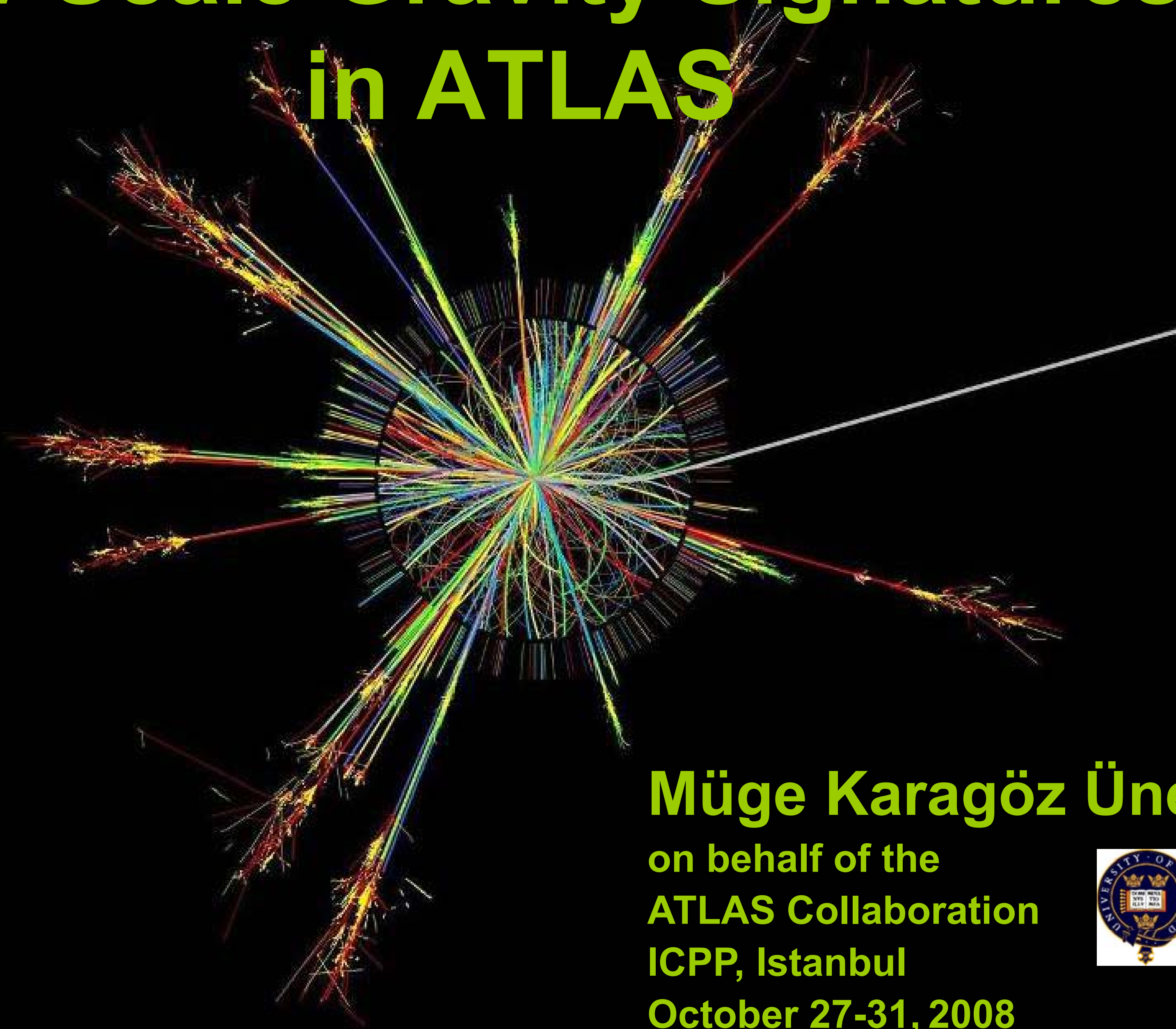
Low Scale Gravity Signatures in ATLAS

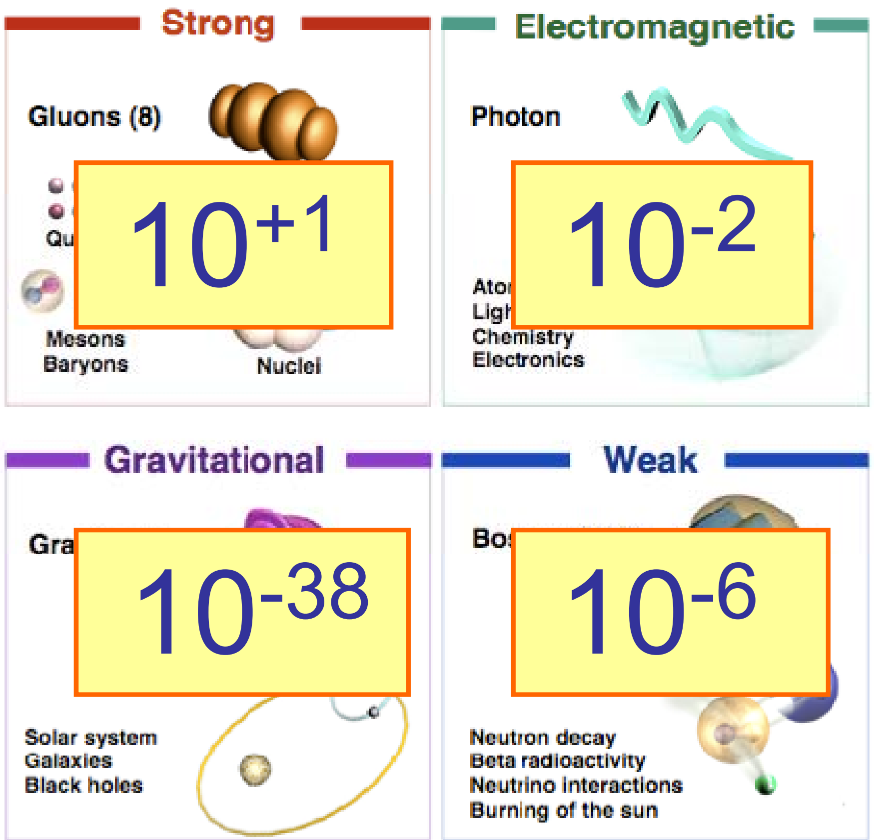


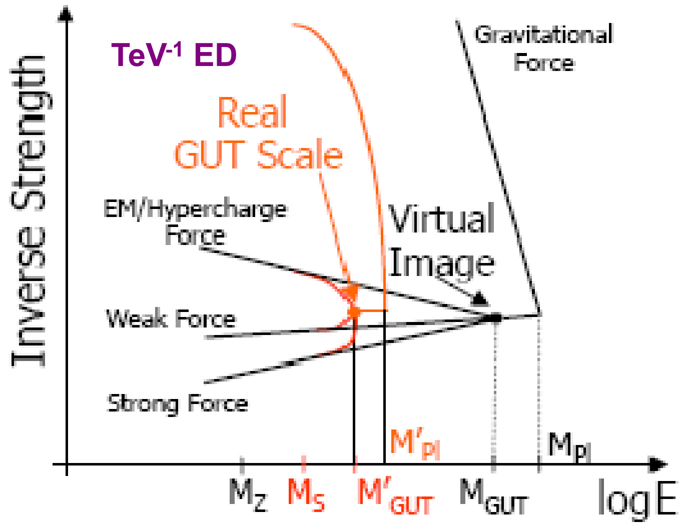
Müge Karagöz Ünel

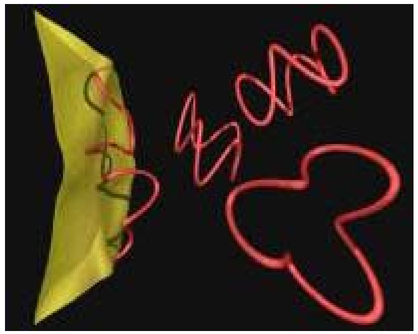
on behalf of the
ATLAS Collaboration

ICPP, Istanbul
October 27-31, 2008

A motivation: the Unbearable Lightness of Being



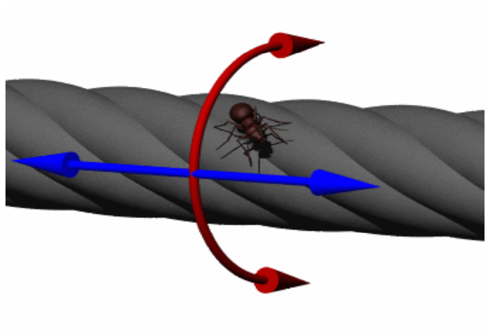




Gravity is weak, governed by Planck scale ($M_{Pl}=10^{19}$ GeV)
How to unify forces & solve the hierarchy problem ($M_{Pl} >> M_{EW}$)?

Extra Dimensions: Not a Flatland

- In 1920's Kaluza&Klein attempted to unify EM with gravity in 5D
- In late 1990's, models built to solve the hierarchy problem
- We observe apparent gravity; actual gravity is stronger and its scale can be as low as ~ TeV
- Many ED models: flat (ADD, TeV^{-1}), warped (RS); various particles escaping into "bulk" while SM is confined to our 3-brane

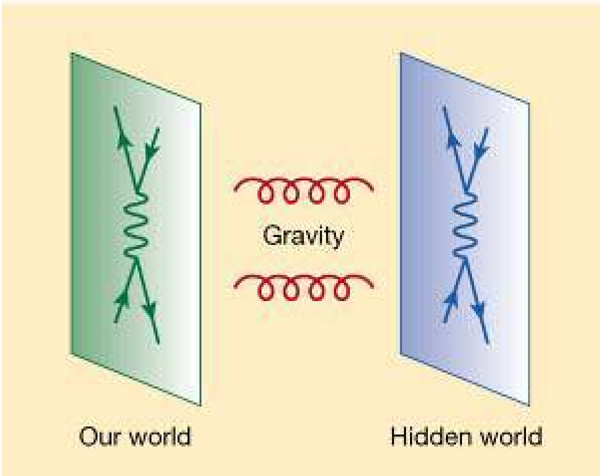


$$G_N = \frac{1}{(M_{PL(4+n)})^2} \equiv 1/M_D^2$$

$$M_{Pl}^2 = M_D^{2+n} R^n$$

$M_{Pl} \sim 10^{19}$ GeV, $M_{Pl(4+n)} \sim M_{EW}$

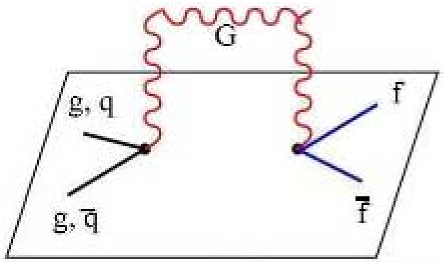
Obtain size of the ED from gravitational potential

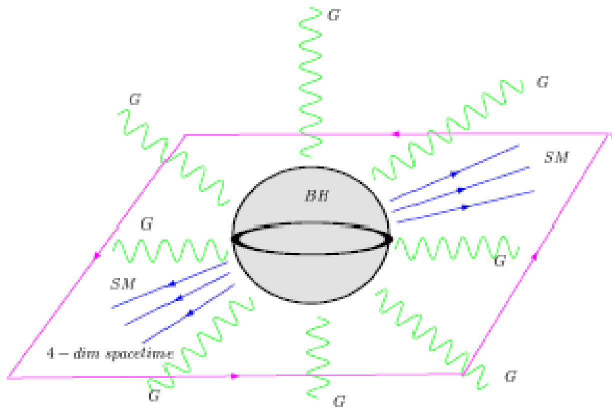


$1/r^2$-law valid for R=44 μm @ 95% CL

Gravity in ATLAS

- Analyses being optimised for observation of TeV-scale gravity effects in ATLAS
- Here, 3 signatures in 3 different models with increasing signature complexity presented *published only*
  - Exclusive resonance searches:
    - New particles: A set of particles have higher order modes (KK) with model dependent mass separation
    - Randal-Sundrum graviton in dielectron channel *CERN-OPEN-2008-020*
    - TeV^{-1} ED KK gluon in heavy diquark channel *ATL-PHYS-PUB-2006-002*
  - Inclusive searches:
    - ADD black holes in high-multiplicity events *CERN-OPEN-2008-020*

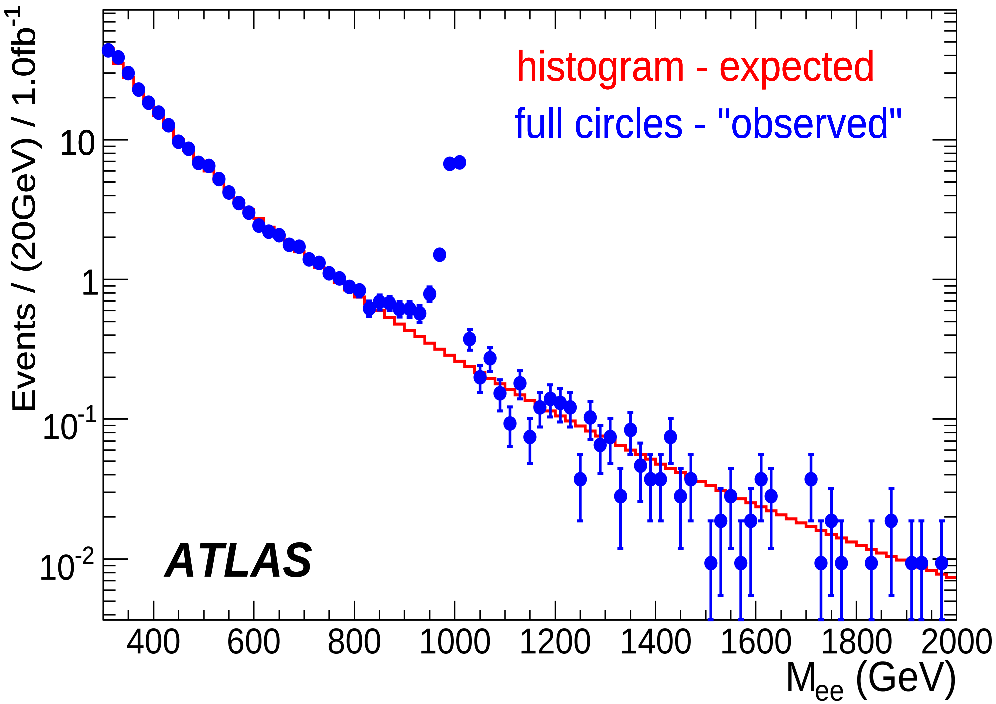




RS KK Graviton Search in Dielectrons

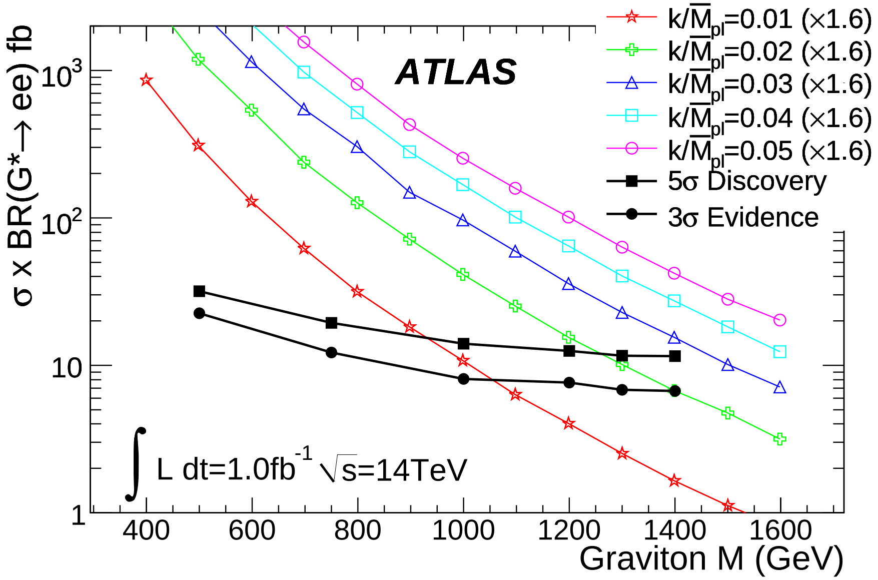
- Well-separated narrow resonances predicted by highly-warped RS ED *PRL83/3370/99*
- Graviton coupling constant: $c = k/\underline{M}_{Pl}$, k: curvature scale
- Cross-section varies from ~200 fb - ~20 fb, for 0.5-1.4 TeV Graviton.

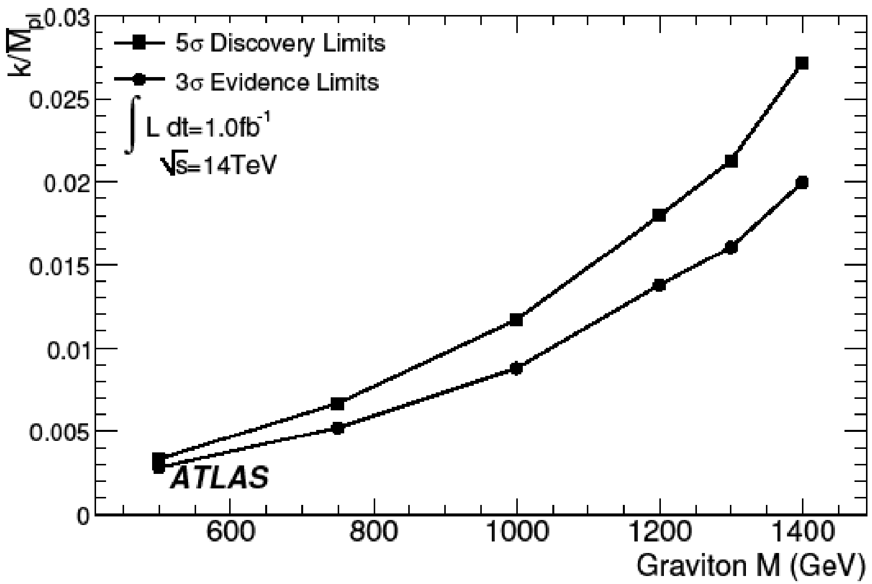
- Select 2 back-to-back electrons $p_T > 65$ GeV, no charge requirement
  - "loose" cuts to increase high p_T efficiency: 66-54%, for 0.5-1.4 TeV G^*
- Main background irreducible Drell-Yan (no interference accounted for).
- Effect of systematics on discovery ~ 10-15% (model parameter dependent)



RS KK Graviton Reach in Dielectrons

- Uses extended maximum likelihood fitting for discovery potential using pseudo-experiments with null and test hypotheses





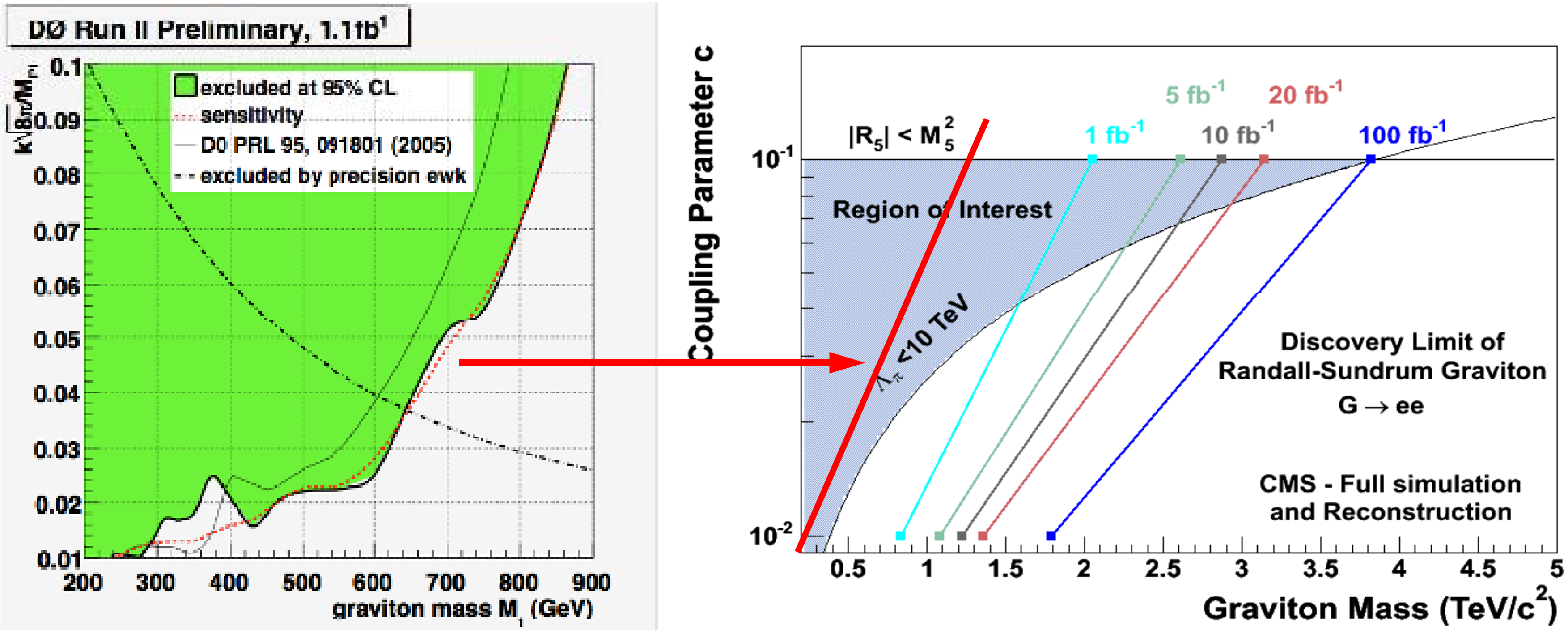
A 900 GeV G^* can be discovered with ~ 1.0 fb^{-1}, for $k/\underline{M}_{Pl} = 0.01$

- Spin-2 nature of G^* resonance is also a powerful discriminant using polar angular distribution of dielectron system *hep-ph/0006114*

LHC may easily confirm/refute ED

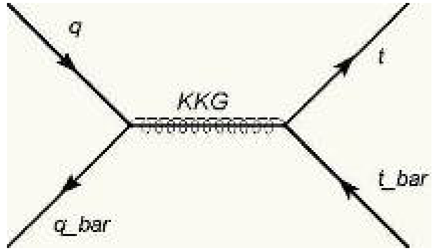
Most stringent limits to date from Tevatron on RS ($k/\underline{M}_{Pl} > 0.1$):

- CDF : $m_G > 889$ GeV ($\gamma\gamma$ +ee, 1 fb^{-1}), 850 GeV (ee, 2.5 fb^{-1}) *CDF9160/08*
- D0 : $m_G > 900$ GeV (diEM,1 fb^{-1}) *PRL100/091802/08*



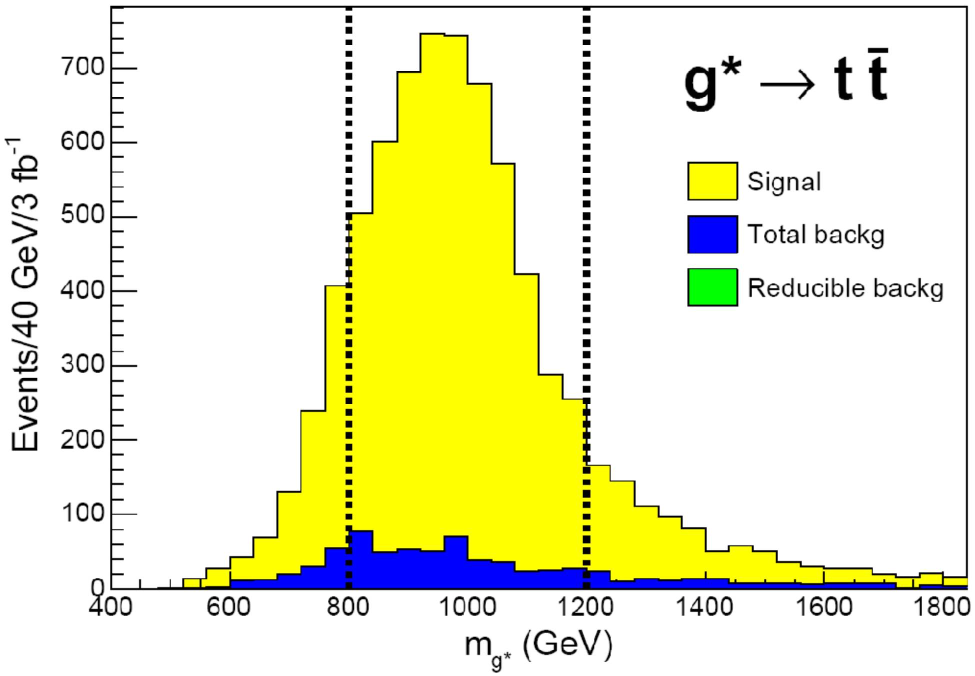
Excited KK Gluon Searches in QQ

- KK g* predicted by TEV^{-1} EDs allowing bulk Gauge bosons *PRD65/076007/08*
- Purely quark couplings, $c_{KK} = \sqrt{2}\, c_{SM}$
- Resonance signatures via heavy diquarks QQ (bb,tt)
  - Large phase-space for high p_T tt production at the LHC!
  - canonical dijet signatures by Balazs et al@Les Houches 2003



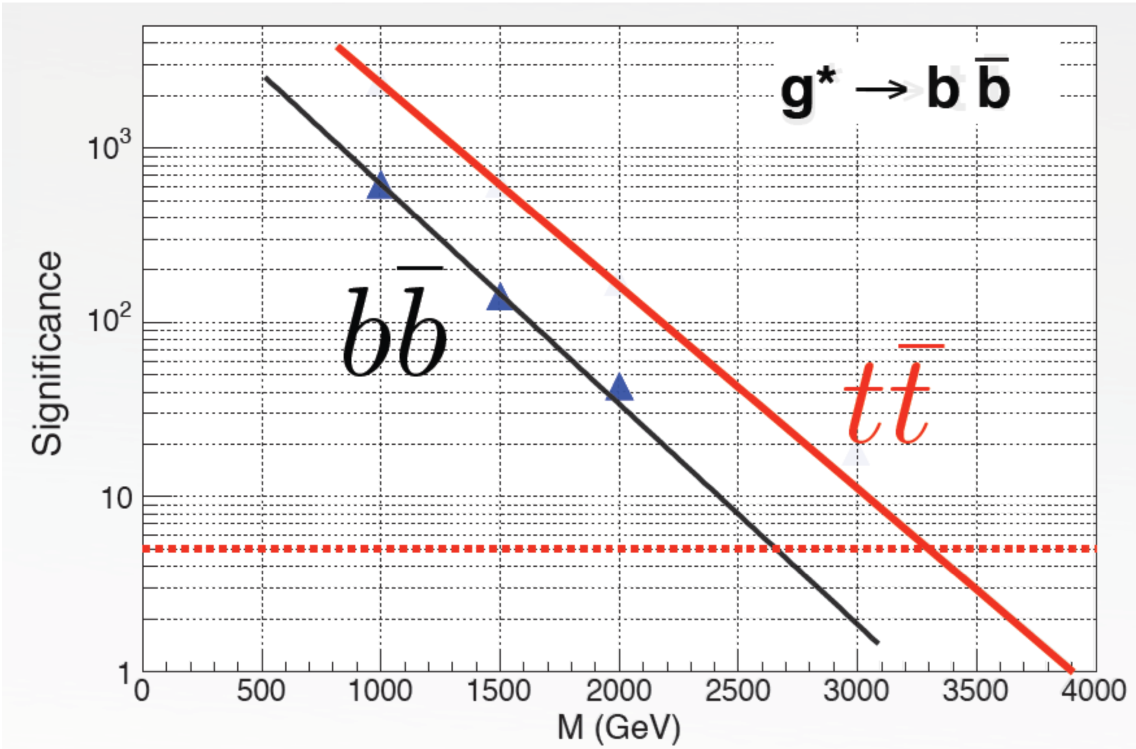
- Min p_T cuts on both Q using fast simulation
- ε(bb) ~30% (flat), ε(tt) ~12% (up to 2 TeV g*)
- High p_T b-tag: 0.1 for 1 TeV g*
- Main backgrounds: irreducible SM JJ. Reducible W+j and dijet (for bb).
- Semileptonic tt selection (a leptonic and a hadronic top)
- Simple mass window counting significance

Mg* = 1TeV, σ= 1100 pb

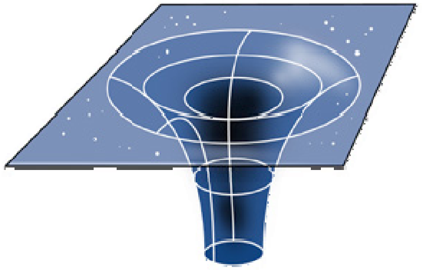


KK Gluon Reach in $Q\bar{Q}$

- Channels are complementary for discovery
  - $t\bar{t}$: discovery in 3 years of high luminosity (10^{34} cm^{-2}s^{-1}) running
  - $b\bar{b}$: reach is lower due to larger uncertainties in the background calculations and worse mass peak separation

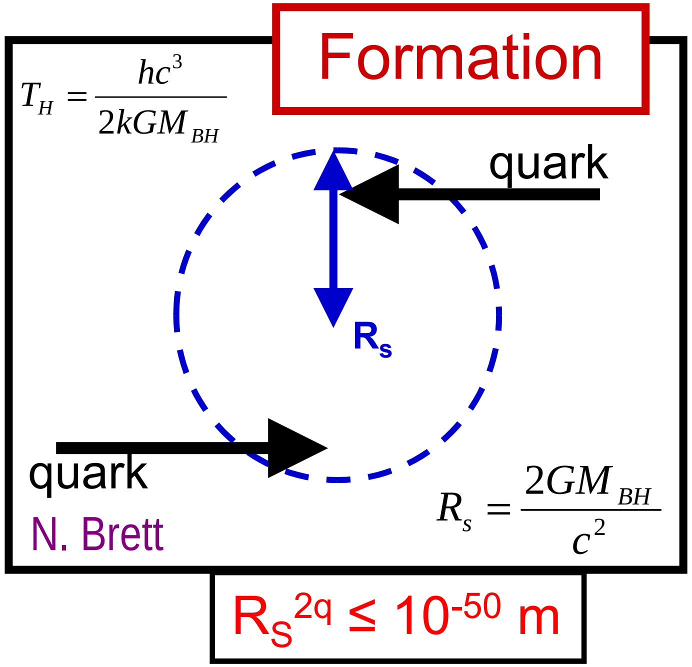


5σ reach up to 2.7 (3.3) TeV for $b\bar{b}$ ($t\bar{t}$) with 300 fb^{-1} @ $\sqrt{s}$=14 TeV



Those μ-Blackholes

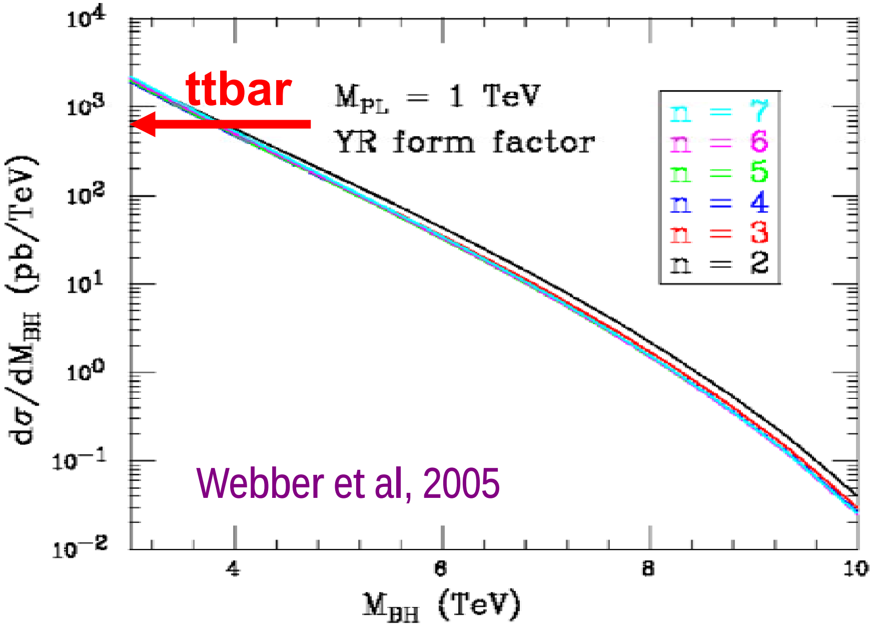
- A beautiful theory that combines thermodynamics, QFT and gravity
- BH can be produced when $\sqrt{s} > M_{Pl}$
- $\sigma \sim \pi R_S^2 \sim 1\ \mathrm{TeV}^{-2} \sim 10^{-38}\ \mathrm{m}^2 \sim$ O(100)pb
- $M_{BH} = \sqrt{(s \cdot x(q_1) \cdot x(q_2))}$
- BH production rate at nominal LHC is O(0.1 Hz)
- Lifetime ~ $10^{-27} - 10^{-25}$ seconds!
- Decays to all particles via Hawking Radiation (μ-BH are hot!)
- LHC → Black Hole Factory!

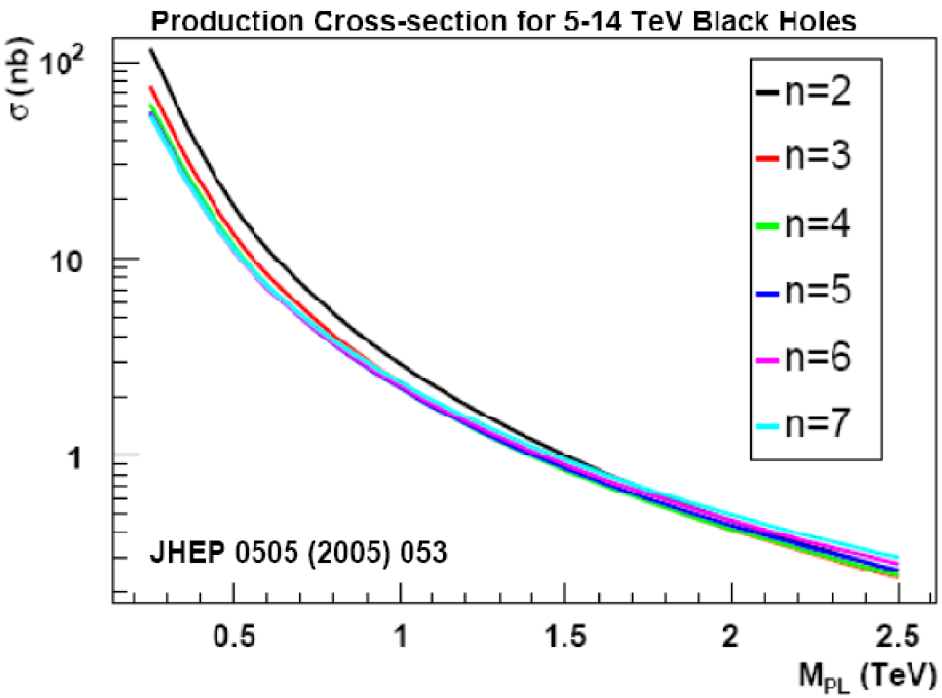


Collide 2 partons (bring their mass together) with impact parameter < Schwarzschild radius R_s and form a BH!

μ-Blackhole Production at ATLAS

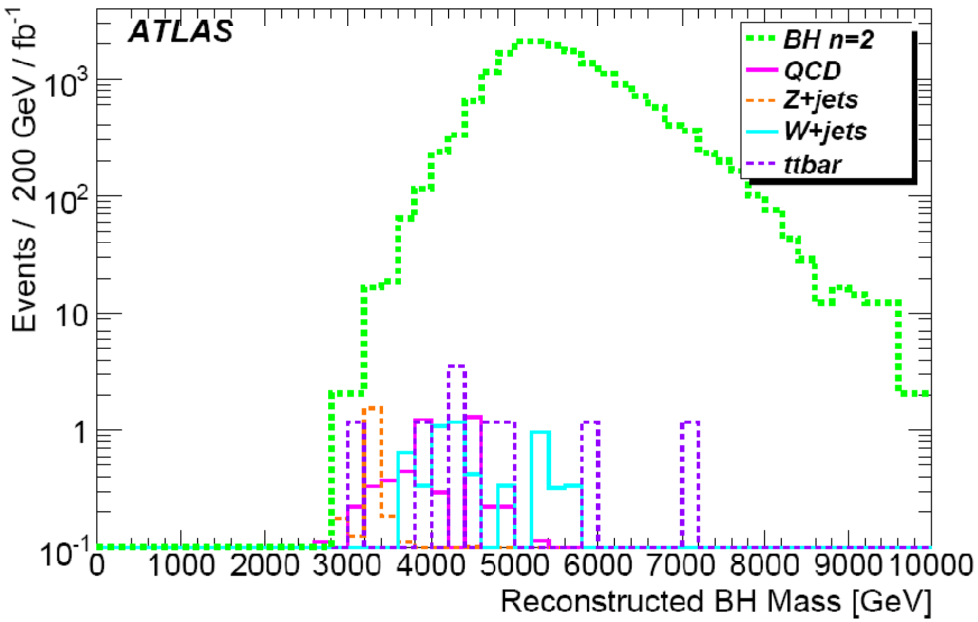
- Production with dedicated event generators
  - difficult modelling, theory uncertainties dominate
- CHARYBDIS event generator used (for GR BH) *JHEP08/033/03*
  - semi-classical approximation well above M_{Pl} needed
  - minimum BH mass must be imposed





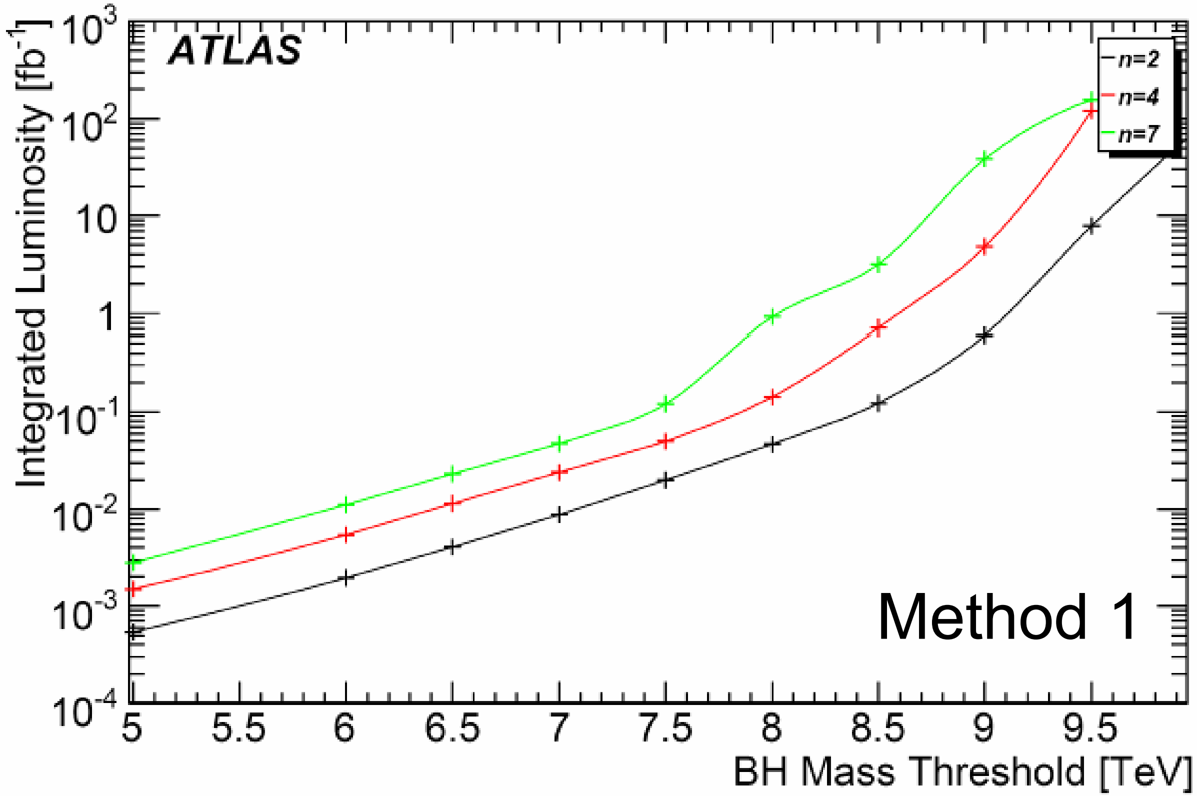
μ-Blackhole Detection at ATLAS

- Distinguishing features
  - High Multiplicity (>10 energetic particles in event), large total energy in event.
- Backgrounds: $t\bar{t}$+j, QCD and W+j tails in BH region
- Inclusive selection, robust over theory parameters and uncertainty (for a given mass, $T_H \Uparrow$, $n_{ED} \Uparrow$, $n_{part} \Downarrow$, $E_{part} \Uparrow$)
- 2 complementary methods
  - Method 1:
    - $\Sigma|p_T|$ >2.5 TeV
    - 1 lepton (e/μ) p_T > 50 GeV
    - M_{BH} > 5GeV acceptance
      - 0.46 - 0.17, for n=2-7
  - Method 2:
    - 4 particles p_T > 200 GeV
    - 1 lepton p_T > 200 GeV
- Extracting model parameters non-trivial *backup*



Discovery Reach for BH @ ATLAS

- Black holes may be the "smoking gun" from early data



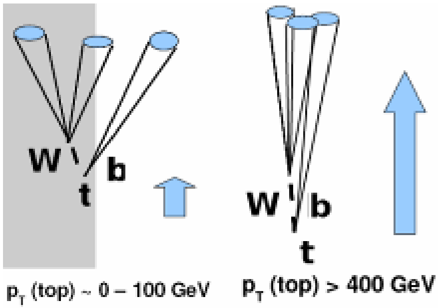
For S>10 and S/√B > 5, n=2:

M_{BH} > 5 TeV with 1+ pb^{-1}

M_{BH} > 8 TeV needs 1 fb^{-1}

Current and Future Directions

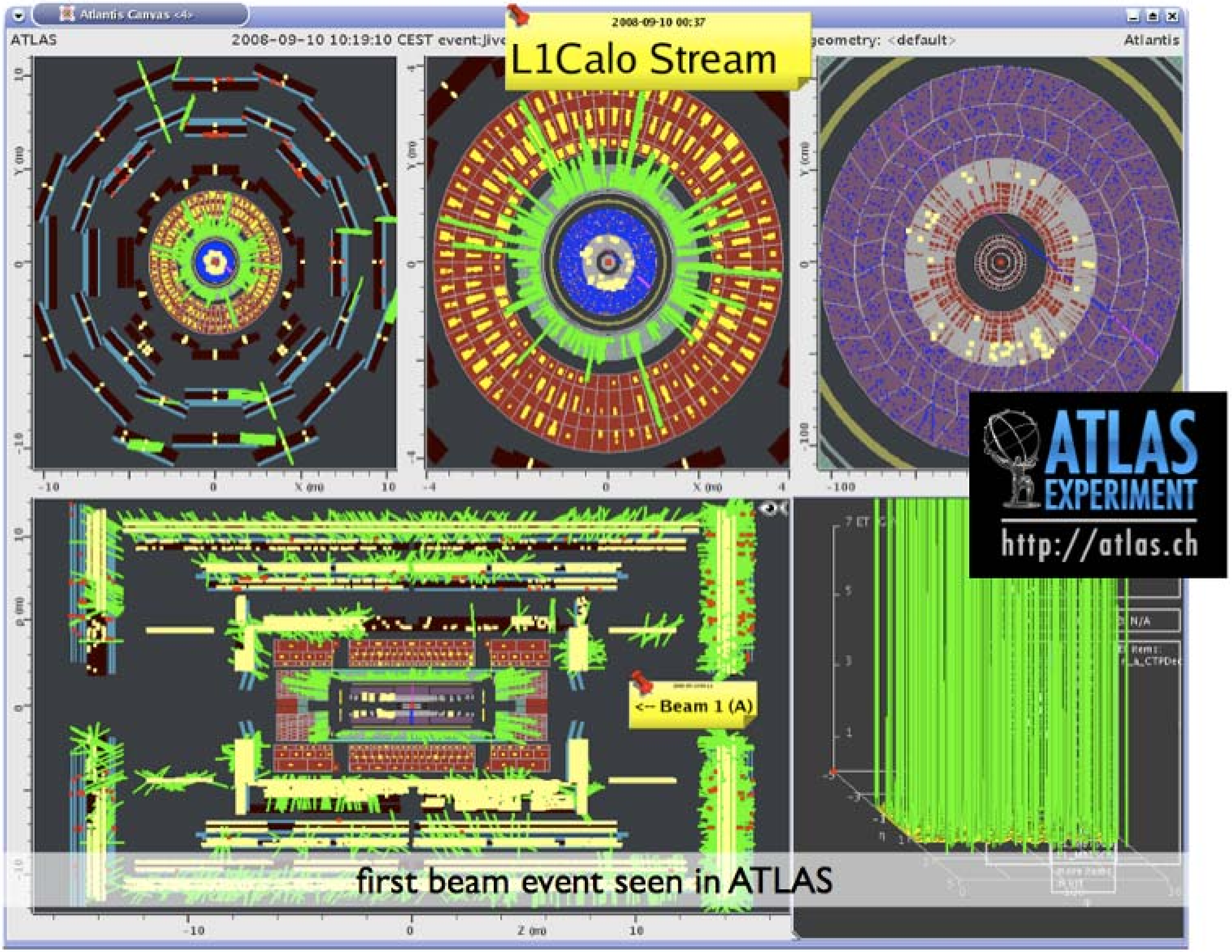
- ATLAS has a very rich discovery potential for predicted TeV-Scale gravitational effects. Work ongoing on many fronts.
- BH specific news
  - String balls, highly excited string states in ADD *hep-ph/08082512* (in Charybdis)
  - BH near Planck scale: low-mult, dijet-like BH events viable at LHC (MR, *JHEP05/003/08*) (in BlackMax *PRD77/076007/08*)
    - Compositeness-like signatures, alas, lower cross sections
- ED in heavy and boosted objects
  - Exploit techniques to efficiently reconstruct heavily-boosted t & b quarks at the LHC
  - RS KK gluons *JHEP0709/074/07*
    - Already ruled out by Tevatron up to 800 GeV/c^2 *hep-ph/0703060*

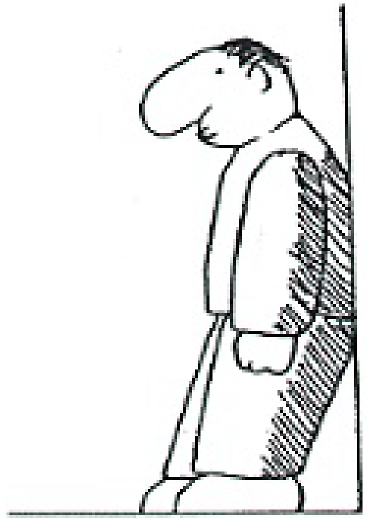


3-body **monojet**

- Cross section calculations and simulation production of 10 TeV samples are ongoing in preparation for 2009.

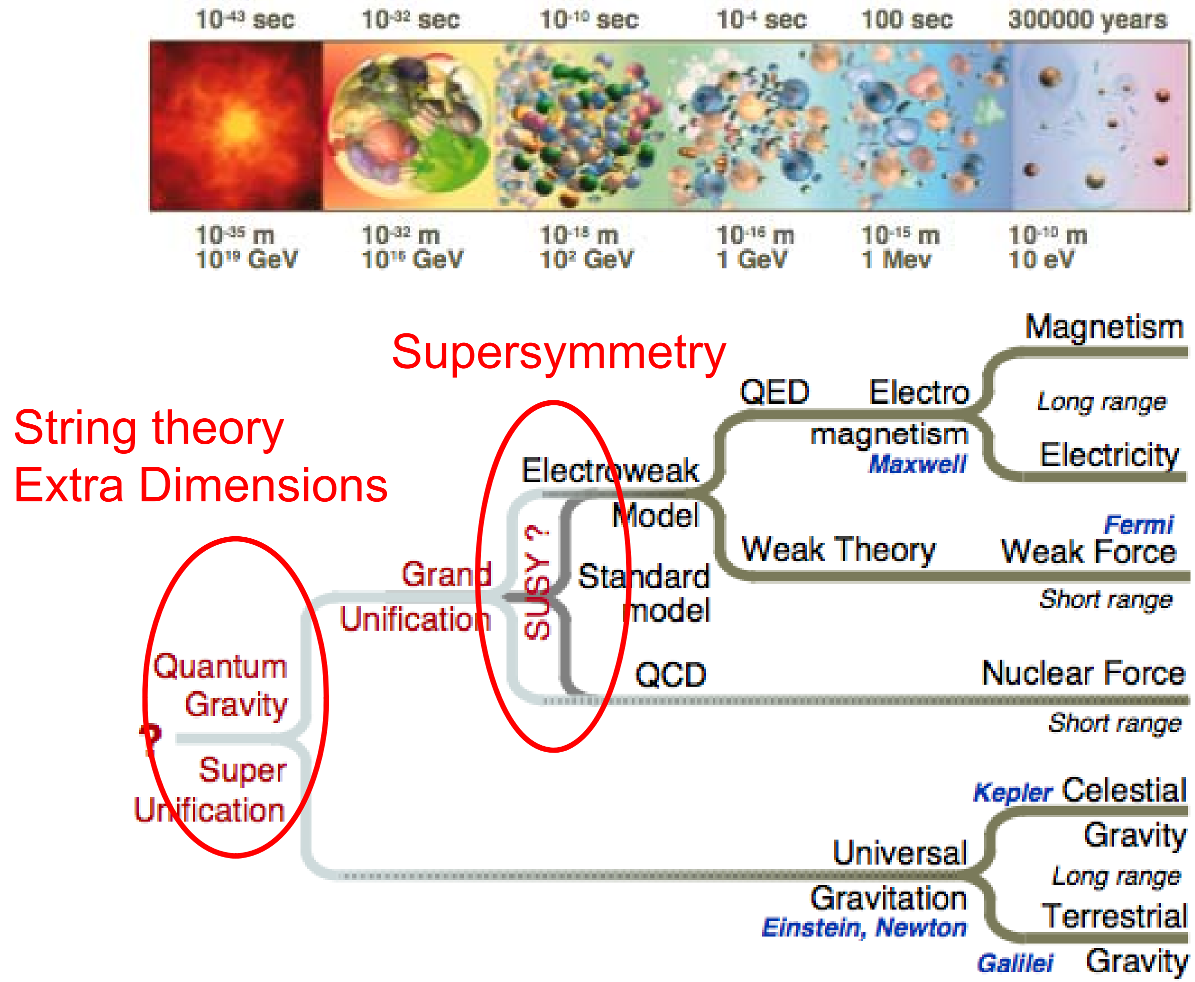
No black holes yet… Watch this space!





BACKUP

Forces of the Universe, Unite!



If we can study particles and interactions at the beginning of the universe, we may solve "the equation" to the laws governing the universe!

Comparison of Production Rates

process	events/s	Σ events/ $10fb^{-1}$	total events in previous experiments as of 2007
$W \rightarrow e\nu$	15	10^8	10^4 LEP/10^7 Tevatron
$Z \rightarrow ee$	1.5	10^7	10^7 LEP
t tbar	1	10^7	10^4 Tevatron
b bbar	10^6	$10^{12}..10^{13}$	10^9 Belle/Babar
H $_{m=130\ GeV}$	0.02	10^5	?
Susy, $m_{\tilde{g}}$=1 TeV	0.001	10^4	-
Black Holes (m_D=3 TeV)	0.0001	10^3	-

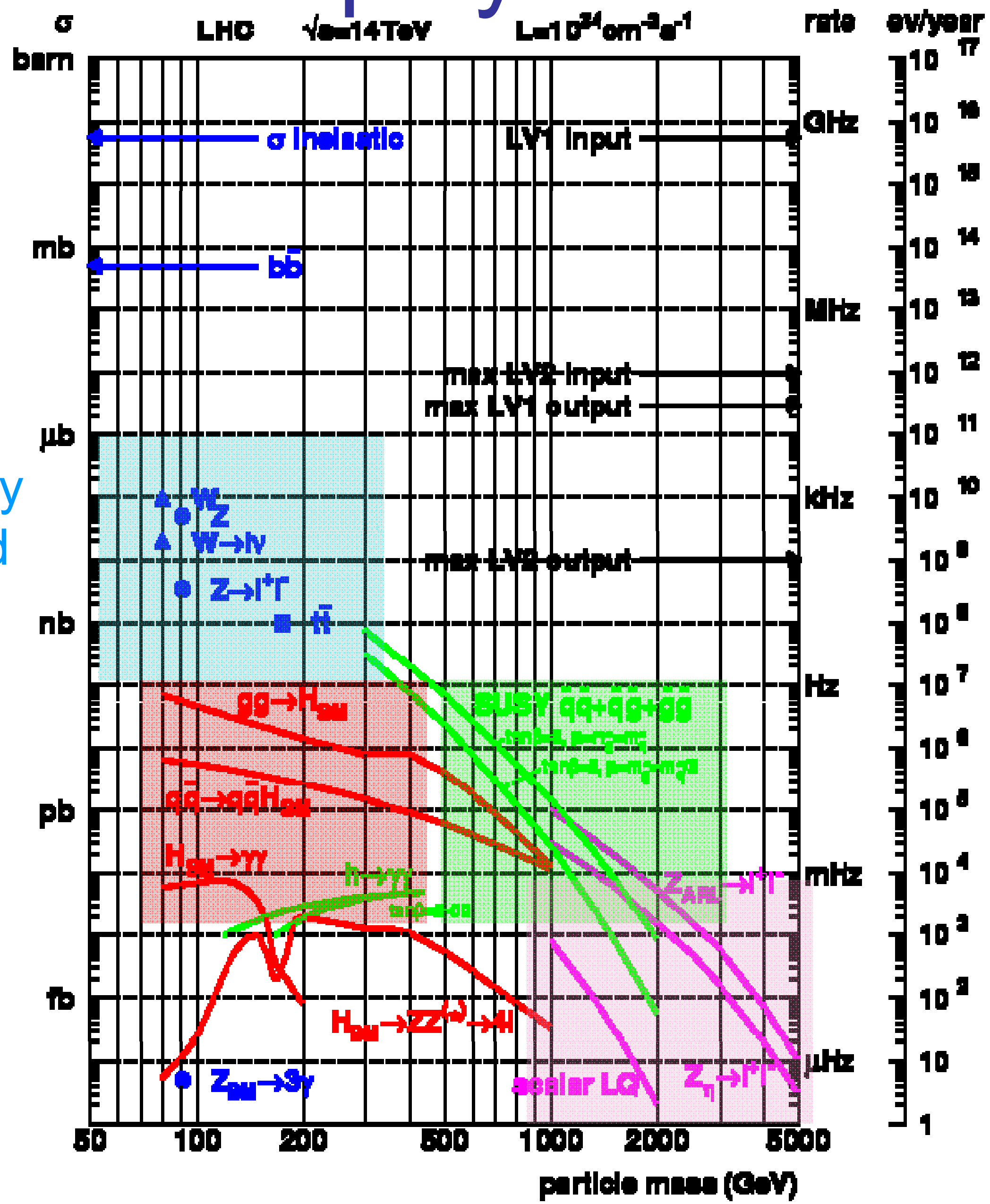
Monopoly Game

Rediscovery background

Higgs

SUSY

Heavy exotics



“Tencerenin dogurduguna...”

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Original URL:
http://www.theregister.co.uk/2008/03/28/lhc_cern_hawaiian_botanist_lawsuit/

Botanist sues to stop CERN hurling Earth into parallel universe

By Lewis Page
Published Friday 28th March 2008 14:11 GMT

A lawsuit has been filed in Hawaii in an attempt to hold up the start of operations by the Large Hadron Collider (LHC) atom-smasher on the French-Swiss border.

A colourful American botanist, teacher, former biologist and sometime physicist says (in outline) that the LHC may rip a hole in the fabric of the space-time continuum and so destroy the Earth. He wants the US government to act now and delay the LHC's startup while a new safety review is carried out.

Walter L Wagner and his fellow Hawaiian Luis Sancho, according to a report (http://cosmiclog.msnbc.msn.com/archive/2008/03/27/823924.aspx) on MSNBC, filed

Convincing the public about LHC

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- Why the LHC
- How the LHC works
- The LHC Experiments
  - ALICE
  - ATLAS
  - CMS
  - LHCb
  - TOTEM
  - LHCf
- Computing
- Safety at the LHC
- Facts and figures
- LHC Milestones

Safety at the LHC

The Large Hadron Collider (LHC) can achieve energies that no other particle accelerators have reached before. The energy of its particle collisions has previously only been found in Nature. And it is only by using such a powerful machine that phyicists can probe deeper into the key mysteries of the Universe. Some people have expressed concerns about the safety of whatever may be created in high-energy particle collisions. However there are no reasons for concern.

Modest by Nature's standards

Accelerators recreate the natural phenomena of cosmic rays under controlled laboratory conditions. Cosmic rays are particles produced in

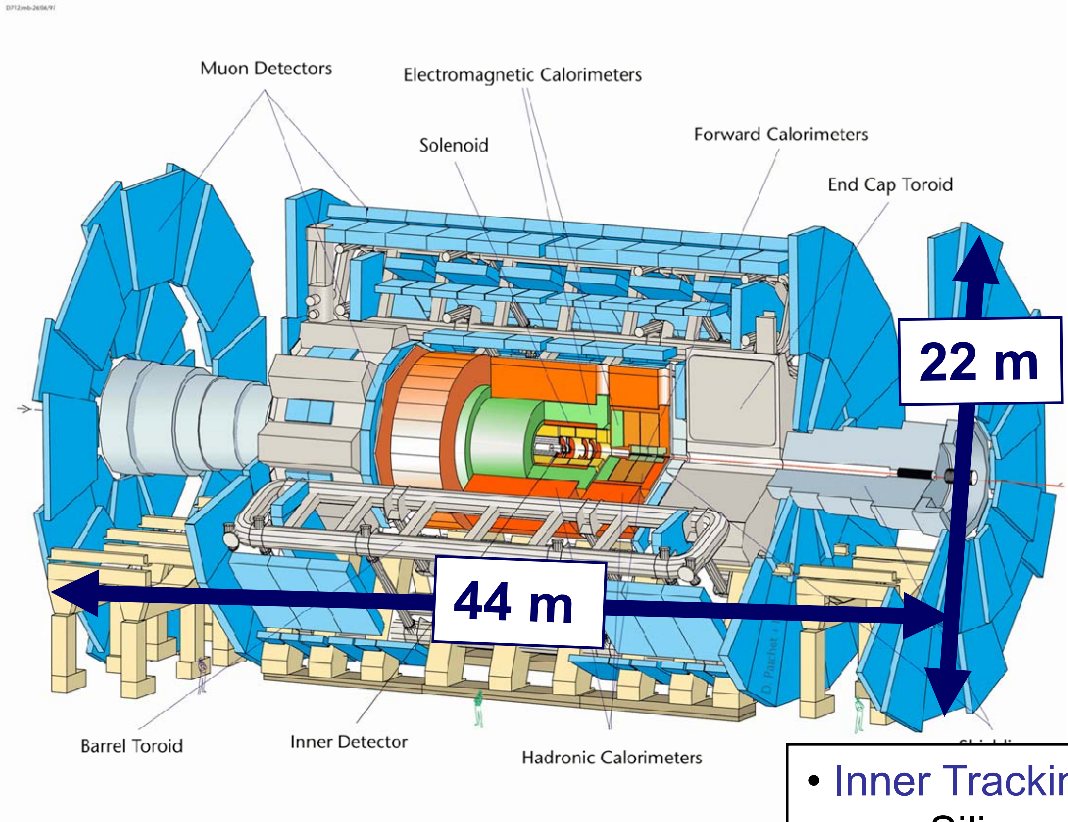
"I have never won the national lottery, so go for it!" – anony, on BH threat!

“The LHC is safe”, John Ellis (*CERN*)

Summary on Microscopic Black Holes

- Existence very speculative
  - particular extra D scenarios
- **IF** they exist, surely unstable
  - Hawking, decay related to production
- **EVEN IF** stable, accretion rate negligible if high D
- **EVEN IF** low D, some of those produced by cosmic rays would be charged
  - would have stopped in Earth: not been ‘eaten’
- **EVEN IF** all neutral, some would have been produced on white dwarfs and neutron stars
  - would have stopped: not been ‘eaten’

ATLAS Detector Specifics



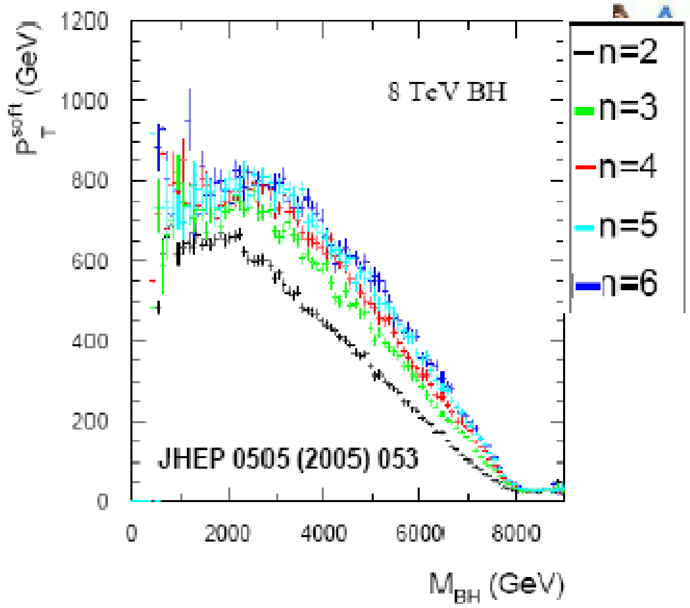
A toroidal LHC apparatus

ID:	$\sigma/p_T \approx 5 \times 10^{-4}\, p_T \oplus 0.001$
	$\sigma(d_0)$=15μm at 20GeV
ECAL:	$\sigma/E \approx 10\%/\sqrt{E(GeV)} \oplus 0.7\%$
HCAL:	$\sigma/E \approx 50\% / \sqrt{E(GeV)} \oplus 3\%$
Muon:	$\sigma/p_T \approx 10\%$ at 1 TeV/c

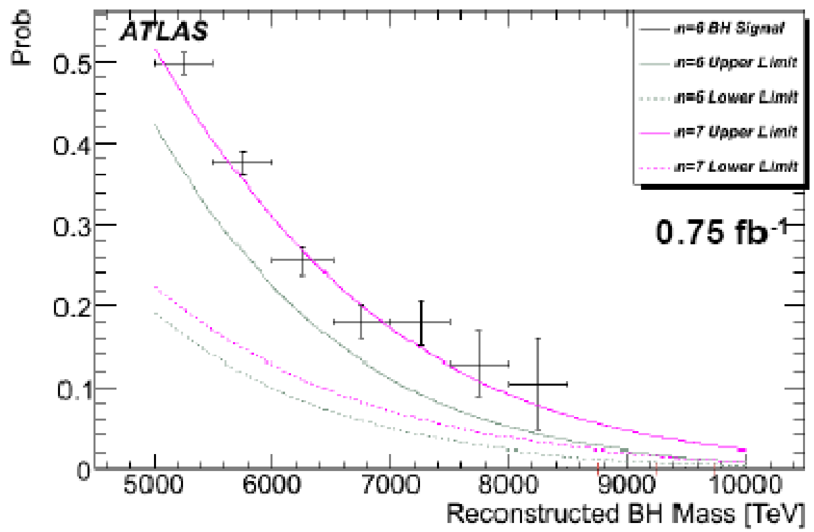
- Inner Tracking ($|\eta|<2.5$, 2T solenoid) :
  - Silicon pixels and strips
  - Transition Radiation Detector (e/π separation)
- Calorimetry ($|\eta|<5$) :
  - EM : Pb-LAr, Accordion shape
  - HAD: Fe/scintillator (central), Cu/W-LAr (fwd)
- Muon Spectrometer ($|\eta|<2.7$, 4T toroid) :
  - air-core toroids with muon chambers

How many extra dimensions?

- Initial attempts tried to reconstruct the Hawking temperature dependence with black hole mass, either averaged over an event, or on an emission-by-emission basis.
- Unfortunately, the effect is small and is strongly affected by the theoretical uncertainties.
- Cannot extract n without great trust in Monte-Carlo.



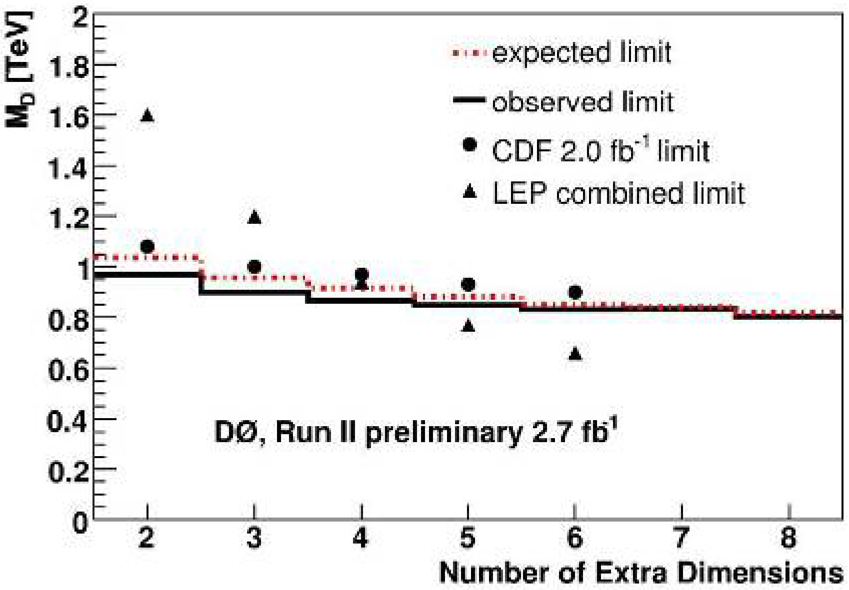
- One method for estimating n, given an estimate of the Planck scale, was first described in JHEP 0505 (2005) 053,
- Now compatible with cuts for signal selection and background rejection.
- The method is insensitive to some of the model uncertainties, such as threshold behaviour.

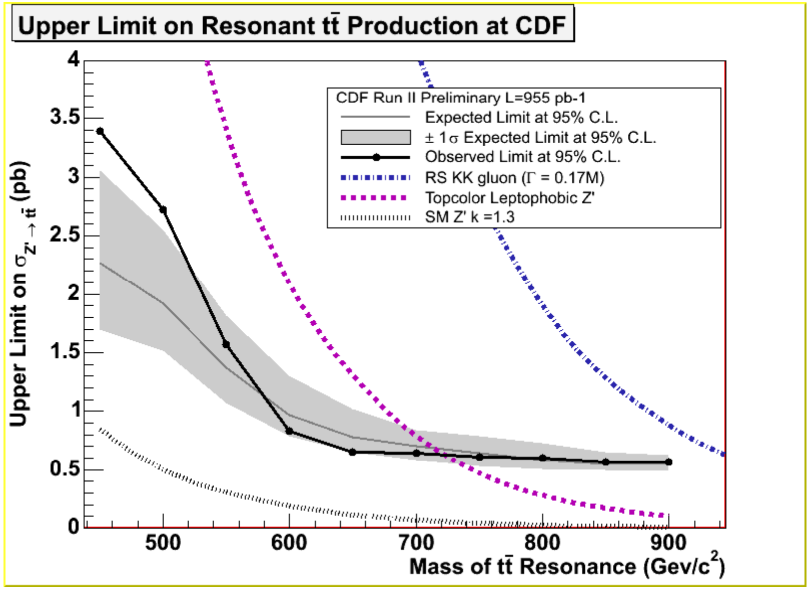


Other limits from Tevatron

- LED via Single Photon plus Missing Energy Final States
- Current Best: D0: At 95% C.L., limits on the fundamental mass scale M_D from 970 GeV to 816 GeV, for 2-8 ED

- CDF Limits on $t\bar{t}$ resonances *PRD77/051102/08*
- Also limits on “massive gluon coupling” in 1.9 pb^{-1} data *CDF9164/07*

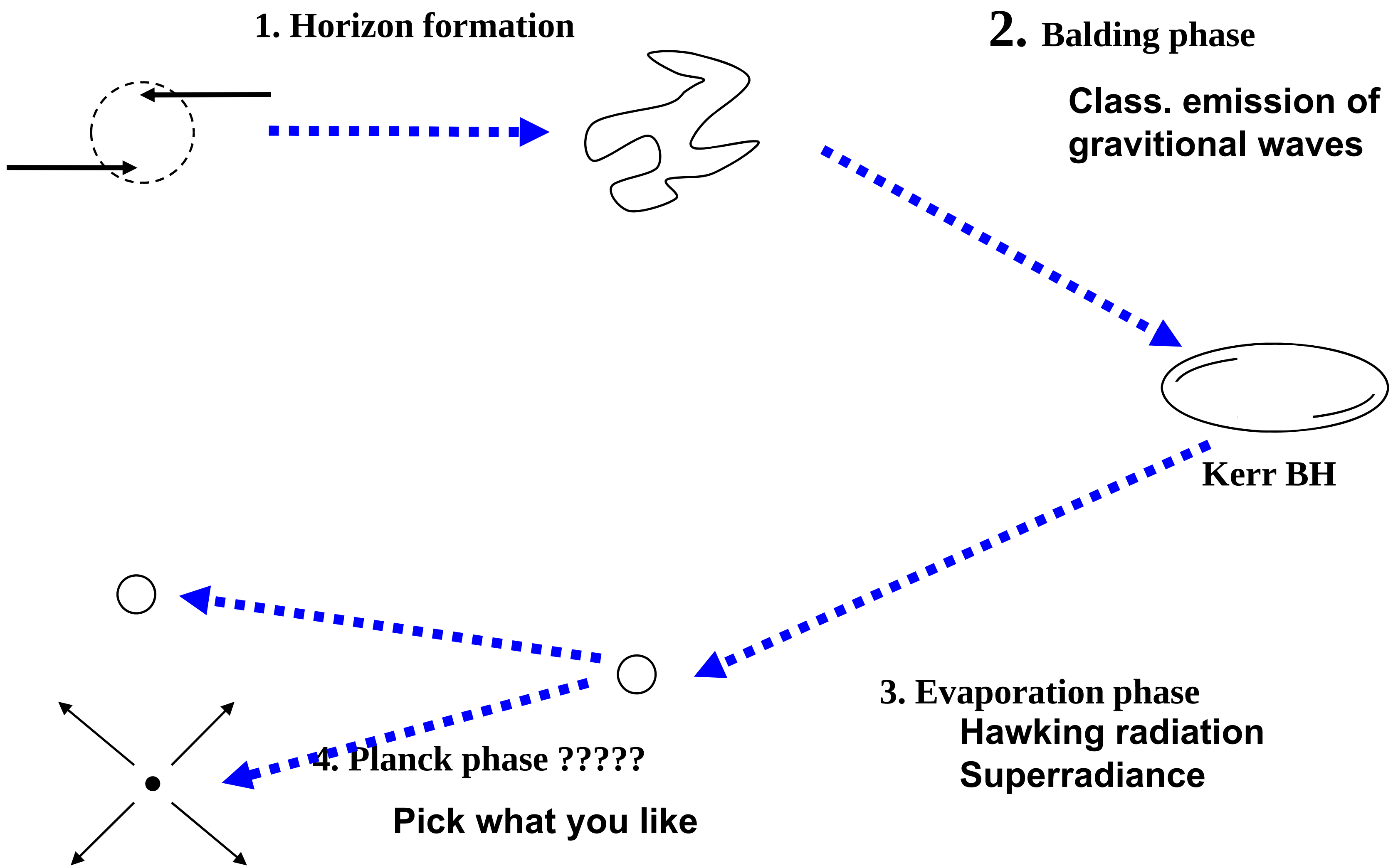




Limits from Others
(based on G. Landsberg)

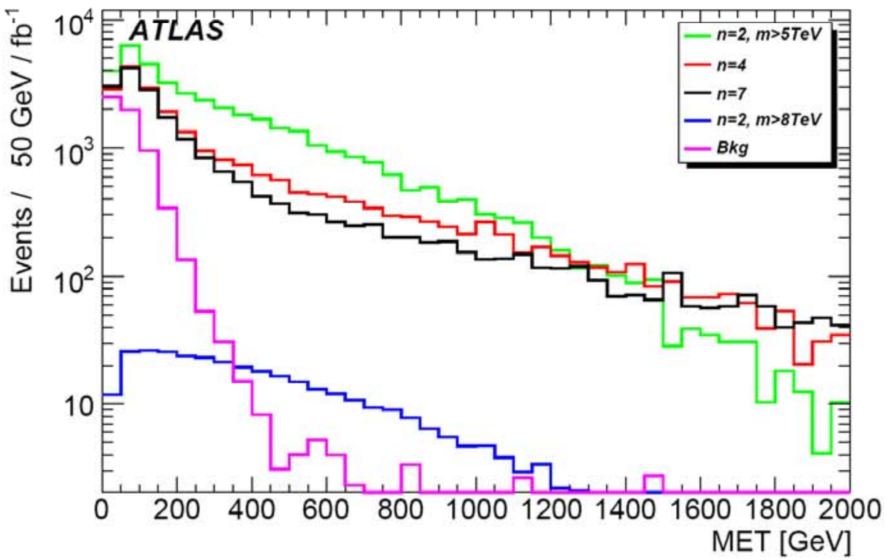
- Table top: Sub-mm gravity measurements could probe *only* n=2 within ADD - U of Washington torsion balance "Cavendish" experiment **hep-ph/0307284**
  - R < 0.16 mm (M_D > 1.7 TeV)
- Supernova cooling due to graviton emission – measurement of the SN1987A neutrino flux by the Kamiokande and IMB, application to ADD (C&P, PRL**83**/268, 1999; HPRS, NP**B595**/335, 2001):
  - M_D > 25-30 TeV (n=2), > 2-4 TeV (n=3)
- Distortion of the cosmic diffuse gamma radiation (CDG) spectrum due to the $G_{KK} \to \gamma\gamma$ decays (H&S, PRD**60**/085008, 1999):
  - M_D > 100 TeV (n=2), > 5 TeV (n=3)
- Overclosure of the universe, matter dominance in the early universe (Fairbairn, PL**B508**/335, 2001; F&G, JHEP0202/**024**, 2002):
  - M_D > 86 TeV (n=2), > 7.4 TeV (n=3)
- Neutron star γ-emission from radiative decays of G_{KK} trapped during the supernova collapse (H&R, PRL**88**/071301, 2002):
  - M_D > 1700 TeV (n=2), > 60 TeV (n=3)
- Astrophysical and cosmological limits are the most stringent. However, many uncertainties, bounds are reliable only as an order of magnitude estimate
- **n=2 is largely disfavored**

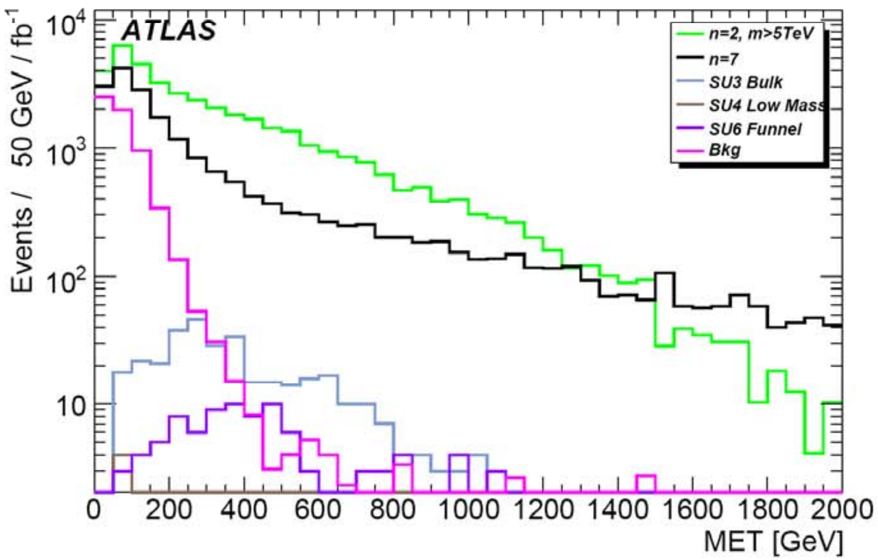
Time Evolution of Black Holes



Distinguishing μ-BH

- Different characteristics than SUSY or SM in Missing ET (depends highly on graviton emission process)





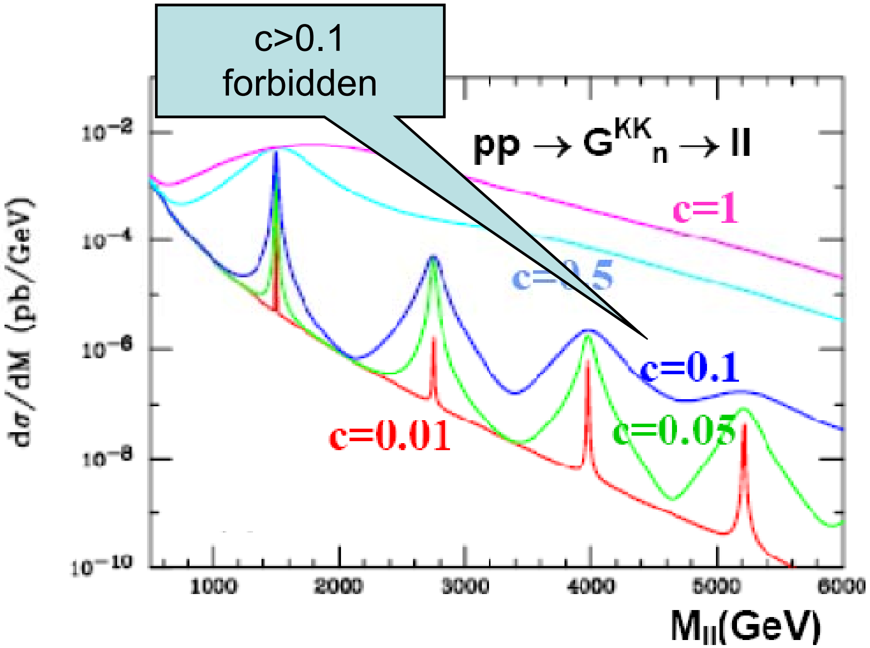
Warped Extra Dimensions

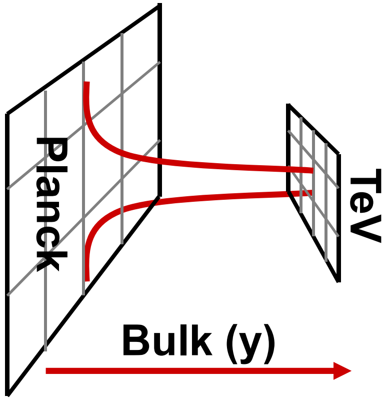
Randall Sundrum (Type I)

- Brane metric scales as function of bulk position
- Coupling constant:

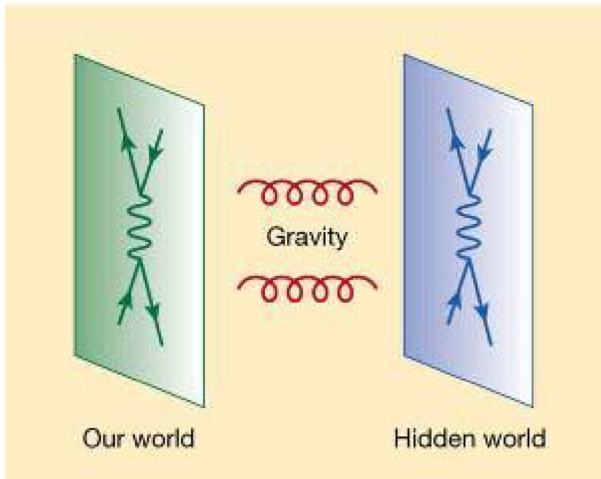
  $c = k/M_{Pl}$, k: curvature scale
- Well separated narrow-width graviton mass spectrum with masses

  $m_n = k x_n e^{krc\pi}$ $(J_1(x_n)=0)$

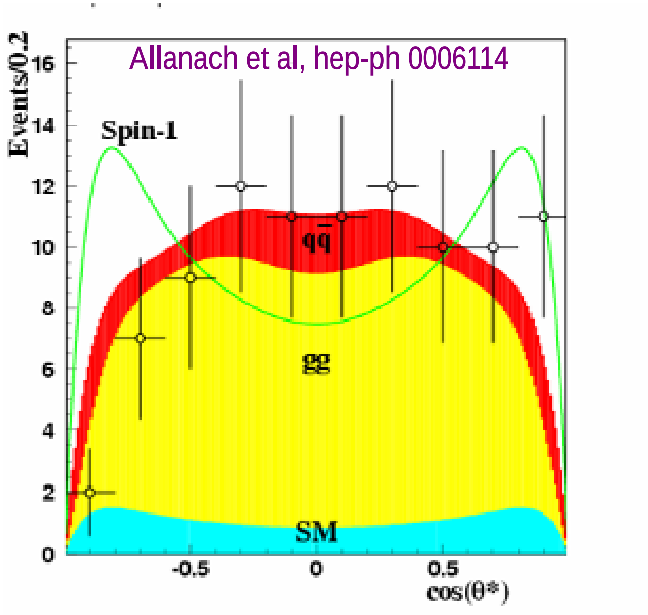




$$ds^2 = e^{-2ky}\eta_{uv}dx^u dx^v - dy^2$$



Is it a Z' or RS Graviton?



Spin-1 particle exchange (Z, γ, Z')

depends on couplings

$$\frac{d\sigma}{d\cos\theta^*} = \frac{3}{8}[1 + \cos^2\theta^*] + A_{\mathrm{FB}}\cos\theta^*$$

model-dependent

Spin-2 graviton exchange

depend only on graviton mass

fraction of $q\bar{q}$

$$\frac{d\sigma}{d\cos\theta^*} = \frac{5}{8}[1 - 3\epsilon_q\cos^2\theta^* + (\epsilon_g - 4\epsilon_q)\cos^4\theta^*]$$

fraction of gg

J Aguilar

Handles:

- **Mass** ➔ little info about models (unless series of KK bumps)
- **Cross section** ➔ info about couplings
- **BR** ➔ test couplings & universality (G has well-defined ratio between ll/γγ/ZZ and Z' has no γγ coupling)
- **Angular distribution/asymmetries** ➔ spin and couplings (even then various Z' are not easy to tell)