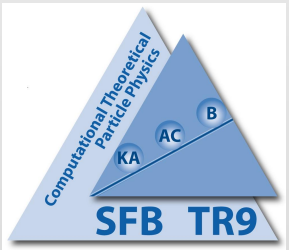
Graviton plus monojet production at NLO QCD in large extra dimensions

Stefan Karg



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PHENO 09

Large Extra Dimensions ADD, Arkani-Hamed, Dvali & Dimopoulos (1998)

- Gravity is weaker by a factor 10^{40}. Why? (or equivalently, why is $\nu \ll M_{Planck}$?) $\rightarrow$ Hierarchy problem
- one possible solution:
  Extra Dimensions allow the fundamental Planck scale to be as low as the EW scale

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- various models, e.g. the ADD model:
  - δ extra dimensions, compactified at radius r
  - SM is confined to a brane in a higher dimensional space
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  - SM is confined to a brane in a higher dimensional space
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- From dimensional analysis, we have $M_{Pl}^2 \propto r^\delta M_s^{\delta+2}$
  - If $\delta = 1$ and $M_s \sim 1$TeV, $\rightarrow r \sim 10^{15}$cm, excluded
  - If $\delta = 2$ and $r < 0.2$mm, $\rightarrow M_s > 1.5$TeV (direct probes of Newtons law)
  - If $\delta > 2$ and $M_s \sim$TeV, $\rightarrow r < 10^{-6}$cm $\rightarrow$ only testable at high energy colliders

Kaluza-Klein (KK) tower

- periodic boundary conditions for the compactified extra dimensions
- quantized momentum in extra dimensions ($p = n/r$) $\rightarrow$ massive Gravitons: $m^2 = m_0^2 + p^2$
- Infinite tower of 4D KK modes: mass splittings $\Delta m \propto 1/r$
  $\delta = 2 : \Delta m \propto 10^{-4}$eV, $\delta = 6 : \Delta m \propto 10$MeV
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  $\mathcal{L}_{\text{int}} = -\frac{1}{\overline{M}_{Pl}} \sum_{\vec{n}} (h^{(\vec{n})})^{\mu\nu} T_{\mu\nu}$ (h: KK mode, T: energy mom. tensor)

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- summation over the KK tower: M_{Planck} suppression replaced by M_s suppression in cross sections!

Collider Signatures and Existing Limits

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- direct graviton production and virtual graviton exchange (more model dependent)

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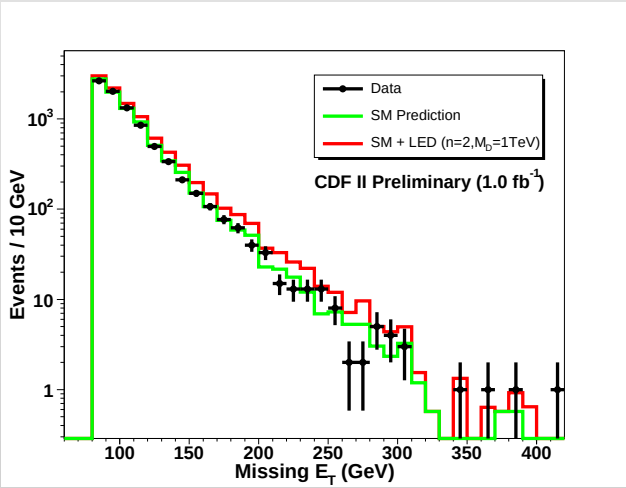
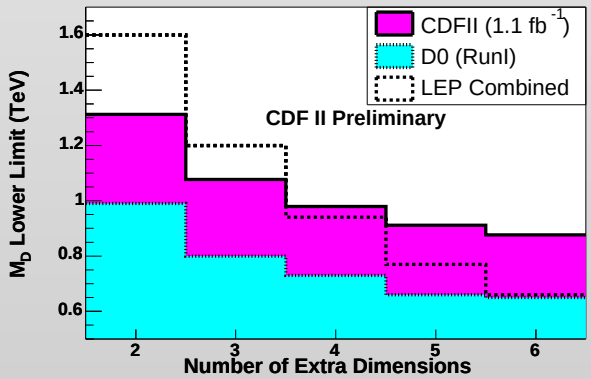
- Constraints from Non-Collider experiments:
  - short range gravity experiments: $r < 130\mu m$ (n=2) $\Leftrightarrow M_s > 1.7$ TeV
  - cosmological constraints: $M_s > 20 - 100$ TeV (n=2), $M_s > 2 - 5$ TeV (n=3), depending on many assumptions

Graviton plus 1-jet production

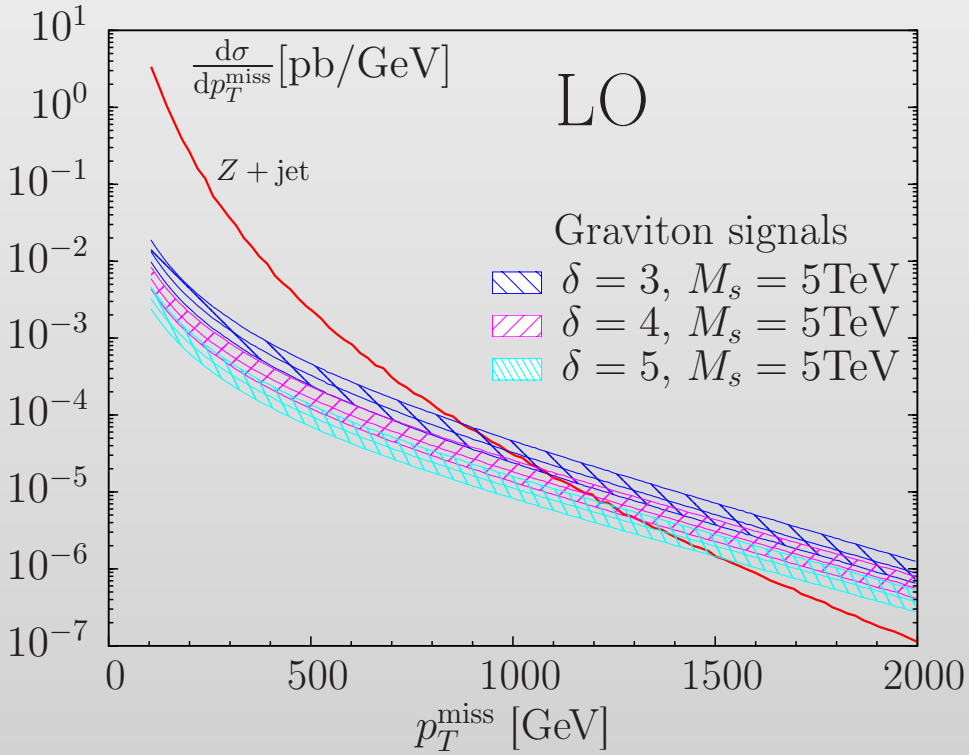
- Monojet + nothing is a striking signal for new physics at the LHC
- major background: $Z(\rightarrow \nu\bar{\nu}) + jet$ both theoretically and experimentally under good control
- Experimental studies (Tevatron) for Graviton production with monojet have found a strong ability to probe higher extra dimension scale: jet+missing Energy, photon+missing Energy,



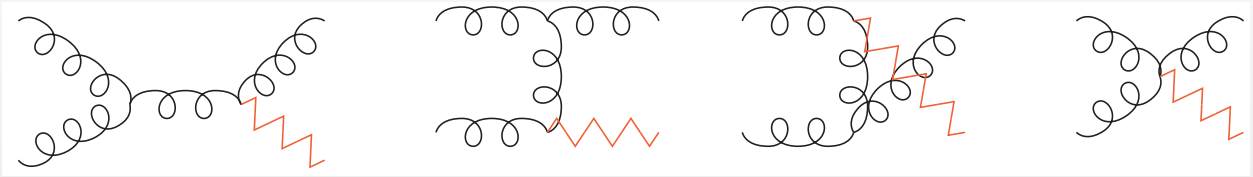


Graviton plus 1-jet at NLO QCD

- Need for QCD corrections: reduction of large scale uncertainties at LO, sizable contribution to the cross section possible (K-factor)



- 2 subprocesses at LO: $gg \to Gg$, $q\bar{q} \to Gg$ + crossed



- Graviton = massive spin-2 vector boson
  (polarization tensor: $\epsilon_{\mu\nu}^{\lambda_4}$, $\lambda_4 = \{++, +, 0, -, --\}$)
- 3 scales: s, t, M_G
- simple colour structure: $\mathcal{M} \propto f^{abc}$ or T_{ij}^{a}

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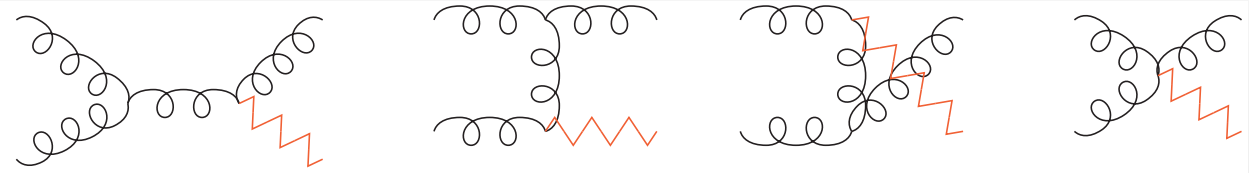

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- virtual corrections: 43 diagrams for $q\bar{q}$, 108 diagrams for gg
  Most complicated diagrams: box diagrams with tensor rank $r = 5$ due to the complicated tensor structure of the Graviton
- application of the spinor formalism to project onto helicity amplitudes
- fully analytic reduction to scalar integrals: I_4^{n+2}, I_3^n, I_2^n
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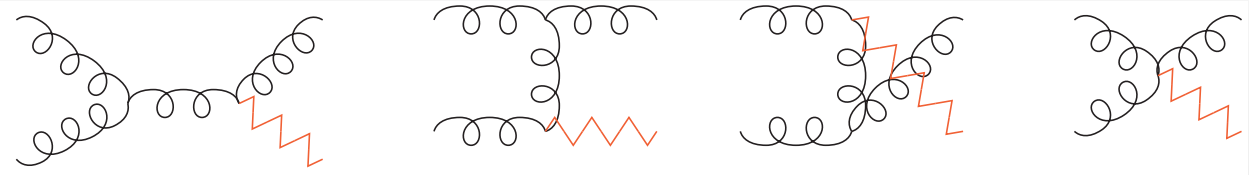

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- real corrections: dipole subtraction method, code based on modified MADGRAPH

Checks of the calculation

- gauge invariance
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- discrete symmetries
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- two independent calculations (not yet fully completed)

Preliminary results for Graviton + jet at NLO

Setup:

- $\delta = 4$, $M_S = 4\,\text{TeV}$, LHC, PDFs: Cteq6L1 for LO, Cteq6m for NLO
- cuts: $p_{T\text{miss}} > 500\ \text{GeV}$
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	$\sigma(\mu = 0.5\mu_0)[\text{fb}]$	$\mu = \mu_0$	$\mu = 2\,\mu_0$
LO	175.1	136.3	108.4
NLO	291	262	231

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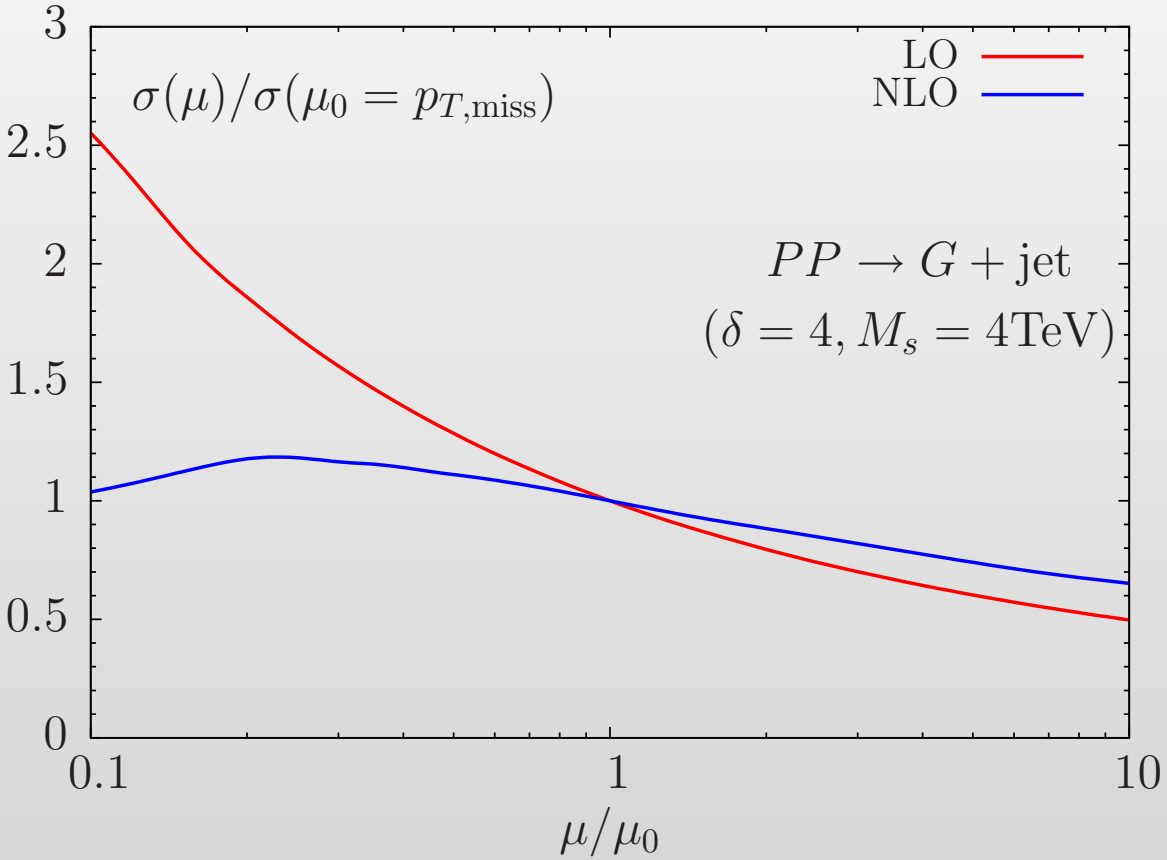
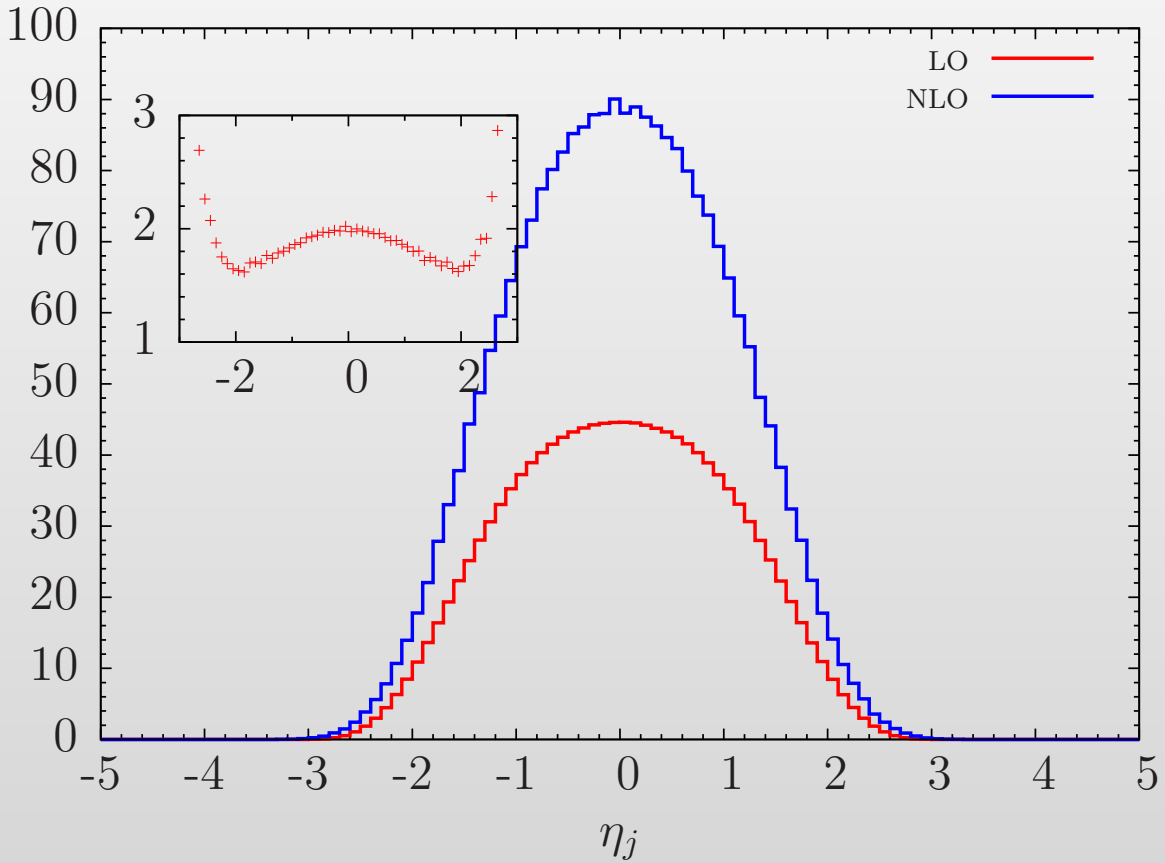
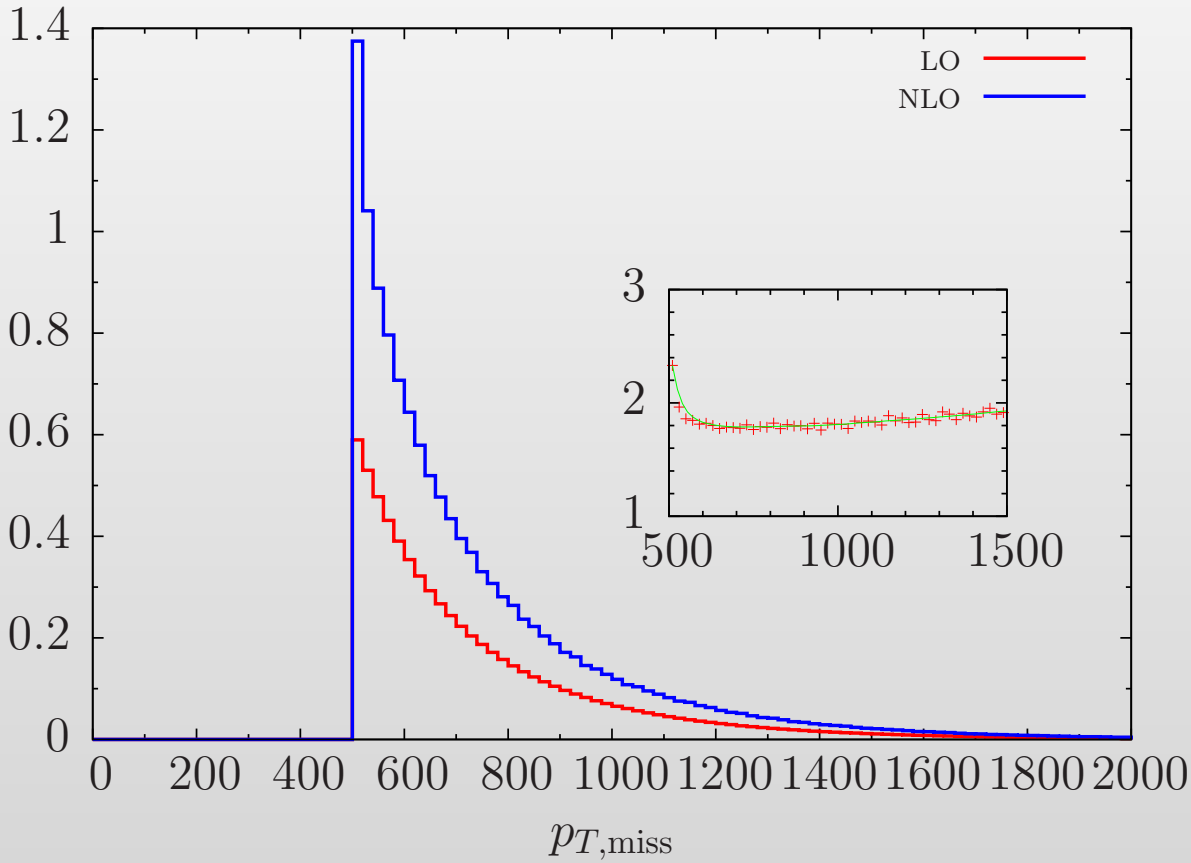
$\longrightarrow$ scale variation by a factor 2: $\pm 25\%$ for LO, $\pm 10\%$ for NLO

$\longrightarrow$ K-factor: $\sigma_{NLO}/\sigma_{LO} = 1.9$ (at $\mu = \mu_0$


3
2.5
2
1.5
1
0.5
0
0.1
1
10
μ/μ_0
$\sigma(\mu)/\sigma(\mu_0 = p_{T,\mathrm{miss}})$
LO
NLO
$PP \to G + \mathrm{jet}$
$(\delta = 4, M_s = 4\mathrm{TeV})$


LO
NLO
100
90
80
70
60
50
40
30
20
10
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
η_j
3
2
1
-2
0
2


LO
NLO
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0 200 400 600 800 1000 1200 1400 1600 1800 2000
$p_{T,\mathrm{miss}}$
3
2
1
500 1000 1500

Summary of results and Conclusion

- Computation of Graviton plus 1 jet production at NLO QCD as an important probe for large extra dimensions
- Significant reduction of large scale variations at LO
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- Computation of Graviton plus 1 jet production at NLO QCD as an important probe for large extra dimensions
- Significant reduction of large scale variations at LO
- Large contribution of radiative corrections to cross sections
- Results should be taken into account in experimental studies