Missing Energy in $t\bar{t}$ Production in an e^+e^- collider as a Probe of the Large Extra Dimensions

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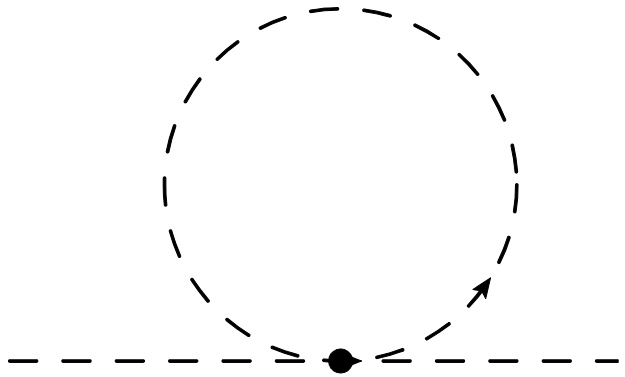
Outline

- Motivation
- ADD Model
- Cross-section calculation
  - $e^+e^- \rightarrow t\,\bar{t}$
  - $e^+e^- \rightarrow t\,\bar{t}\,G_{\vec{n}}$
- Signals for the ADD Model
- Summary

Motivation

- LHC found the Higgs boson, but no BSM Physics
- LHC is now undergoing an upgradation to 13 TeV
- A new e^+e^- collider (ILC) has been proposed
- Expected energy 3 TeV
- Heavy particles from new theory may be detected at this high energy
- Final state with $t\bar{t}$
  - $t\bar{t}$ must be produced directly, not through W, Z decay.
  - Distinct signatures: decay through weak interaction

Hierarchy Problem



$$\delta M_H^2 = \lambda\,\Lambda^2 + \lambda M_H^2 \log\frac{\Lambda^2}{M_H^2} + \text{ finite terms}$$

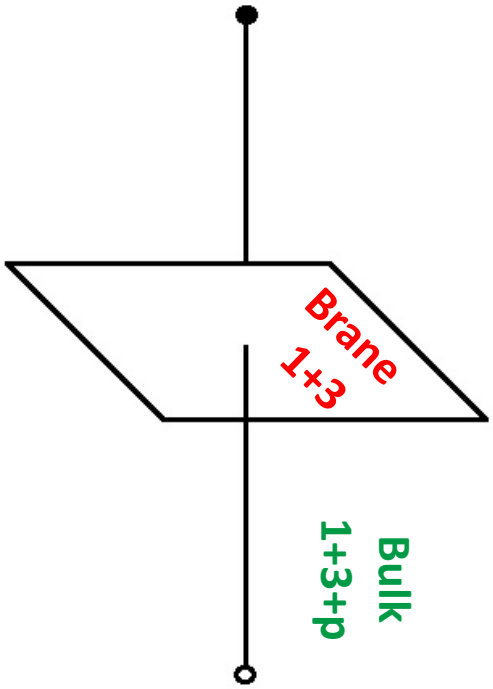
$$\Lambda \sim M_P \sim 10^{19}\ \text{GeV}$$

Diverges

'ADD' Model

- Introduce compact extra dimensions with large radius ($\sim \mu m$)
- Reduce bulk Planck mass to TeV scale
- Gravitational field is free to propagate through ***bulk***
- SM fields are confined to ***brane***
- Tower of graviton: $M_{\vec{n}} = \frac{|\vec{n}|}{R_c}$
- Quasicontinuum states

$$\rho(M^2) = \frac{16\pi \mathrm{M}}{M_S^4}\left(\frac{M}{M_S}\right)^{p-2}$$



ADD Model

$$M_S^{2+p}\, R_c^p = 2\pi(4\pi)^{\frac{p}{2}}\Gamma(p/2)M_P^2$$

	p	M_S (GeV)	LHC
$R_c \leq 60\ \mu m$	1	$> 1.74 \times 10^9$	
	2	$> 9.95 \times 10^3$	3.68×10^3
	3	> 7.78	3.79×10^3
	4	$> 6.88 \times 10^{-2}$	3.18×10^3
	5	$> 2.40 \times 10^{-3}$	2.88×10^3
	6	$> 1.97 \times 10^{-4}$	2.68×10^3
	7	$> 2.85 \times 10^{-5}$	2.53×10^3

Graviton Interaction

- SM fields confined to brane only
- Interaction term

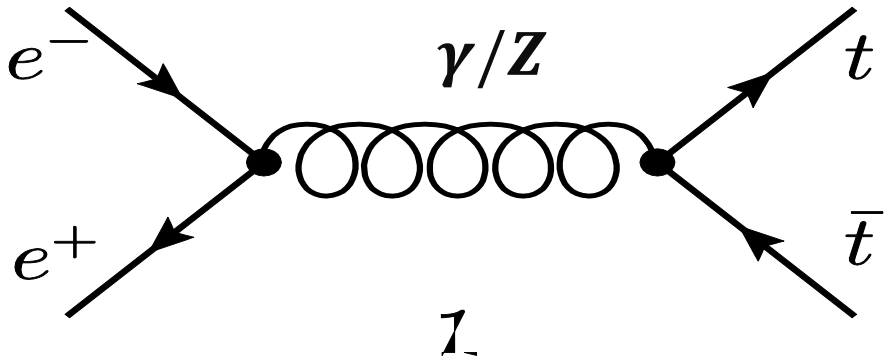
$$S_{int} = \frac{\kappa}{2} \int d^4x \, d^p y \, h_{\mu\nu}\left(x^\lambda, \vec{y}\right) T^{\mu\nu}\left(x^\lambda\right) \delta^p(\vec{y})$$

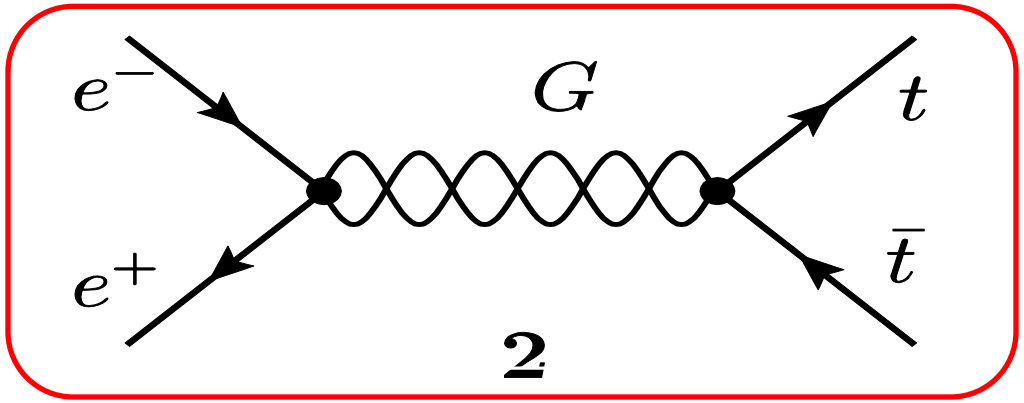
$$\Rightarrow \; S_{int} = \sum_{\vec{n}=\vec{0}}^{\infty} \frac{\kappa}{2} \int d^4x \, h_{\mu\nu}^{(\vec{n})}\left(x^\lambda\right) T^{\mu\nu}(x^\lambda)$$

- Coupling $\kappa \propto M_P^{-1}$
- But collectively gives observable strength

$e^+ + e^- \rightarrow t + \bar{t}$

- Lowest order Feynman diagrams

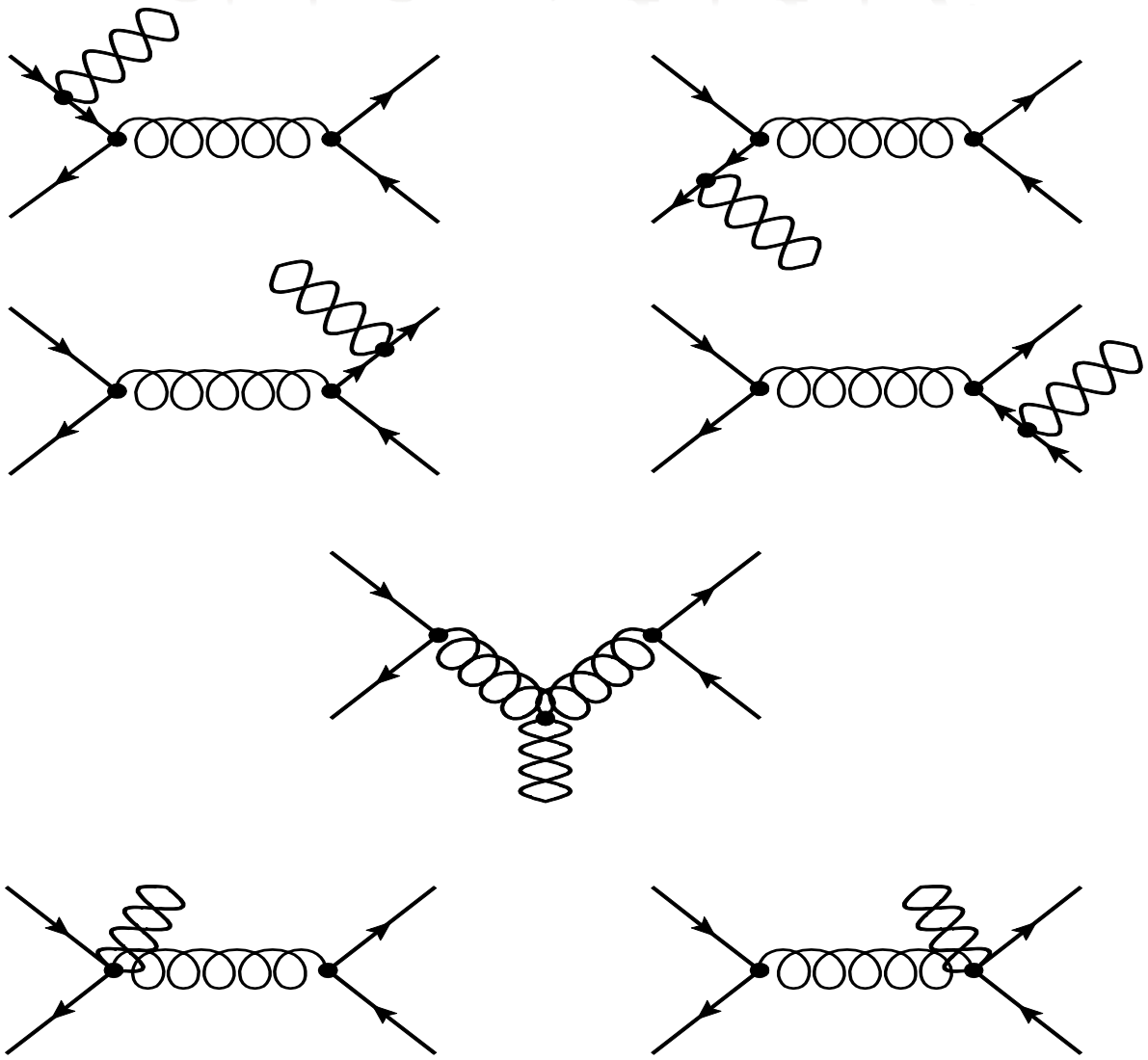




Contribution $\propto \frac{s^2}{M_S^4} \sim 0.08$

$E_{CM} = 3\ TeV, M_S = 4\ TeV$

$e^+ + e^- \rightarrow t + \bar{t} + G_{\vec{n}}$



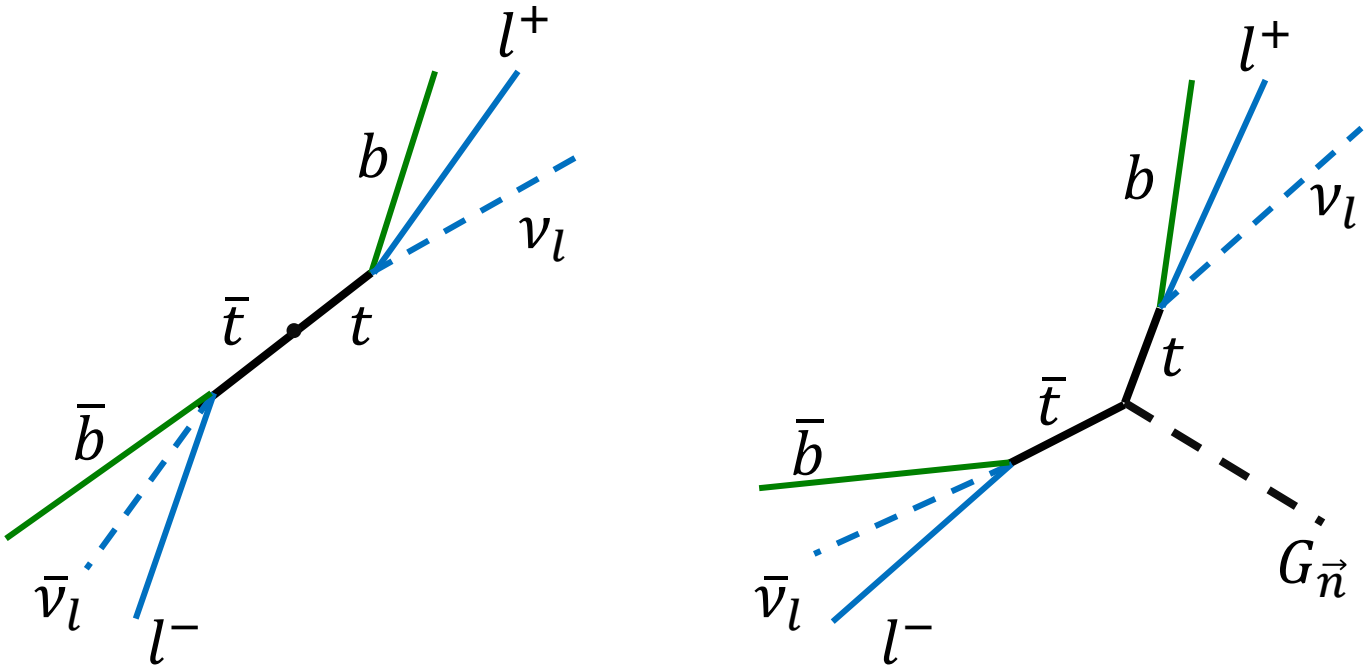
Decay of top

- top further decays: $t \rightarrow b + W^+$ and $\bar{t} \rightarrow \bar{b} + W^-$
- Further decay of W boson: $W^+ \rightarrow l^+ + \nu_l$
  $\rightarrow u + \bar{d}$
  $\rightarrow c + \bar{s}$
- Neutrinos are not detected & leaves missing $\vec{P}_T$

$$\vec{P}_T^{missing} = -\sum \vec{P}_T^{visible}$$

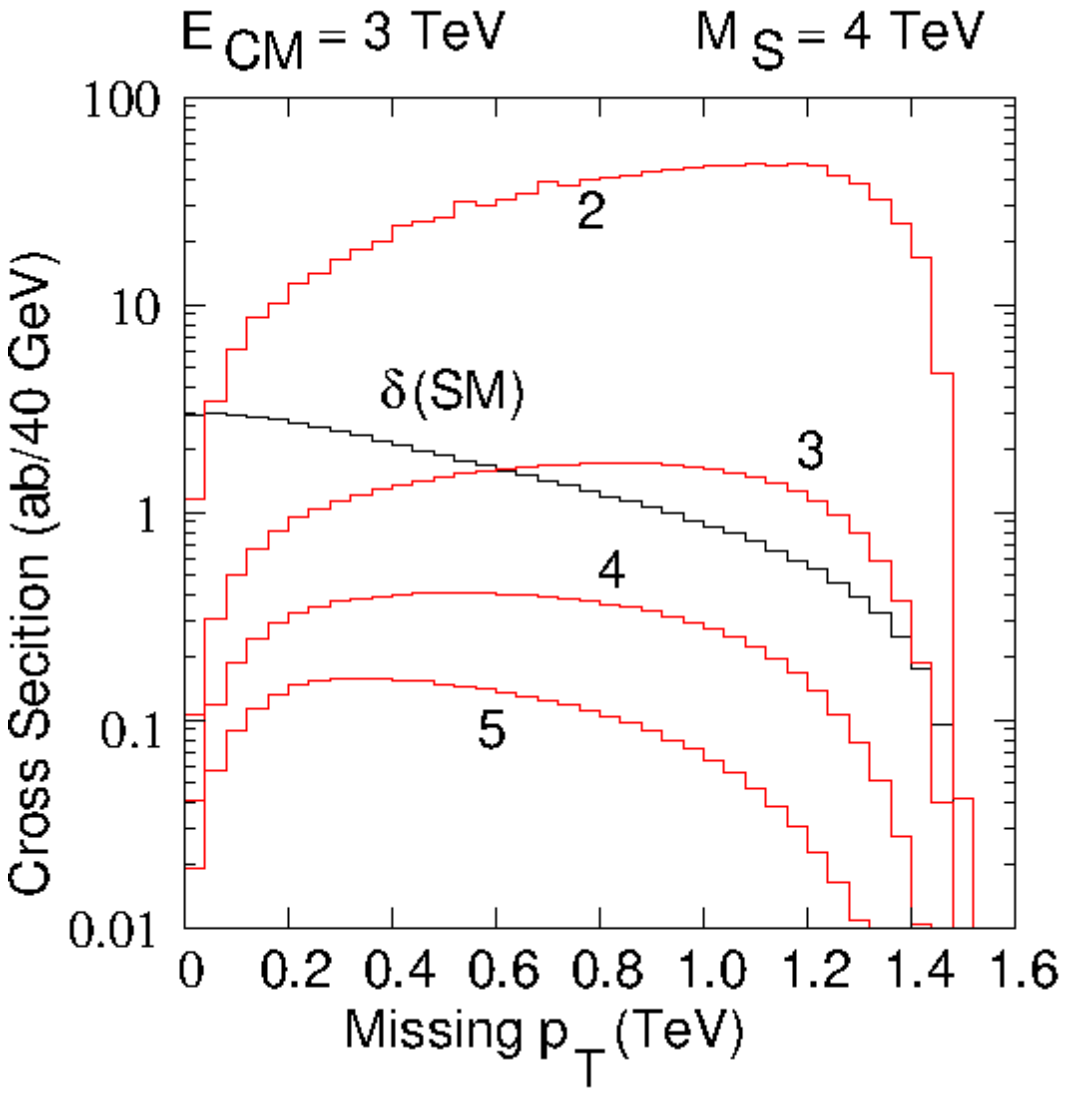
- 3 kinds of final states:
  - 6 jet events – both tops decay hadronocally
  - Single-lepton event – one top decay hadronically, one semileptonically
  - Di-lepton event – both tops decays semileptonically

Di-lepton event

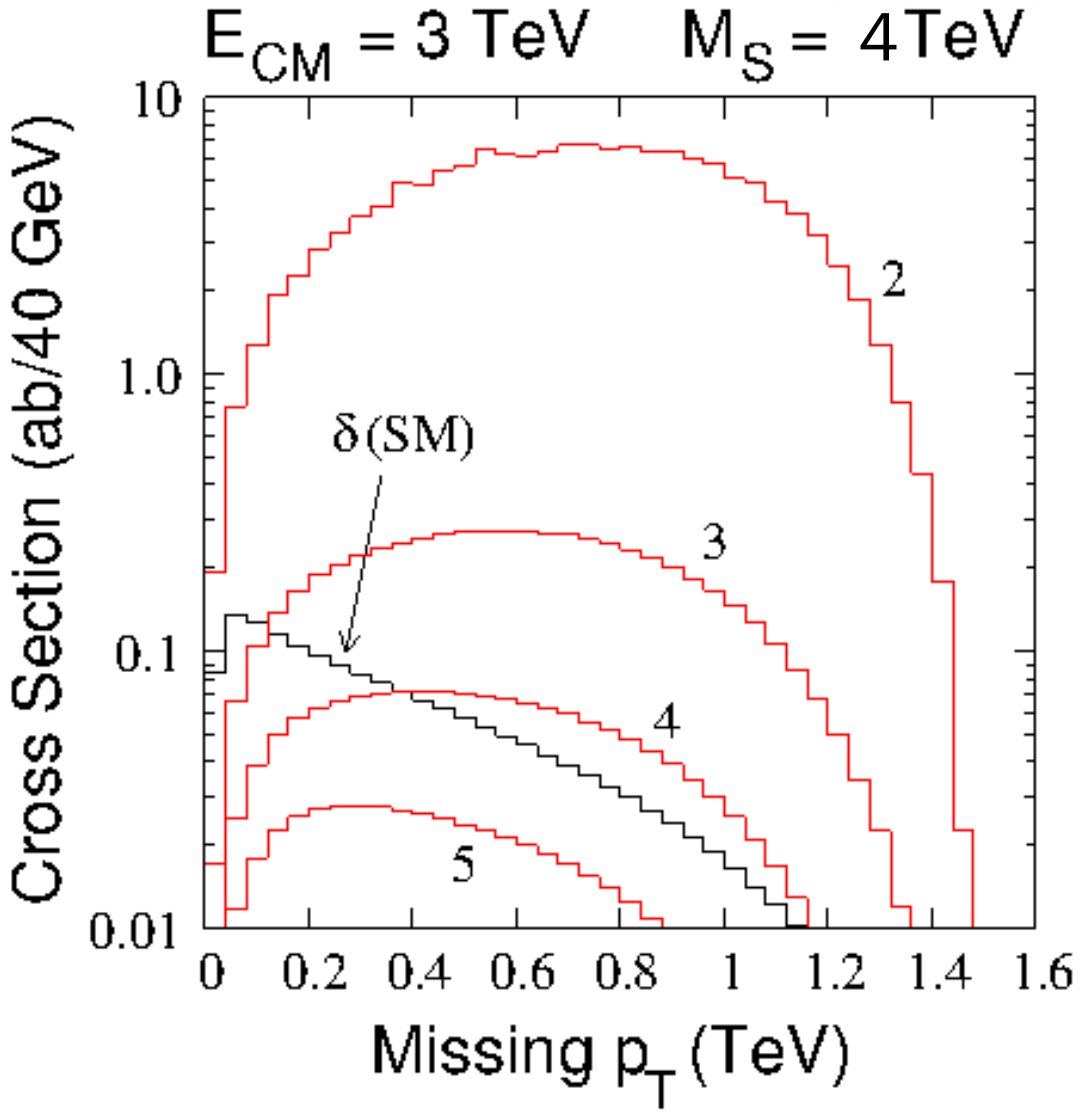


- SM Missing P_T falls sharply after ~ 50 GeV
- Graviton P_T contributes to missing P_T gives distribution in higher energies

Single-lepton Signals



Di-lepton Signals



Cross-section

	p	σ_l (fb)	1000 fb^{-1}	σ_{2l} (fb)	1000 fb^{-1}
$M_S = 4\ TeV$ $E_{CM} = 3\ TeV$	SM	4.39	4390	0.52	520
	2	43.72	43720	5.85	5850
	3	1.74	1740	0.23	230
	4	0.39	390	0.06	60
	5	0.13	130	0.02	20
	6	0.05	50	7.7×10^{-3}	7.7
	7	0.02	20	3.4×10^{-3}	3.4

Summary

- We studied the Single-lepton and di-lepton cross-section of $ttG_{\vec{n}}$
- For extra dimension 2 and 3 signals are observable with luminosity 1 ab^{-1} for $E_{CM} = 3\ \mathrm{TeV}$ and $M_S = 4\ \mathrm{TeV}$
- For extra dimension 4 signals may be observed with luminosity 10 ab^{-1}
- With higher energy machine higher extra dimensions may be observable

THANK YOU