Sensitivity of ATLAS to Extra Dimensions

Nick Brett
University of Oxford

Large Extra Dimensions

Warped Extra Dimensions

Universal Extra Dimensions

Micro Black Holes

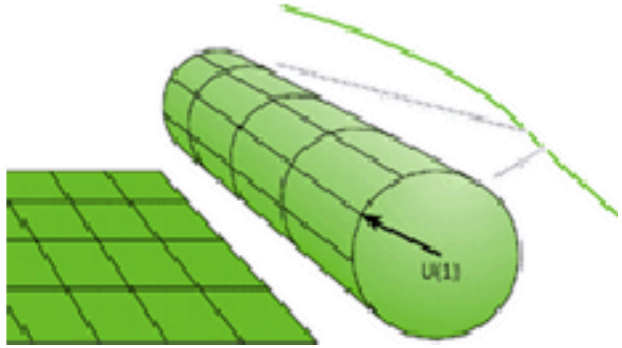
Physics at LHC 3-8 July 2006

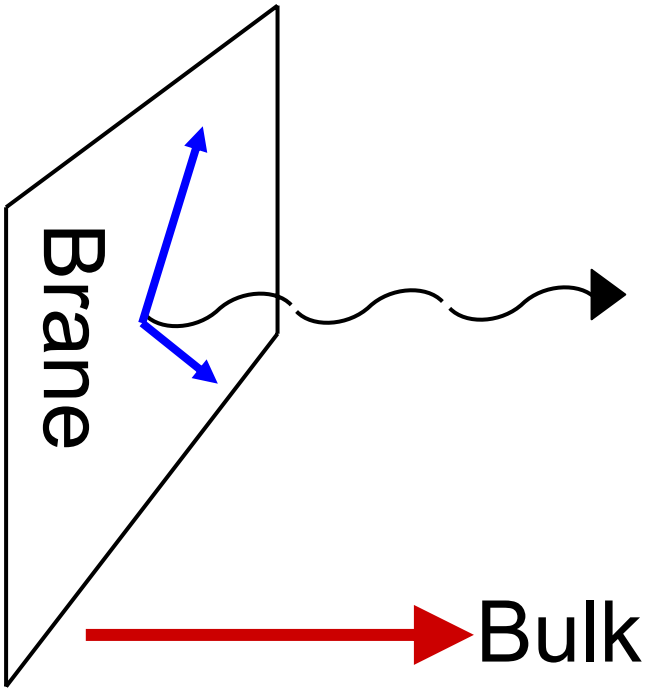
ATLAS

Extra Dimensions

Not a new idea (1920's)

Kaluza and Klein tried to unify Electro-magnetism and General Relativity





Undergoing a Revival

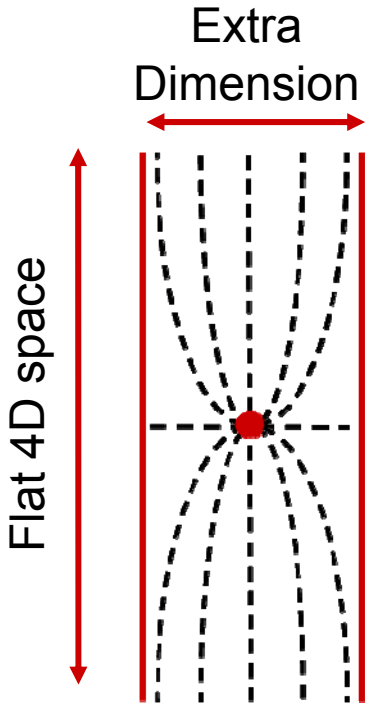
Access to Extra Dimensions can be restricted

- Can Solve Hierarchy problem
  - M_{pl} is only an effective scale
  - New fundamental scale M_f
- Essential for String Theory
- Can be compactified

Large Extra Dimensions

ADD

- Extra Dimensions are flat
- Only accessible to Gravity
- SM particles restricted to 4D Brane
- Could be as large as 0.1mm



Generates Tower of KK gravitons

- Coupling proportional to $1/M_{pl}$
- Mass splitting ~ 1/R
- Observe a continuum of graviton states

Extra dimensional momentum looks like a mass

$$E^2 = P^2 + m^2$$

$$= P_x^2 + P_n^2$$

Large Extra Dimensions

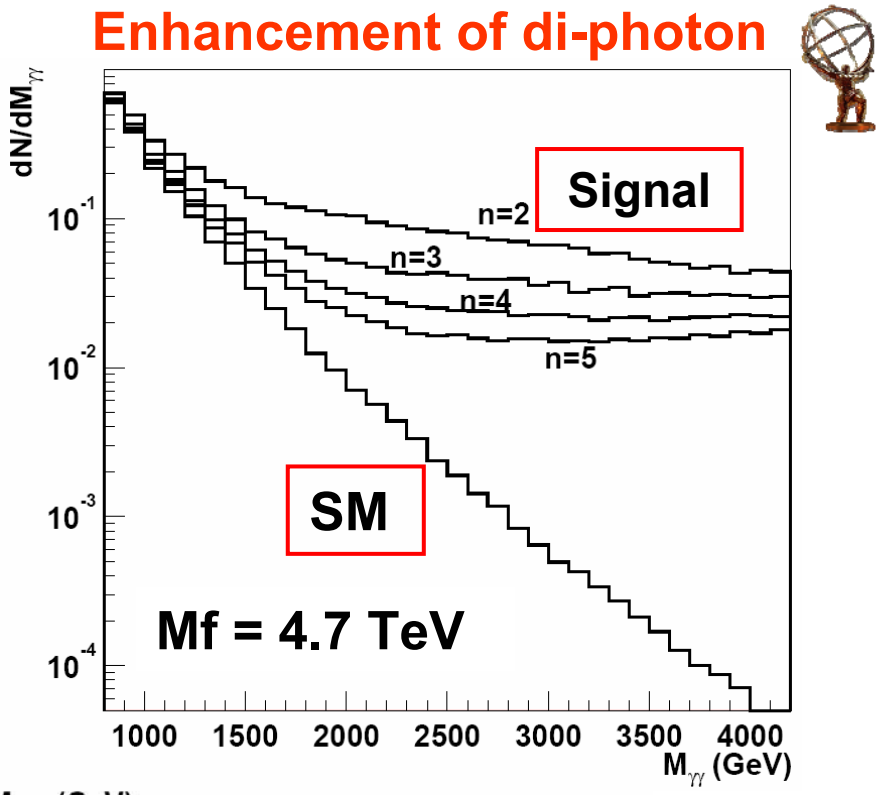
Di-photon/lepton

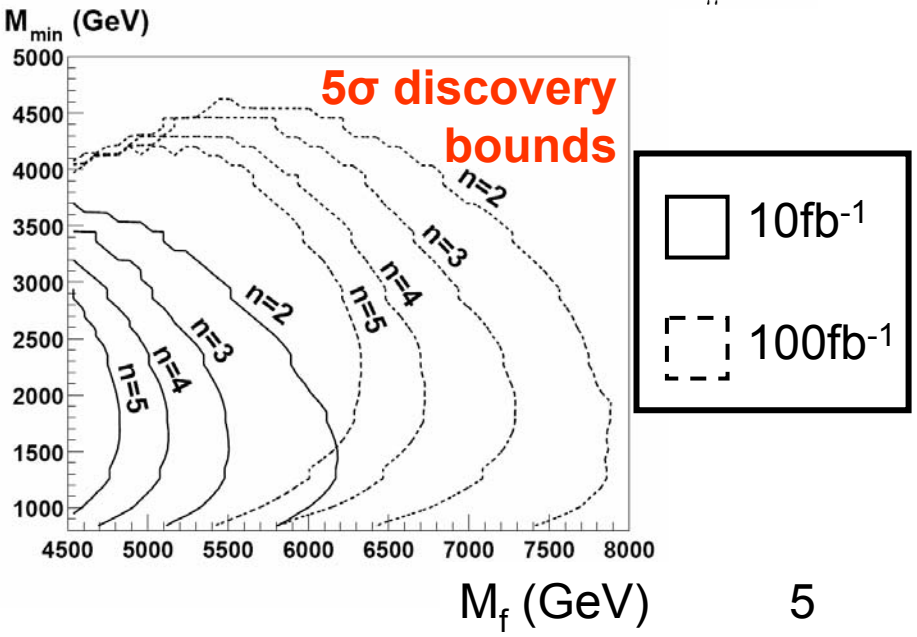
Kabachenko, Miagkov, Zenin

[ATL-PHYS-2001-012]

- virtual graviton exchange
- Tower of KK gravitons
- Measure invariant mass of photon/lepton pair
  - Min invariant mass cut extends reach

Sensitivity @ 100fb^{-1}
5σ for M_f 6.3-7.9 TeV





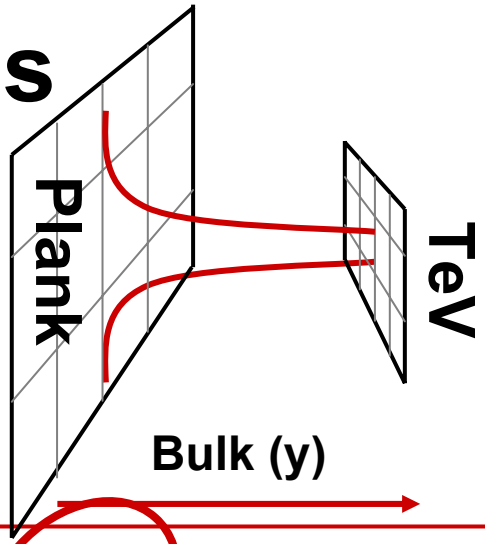
Warped Extra Dimensions

Randall Sundrum (type I)

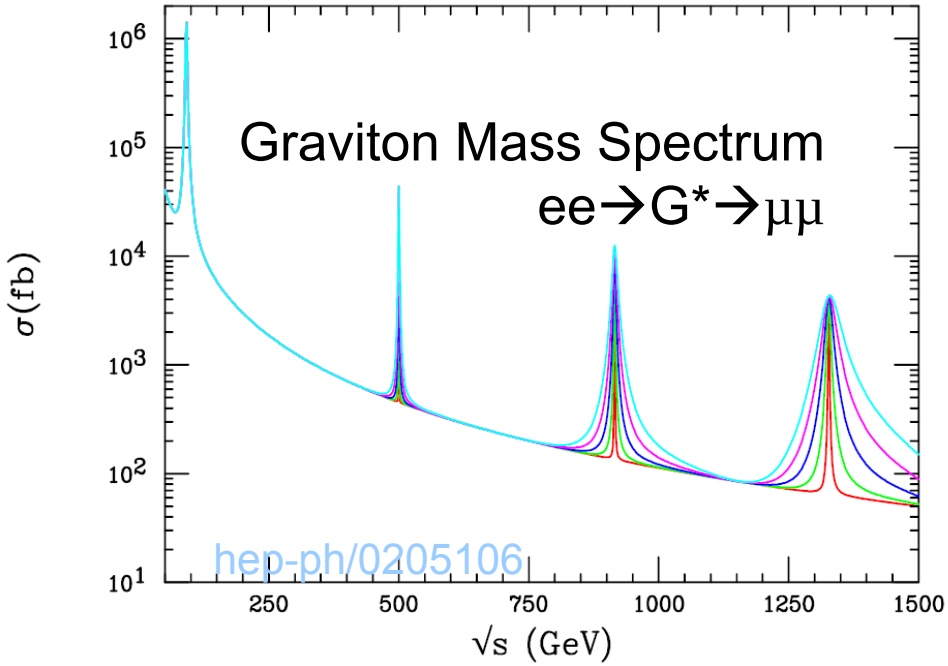
Randall, Sundrum

[PRL 83 (1999) 3370]

- Brane metric scales as function of bulk position
- Solves Hierarchy problem using warp factor
- Small extra space dimensions
- Well separated graviton mass spectrum



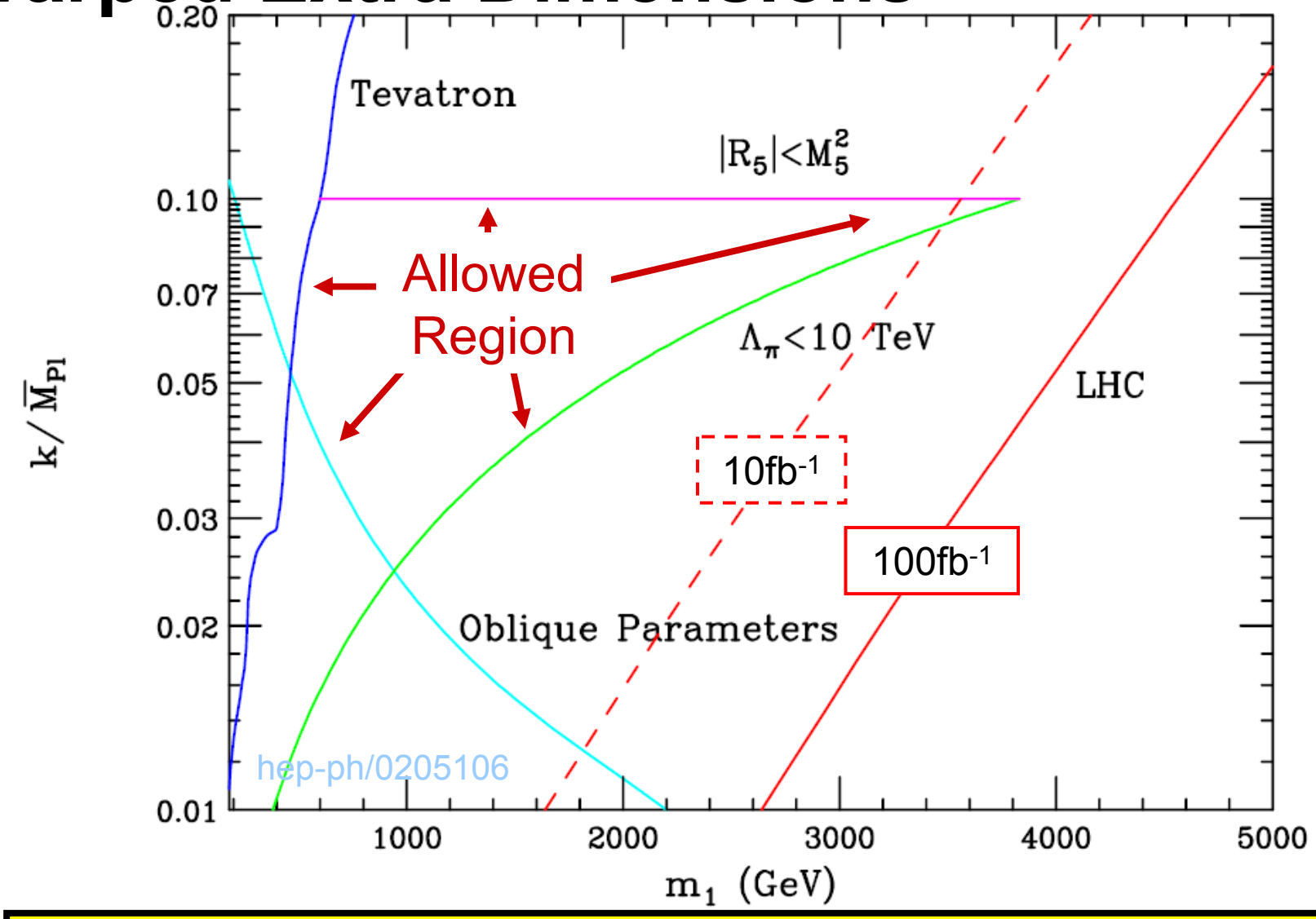
$$ds^2 = e^{-2ky}\eta_{uv}dx^u dx^v - dy^2$$



Characterized by

$$k/\overline{M}_{pl}$$

Warped Extra Dimensions



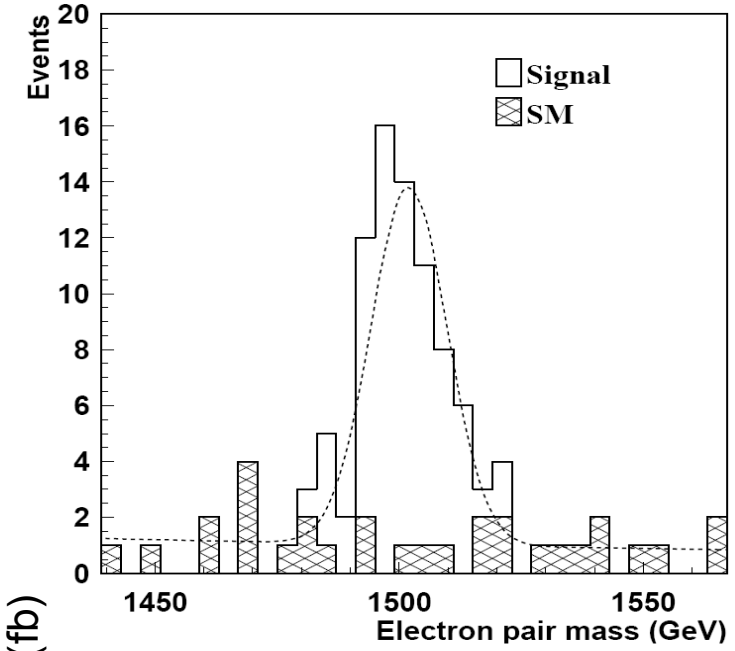
ATLAS is able to explore the entire allowed region

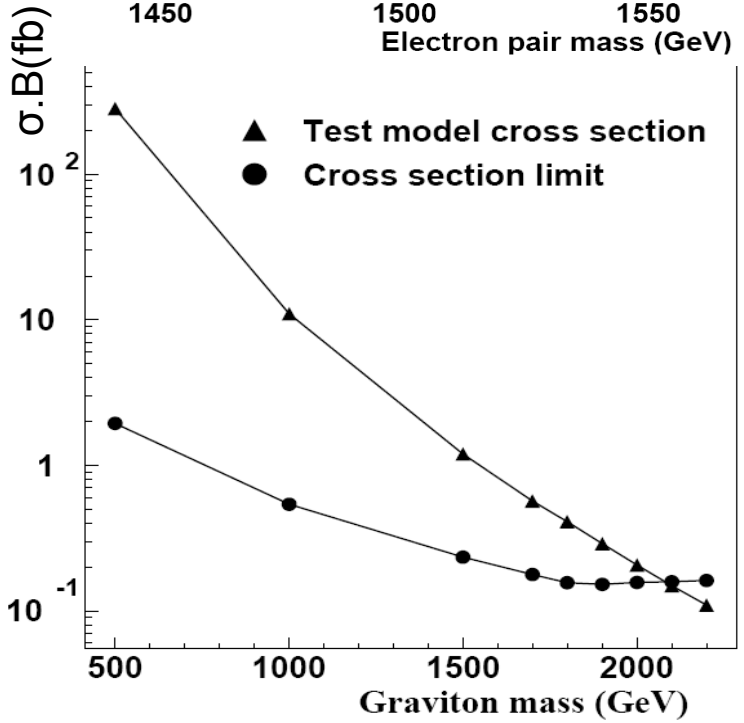
Warped Extra Dimensions

$G^* \rightarrow e^+e^-$

Allanach, Odagiri,Palmer,
Parker Sabetfakhri,Webber
[JHEP09(2000)019]
[JHEP12(2002) 039]

- Graviton
  - Produced in kk spectrum
  - Looked for 1st KK mode
  - Studied models with narrow resonance





Sensitivity @ $100fb^{-1}$
5σ up to M_G 2.08TeV

Universal Extra Dimensions

Beauchemin, Azuelos

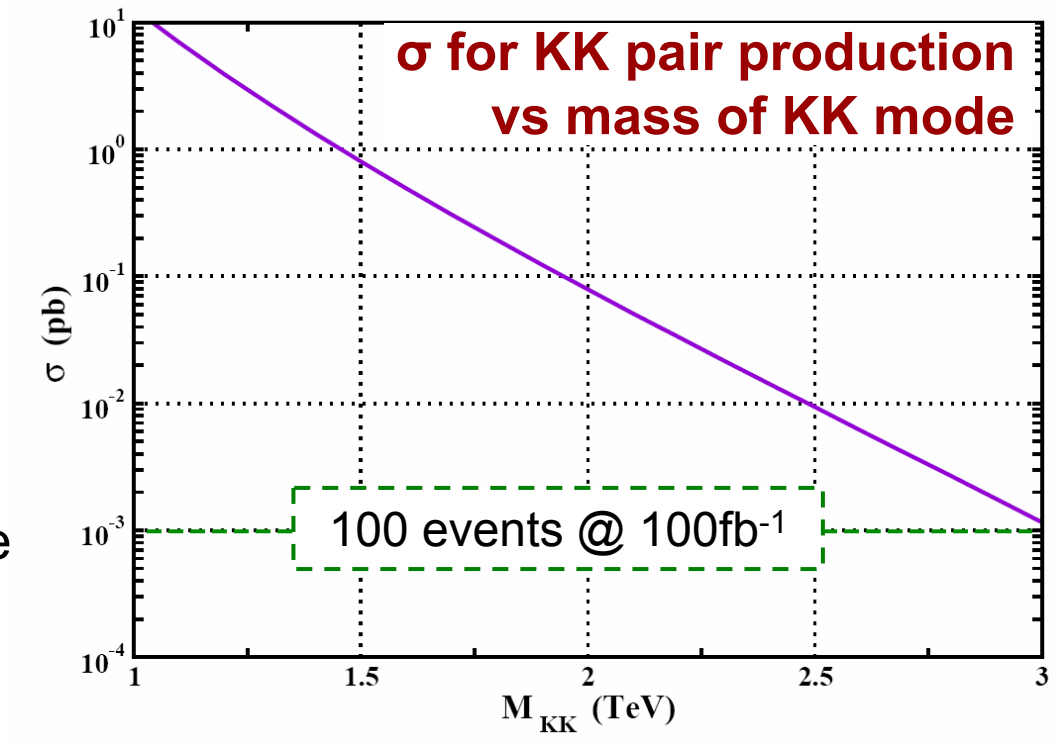
[ATL-PHYS-PUB-2005-03]

SM particles propagate in Extra Dimensions

- can move in small Extra dimensions
- Often embedded in large Extra Dimensions

KK parity

- similar effect to R-Parity
- conserved at Tree level
- KK particles always in pairs
- no virtual KK particles

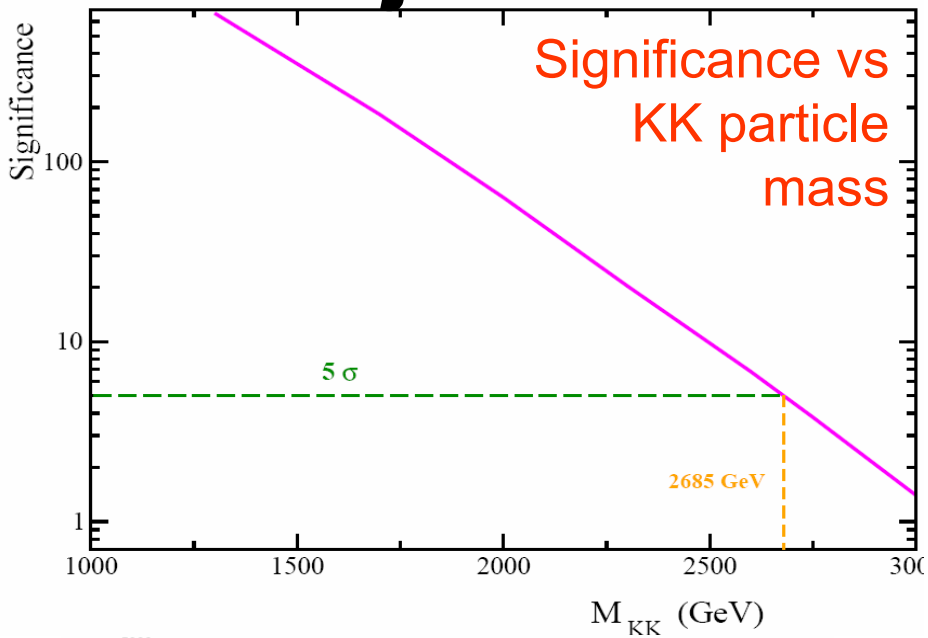


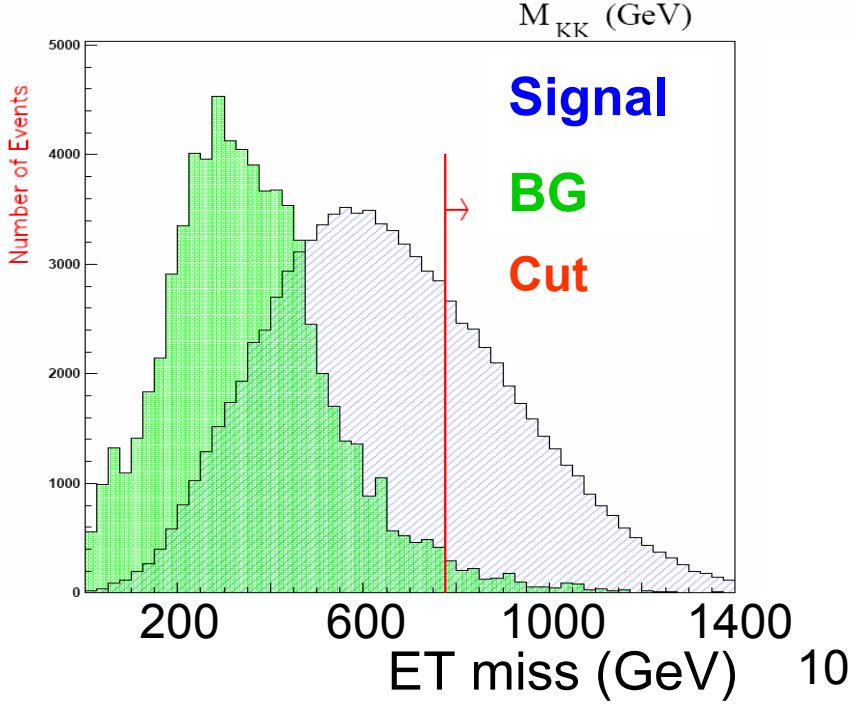
KK parity conservation means limits on UED are much weaker

UED: KK quark/gluon → di-jet

Beauchemin, Azuelos [ATL-PHYS-PUB-2005-03]

- Direct KK mode production only
- Measure excess of dijets with large missing E_T
- Assume all KK modes decay to gravitons (invisible)





Sensitivity @ 100 fb^{-1}
5σ up to 2.7 TeV

UED: KK gluons → Heavy quarks

g* → bb/tt

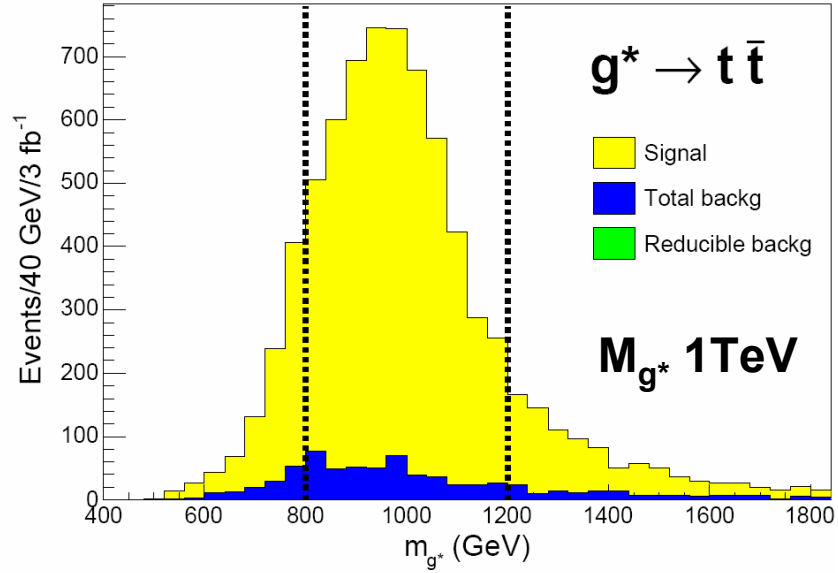
March, Ros, Salvachua

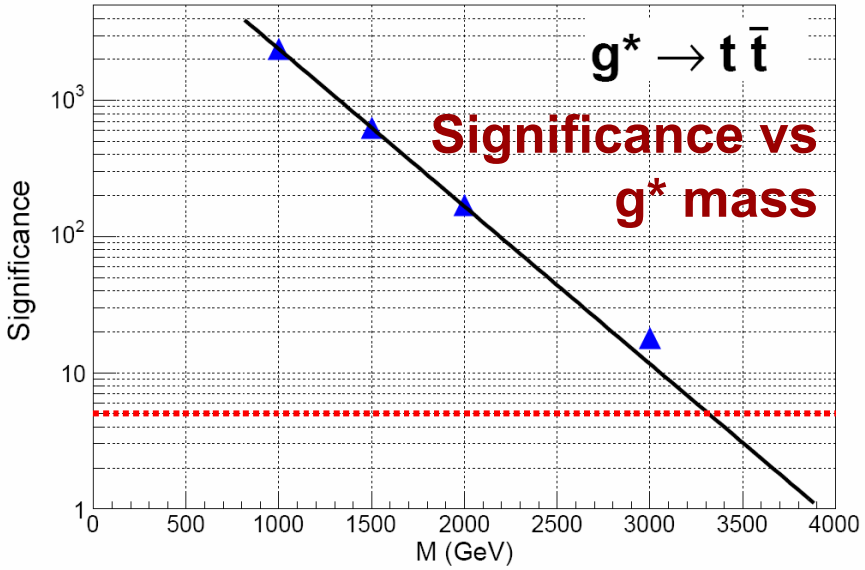
[ATL-PHYS-PUB-2006-002]

- Only produce hadronic decays
- Tag Heavy quark decays
- Excess of di-jets
- b-quark decays difficult to detect
- t-quark channel provides clearest signal

Sensitivity @ 100fb^{-1}

5σ M_{g^*} up to 3.3TeV



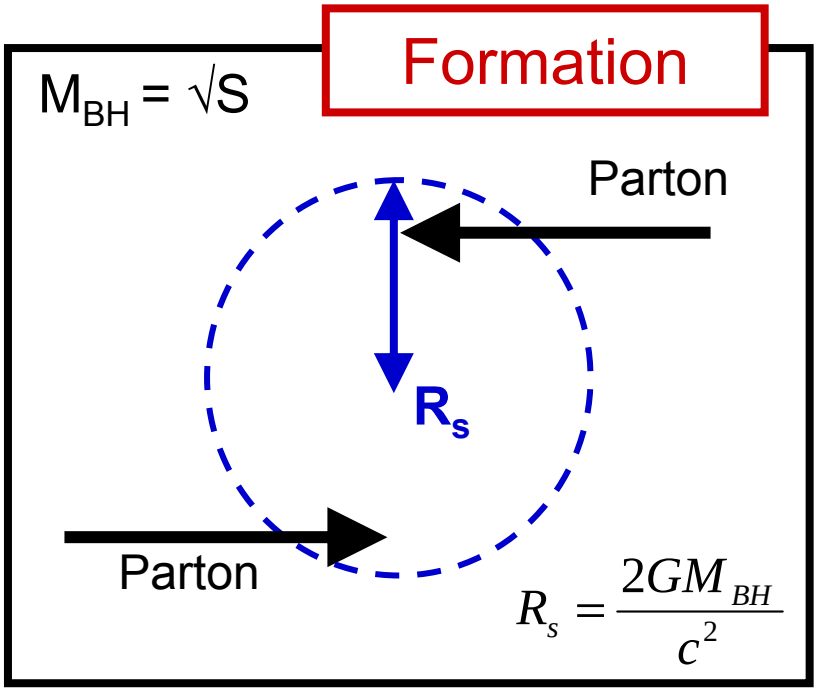


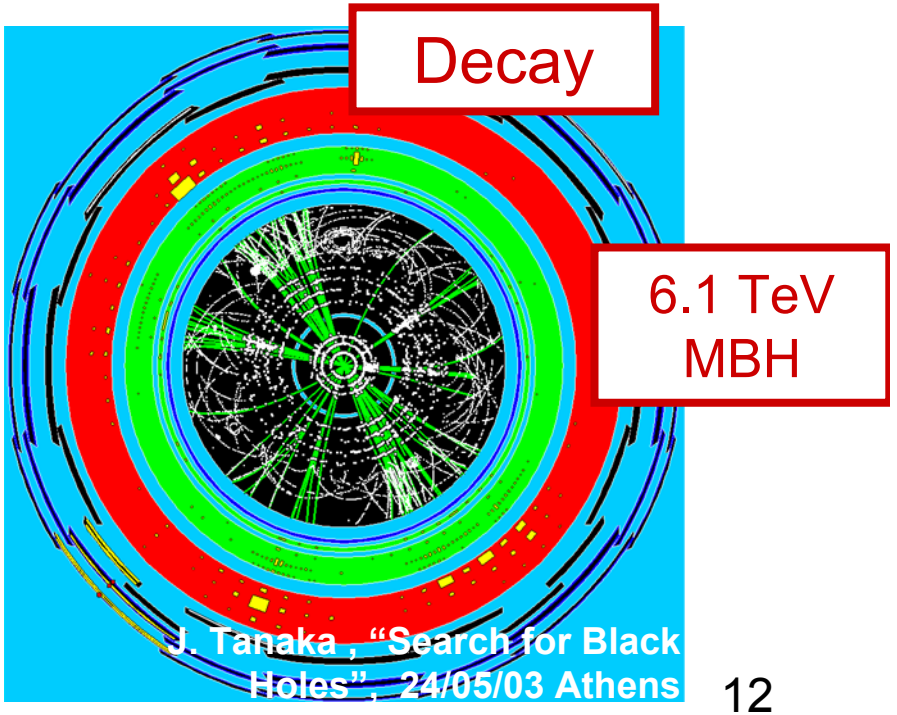
Micro Black Holes

Harris, Palmer, Parker, Richardson, Sabetfakhri, Webber [JHEP05 (2005) 053]

- $\sigma \sim \pi R_S^2 \sim O(100)pb$
- LHC → Black Hole Factory
- BH lifetime ~ 10^{-27} – 10^{-25} seconds!
- Decays with equal probability to all particles via Hawking Radiation
- Follows almost black body spectrum

$$T_H = \frac{1+n}{4\pi R_{BH}} \approx \frac{1+n}{M_{BH}^{1/(1+n)}}$$





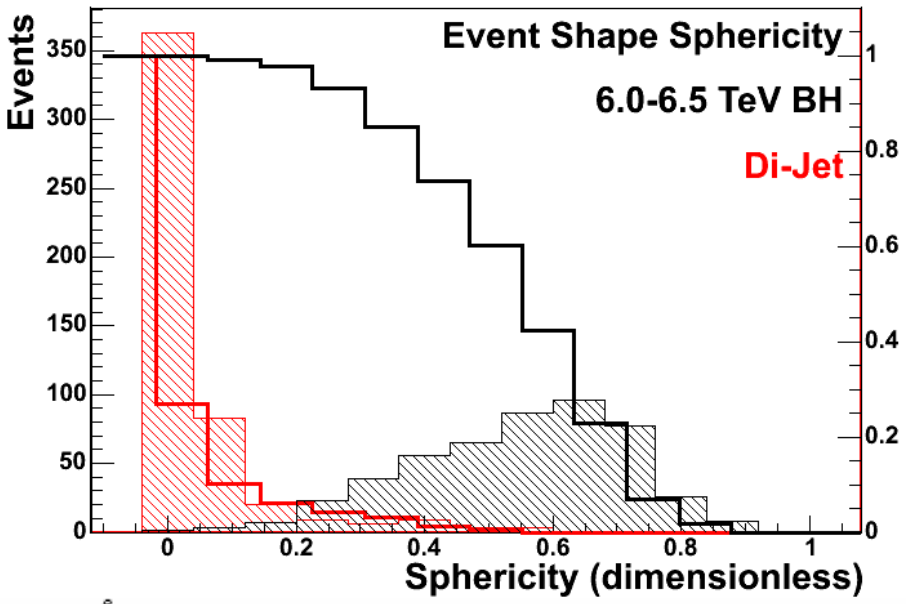
Micro Black Holes

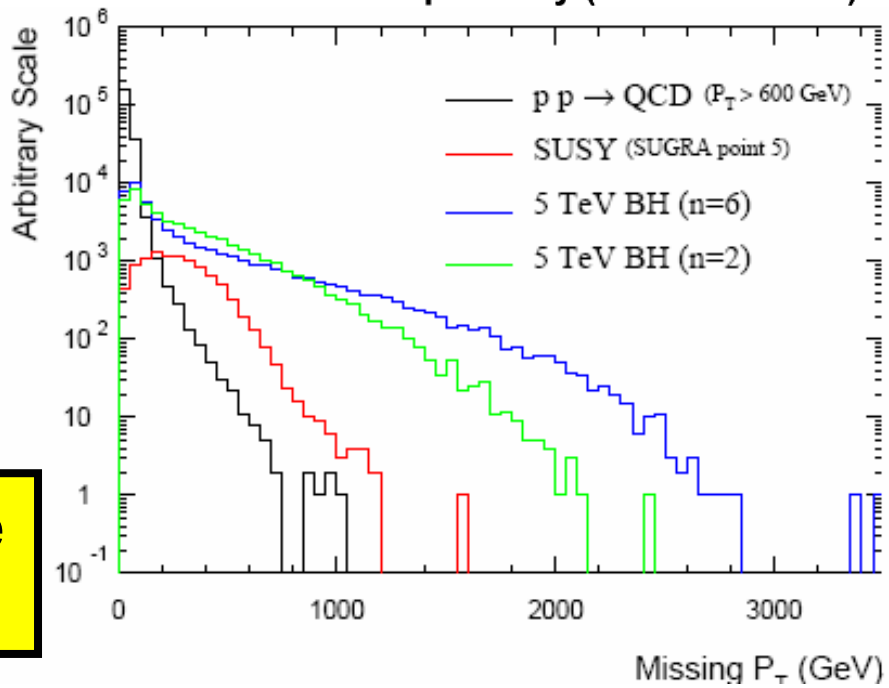
Distinguishing features

- High Multiplicity
- High ΣE_T
- High Sphericity
- High Missing P_T
- Democratic Decay

Sensitivity Dominated by Theoretical uncertainty

If M_{pl} ~ O(1 TeV) → Black Hole Production possible at LHC





Summary

5σ discoveries with *100fb^{-1}*

- ADD fundamental M_{pl} up to 7-8 TeV
- RS graviton up to 2.08 TeV
- UED KK particles up to ~3 TeV
- If Micro Black Holes are produced we will know!

Backup Slides

Large Extra Dimensions

Jet + E_T miss

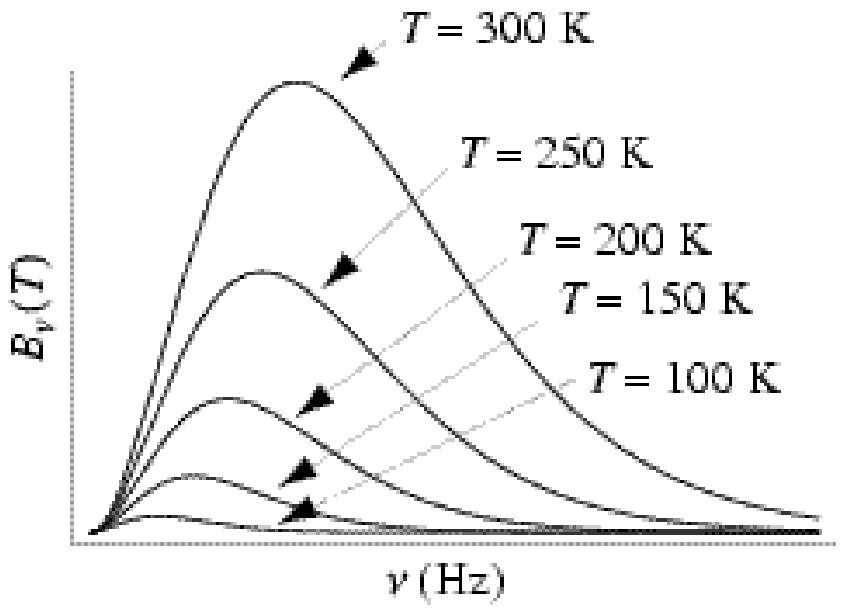
- Direct graviton production

Vacavant, Hinchliffe

[JPG 27(2001) 1839]

Black Hole Decay

- Decay via Hawking Radiation
- Emit particles following an approximately black body thermal spectrum



$$T_H = \frac{1+n}{4\pi \cdot R_{BH}} \approx \frac{1+n}{M_{BH}^{1/(1+n)}}$$

n = number of extra dimensions

- Spectrum modified by Grey Body factors
- Black Hole might not maintain Thermal equilibrium

- Astrological BH -- **COLD** -- Low Evaporation
- Micro BH -- **HOT** -- High Evaporation

Black Hole Events in ATLAS

BH evaporates into

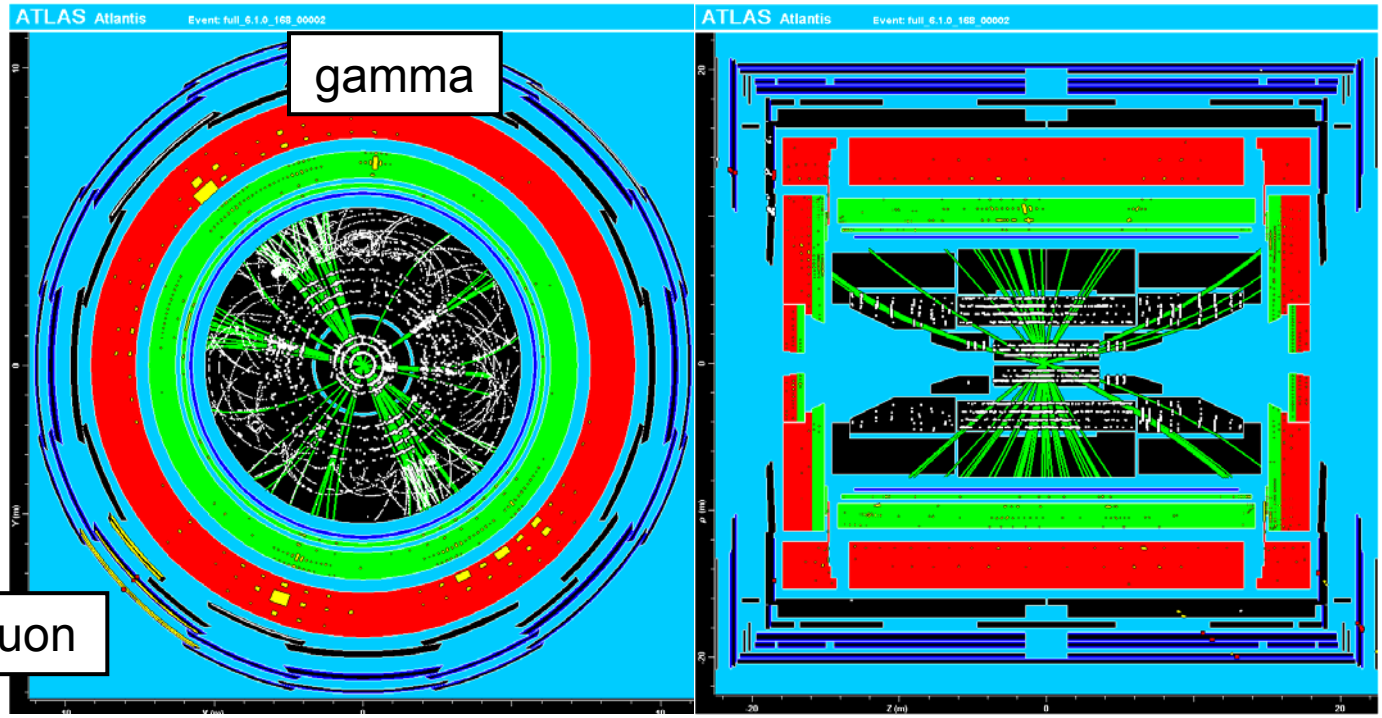
(q and g : leptons : Z and W : ν and G : H) = (72%:11%:8%:6%:2%:1%)

(hadron : lepton) is (5 : 1) accounting for t, W, Z and H decays

S.B. Giddings, S. Thomas, [Phys.Rev.D65(2002)056010]

Decay of 6.1 TeV Black Hole

High multiplicity events



J. Tanaka, "Search for Black Holes", 24th May 2003 at Athens