Search for Contact Interactions Using Inclusive Jet p_T Spectrum
Plans for 13 TeV

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Exotica Jets+X Working Group Meeting

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Outline

1. Overview
2. Proposed Analysis
3. Status
4. Near Future

Overview

Goal

- Search for new QCD-like interactions that can be modeled as contact interactions (CI). Look for deviations in the inclusive jet p_T spectrum at high p_T.
- Aim for preliminary results by end of June 2016 using existing inclusive jet cross section measurement.
- Publishable result by the end of calendar year 2016.
- Thereafter, update result periodically.

Manpower

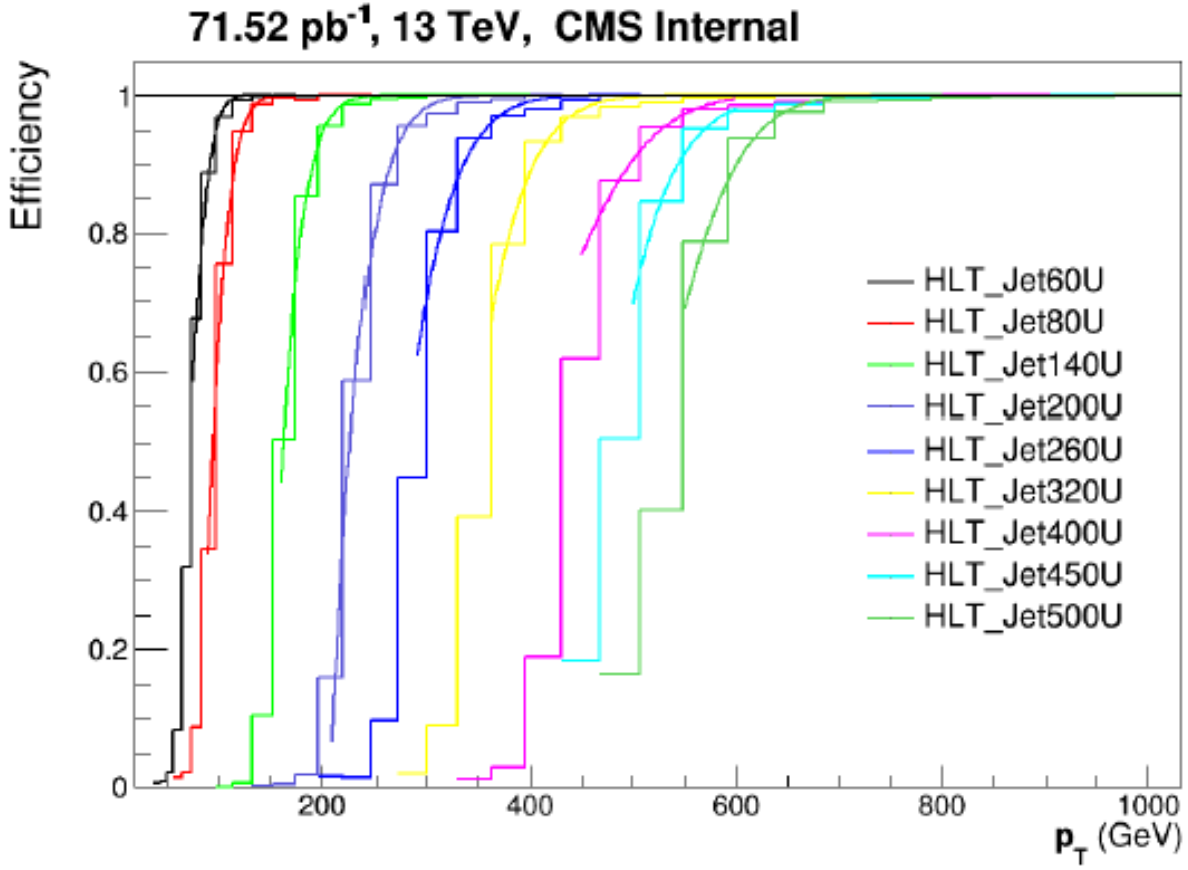
- Bipen Kotwal (Ph.D. student), co-supervisors S. Beri (Panjab U.) , S. Dutt (Shoolini U.)
- H.B. Prosper (FSU)

Overview

Experimental Input

- Inclusive jet p_T spectrum in $|y| < 0.5$, $638 \leq p_T \leq 3000$ GeV. Use a single high p_T jet trigger and work on trigger plateau
- Jet response function (JRF)
- Jet energy scale (JES) uncertainty
- Jet energy resolution (JER) uncertainty

Overview: Triggers



Requirement of ak7chs jet in $|\eta| < 4.7$

Trigger	Turnon
HLT60	105
HLT80	132
HLT140	220.6
HLT200	315.7
HLT260	399.8
HLT320	505.6
HLT400	602.1
HLT450	632.5

SMP-15-007

Overview

Theoretical Input

- PDFs (LHAPDF-6.1.6)

  CT14nlo, MMHT2014nlo68cl, NNPDF30_nlo

- Program to calculate QCD@NLO

  fastnlo_toolkit-2.3.1pre-2163
  InclusiveNJets_fnl5332g_v23_fix.tab

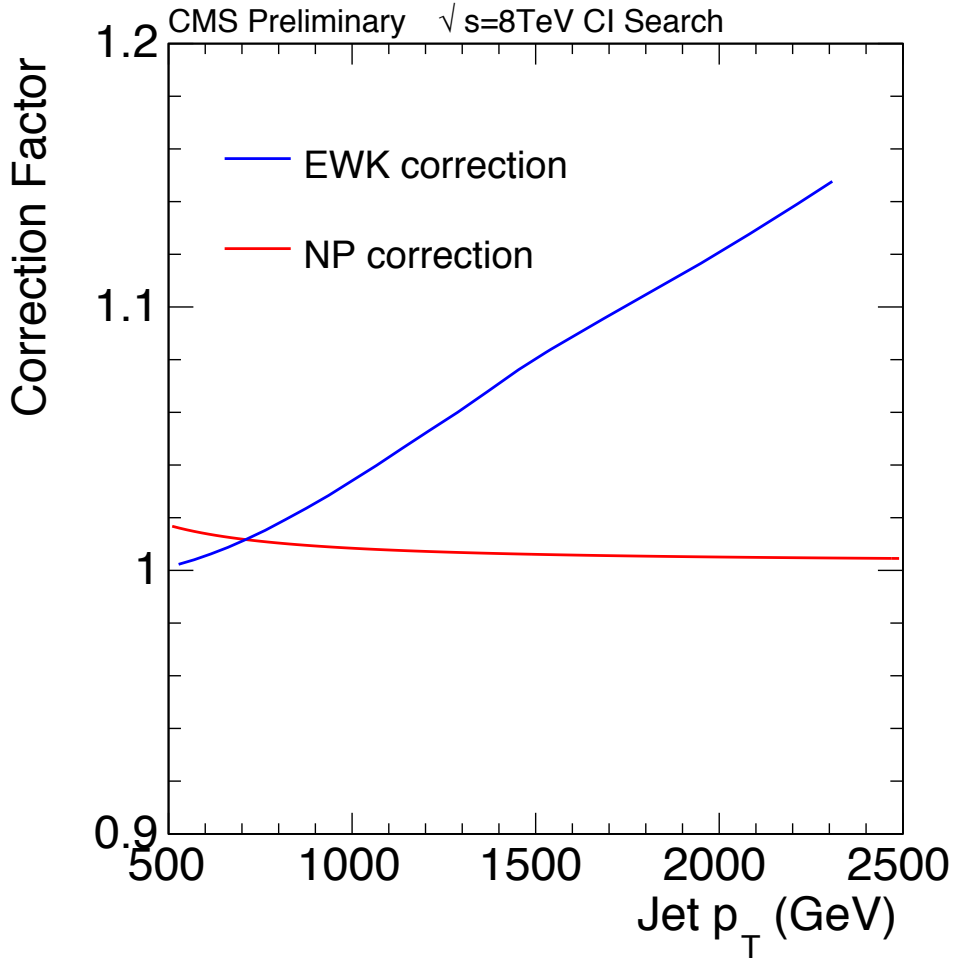
- Program to calculate CI@NLO

  CIJET-1.1

- Non-perturbative corrections

- Electroweak corrections

Overview: NP & EWK Corrections



From inclusive jet group

Overview: Models

At NLO accuracy, new QCD-like interactions can be described using an effective Lagrangian of the form

$$L = L_{QCD} + \frac{2\pi}{\Lambda^2} \sum_{i=1}^{6} \kappa_i O_i$$

where Λ is a mass scale, κ_i are additional free parameters, and each O_i is a sum over dim-6 operators:

$$O_{1,2} \sim \bar{u}_L \gamma_\mu u_L \; \bar{u}_L \gamma^\mu u_L$$
$$O_{3,4} \sim \bar{u}_L \gamma_\mu u_L \; \bar{u}_R \gamma^\mu u_R$$
$$O_{5,6} \sim \bar{u}_R \gamma_\mu u_R \; \bar{u}_R \gamma^\mu u_R$$

Overview: Models

In principle, the parameters $\kappa_1 \ldots \kappa_6$ are free to assume any values. However, we plan to consider only the following discrete set of values:

Model	η_{LL}	η_{RL}	η_{RR}
LL	± 1	0	0
RR	0	0	± 1
VV	± 1	± 1	± 1
AA	± 1	∓ 1	± 1
V-A	0	± 1	0

where $\kappa_1 = \eta_{LL}$, $\kappa_3 = 2\eta_{RL}$, $\kappa_5 = \eta_{RR}$, and $\kappa_2 = \kappa_4 = \kappa_6 = 0$.

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Proposed Analysis

- For the results of the proposed analysis to be reliable, it is critical that the uncertainties be correctly accounted for, including the correlations across bins, and across models.

- We therefore propose to *integrate* over the jet energy scale (JES), jet energy resolution (JER), and parton density function (PDF) parameters by *sampling* over these quantities.

- Furthermore, we plan to *sum* over three different PDF sets in order to account for the uncertainty arising from the different estimates of the PDFs by different PDF groups.

Proposed Analysis

Analysis Steps

1. For each PDF, we shall generate 500 *randomly* sampled PDF sets using the tool hessian2replicas in LHAPDF6.1.6, except for NNPDF30_nlo for which the sample already exists.

2. For each of the randomly sampled PDF sets and 7 combinations of the renormalization and factorization scales, we shall compute the QCD inclusive jet p_{T} spectrum. This will yield 3500 spectra.

3. Do the same for the 57 differential coefficients needed to compute the CI spectra for *arbitrary* values of κ and Λ.

Analysis Overview

Analysis Steps

4. Convolve each differential spectrum, $f(p_T) = d^2F/dp_T d|y|$ (either QCD or the 57 CI coefficients),

$$f_{obs}(p_T) = \int_0^\infty R(p_T\ |,z)\ f(z)\ dz$$

with the jet response function R, while accounting for the uncertainty in the jet energy scale and jet energy resolution, taking care to maintain the correlations across all bins and all spectra.

Analysis Overview

Analysis Steps

5. Compute the likelihood

$$p(D \mid \Lambda,\kappa) = \int \text{multinomial}(D \mid \Lambda,\kappa,\nu)\,\pi(\nu)\,d\nu$$

$$\simeq \frac{1}{K}\sum_{i=1}^{K} \text{multinomial}(D \mid \Lambda,\kappa,\nu_i)$$

where D denotes the counts per bin, ν denotes the JES, JER, and PDF nuisance parameters and, in the absence of evidence of a significant deviation from QCD, set limits on Λ for different choices of κ.

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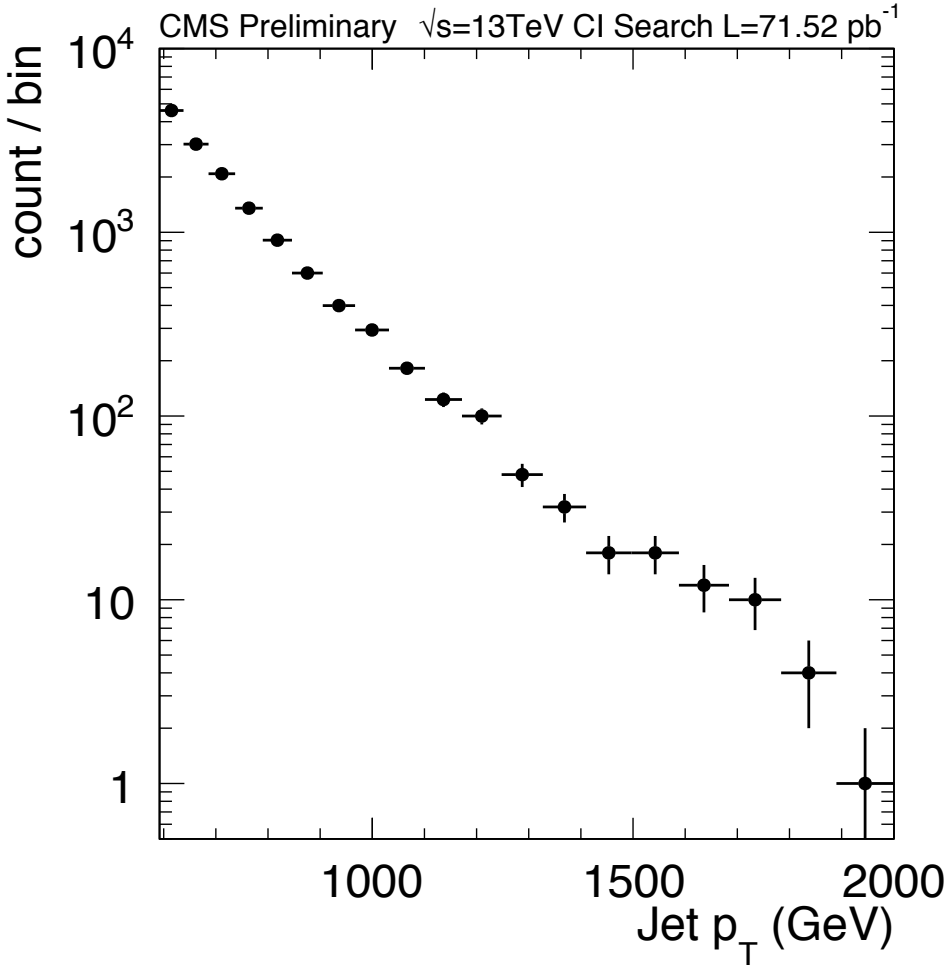
Status

1. Machinery for computing and smearing spectra thoroughly exercised at 8 TeV. The 13 TeV version requires minor updates.

2. Corrections: Non-perturbative corrections obtained from inclusive jet cross section group (Paolo Gunnelli). 13 TeV electroweak corrections not yet available.

3. Data: Have in hand details of first measurement of inclusive jet spectrum from inclusive jet cross section group. Bipen will work with that group on subsequent cross section measurements.

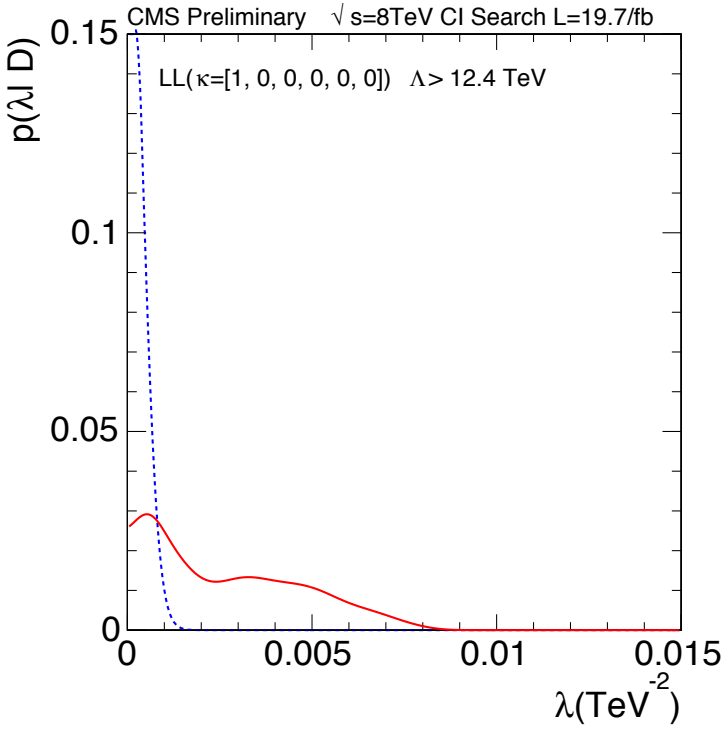
Data: 71.52 pb^{-1}

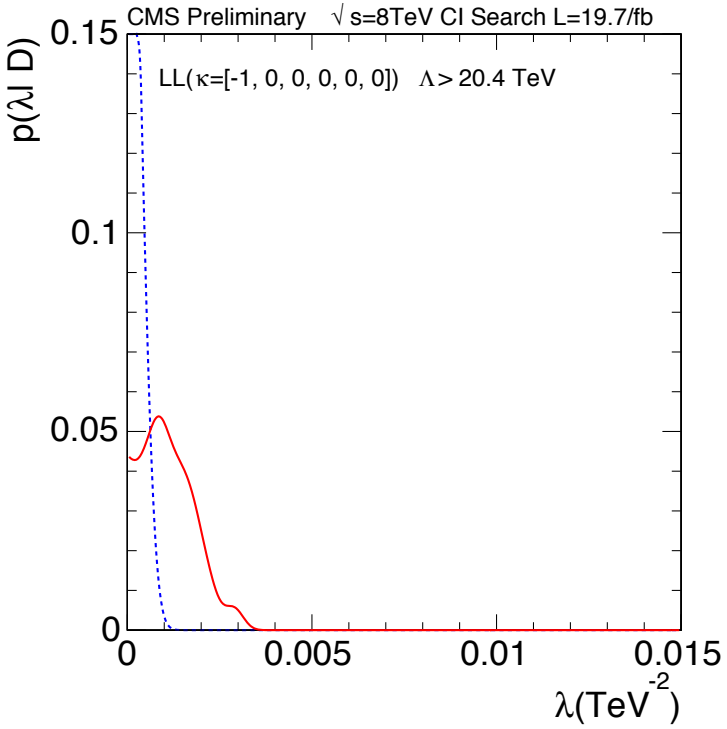


Status: Lessons Learned from 8 TeV

1. Large range in counts (~700,000 at 500 GeV to 6 at 2000 GeV for 8 TeV data) induces huge dynamic range in likelihood function.
2. This makes integrating over JES, JER, and PDF parameters difficult (see next two slides).
3. Therefore, need to sample over larger and larger numbers of spectra to check for convergence of Monte Carlo integration.
4. Should explore whether the use of smaller bins (at lower p_T), in order to limit count per bin, yield likelihoods with a more manageable dynamic range.
5. PDF uncertainties now dominate over JES and JER.

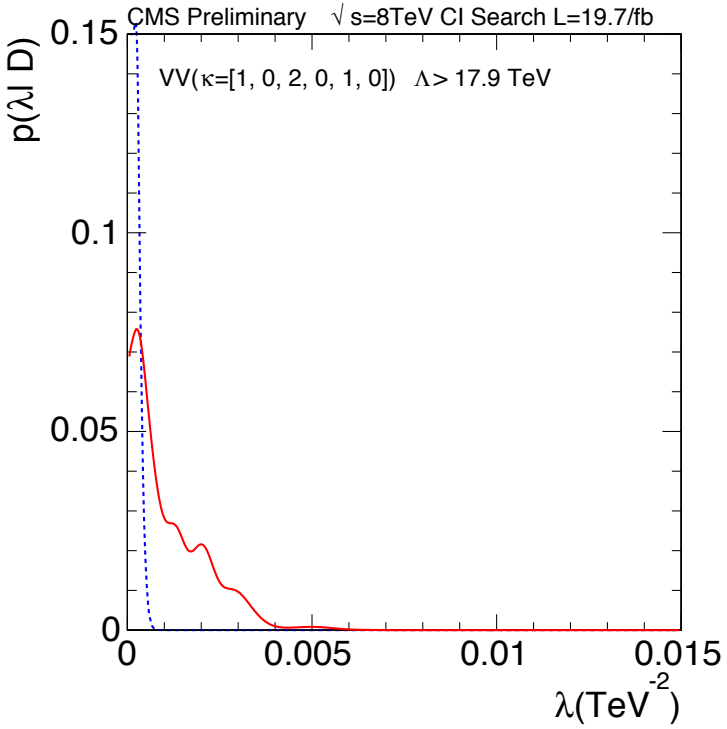
Likelihoods: LL @ 8 TeV

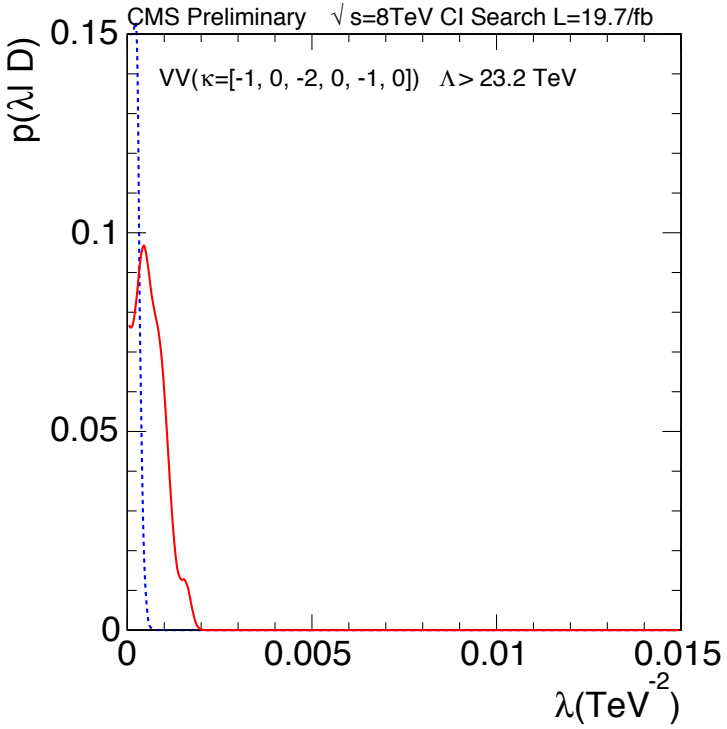




CT10nlo

Likelihoods: VV @ 8 TeV

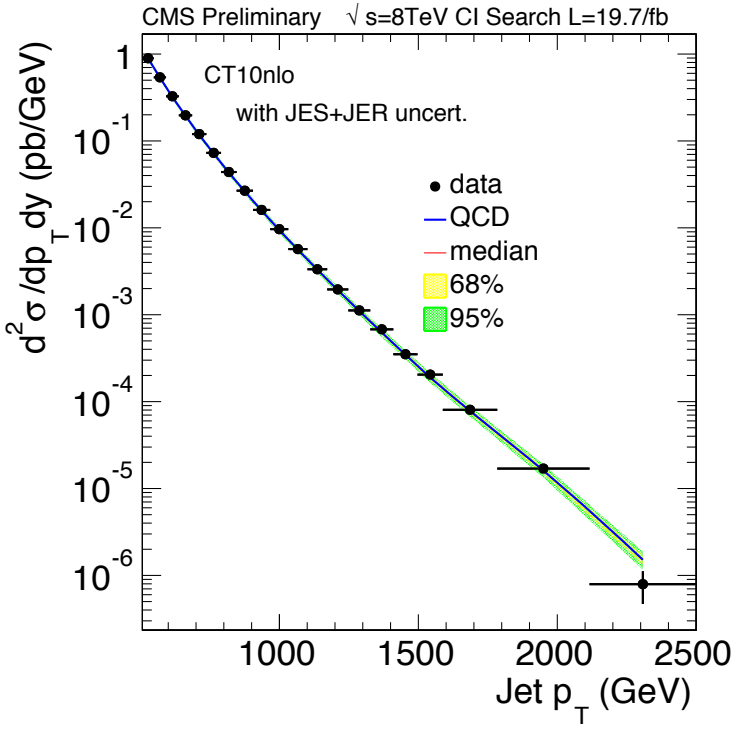


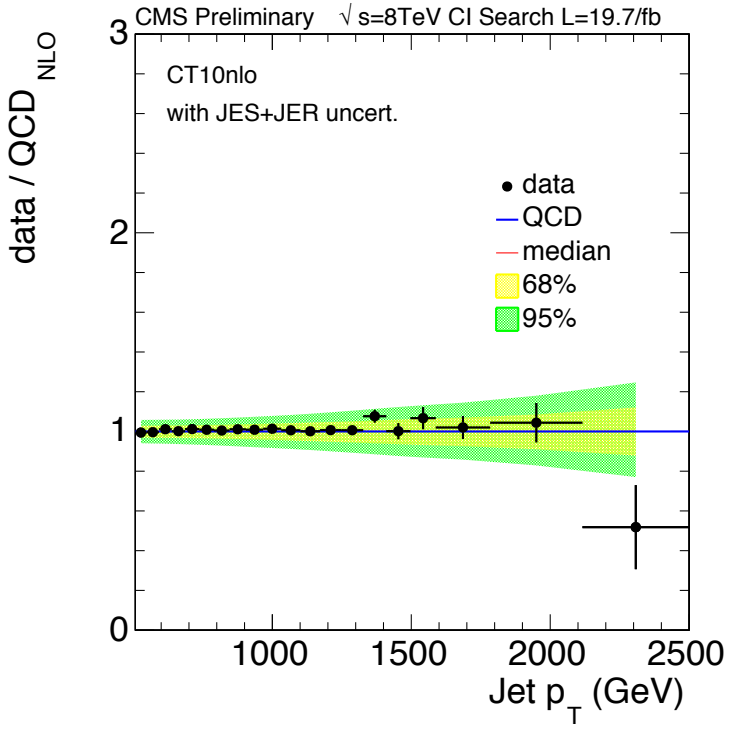


CT10nlo

Data vs. QCD (19.7fb^{-1} @ 8 TeV)

JES + JER (Winter 14 V5) uncertainties

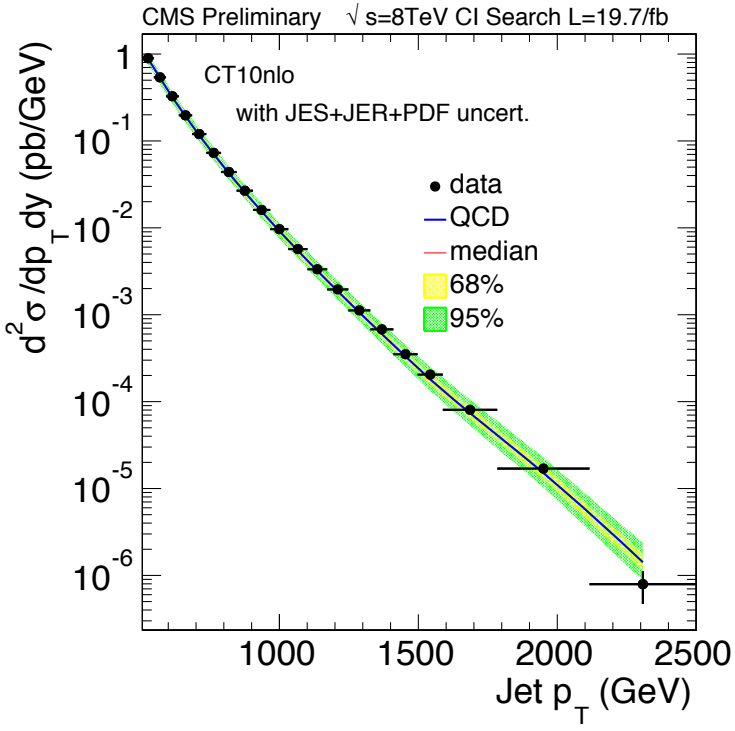


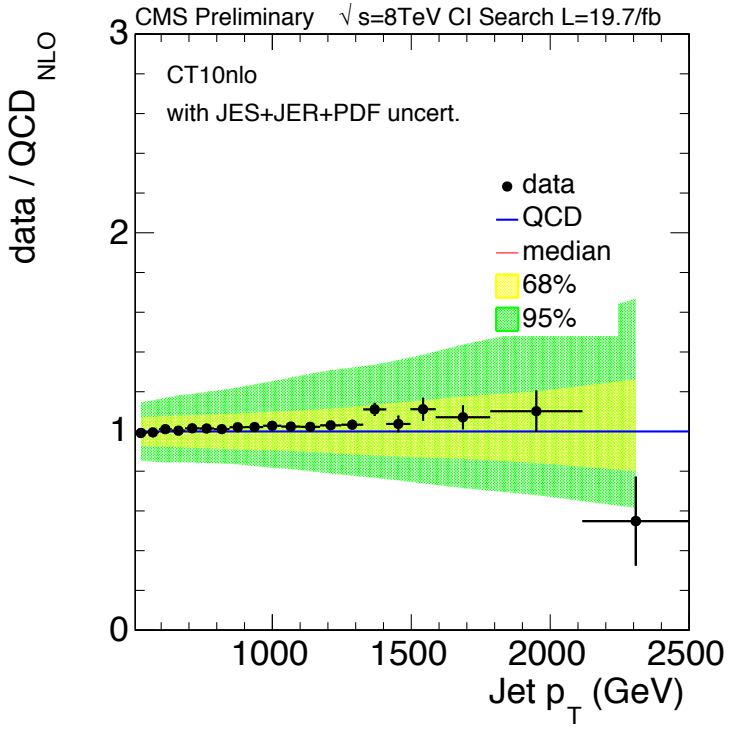


CT10nlo

Data vs. QCD (19.7fb^{-1} @ 8 TeV)

JES + JER (Winter 14 V5) + PDF uncertainties





CT10nlo

Near Future

1. Compute QCD spectra @ 13 TeV.

2. Compute 57 CI coefficient spectra @ 13 TeV.

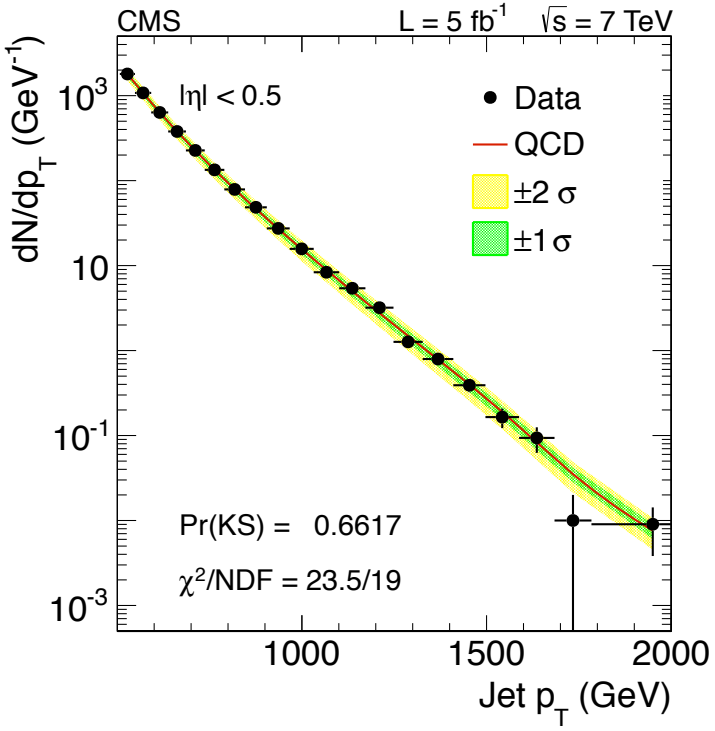
3. Smear spectra.

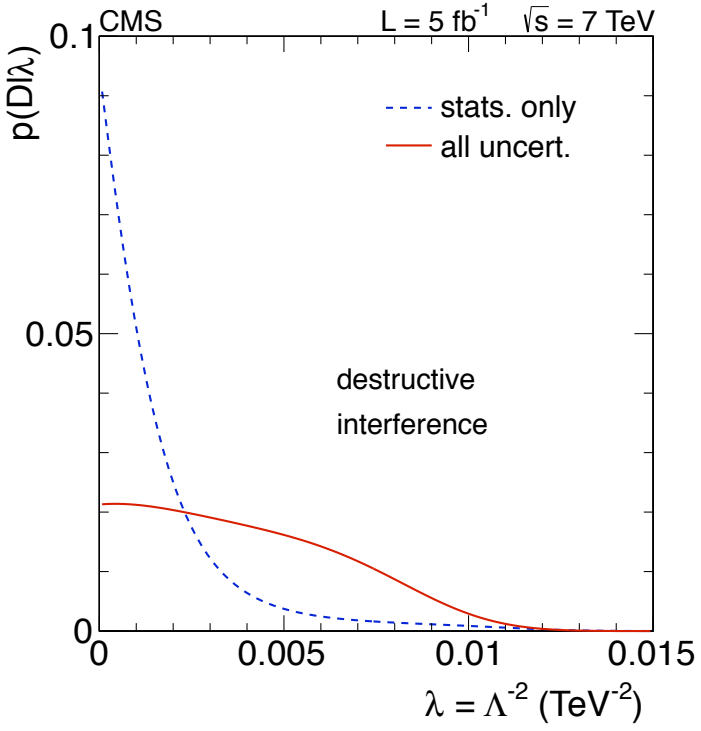
4. Obtain preliminary limits on all models using existing inclusive jet cross section measurements. For now, use electroweak corrections from 8 TeV.

5. Bipen will make regular presentations at this meeting.

BACKUP

Contact Interaction Search @ 7 TeV





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Search for contact interactions using the inclusive jet p_T spectrum in pp collisions at $\sqrt{s} = 7$ TeV

S. Chatrchyan *et al.**
(CMS Collaboration)

(Received 21 January 2013; published 26 March 2013)

Overview: Models

The QCD+CI cross section, at NLO, can be written as

$$\sigma = \sigma_{\text{QCD}} +$$

$$+ \lambda \sum_{i=1}^{6} \kappa_i [b_i + a_i g + a_i f]$$

$$+ \lambda^2 \sum_{i=1}^{6} \kappa_i^2 [b_{ii} + a_{ii} g + a_{ii} f]$$

$$+ \lambda^2 \sum_{i=1,3,5} \kappa_i \kappa_{i+1} [b_{ii+1} + a_{ii+1} g + a_{ii+1} f]$$

$$+ \lambda^2 \sum_{i=1,2,5,6} \kappa_i \kappa_4 [b_{i4} + a_{i4} g + a_{i4} f]$$

where $g = -\ln(\mu_0 \sqrt{k})$
and $\lambda = 1/\Lambda^2$

$f = \ln(\sqrt{(k / \lambda)})$

The CI term comprises 57 coefficients

CI Cross Section Coefficients (8 TeV)

Likelihood Calculation

Our likelihood is

$$p(D \mid \lambda,\kappa) = \int \text{multinomial}(D \mid \lambda,\nu,\kappa)\pi(\nu)d\nu$$

$$\simeq \frac{1}{K}\sum_{i=1}^{K} \text{multinomial}(D \mid \lambda,\nu_i,\kappa)$$

Note: the counts range from

$D_1 = 722{,}864$ in the first bin to

$D_{20} = 6$ in the last bin!

So it is perhaps not surprising that computing the multinomial function $D_{tot}!\prod_{n=1}^{20}\frac{1}{D_n!}\left(\frac{\sigma_n}{\sigma_{tot}}\right)^{D_n}$ is problematic