Search for Contact Interactions using Inclusive Jet Production Cross Sections @ 13 TeV

Suman Beri [1], Suneel Dutt, Bipen Kotwal [2], and Harrison B. Prosper [3]

[1]Panjab University, [2]Shoolini University

[3]Florida State University

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Outline

1 Introduction

2 Strategy

3 Preliminary Results

4 Near Term Plans

Search for Contact Interactions

Look for deviations in the high-p_{T} tail of the inclusive jet p_{T} spectrum at 13 TeV from the predictions of QCD and interpret deviations as potential evidence of new QCD-like interactions that cannot be resolved at LHC energies.

Assumptions

1. At LHC energies, the Lagrangian L can be written as

$$L = L^{(0)}_{SM} + \frac{1}{\Lambda} L^{(1)} + \frac{1}{\Lambda^2} L^{(2)} + \cdots ,$$

2. with $L^{(2)}$ a sum $2\pi \sum_{i=1}^{6} \kappa_i O_i$ over dim-6 operators $O_{1,2} \sim \bar{\psi}_L \gamma_\mu \psi_L \, \bar{\psi}_L \gamma^\mu \psi_L$, $O_{3,4} \sim \bar{\psi}_L \gamma_\mu \psi_L \, \bar{\psi}_R \gamma^\mu \psi_R$. $O_{5,6} \sim \bar{\psi}_R \gamma_\mu \psi_R \, \bar{\psi}_R \gamma^\mu \psi_R$ that describe contact interactions (CI). κ_i are additional free parameters[1].

[1] J. Gao, Comput.Phys.Commun. 184 (2013) 2362.

Outline

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3 Preliminary Results

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Strategy

1. Given observed jet counts, N_i in M p_{T} bins, construct a multinomial likelihood

$$p(D \mid \lambda, \kappa, \nu) = \prod_{i=1}^{M} \left(\frac{\sigma_i}{\sigma}\right)^{N_i},$$

where $\lambda \equiv 1/\Lambda^2$, σ_i is the predicted cross section in the i^{th} bin, $\sigma = \sum_{i=1}^{M} \sigma_i$, and ν denotes the nuisance parameters.

2. Given a prior density $\pi(\lambda, \kappa, \nu) = \pi(\nu \mid \lambda, \kappa)\pi(\lambda|\kappa)\pi(\kappa)$, compute the marginal likelihood

$$p(D \mid \lambda, \kappa) = \int p(D \mid \lambda, \kappa, \nu)\pi(\nu \mid \lambda, \kappa)\, d\nu,$$

and then the posterior density $p(\lambda|D) \sim p(D \mid \lambda, \kappa)\pi(\lambda|\kappa)$ from which we estimate λ or set limits.

Cross Section The cross section per p_{T} bin can be written as

$$\begin{aligned}\sigma &= \sigma_{QCD} \\ &+ \lambda \sum_{i=1}^{6} \kappa_i (b_i + a_i g + a_i f) \\ &+ \lambda^2 \sum_{i=1}^{6} \kappa_i^2 (b_i + a_i g + a_i f) \\ &+ \lambda^2 \sum_{i=1,3,5} \kappa_i \kappa_{i+1} (b_{ii+1} + a_{ii+1} g + a_{ii+1} f) \\ &+ \lambda^2 \sum_{i=1,2,5,6} \kappa_i \kappa_4 (b_{i4} + a_{i4} g + a_{i4} f),\end{aligned}$$

where $f = \ln(\sqrt{k/\lambda})$ and the 57 coefficients are independent of λ.

Any inference based on the high-p_{T} tail ($> 700\,\mathrm{TeV}$) of the inclusive jet spectrum is sensitive to uncertainties in the predictions. In principle, we need to take into account the uncertainties in

1. the parton-level cross sections,
2. the parton density functions (PDF),
3. the jet energy scale (JES),
4. the jet energy resolution (JER),
5. the non-perturbative corrections (NP), and
6. the electroweak corrections (EWK).

In practice, we account for uncertainties in 1 and 2, which are considered together, and 3 and 4.

The main task is modeling the prior $\pi(\nu \mid \lambda, \kappa)$:

1. Use `hessian2replicas` in `LHAPDF6.1.6` to generate an ensemble of PDF sets.
2. For each PDF set, and 7 combinations of renormalization and factorization scales, use `fastNLO` to compute the QCD cross section and `CIJET1.1` to compute the 57 coefficients. Do this for each of the M p_T bins.
3. Randomly select a consistent set of CI coefficients and QCD cross sections and randomly select a jet response function JRF. Convolve the 58 differential distributions with the (JRF).
4. Repeat 1 and 2 a few hundred times.

This above procedure yields a point set representation of the prior in terms of the QCD cross sections and CI coefficients.

Outline

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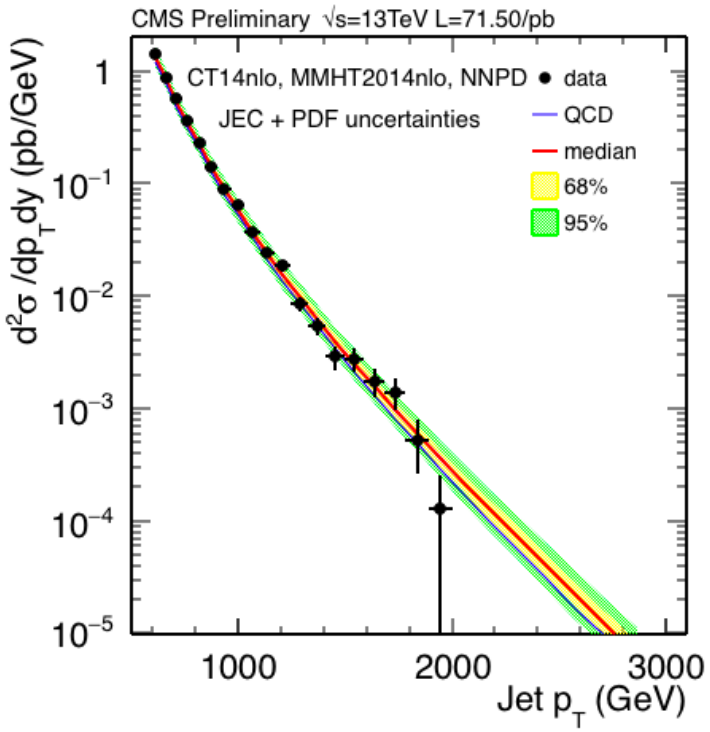
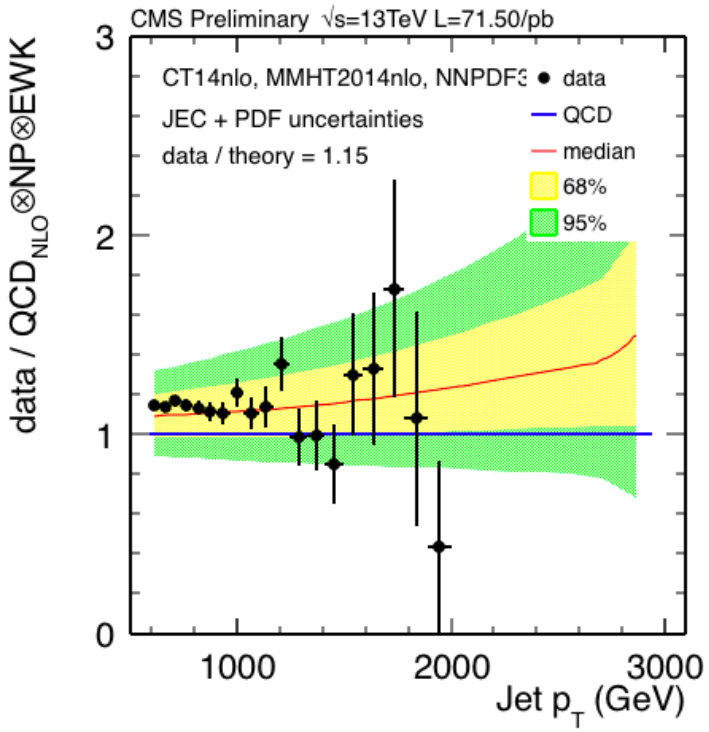
Below is the inclusive jet spectrum at 13 TeV (using $\mathcal{L} = 71.5\,\mathrm{pb}^{-1}$ of integrated luminosity)[2]:

PDF + JES + JER (Summer15 V5) uncertainties

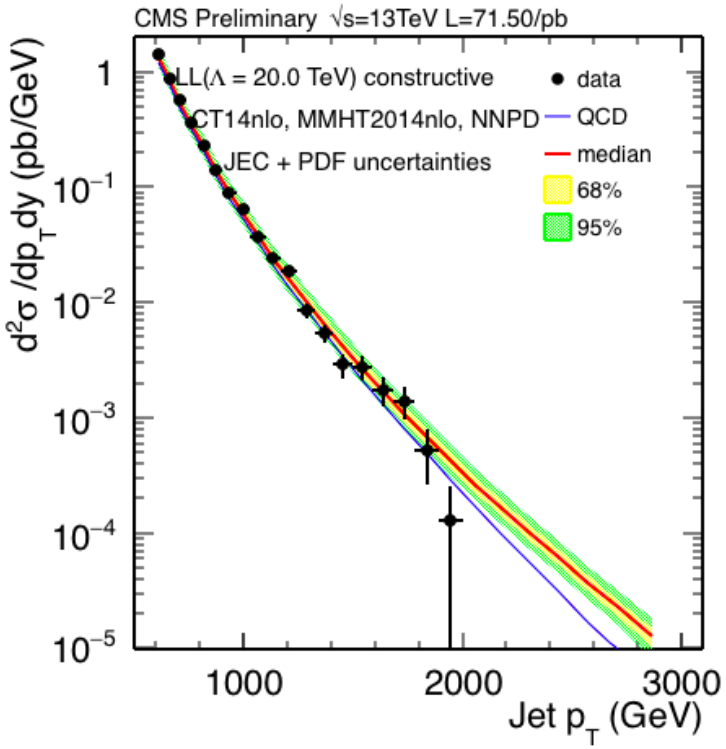


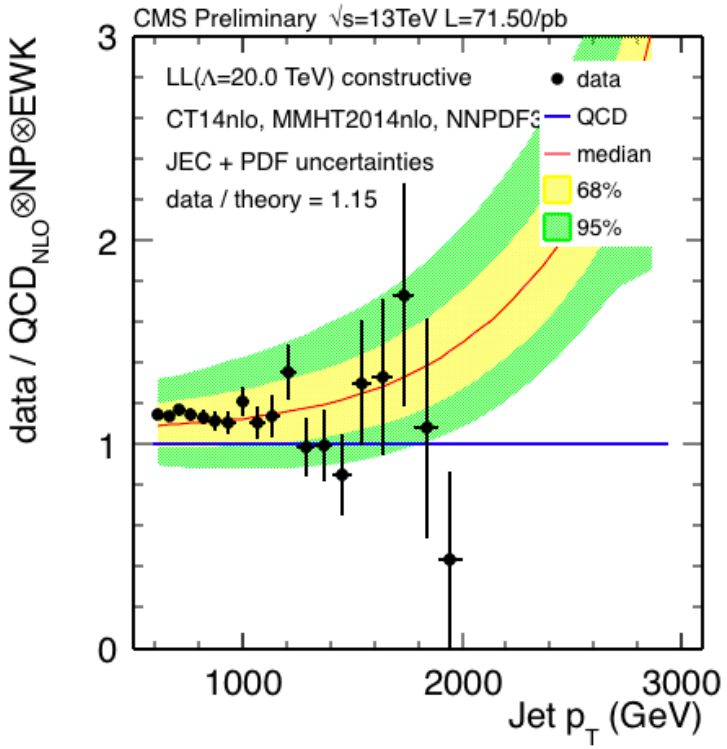


[2]Many thanks to members of the Inclusive Jet p_{T} Group, especially Paolo Gunnellini.

Data vs. LL Model (Λ = 20TeV)

PDF + JES + JER (Summer15 V5) uncertainties





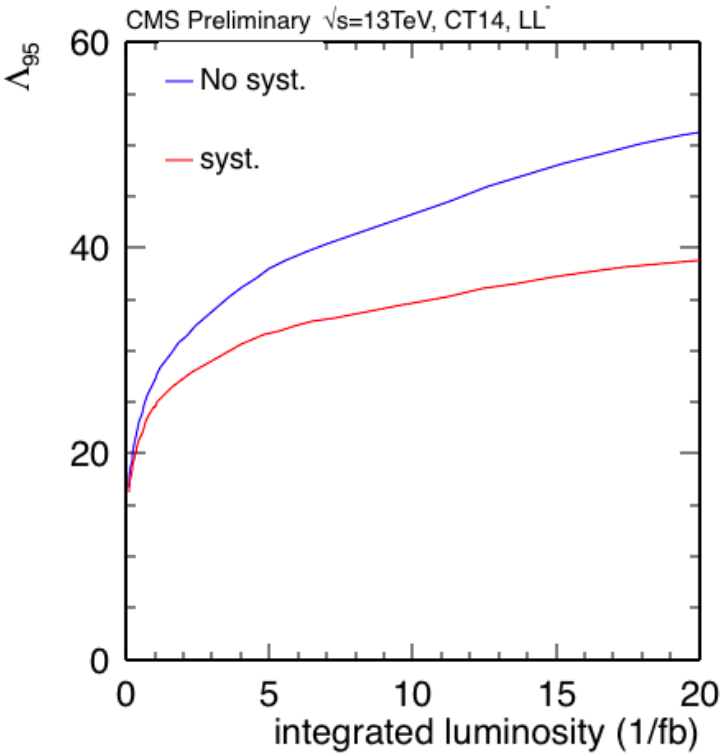
Constructive

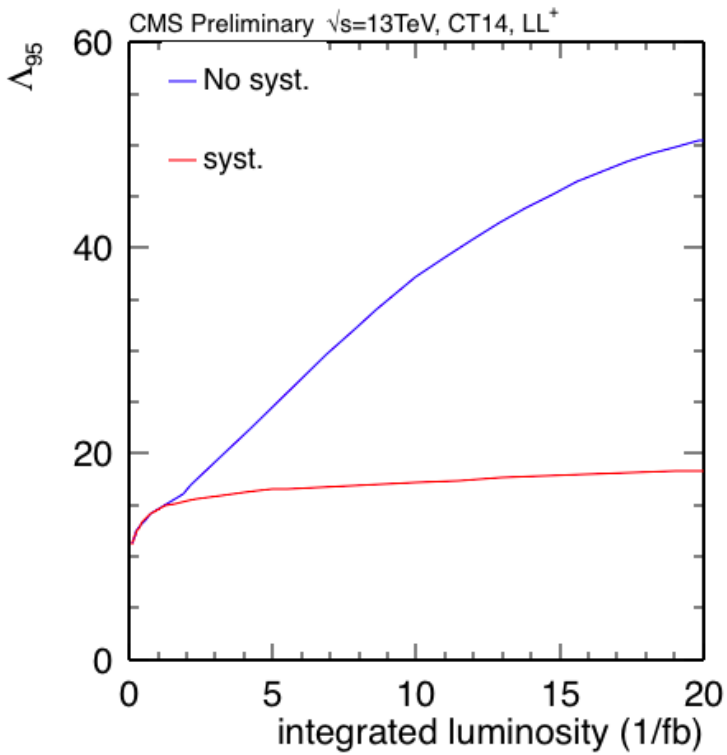
Limits @ 95% CL

Model	Observed (TeV) $L = 0.072$ fb^{-1} AN-16-338	Expected (TeV) $L = 0.072$ fb^{-1} AN-16-338	Expected (TeV) $L = 2.6$ fb^{-1} AN-15-245*
Λ^{+}(LL/RR)	10.5	9.9	12.1
Λ^{-}(LL/RR)	15.1	13.7	17.3
Λ^{+}(VV)	12.0	11.5	13.9
Λ^{-}(VV)	19.5	17.5	22.2
Λ^{+}(AA)	12.1	11.5	13.9
Λ^{-}(AA)	19.3	17.5	22.1
Λ^{+}(V-A)	8.7	8.0	9.5
Λ^{-}(V-A)	8.7	8.0	9.5

*Search for quark contact interactions and extra spatial dimensions in the dijet angular distributions at 13 TeV, AN-15-245, L. Apanasevich *et al*.

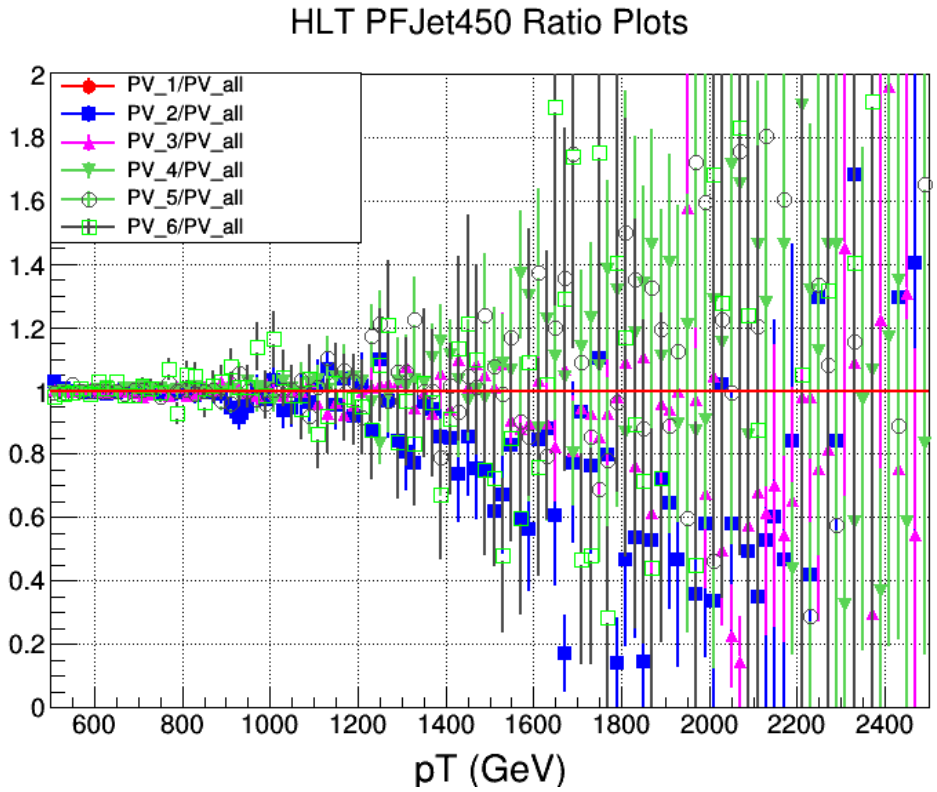
These plots suggest that we can use up to ~ 20/fb for





constructive interference models and up to ~ 2/fb for destructive interference models with 2014 PDFs.

Pileup Studies The plot, based on $2.6\,\mathrm{fb}^{-1}$, show ratios of the AK7 jet p_{T} spectra in different vertex multiplicity bins for jets with $|y| < 0.5, p_{\mathrm{T}} > 600\,\mathrm{GeV}$. The data are collected with the Jet450 trigger. The binning is uniform.



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Near Term Plans ($\sim$ 2 weeks)

- Compute preliminary *expected* limits for models defined by different combinations of κ. Use the existing QCD cross sections computed with `fastnlo_toolkit-2.3.1pre-1871` and `InclusiveNjets_fnl5332g_v23_fix.tab`, and the CI coefficients computed with `CIJet-1.1`. For now, do this only for `CT14nlo`.
- Update our smearing code to use the current JES and JER functions and NP and EWK corrections.
- To proceed, we need:
  - observed jet counts for all bins above $\sim 600\,\mathrm{GeV}$;
  - non-perturbative correction histogram;
  - electroweak correction histogram, and
  - detailed description of current JES and JER functions.