Searching for the Graviton in the Randall-Sundrum model using the fast simulation package Atlfast

> 1<sup>st</sup> Year Transfer Report Tom Byatt University College London 27/6/05

# Overview

- Gravity & Quan. Theory- the motivations
- The revolutionary ED models
- Randall-Sundrum (RS) model
- LHC and ATLAS
- Physics Analysis
- Leptonic Analysis
- Jet Analysis (Brief) & Conclusion
- Truth data
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# Gravity & Quan. Theory- the motivations

Very successful model transcends P.Physics, Standard Model (SM)
 -> incomplete!

•P.Physicists 'Periodic Table'->incomplete!

->have found **<u>nearly</u>** all other force mediators (gauge bosons):strong, weak, EM ( $\geq 10^{-18}$ m). Gravity-?( $\geq 0.2$ mm Table Top Gravity experiments)  $\Rightarrow$  However, Gravity is the most well known.

#### • The problems (theory & experiment):

Theory:QuantumNumerous ∞'sGravity = X = Q.M. + Classical G.R.(incurable<br/>divergences)<br/>(QFT's)

Experiment: Gravity very weak (10<sup>-37</sup> xEM strength). Consequently Energy/mass scale at which Gravity is strong E~10<sup>19</sup> GeV !!!! (Planck scale)

 $\Rightarrow$ no chance.

-> Although so we thought !

### The revolutionary ED models

Ideas of ED's ->1910's/1920's, Einstein, Kaluza-Klein (EM+ Gravity in 5D).
Past decade -> seen some revolutionary ideas (to solve Hierarchy Problem 10<sup>2</sup> GeV-10<sup>19</sup> GeV) -> models about <u>Extra Spatial Dimensions!</u> No temporal. TeV<sup>-1</sup>(Universal),LED (~0.2mm),RS'warped'model (TeV scale phenomenology)
All 3 are 'Brane world' scenarios: 'Our' physical 3D world (hypersurface) membrane, 3-brane or brane, embedded in much larger, <u>compact</u> (KK states), ED space 'bulk'.
TeV<sup>-1</sup> arose in late 1980's, early 1990's, SM & gravity in bulk.
Large Extra Dimensions (LED)-(1998),a novel idea, gravity in bulk only while SM on brane.

$$M_{\rm Pl}^2 = V_{\rm n} M^{2+{\rm n}}$$

=>4D gravity scale, M<sub>PI</sub>, <u>not</u> fundamental ~~ TeV (smaller) if ED large(in PP)

RS 'warped' model(1999) - Lisa Randall & Raman Sundrum
 > natural warping (exponential factor).
 > non-factorizable geometry (ED not independent of 3D's).
 > SM on 1 of 2 branes & gravity in bulk & branes.
 > 1 ED.

### <u>Randall-Sundrum (RS) model</u>





•2 3-branes (4D spacetime) at fixed points of  $S^1/Z_2$  orbifold (the ED). •Brane tension/E density (in 3D) ( $\sigma$ ) ->unique to this model. ->its effect on bulk • Procedure: solve 5D Einstein field equa.  $\Rightarrow$  admits new & different solution to Hierarchy problem (5D metric):  $ds^2 = e^{-2ky}\eta_{uv}dx^{\mu}dx^{\nu} - dy^2$ Warp factor  $M_{TeV} = \underline{e}^{-kry} M_{Pl}$ <u>SM matter=warp factor x M<sub>PI</sub></u> -> TeV scales generated from fundamental scale M<sub>PI</sub> (at Planck brane). =>hierarchy scale reproduced if kr~11-12.

•Predicts massive, spin-2 graviton KK states

=> Detect as resonances - observable rates at LHC !

Natural in theory ->very attractive! Goldberger & Wise hep-ph/9907218 hep-ph/9907447



# LHC and ATLAS

Large Hadron Collider (LHC) 27km tunnel, CERN.Collide 2 counter-rotating accelerated 7TeV p's

 $=>E_{CM}=14TeV$  ! (~100x LEP E<sub>CM</sub>)

•Luminosity: i)Low (initial) =  $10^{33}$  cm<sup>-2</sup>s<sup>-1</sup> ii)High (design value)= $10^{34}$ cm<sup>-2</sup>s<sup>-1</sup> =  $\int$ L=100fb<sup>-1</sup>

Explore multi-TeV energy scale -> a new energy frontier.
As part of LHC->4 gargantuan detectors: CMS, ATLAS, LHC-b and ALICE.

•A Toroidal LHc ApparatuS (ATLAS).
•20m (diameter) x 45m (length) & weight: 7000 tonnes.

Multi-layered structure (4 main layers):
i)Inner detector (yellow)
ii)Calorimeter syst(EM & hadronic)-(orange/greer
iii)Muon spectrometer (blue)
iv)Magnet system-> solenoid (peak)~2.6T
(grey) toroidal (peak)~8T



# **Physics Analysis**

### •Work looked at searching for graviton in full production/decay channel:

pp(gg/qqbar)->G\*->Z<sup>0</sup>Z<sup>0</sup>->e<sup>+</sup>e<sup>-</sup>jetjet

•G\*->lowest excited G state in RS model

•G\* can decay into any SM particle.

•Couples to <u>all</u> SM particles with 'universal' coupling strength.

•At LHC E & 1TeV  $M_{G^*}$  (up to 3.5TeV):  $\sigma(gg->G^*) > \sigma(qqbar->G^*) \sim 4:1$ 

•Background:

• Signal:

•Expected dominant SM background used:

pp(gg/qqbar)->Z<sup>0</sup>Z<sup>0</sup>->e<sup>+</sup>e<sup>-</sup>jetjet





# Physics Analysis continued.....

Problem: gg->Z0Z0 not implemented -> NLO & MC event generator used (PYTHIA)->LO, but σ for this is >> than for qqbar->Z0Z0!!! => This analysis is incomplete. Background too small.

• Procedure:

•PYTHIA->capable of simulating production/decay of G\* states in RS model.
•Constant G\* mass =1TeV was used.
•Low luminosity (=10fb<sup>-1</sup>) used throughout work.

Use chain: jobscript -> PYTHIA -> Atlfast -> data (ROOT file)

Use a jobscript->explicit PYTHIA commands->generates processes asked for.
 ->generated 15,000 events for each signal(S) & background(B) channels.

•Atlfast-takes in MC 'truth' data & smears->carries out simulation of particles passing through ATLAS detector. Much faster than Full Simulation.

•Data ->ROOT & use C++ algorithms (self written) to do analysis & plots.

•<u>Analysis:</u> 2 parts-> (i)Leptonic (ii)Jet

### Leptonic Analysis

• Subdivided into 2 parts:

(i) Specific case-> No. of  $e^{-}/e^{+}'s=2$  from each event. Reject No.  $e^{-}/j's=1/\geq 3$ 

(ii) General case (More realistic)->consider all possible (N) e<sup>+</sup>-e<sup>-</sup> pairs from each event.

Important: Knew purity of sample was 100%->generated (PYTHIA) But in (i) assumption was reconstruction efficiency =100% => all e<sup>+</sup>-e<sup>-</sup> pairs came from a Z<sup>0</sup>. NOT TRUE! Possible decay products of: some other heavy particle (i.e. not Z<sup>0</sup>) or underlying events or some 'unknown' (non-SM) particle. So in (ii) reject these events: ?(not a Z<sup>0</sup>)->e<sup>+</sup>-e<sup>-</sup>.

#### •<u>How?</u>

Combine all  $e^+/e^-$ 's into pairs->Look at all possible  $e^+-e^-$  pairs contained in generated 15,000 events.

-Employ a <u>filter system</u> of kinematic cuts (1<sup>st</sup> set) & Z<sup>0</sup> kinematics->reject pair don't pass cuts (so haven't come from a Z<sup>0</sup> boson).

=>

-Once left with ~100% 'true' Z<sup>0</sup>->e<sup>+</sup>-e<sup>-</sup>'s->employ 2<sup>nd</sup> set of (usual) cuts, to increase S and decrease B as much as possible.

# Leptonic Analysis continued.....

•Kinematic cuts used in both (i) & (ii) were:  $\theta$ ,  $\eta$ ,  $\Phi$ ,  $\Delta \eta$ ,  $\Delta \Phi$ ,  $\Delta R$ ,  $P_T$ ,  $E_T$ ,  $E_{Tot}$ ,  $\Delta E_T$  and  $\Delta E_{Tot}$ .  $\rightarrow$  Due to large difference in E/P<sub>T</sub> between e1/e2 of pair (signal). •Example plots for general case:



### Leptonic Analysis continued.....

•Final, independent cuts were:  $P_T > 220GeV$ ,  $\Delta R = 1$ ,  $-1 \le |\Delta \eta| \le 0$ ,  $\Delta E_T > 100GeV$ , and  $\Delta E_{Tot} > 300GeV$ .

#### Before cuts employed:

After cuts employed:



## Leptonic Analysis continued.....

•Normalised plot before cuts employed:

Used N=σ•Br•∫Ldt

# => Need more statistics!!



## Jet Analysis & Conclusion

Jet analysis:

•Small & not great detail for 'harder' jet analysis-> time limit.

•Analyse cases when Z<sup>0</sup>->jetjet.

•Basic analysis carried out->similar manner to leptonic analysis-> same code (with minor changes, of course).

•Use same kinematic variables to cut on.

•In addition to high background from 2/multi-jet events(initial &/or final state radiation) + have problem of highly boosted jets->very close together in  $\eta$ - $\Phi$  =>1 jet not 2 (correct) by Atlfast.

Conclusion/ signal characteristics:

 Conclusion from both leptonic & jet analyses are that the characteristics of the signal decay products are:

i) Highly boosted-> High values for  $P_T$ ,  $E_T$ ,  $E_{Tot}$ .

ii) Very close together (e<sup>+</sup>/e<sup>-</sup> or jet/jet)-> low values for  $\Delta R \& \Delta \eta$ .

iii) Centrally produced-> low values for  $\eta$  ( $\eta \approx 0$ ).

### Truth data

 For signal->large energy(E<sub>T</sub> & E<sub>Tot</sub>) & P<sub>T</sub> difference between e1+e2 of e<sup>+</sup>-e<sup>-</sup> by ~280GeV !!! (Unexpected & unknown?)



Use 'truth' MC data (before Atlfast smears)->compare with Atlfast data. If: (i) Agree->Large  $\Delta E$  true->Asymmetry in no. of  $Z_L^0$ ,  $Z_T^0$ , E/p's of pair depend upon initial polarisation state of  $Z^0$  boson.

(ii) False->Atlfast incorrect-> a bug.

= > Found agreement-> TRUE->look at angular dis.+spins in Z<sup>0</sup> rest frame.

### Future plans

- Truth data-> Is there an asymmetry in no.  $Z_{L}^{0}/Z_{T}^{0}$  polarised bosons.
- Variation of G\* mass.
- More detailed jet analysis->K<sub>T</sub>-jet clustering algorithm.
- More extensive search for backgrounds & how to generate NLO process: gg->Z<sup>0</sup>Z<sup>0</sup> not implemented, analysis incomplete. (Very Important).
- Full simulation (GEANT 04) & compare with fast simulation (Atlfast).
- Consider another G\* production & decay channel.