Virtual Gravitons at the LHC

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Outline

Real and virtual gravitons at LHC

Gravitational fixed point

Virtual gravitons

LHC signal

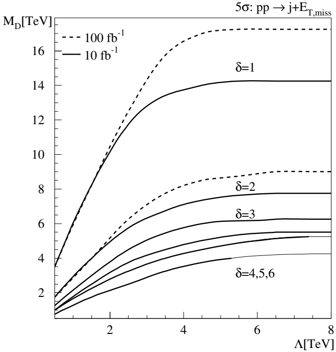
Outlook

Real and virtual gravitons at LHC

Effective theory of KK gravitons [Giudice, Rattazzi, Wells; Han, Lykken, Zhang; Hewett & Spiropulu,...]

- real graviton emission $pp \to G_{\rm KK}$+jets [coupling $G \sim 1/M_D^{2+\delta}$]
- recoil against hard jet $E_j > E_{\rm min} \sim M_D/4$ [Vacavant, Hichliffe,...]
- towers of ADD gravitons $dN \propto S_{\delta-1}\,(M_{\rm Planck}/M_D)^2\, m^{\delta-1}\,dm$
- cutoff setting $\mathcal{M}_{\rm KK} = 0$ for $E_{\rm parton} > \Lambda \sim M_D$
- observable: 5σ discovery reach as function of Λ
- UV-insensitive predictions for $\Lambda \to \infty$?

$\Rightarrow$ real emission cutoff irrelevant because of gluon densities



Real and virtual gravitons at LHC

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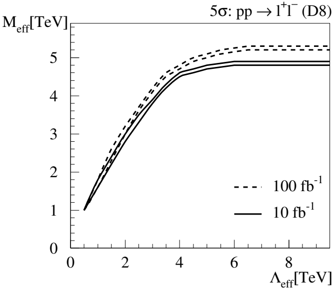
Virtual gravitons in Drell–Yan process [Giudice, Strumia, TP; Kachelries & Plümacher,...]

– D8 operator $\mathcal{S} = \frac{S_{\delta-1}}{M_D^{2+\delta}} \int dm\, \frac{m^{\delta-1}}{s+m^2}$ [requiring cutoff, leading constant in $\sqrt{s}/\Lambda$]

– effective theory fine for $\mathcal{S} = 4\pi/M_{\rm eff}^4$



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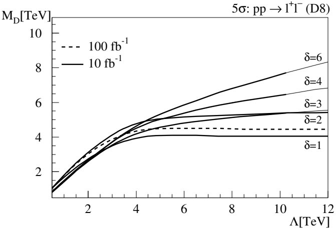
– bad in NDA $\mathcal{S}^{(\rm NDA)} = \frac{S_{\delta-1}}{2M_D^4} \left(\frac{\Lambda}{M_D}\right)^{\delta-2}$

– bad with cutoff $\mathcal{S}^{(\Theta)} = \frac{S_{\delta-1}}{M_D^4} \left(\frac{\Lambda}{M_D}\right)^{\delta-2} \frac{1}{\delta-2}$

– scaling reach $M_D^{\rm max} \sim \Lambda^{(\delta-2)/(\delta+2)}$

$\Rightarrow$ rates strongly cutoff dependent



Gravitational fixed point

Renormalization flow of gravity [Litim, Wetterich, Niedermaier, Reuter,...]

– effective action to scale k: $\Gamma_k = 1/(16\pi G_k) \int d^{4+\delta}x \sqrt{g}\,[-R(g) + \cdots]$

– IR — no running; M_D regime — strong effects; UV — fixed point

– dimensionless coupling $g(\mu) = G(\mu)\mu^{2+\delta} = G_0 Z_G^{-1}(\mu)\mu^{2+\delta}$

– RGE $\mu\partial_\mu g(\mu) = (2 + \delta + \eta(g))\; g(\mu)$ [anomalous dimension: $\eta = -\mu\partial_\mu \log Z_G \propto g$]

– UV fixed point

$$\beta_g = 2 + \delta + \eta(g) \sim \frac{1 - 4(4+\delta)\,g}{1 - (4+2\delta)\,g}\,(2+\delta)\;g = 0 \quad \text{for} \quad \eta(g) = -2 - \delta$$

– UV scaling $G(\mu) \sim Z_G^{-1} \sim \mu^\eta = \mu^{-2-\delta} \to 0$ [asymptotic safety]

$\Rightarrow$ gravity weak enough at high energies?

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$\Leftrightarrow$ can LHC phenomenologists have fun with physics?

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Graviton propagator [scooped by running coupling: Hewett & Rizzo]

- iterative approach: start with anomalous dimension [similar to QCD analyses]
- IR: everything as usual
- UV: dressed scalar propagator $\left[Z_G(|p|)\, p^2\right]^{-1} \sim 1/p^{2-\eta} = 1/p^{4+\delta}$
- built-in UV cutoff, just good enough for our needs

Virtual gravitons

Matched graviton propagator [Litim & TP]

– IR and UV form of scalar graviton propagator

$$P(s,m) = \begin{cases} \dfrac{1}{s+m^2} & \sqrt{s}, m < k_{\text{trans}} \\[2ex] \dfrac{M_D^{\delta+2}}{(s+m^2)^{\delta/2+2}} & \sqrt{s}, m > k_{\text{trans}} \end{cases}$$

– add IR and UV contributions by virtual gravitons [UV: gluon pdf $\longrightarrow$ leading in $\sqrt{s}/m$]

$$\mathcal{S}^{(\text{FP})} = \frac{S_{\delta-1}}{M_D^4} \left(\frac{k_{\text{trans}}}{M_D} \right)^{\delta-2} \frac{\delta-1}{\delta-2} = (1 + (\delta-2)) \; \mathcal{S}^{(\Theta)}$$

– only assumption $k_{\text{trans}} \sim M_D$ [for numerics, will be tested]

– parameters:

(1) gravitational coupling $G \sim 1/M_D^{2+\delta}$

(2) transition scale $k_{\text{trans}} \sim M_D$

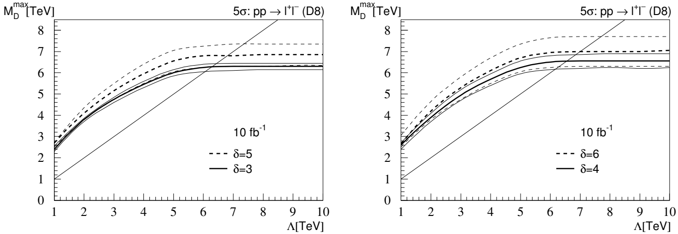
(3) no artificial UV cutoff Λ [setting $\mathcal{M}_{\text{KK}} = 0$]

$\Rightarrow$ UV fixed point predicts finite KK integral

LHC signal

Effective theory: artificial Λ setting $\mathcal{M}_{\text{KK}} = 0$

- perfect decoupling, as expected [similar to real emission]
- mild effects for $k_{\text{trans}} = M_D \pm 10\%$ [more details to be studied]
- reach largely independent of δ



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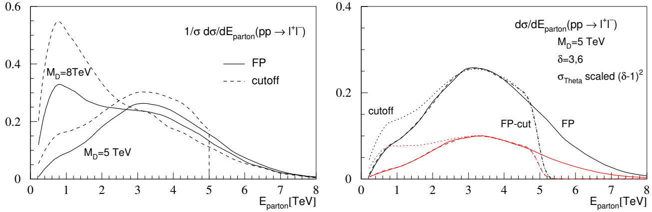
Shape of graviton kernel

- non-trivial structure from interference [shown $\delta = 3$]
  small $m_{\ell\ell}$: factor $(\delta - 1)$; large $m_{\ell\ell}$: factor $(\delta - 1)^2$
- UV contribution not negligible



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predicted LHC rates

- link between $\mathcal{S}^{(\rm NDA)}$ and $\mathcal{S}^{(\Theta)}$ trivial
- $\mathcal{S}^{(\rm FP)}$: IR regime identical to $\mathcal{S}^{(\Theta)}$; UV regime in addition

σ[fb]	$\delta = 3$			$\delta = 6$		
M_D	2 TeV	5 TeV	8 TeV	2 TeV	5 TeV	8 TeV
$\mathcal{S}^{(\rm NDA)}$	43.6	0.18	0.0053	263	1.11	0.031
$\mathcal{S}^{(\Theta)}$	173	0.72	0.0204	66	0.28	0.008
$\mathcal{S}^{(\rm FP)}$	5816	3.57	0.0802	13860	8.55	0.188
$\mathcal{S}^{(\rm FP)}_{\Lambda}$	688	2.87	0.0799	1634	6.89	0.187

$\Rightarrow$ fixed–point graviton effect stable and large

Outlook

Gravitons at LHC

– effective field theory:

(1) real emission well defined [accidentally]

(2) virtual–graviton predictions cutoff dependent

– fixed point picture: gravity weak at large scales [non-perturbative asymptotic safety]

RG analysis or lattice: effects computable [review: Niedermaier & Reuter, I'm on page 10/160]

(our) leading effect: anomalous dimension [Hewett & Rizzo: coupling]

⇒ testable rates predicted at LHC [Litim & TP, to appear tomorrow morning]

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