What We Know from MET Signatures at the LHC?

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LHC signature

- Several new physics scenarios can lead to single/multiple jet(s) with large missing transverse energy (MET) signatures at the LHC.
- With strong couplings, jet(s) production can be one of the significant channels.
- They can reveal the physics on the early phase of LHC.
- Any excess signal over well understood SM background would lead us to identify the non-standard origin of these signal.
- One would like to compare the respective shapes of the several independent distributions.
- Better performance can be achieved by comparing several independent distributions at the same time to quantify this analysis.

LHC signature

- Both SUSY and Extra-dimension have got lots of attention as a solution to the Naturalness problem.
- If SUSY or ED exists at TeV scale, signals of new physics should be found at LHC.
- Discrimination of SUSY signals from Large Extra Dimension (LED).
- Large Missing energy from lightest supersymmetric particle (LSP) is in general a signature of most of the R-parity conserving SUSY processes.
- Situation is similar for LED scenario (direct graviton production) where the tower of graviton produces large missing energy.

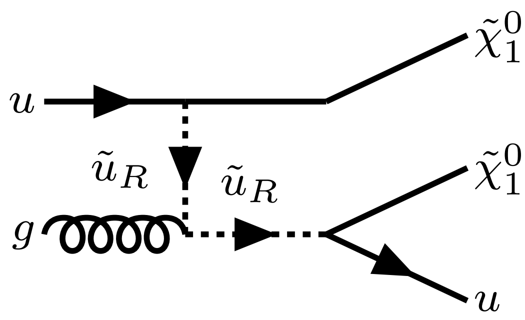
SUSY scenario

- Simple case:

  Lightest Supersymmetric Particle : LSP : Bino $\tilde{B}$

  Lightest Coloured Supersymmetric Particle : LCSP : Right Squark $\tilde{u}_R, \tilde{d}_R$

- Associate production of Right Squark $\tilde{u}_R, \tilde{d}_R$ at the LHC.



- Kinematic distributions depend only on two parameters : LSP mass $m_{\tilde{B}}$ and LCSP mass $m_{\tilde{q}_R}$.

LED scenario

- $(4+\delta)$ dimensional theory with extra δ dimension(s) which are compactified (with radius R).
- Standard Model fields are confined on (1+3)- dimensional brane though gravity can propagate anywhere in the $(4+\delta)$ dimensional bulk.
- Our 4 dimensional Planck scale (M_p) is related to the $(4+\delta)$ dimensional Planck scale $(\bar{M}_s)$ which is actually fundamental scale in this scenario.

$$M_p^2 = 8\pi . V_\delta R^\delta \times \bar{M}_s^{\delta+2}$$

Volume element $V_\delta = (2\pi)^\delta$ assuming toroidal compactification of extra dimensions.

- By choosing large R (exp. limit $\approx \# \, mm$), fundamental scale $(\bar{M}_s \sim 1 \, TeV)$ can produce the Planck scale $(M_p \sim 10^{19} GeV)$ in 4 dimension.

LED scenario

- δ compact extra spatial dimensions
  $\Rightarrow$ Infinite tower of Kaluza-Klein states with masses
  $m_n^2 \sim \frac{\vec{n}^2}{R^2}$ $\quad \vec{n} = (n_1, n_2, \dots n_\delta)$
  $n_i = 0, \pm 1, \pm 2, \dots$
- The coupling of each graviton KK states to the SM fields remain small, being proportional to $1/M_p$.
- But cumulative effect from full tower of KK states, considering KK state density

$$\rho(m)dm = \left[\frac{2\pi^{\frac{\delta}{2}}}{\Gamma(\frac{\delta}{2})}\right] \frac{\bar{M}_p^2}{M_s^{2+\delta}} m^{\delta-1} dm$$

$\longrightarrow$ cross-section sizable to have collider signature.
$e.g.$ final cross section $\sim \frac{1}{M_s^2}$ for graviton emission.

LED scenario

- Real graviton emission :
  $\Rightarrow$ Incoherent sum
  $\Rightarrow$ missing energy-momentum.
- Graviton production with a monojet @ LHC :

$$pp \to j\, G_n \to j\, P_T^{\text{miss}}$$

  Through processes: $qq \to gG_n$, $gg \to gG_n$ and $qg \to qG$.
- Only 2 parameters: number of extra dimensions δ the higher dimensional Planck scale, M_S
- At subprocess level cross sections scale as $M_S^{-(2+d)}$
- effective theory - truncation schemes.

Vacavant, Hinchliffe

Comparison single jet

- Observing an excess in the mono jet channel relies on our thorough understanding of the SM background.
- At low P_T, this background can be dominated by QCD/jet energy mis-measurements.
- QCD production of Wj with subsequent decay $W^{\pm} \to l^{\pm}\nu$ when the charged leptons $l = e, \mu, \tau$ are not identified.
- At high P_T it is largely dominated by Z + j production followed by the invisible decay of $Z \to \nu\bar{\nu}$.
- At high P_T SM background can be better understood by looking at the leptonic decay channel of Z in $Z \to e^+e^-/\mu^+\mu^-$.
- Z-induced SM mono jet background can be estimated directly from data.
- Other sources of background, from dijet production can be handled similarly.

Comparison single jet

- If these backgrounds will eventually be well understood in the very high P_T region.

$$P_{T_j} > 500GeV$$
$$H_T = P_{T_j} + MET > 1TeV$$

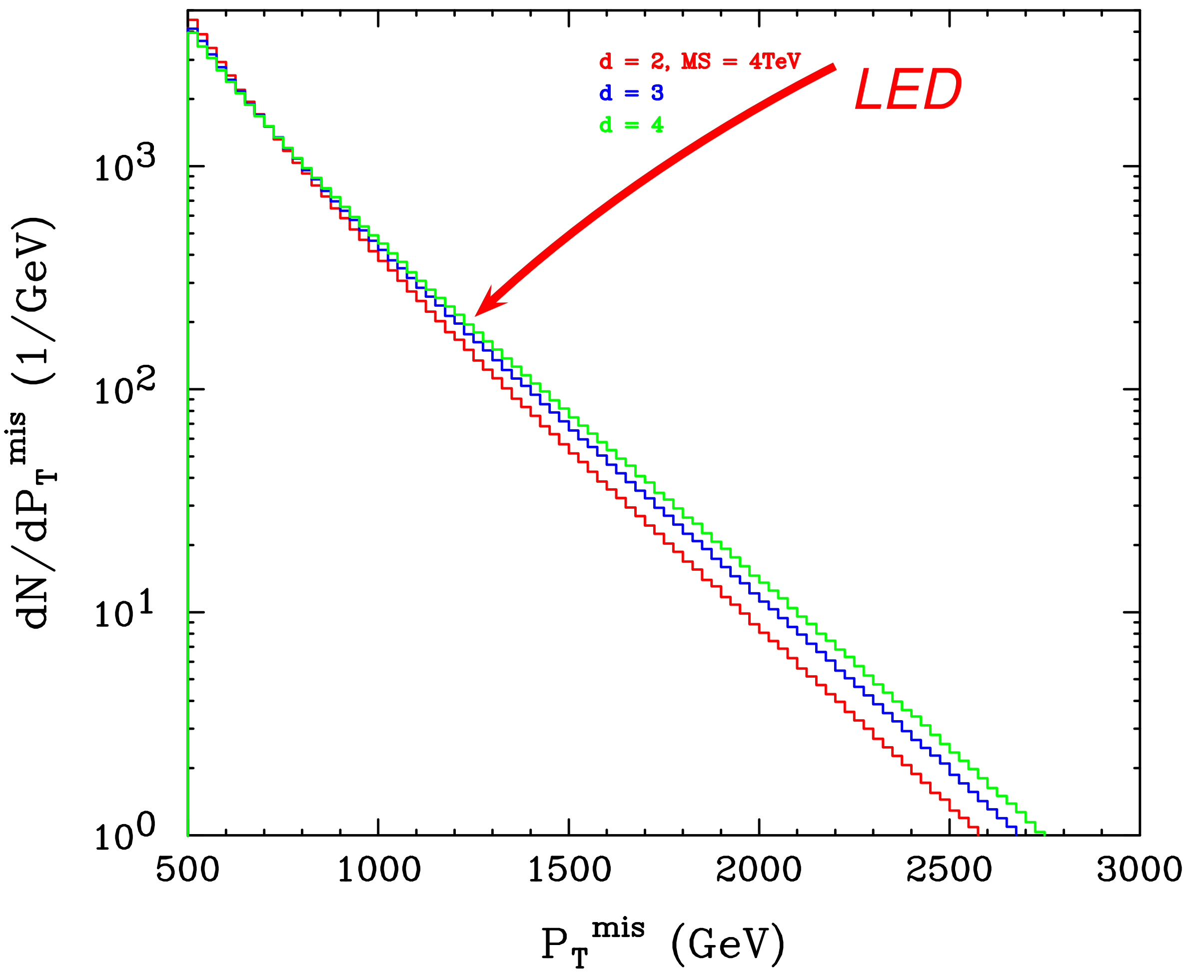
- We can try to inquire whether LED signal is distinguishable from one of supersymmetric origin.
- differentiate mono jet signals arising in different models by the shapes of their jet P_T distributions
- Similar analysis was done recently to differentiate the LED and unparticle predictions provided a well-defined signal over background is already clearly observed.

T.G. Rizzo; arXiv:0805.0281

Comparison single jet

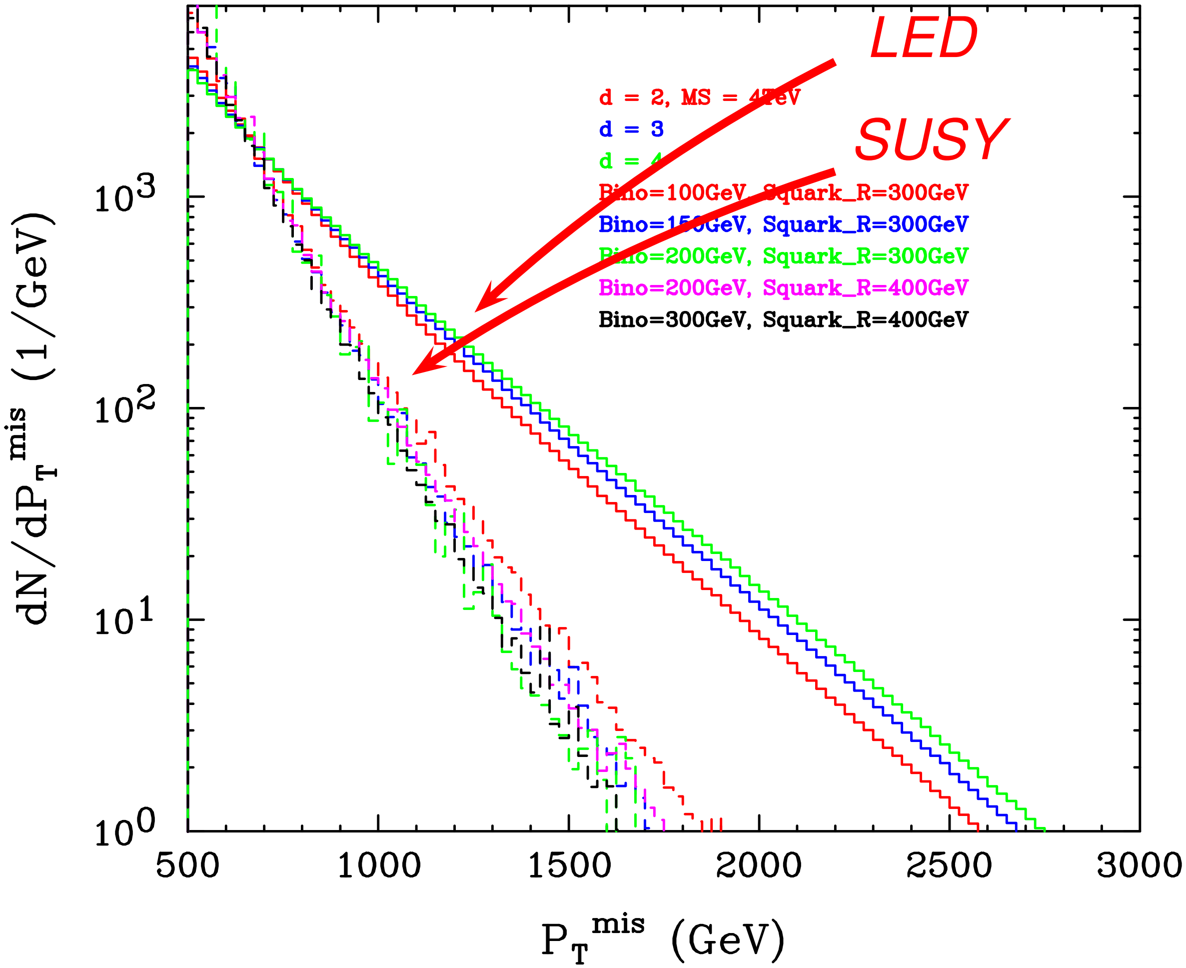
- Compare the ADD predictions for different values of while simultaneously varying the value of M_s (as a function of) so that the models all predict the same cross section at some fixed value of the jet P_T.
- Demanding that the mono jet can be identified in central rapidity, i.e., $|\eta_j| < 4.5$ along with very large jet PT $P_{T_j} > 500 GeV$ and $H_T = E_{T_j} + MET > 1 TeV$.
- CTEQ6L1 parton distribution functions.
- Factorization scale chosen as $\mu_f = \min(P_T)$ of the jets
- QCD coupling is set to the geometric mean value, $\alpha_s = \sqrt{\alpha_s(P_T^{j_1})\ \alpha_s(P_T^{j_2})}$. (for di-jet processes)

Single jet analysis



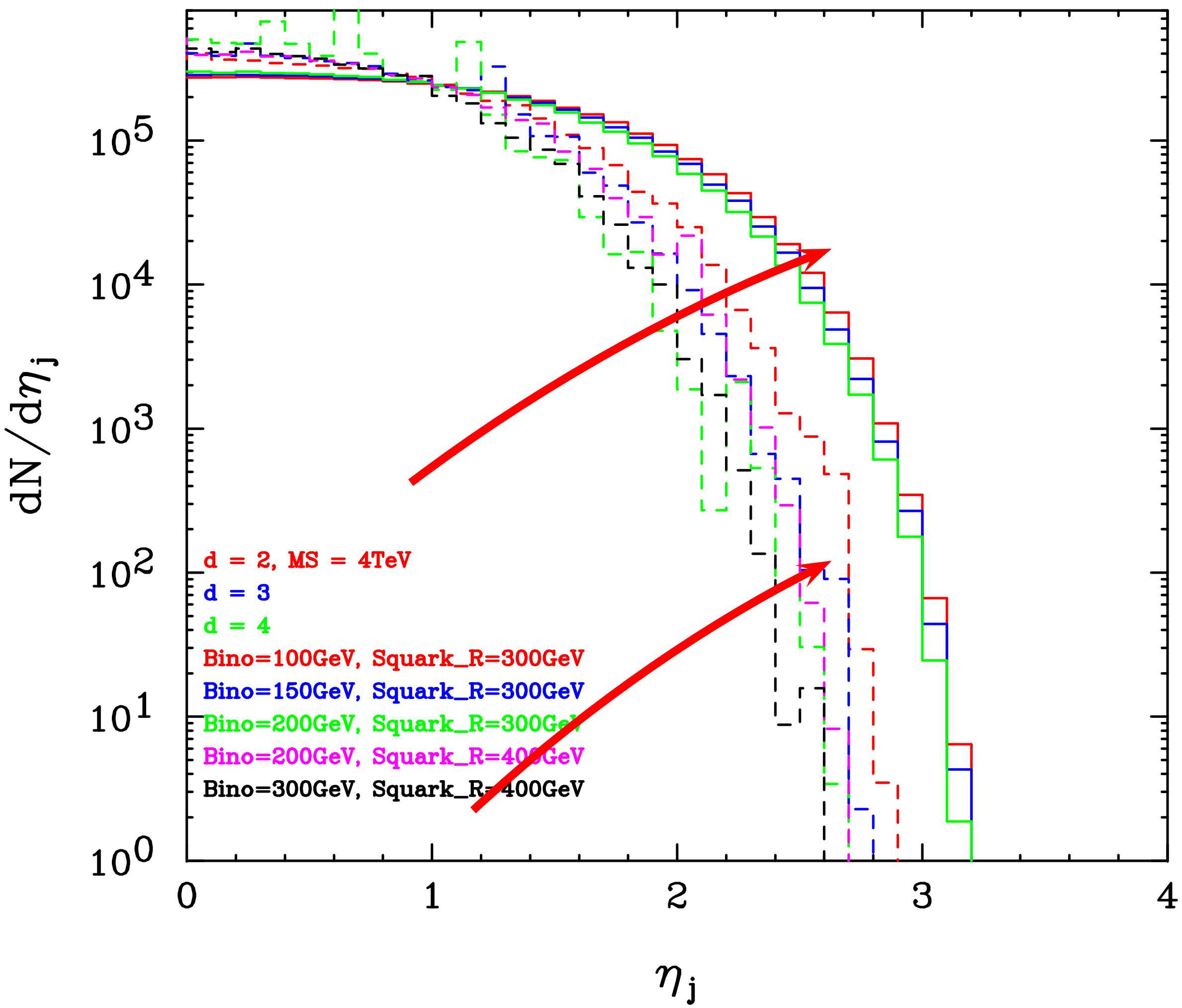
⊙ P_T^j dependence of mono-jet event rate for $pp \to jG_nX$ at the LHC for various no of extra dimensions. With 25 GeV bins and luminosity $100 fb^{-1}$

Single jet analysis



⊙ P_T^j dependence of mono-jet event rate for SUSY and LED at the LHC for various no of extra dimensions. With 25 GeV bins and luminosity $100 fb^{-1}$.

Single jet analysis



⊙ η^j dependence of mono-jet event rate for SUSY and LED at the LHC for various no of extra dimensions. With 100 bins and luminosity $100 fb^{-1}$.

Single jet analysis

- Mono-jet carry little information on the underlying physics.
  : transverse momentum ($p_{T\,j}$) and rapidity (η_j) of the single jet
- At the LHC it is difficult to determine both the values of M_S and δ simultaneously from the observation of a mono jet excess.
- But characteristic different jet pT can be utilised to differentiate several models like LED and SUSY.
- Reconstruction of some interesting shape-variable can distinguish efficiently over reasonable parameter space.

P.K.,Roy; 2006

Summary and farther work

- It is essential to quantify the capability to differentiate two sets of new physics models that can lead to visible missing ET /mono jet signatures.
- Any additional jet production can be used as a more sophisticated probe.
- Interesting jet correlations can arrive in multi-jet events at LHC. [a]

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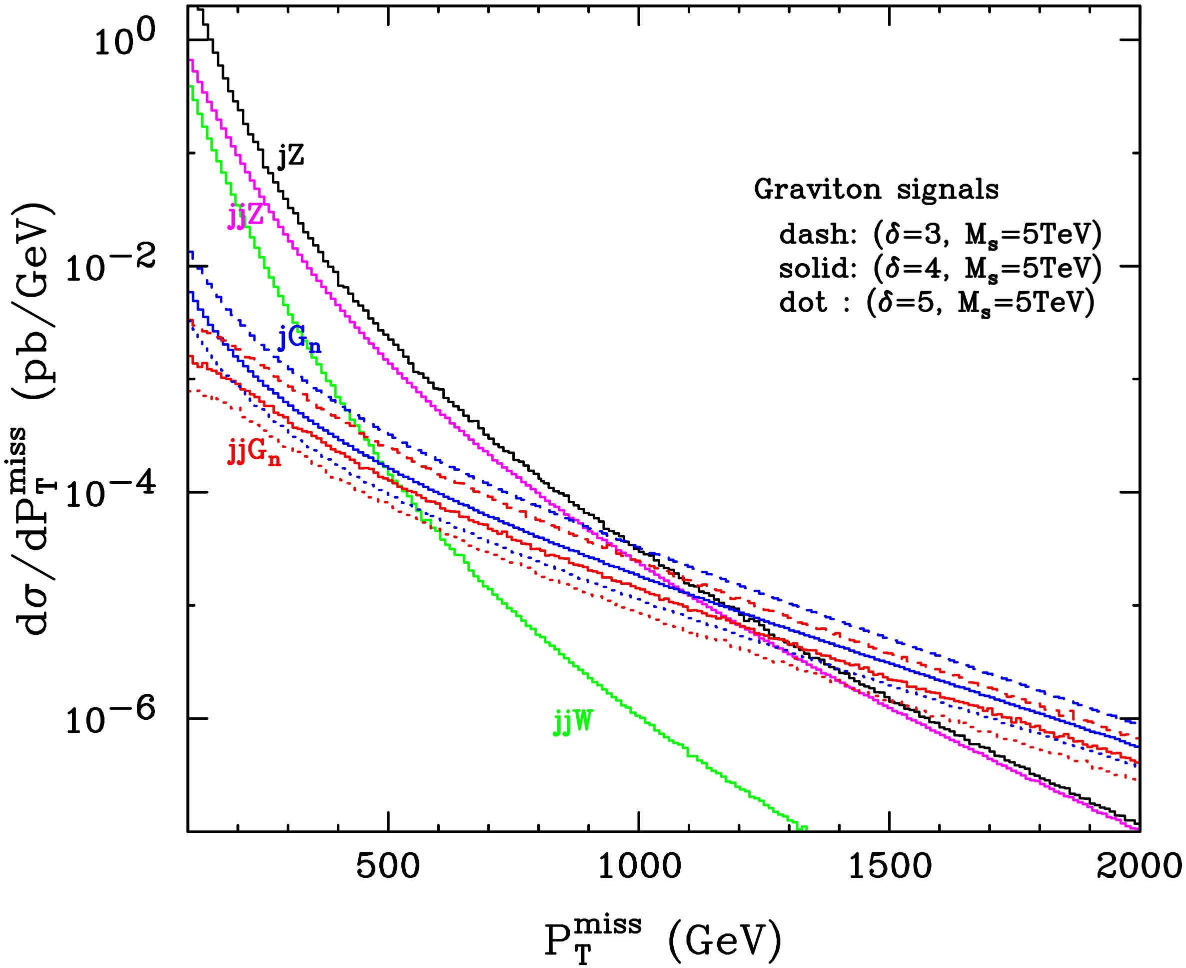
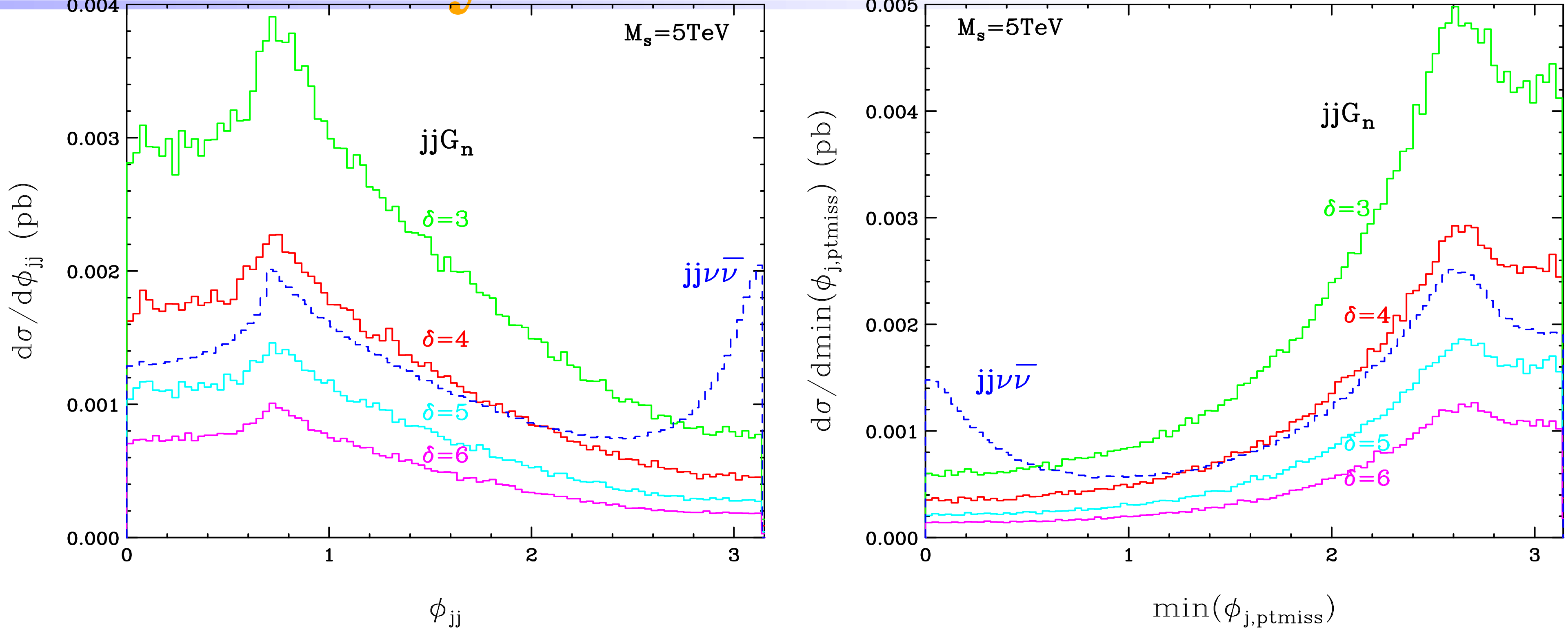
[a] Hagiwara, P.K., Li, Mawatari, Zeppenfeld; JHEP 0804:019

Summary and farther work



⊙ P_T^{miss} dependence of the total cross sections for the 1-jet and 2-jet LED signals and background

Summary and farther work



ϕ_{jj} and $min(\phi_{j,ptmiss})$ distributions for 2-jet LED signal and background

- Zjj background shows a enhancement for back to back jets.
- Reflects collinear Z emission along one of the jets.

Summary and farther work

- It is essential to quantify the capability to differentiate two sets of new physics models that can lead to visible missing ET /mono jet signatures.
- Any additional jet production can be used as a more sophisticated probe.
- Interesting jet correlations can arrive in multi-jet events.
- They can be instrumental to differentiate different models.
- We try to compare dijet supersymmetric production at LHC along with graviton production with dijet.

Summary and farther work

Thank You