Graviton + multi-jet production at colliders

"GDR Terascale International meeting"

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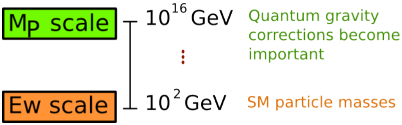
[P.d.A, K. Hagiwara, Q. Li and F. Maltoni, in preparation]

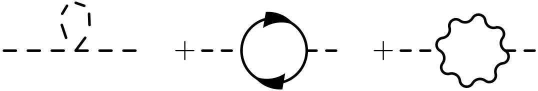
Introduction

The SM agrees to a great deal with the experimental data we have today, but there are several reasons to expect new physics at TeV scale.

For example: **The Hierarchy Problem**



Standard Model $\Rightarrow$ radiative corrections to Higgs mass:



To have a Higgs boson with $m_H \leq 200\ GeV$:

There might be new physics at TeV scale!!

Beyond the Standard Model

Attempt to explain the HP: **Extra-dimensional models**

- ADD models = Large Extra Dimensional model

  [N. Arkani-Hamed, S. Dimopoulos, G. R. Dvali, 1998]

- RS models = Warped Extra Dimensional model

  [L. Randall, R. Sundrum, 1999]

Attempt to explain the HP: **4D model**

- Massless graviton model (4-dimensional with a large hidden sector)

  [G. Dvali, arxiv:0706.2050]

  [X. Calmet, S. D. H. Hsu, D. Reeb, arxiv:0803.1836]

New physics at TeV scale

New physics at the TeV scale

The LHC era: new expectations on the search for the new physics!

With the start of the LHC: very interesting phenomenology at hadron colliders!

- **Many different BSM theories proposed with the same signature!**

"How can we identify a theory?"

- Need of careful phenomenological analysis at colliders
- Simulation becomes very necessary!

Spin-2 particles in MadGraph/MadEvent

- **Spin-2** particles **introduced in MadGraph** by in 2008

  [K. Hagiwara, J. Kanzaki, Q. Li and K. Mawatari, arXiv:0805.2554]

- Sub-routines **updated** and **introduced in MadEvent** in 2009

  [P.d.A, K. Hagiwara, Q. Li and F. Maltoni, in preparation]

With these improvements: MG/ME is ready for phenomenology with ANY spin-2 particle!

On-going phenomenological project

Perform a full analysis on graviton production through **multi-jet** final state processes at hadron colliders for ADD, RS and MGM models.

Phenomenology on Graviton Emission at the LHC

1. Compare all models $\Rightarrow \neq$ final states:

ADD	Weakly coupled massive graviton	$\Rightarrow$	Missing E_T
RS	Strongly coupled massive graviton	$\Rightarrow$	Decayed product
MGM	Weakly coupled massless graviton	$\Rightarrow$	Missing E_T (+ threshold)

$\hookrightarrow$ need of a **general** / **flexible** implementation $\Rightarrow$ **MG/ME**

2. Identification of signature and corresponding model $\Rightarrow$ very difficult!

Need of accurate predictions for non-trivial observables: **Pythia not enough!**

3. Solution $\Rightarrow$ comparison with NLO

- generate inclusive sample $\Rightarrow$ MG/ME + Pythia
- Compare multi-jet final state results X the mono-jet NLO

Use NLO for normalization, and distribution shapes more accurate..

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Multi jet MG/ME + Pythia X Mono jet NLO

MG/ME + Pythia: multi-jet final state $\Rightarrow$ **need of a matching method**

If ME and PS approaches are considered without any control: double counting between samples of different multiplicity!

Matching/Merge method

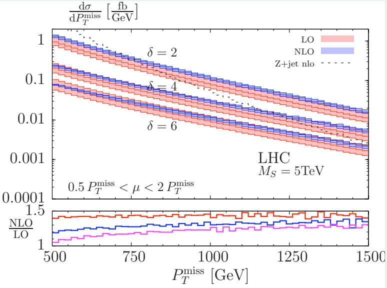
To $\div$ the phase space in 2 regions characterized by the hardness of QCD emission

X

NLO calculation to KK graviton mono jet in ADD

[S. Karg, M. Krämer, Q. Li, D. Zeppenfeld, arXiv:0911.5095]

QCD corrections: sizable at the LHC!



Graviton Emission + Multi jets: MLM matching scheme

On-going project:

comparison MLM-Matching with NLO for **ADD**, **RS** and **MGM**

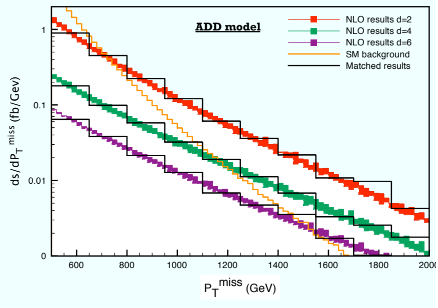
Distributions to be analysed:

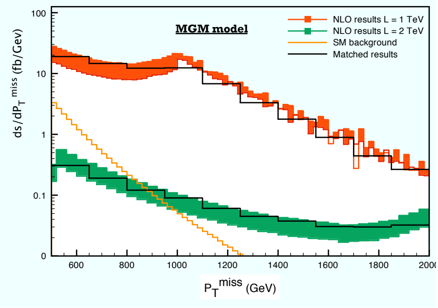
- $\rightsquigarrow$ Missing/graviton P_T
- $\rightsquigarrow$ Pseudo-rapidity (jets, graviton)
- $\rightsquigarrow$ P_T (first and second jets)
- $\rightsquigarrow$ $H_T = \sum |P_T^{jets}|$

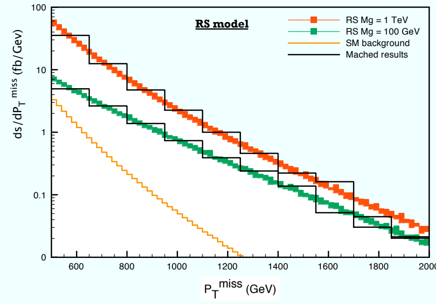
Cuts imposed (LHC and Tevatron):

	P_T^{miss}	$P_T^{1st\,jet}$	$\lvert\eta\rvert$	Q^{match}
LHC	> 500 GeV	> 50 GeV	< 4.5	> 50 GeV
Tevatron	> 120 GeV	> 20 GeV	< 4.5	> 30 GeV

Graviton Emission + Multi jets: P_T^{miss} results







Results for ADD, RS and MGM

- MLM-matched normalized with NLO results
- Excellent agreement between MLM-matched and NLO shapes
- Clearly, the irreducible background has a different shape!

Graviton Emission + Multi jets: H_T results

Important: Matching results ⇒ more accurate

- Because of extra jets;
- ∃ of variables that can only be well predicted by matching, such as H_T

Introduction of variable by CMS:

[CMS Collaboration, CMS-PAS-EXO-09-013]

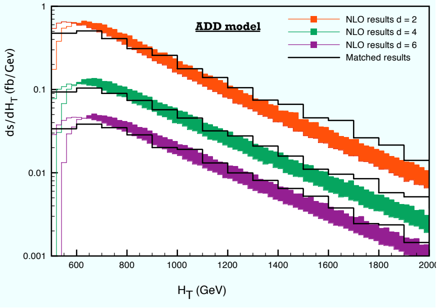
- Defined as the vectorial sum of jets $p_T(jet)_i$ above a threshold p_t^0

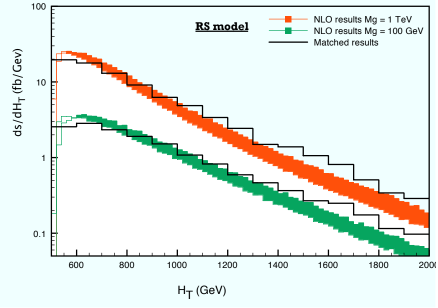
$$H_T = \left| \sum_{p_{T(jet)_i} > P_T^0} p_T(jet)_i \right|$$

  - H_T has been prove to be larger in signal than in QCD events
  - More useful variable than E_T^{miss} in this case

Graviton Emission + Multi jets: H_T results

- H_T comparison MLM-matching X NLO results:





Results

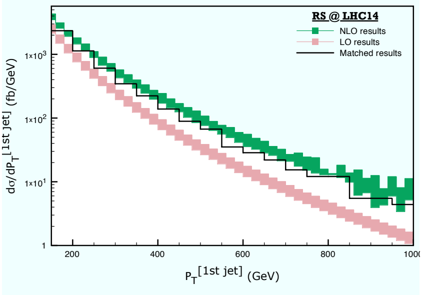
⇝ Good agreement for low H_T

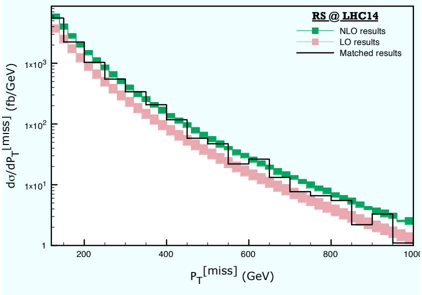
⇝ Harder distribution for large H_T

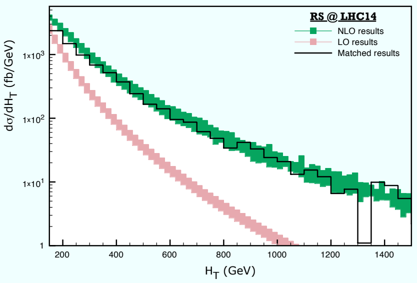
$\Rightarrow$ **because matching considers up to 3-jets!**

Comparison MLM-matching & NLO X LO results

Example: RS model with $M_g = 100\, GeV$**. Matching up to 2 jets here.**







A) Large NLO/LO K-factor

B) Excellent agreement between MLM-matched and NLO shapes

C) Clearly, LO results is not enough!

Summary and Conclusions

- **4D Massless Graviton Model**: an alternative for solving the HP
- **Spin-2 particles in MadGraph/MadEvent:**
  - Ready for phenomenology!
- **Phenomenology** $pp \to$ **Multi-jets** $+ G$**:**
  - Detailed comparison btw **NLO and MLM matching** for **ADD**, **RS** and **MGM**
  - P_T^{miss} and P_T^{grav} shows good agreement between matched and NLO
  - Harder distributions for large H_T: **matched computed up to 3 jets**

Conclusion: Matching is needed to compute expectation at hadron colliders

$\rightsquigarrow$ and it is **crucial depending on the distribution** requested!

Thank you!

Acknowledgments:

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Explaining the HP with extra dimensions

How can they bring Mp to 1Tev?!

ADD/LED:

- Flat metric;
- δ **extra-dimensions:** Spatial and compact

$$M_p^2 = M_*^{\delta+2}\, V_\delta \quad \Rightarrow \quad V_\delta = 8\pi R^\delta$$

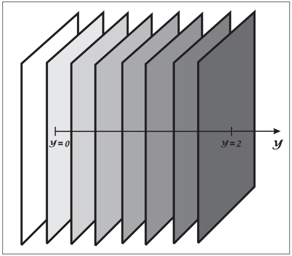
RS/WED:

- Warped metric:

$$ds^2 = e^{-2k|y|}\eta_{\mu\nu}dx^\mu dx^\nu + dy^2$$

- Planck brane @ $y = 0$, TeV brane @ $y = \pi R$

$$M_e = e^{-k\pi R} M_p$$

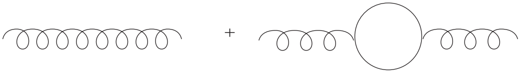


Explaining the HP in 4 dimensions

If strength of gravitational interactions = scale dependent:

$$G(\mu_*) \sim \mu_*^{-2} \qquad \Rightarrow \qquad M_{planck}(\mu_*) \sim \mu_*$$

Consider a scalar field coupled to gravity:



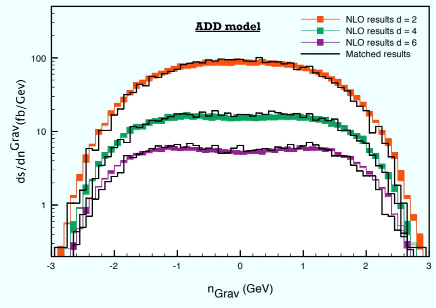
G_N/M_{pl}: It gets renormalized by virtual particles when quantum fluctuations are taken into account

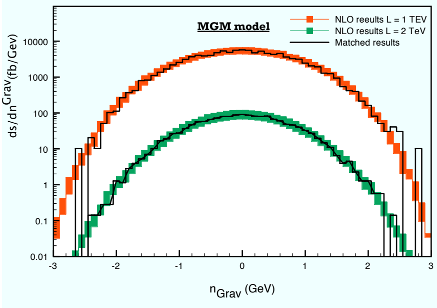
$$\frac{1}{G_{ren}} = \frac{1}{G_{bare}} + c\Lambda^2 \quad \Rightarrow \mu_*^2 = \frac{M_p^2}{(1+c)}$$

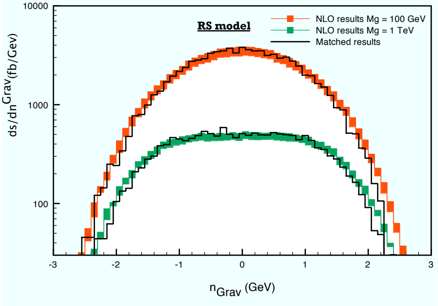
For $\mu_* \sim 1\ TeV \Rightarrow N = 5.6 \times 10^{33}$ new particles!

Therefore it must exist large hidden sector that interacts only gravitationally with the SM!

Graviton Emission + Multi jets: η^{grav} results







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