background estimate.

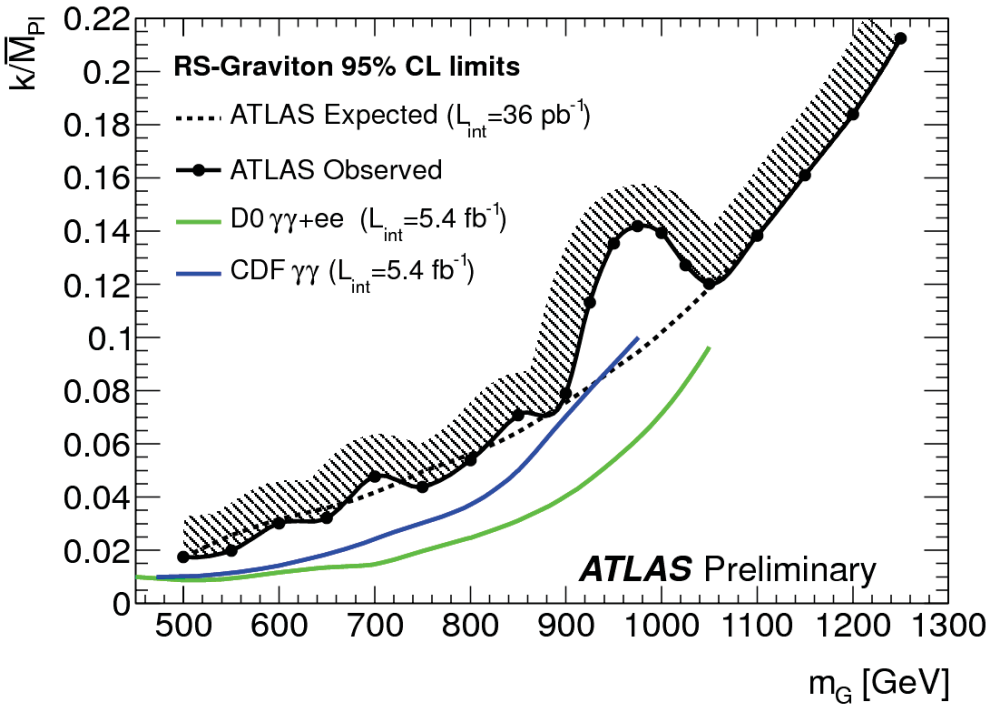


Graviton : diphoton

Extrapolate fit to high masses for background
Signal templates from MC, mass window such that 90% signal included.



For example,
M_G=700 GeV, $k/\overline{M}_{Pl}$ = 0.035
Expect: 1.6 ± 1.3 events
Data : 2 events



For $k/\overline{M}_{Pl}$=0.1, M_G < 920 GeV ruled out.
For $k/\overline{M}_{Pl}$=0.02, M_G < 545 GeV ruled out.

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-044/

Graviton : dilepton

Presented yesterday by Oliver

http://arxiv.org/abs/1108.1582

Search for narrow heavy resonance in dilepton invariant mass distribution

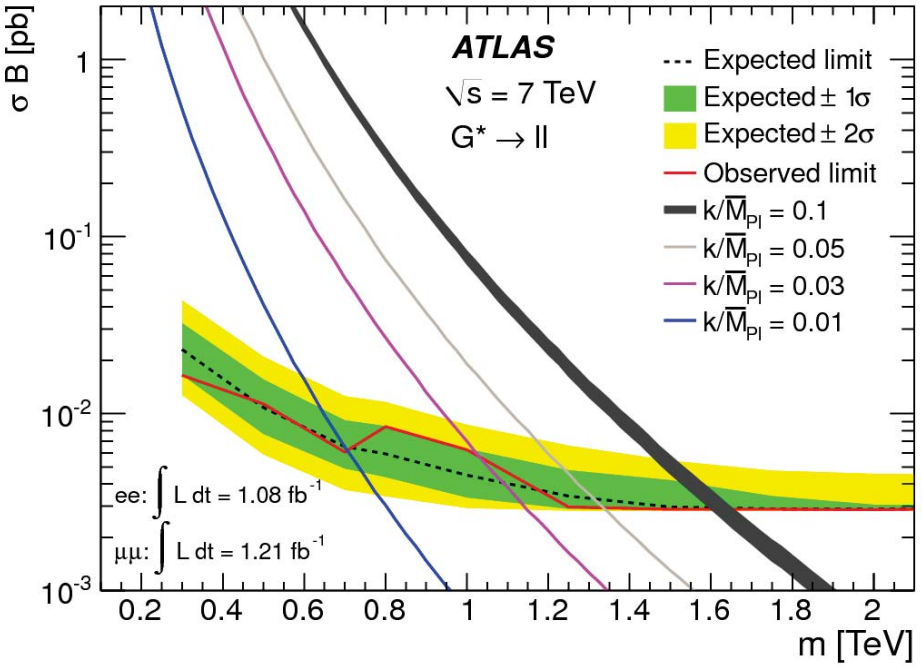
Dilepton σB half as that for diphoton

Data: 2011 data

ee : 1.08 fb^{-1}, μμ : 1.21 fb^{-1}

pT > 25 GeV for e's and μ's.

For $k/\overline{M}_{Pl}$=0.1, M_G < 1.63 TeV ruled out.



Searches for ED with E_T^{miss}

- ADD → Monojet + E_T^{miss}
- UED → Diphoton + E_T^{miss}

Jet + E_T^{miss}

ADD model
KK graviton produced in association with a jet

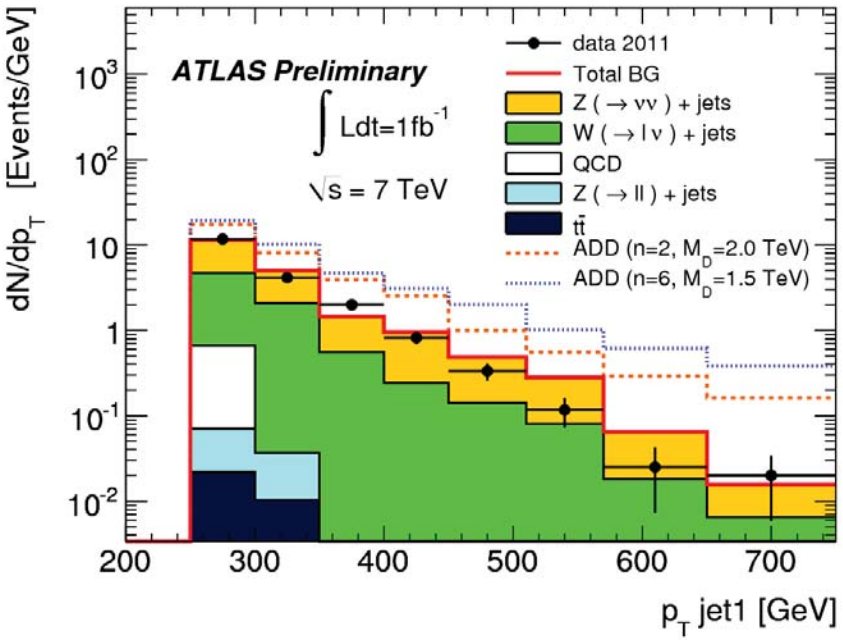
Analysis -

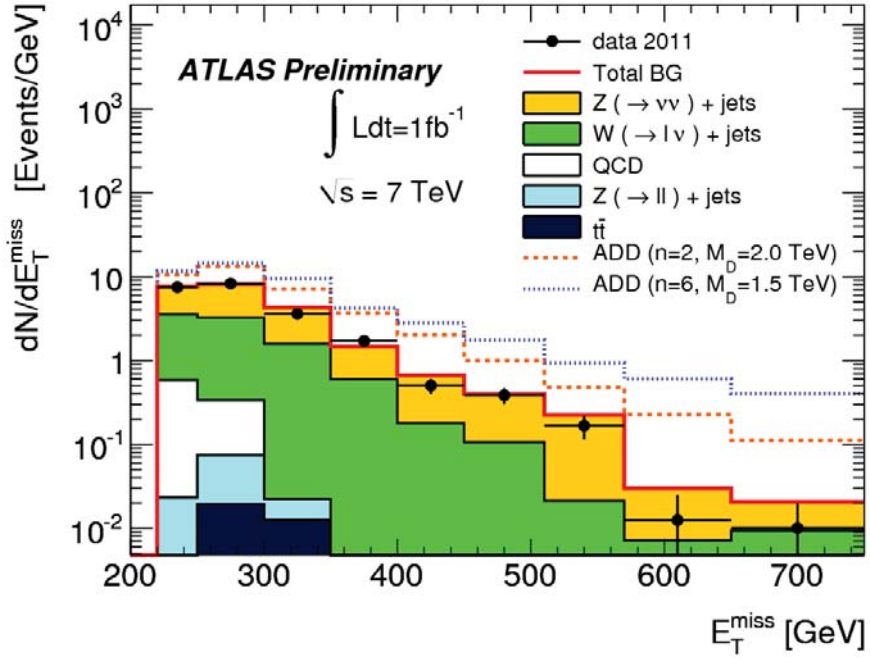
Data: 2011 , 1 fb^{-1}

Jet p_T > 250 GeV, E_T^{miss} > 220 GeV
(no 2nd jet > 60 GeV, no 3rd jet > 30 GeV, no e/μ p_T > 20 GeV)

Background:
- Z+jets, W+jets from MC normalized to data using events with leptons
- Multijet from data

Largest background is Z(→νν)+jets followed by W(→τν)+jets

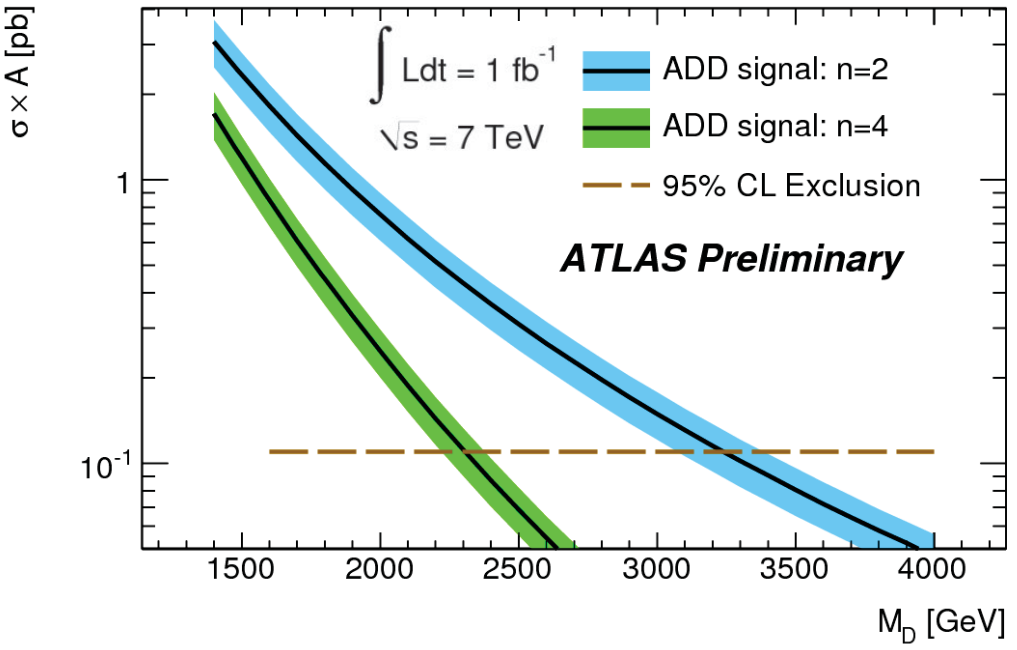




Jet + E_T^{miss}

Predict: 1010 ± 75 events

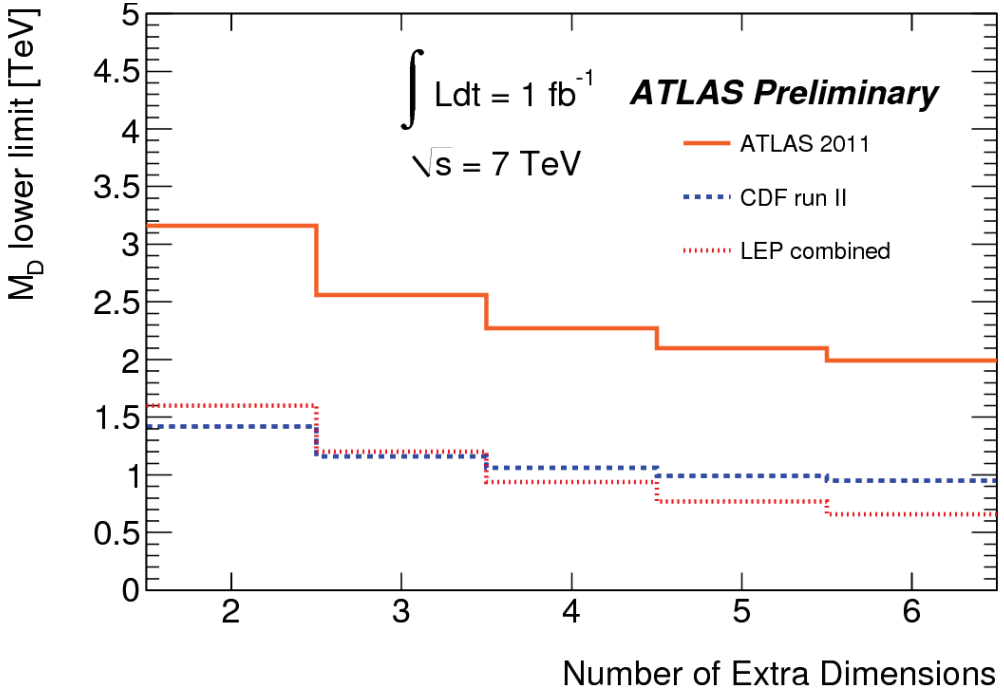
Data : 965 events



Model independent limits on new physics
σxA = 0.11 pb

M_D < 3.2 TeV , excluded for n=2

< 2 TeV , excluded for n=6

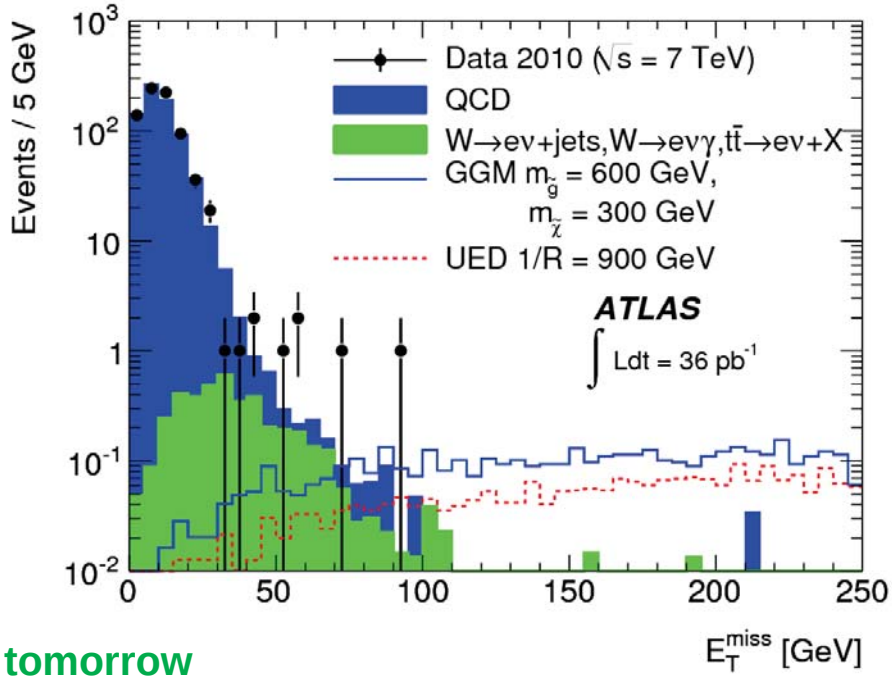


https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-096/

$\gamma\gamma + E_T^{miss}$

UED model:
Produce pair of KK quarks/gluons –
each → KK photon → G + γ

UED specified by R and Λ (ΛR=20)
n=6, M_D=5 TeV



Hear more in SUSY talk tomorrow

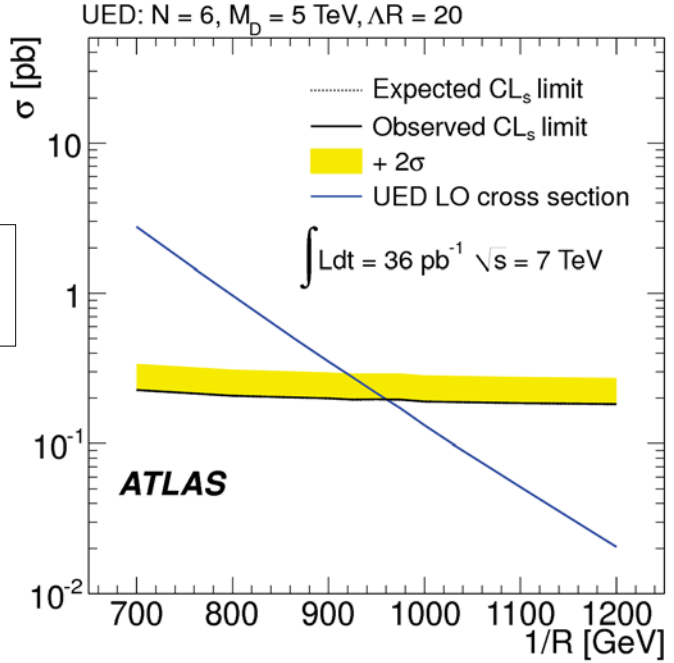
Analysis

Data: 2010 , 36 pb^{-1}
Photon E_T > 30,20 GeV
E_T^{miss} > 125 GeV

Backgrounds
QCD:$\gamma\gamma$,_ γ+jet, multijet
W+jets, tt

Expect: 0.1 ± 0.06 events
Data : 0 events

Exclude 1/R < 961 GeV



http://arxiv.org/abs/1107.0561

Searches for black holes

Within context of ADD models, when $\sqrt{s} > M_D$
black holes can form when impact parameter of collision
is smaller than higher dimensional Schwarzschild radius.

- BH produced with masses between a minimum M_{TH} and $\sqrt{s}$
  ($M_{TH} > M_D$ imposed by hand, $M_{TH}/M_D >> 1$ physical regime)
- BH decay via Hawking radiation, with burst model from BLACKMAX
used for remnant when black hole mass < M_D.

ATLAS searches
- Multijet
- Like-sign

Black holes : multijets

Analysis -

Data: 2010 , 35 pb^{-1}

Signal region

5 or more jets – $N_J \geq 5$

with $\sum p_T > 2$ TeV

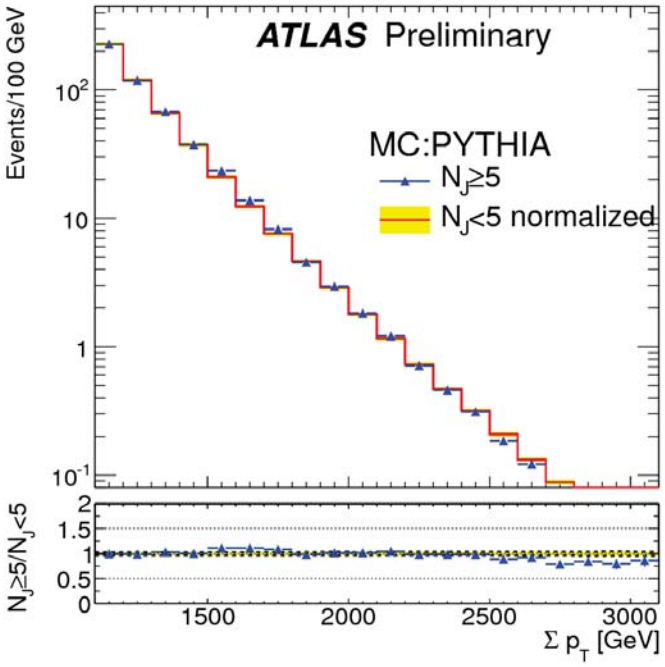
Leading Jet $p_T > 250$ GeV, other jets $p_T > 50$ GeV

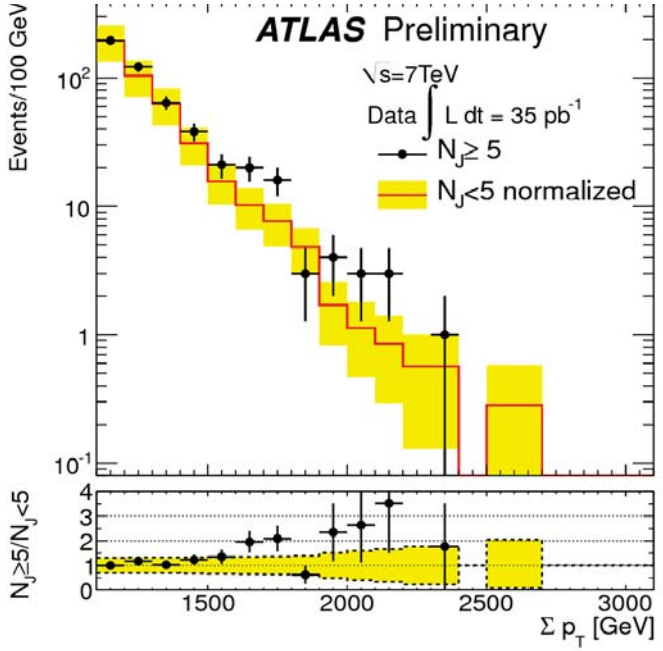
For $\sum p_T > 1$ TeV,

The ratio $\frac{1<N_J<5}{N_J \geq 5}$ is constant in SM

Use ratio to obtain QCD background shape, normalized to data for $1.1 < \sum p_T < 1.2$ TeV

Background obtained from fitting background+signal in four regions defined by $\sum p_T$ and N_J.





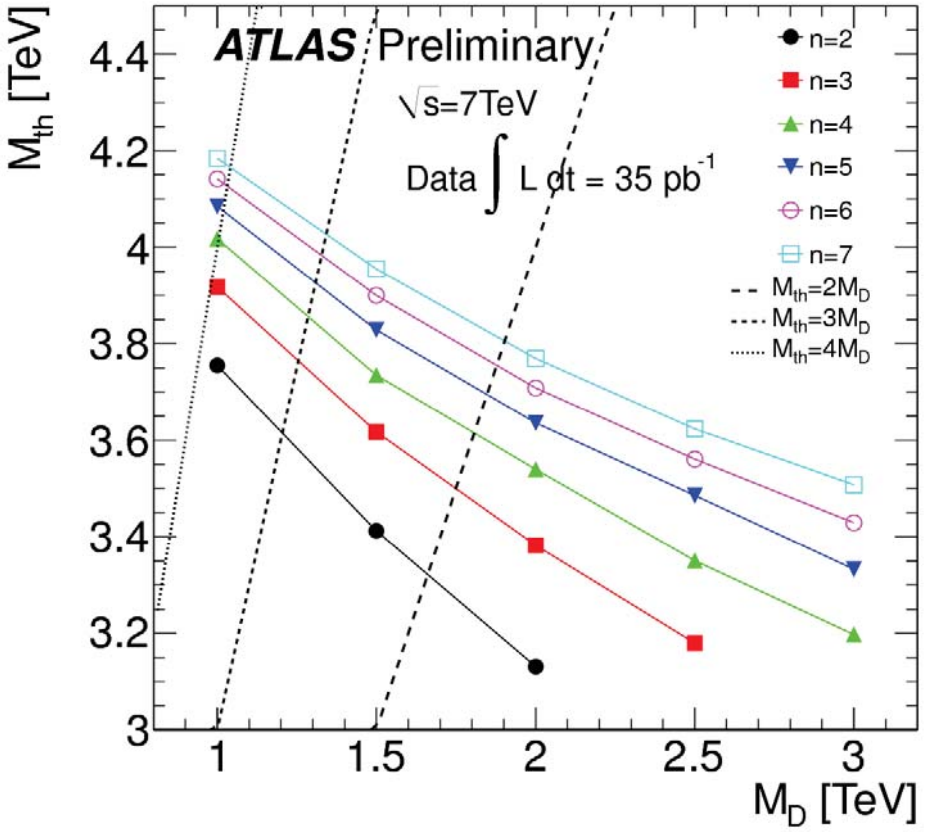
Black holes : multijets

Predict: 3.7 ± 1.5 events

Data : 7 events

Model independent limits on new physics
σxA = 0.29 pb

Exclusion contours are obtained in plane of M_{TH} and M_D for different values of n.



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-068/

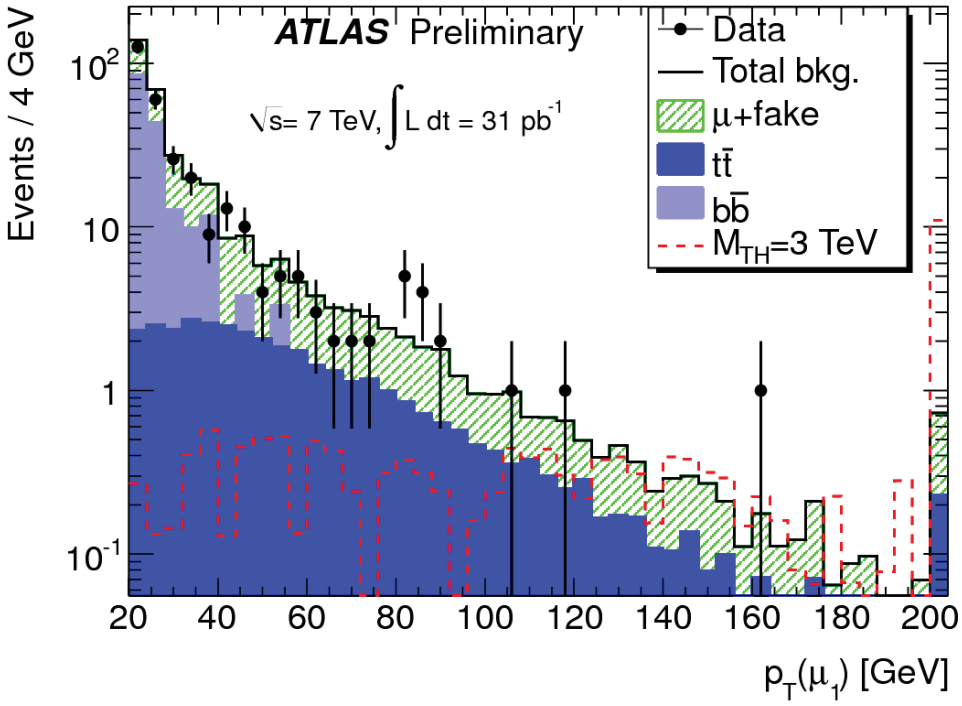
Black holes : $\mu^{\pm}\mu^{\pm}$

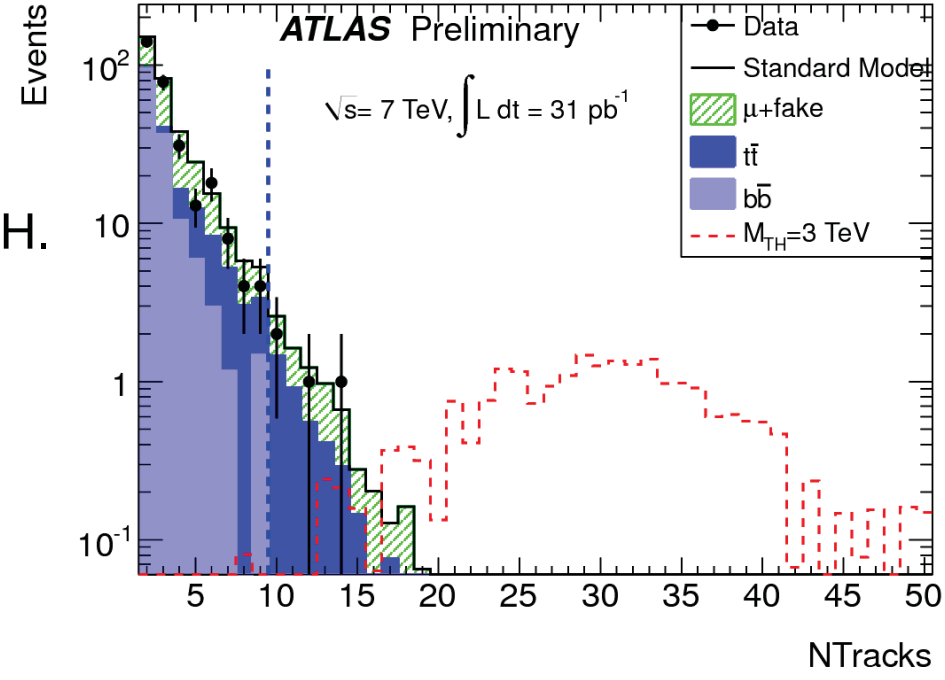
Analysis -

Data: 2010 , 31 pb^{-1}

Two muons of same charge
muon p_T > 20, 10 GeV
NTracks (p_T>8GeV) ≥ 10

- Only leading muon is isolated to gain signal acceptance
- Second muon can come from heavy-flavor decays along with promptly from BH.





Track multiplicity allows clear separation in signal and background

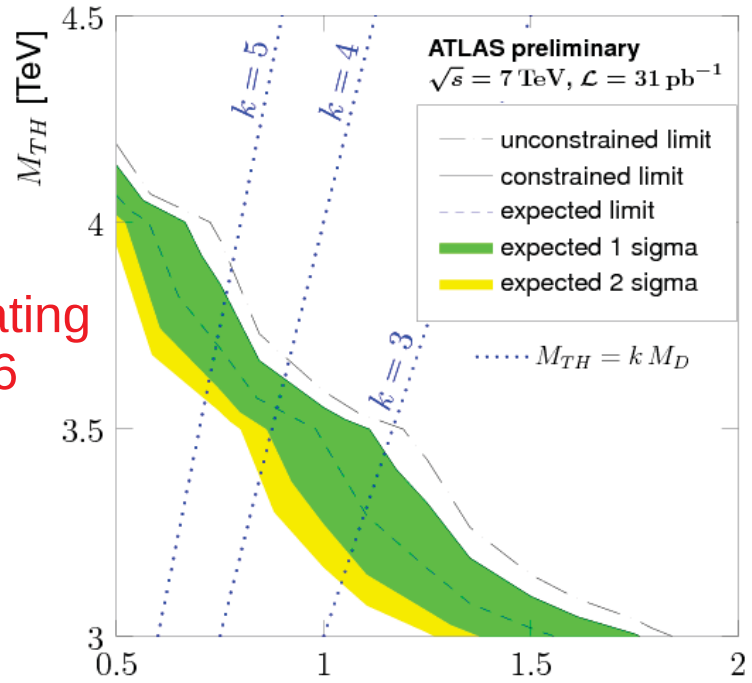
Black holes : $\mu^{\pm}\mu^{\pm}$

Predict: 8.2 ± 2.8 events
Data : 4 events

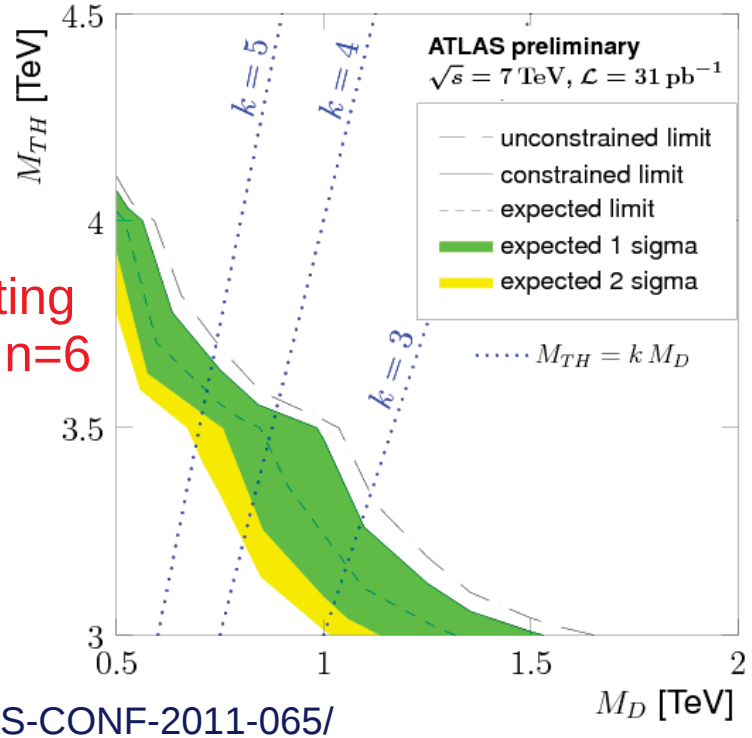
Model independent limits on new physics
σxA = 0.148 pb

Exclusion contours are obtained in plane of M_{TH} and M_D for different values of n and for *rotating* and *non rotating* black holes.

non-rotating BH, n=6



rotating BH, n=6



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-065/

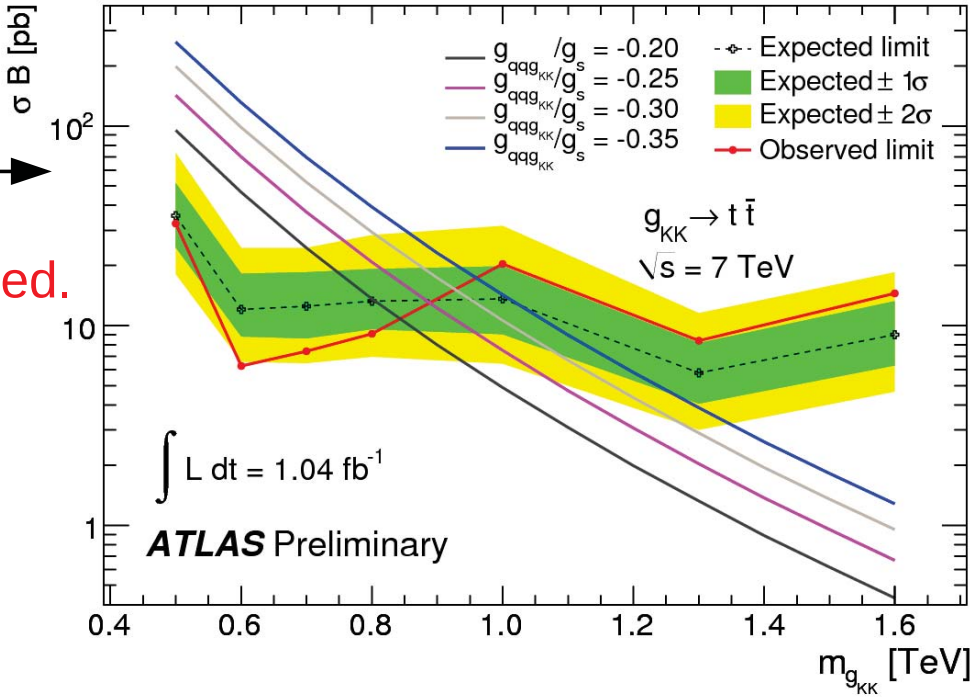
Other Searches

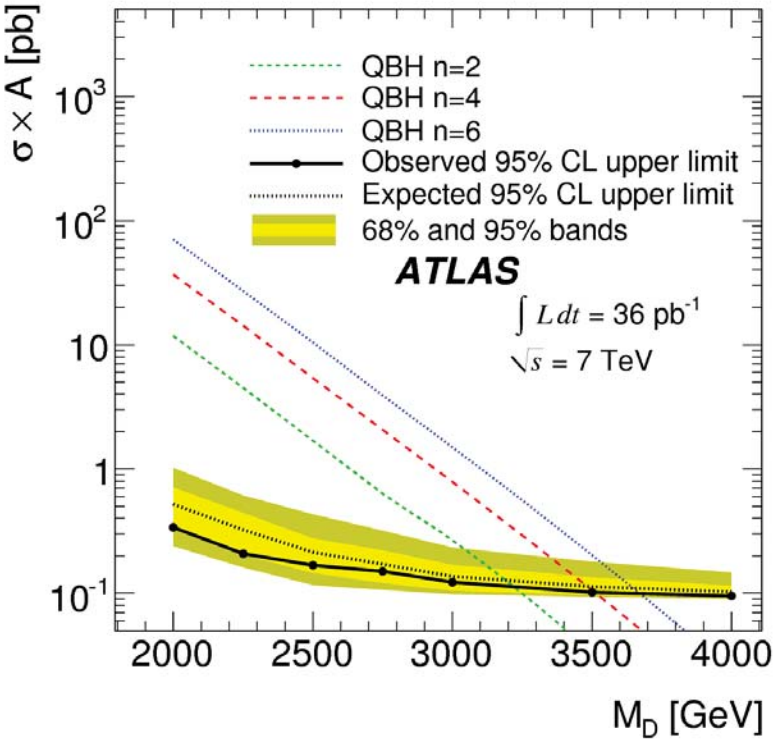
Other searches also being carried out :

- RS KK gluon decaying to $t\bar{t}$
  Search for high mass $t\bar{t}$ resonance.

For $g_{qqg_{KK}}/g_s$=-0.2, $M_{g_{KK}}$ < 0.84 TeV excluded.

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-123/





- RS graviton to dijets
- Randall-Meade quantum black holes to dijet final states

For n=6, M_D < 3.67 TeV excluded.

http://arxiv.org/abs/1103.3864

Conclusions

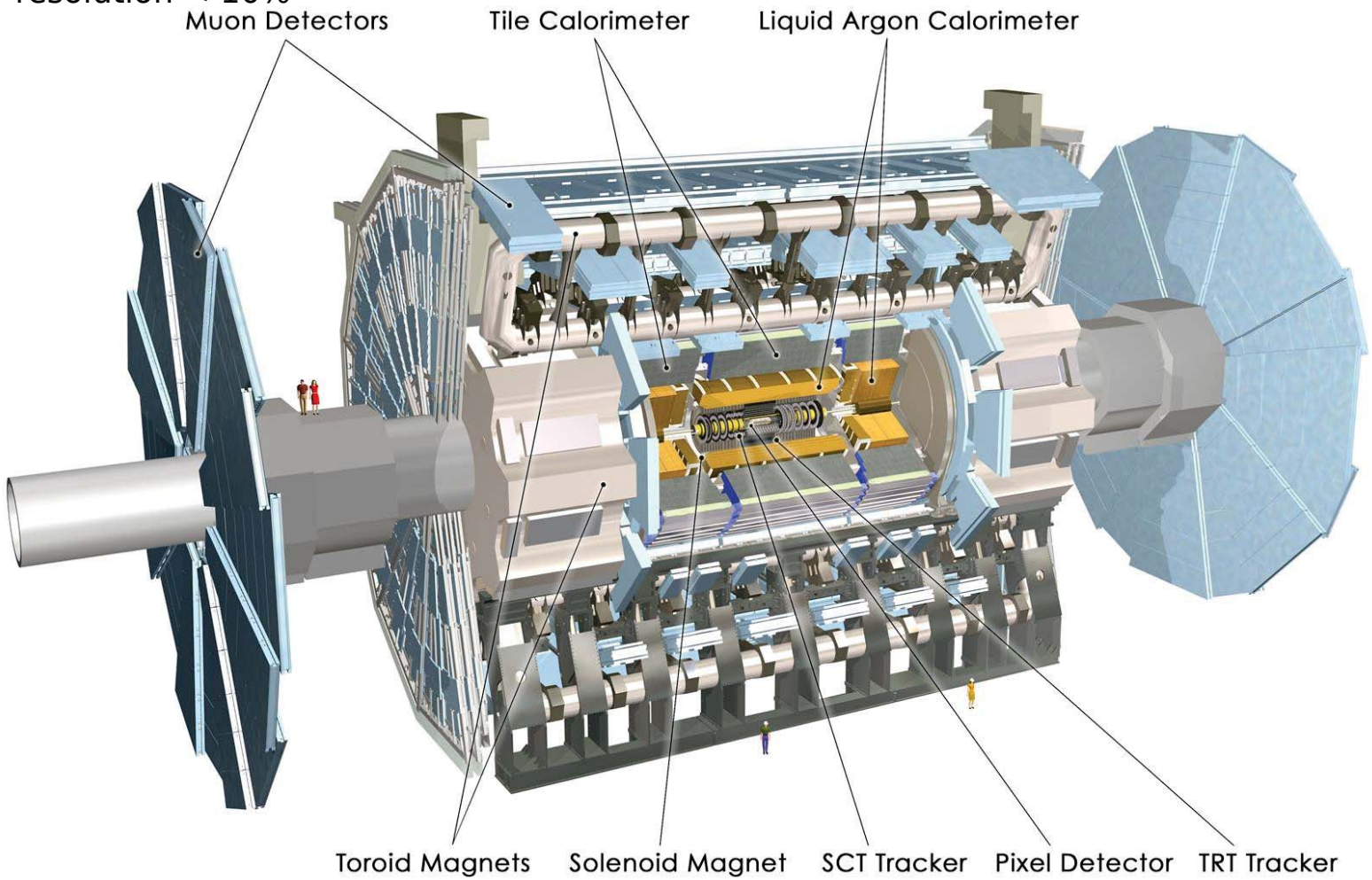
- ATLAS has a rich search program for extra dimensions.
- Searches for graviton resonances, as well as associated production of gravitons. Searches for black holes with different final states.
- Results shown today used either 2010 data or ~ 1 fb^{-1} of 2011 data. Already have little more than 3 fb^{-1}.
- So far no hints of any extra dimension discovery, but with more data, life can always get interesting.

Supplementary Material

The ATLAS Detector

Muon Coverage: |η|<2.7
pT resolution < 10%

EM: |η|<3.2, σ/E~10%/√E
Had: |η|<5, central σ/E~50%/√E⊕0.03, forward σ/E~90%/√E⊕ 0.07



Tracker Coverage: |η|<2.5
$\sigma/pT \sim 3.8 \times 10^{-4}\ pT(GeV) \oplus 0.015$

Some further reading for the theoretical aspects of extra dimensions...

1) K. Nakamura *et al.* (Particle Data Group), J. Phys. G **37**, 075021 (2010)

2) N. Arkani-Hamed *et al.*, Phys. Lett. **B429**, 263 (1998)

3) L. Randall and R. Sundrum, Phys. Rev. Lett. **83**, 3370 (1999)

4) T. Appelquist *et al.*, Phys. Rev. **D64**, 035002 (2001)