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

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Exotica Jets+X Working Group Meeting

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Outline

1. Overview
2. Analysis
3. Results
4. Plans for 2016 Data

Overview

Goal

Search for new QCD-like interactions by looking for deviations from QCD in the inclusive jet p_{T} spectrum.

Inclusive: all jets that fall within a given phase space.

Basic Assumption

At LHC energies, the "true" Lagrangian L can be written as

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

in which the $L^{(2)}$ term contains dim-6 operators that describe 4-quark interactions, which can be approximated as contact interactions (CI).

Overview

Experimental Input

- Inclusive jet p_T spectrum in $|y| < 0.5$, $638 \leq p_T \leq 2000$ GeV[1], anti-k_T R = 0.7 jets.

- Jet response function (JRF)
- Jet energy scale (JES) uncertainty:
  Summer15_50nsV5 for AK8PF jets
- Jet energy resolution (JER) uncertainty: 10%

[1]Eur. Phys. J. C**76** (2016) no.8, 451, SMP-15-007

Overview

Theoretical Input

- PDFs (LHAPDF-6.1.6)

  CT14nlo, MMHT2014nlo68cl, NNPDF30_nlo_as_0118_1000

- Program to calculate QCD@NLO

  fastnlo_toolkit-2.3.1pre-1871
  InclusiveNJets_fnl5332g_v23_fix.tab

- Program to calculate CI@NLO

  CIJET-1.1

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

- Non-perturbative corrections (NP)
- Electroweak corrections (EWK)

Overview

Many thanks to the Inclusive Jet Group!

Sourav Dev

Giannis Flouris

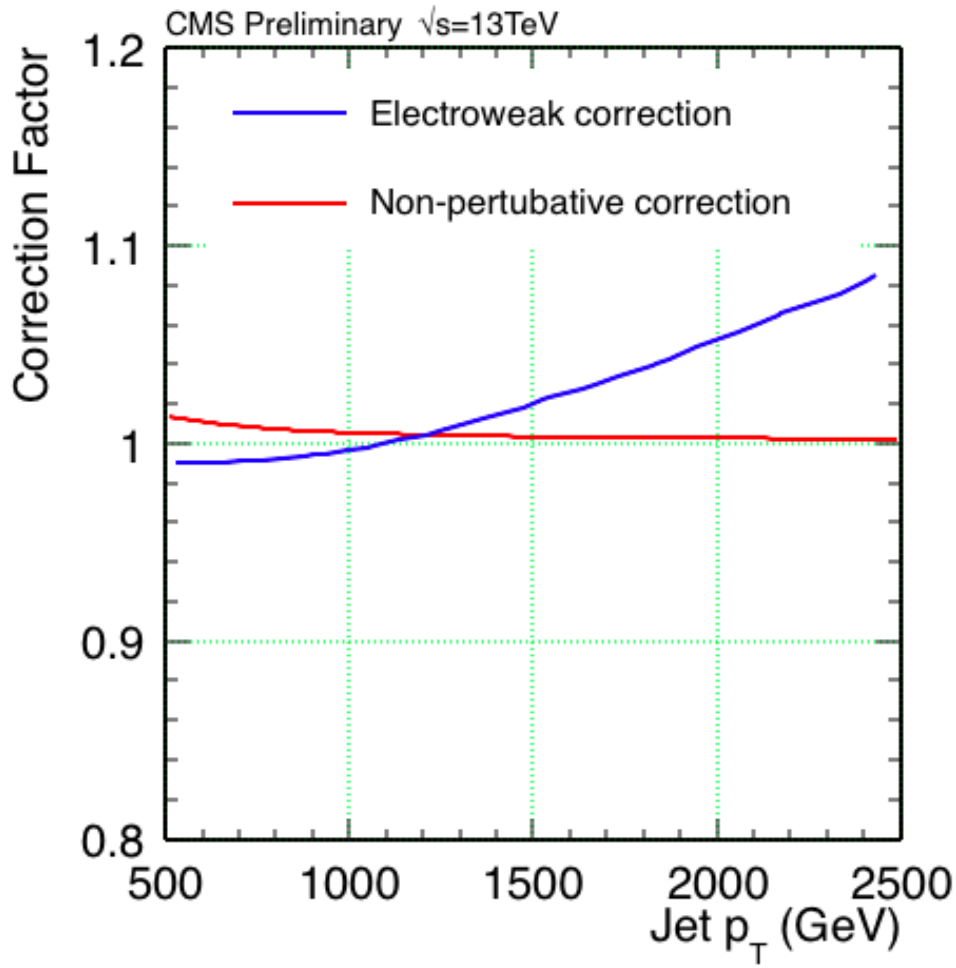
Hannes Jung

Panos Kokkas

Ksenia Shchelina

and especially to Paolo Gunnellini who provided the details of the measured spectrum and the NP and EWK correction functions.

Overview: NP & EWK Corrections



Overview: Models

At NLO accuracy, new 4-quark 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

We consider the following discrete set of values for the κ parameters:

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 $\kappa_2 = \kappa_4 = \kappa_6 = 0$.

Overview: Models

The NLO QCD+CI cross section per jet p_T bin 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

Outline

1. Overview

2. **Analysis**

3. Results

4. Plans

Analysis

Big Picture

1. Integrate multinomial likelihood $p(D|\lambda, \nu)$ over nuisance parameters ν associated with PDFs, renormalization and factorization scales, jet energy scale, and jet energy resolution. ($\lambda = 1/\Lambda^2$ and D denotes the observed counts.)

2. Compute expected limits by setting "observed" counts = expected counts

3. Compute observed limits using observed counts.

See backup for details.

Outline

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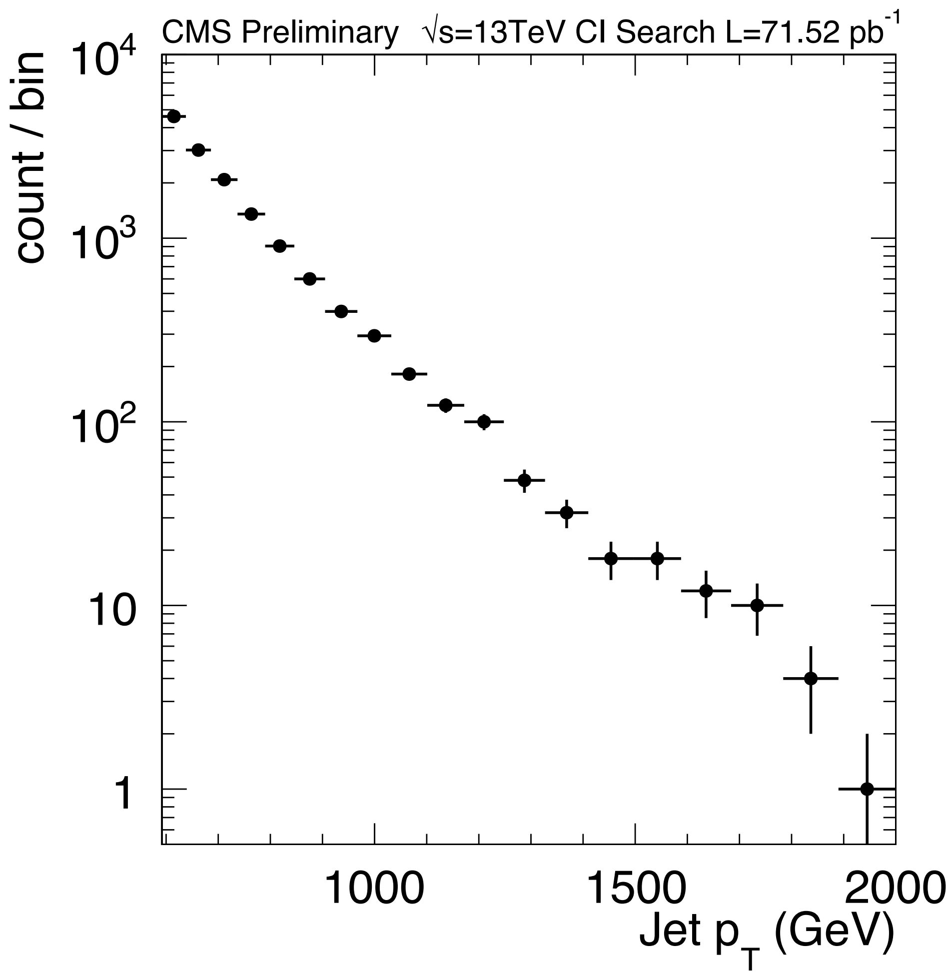
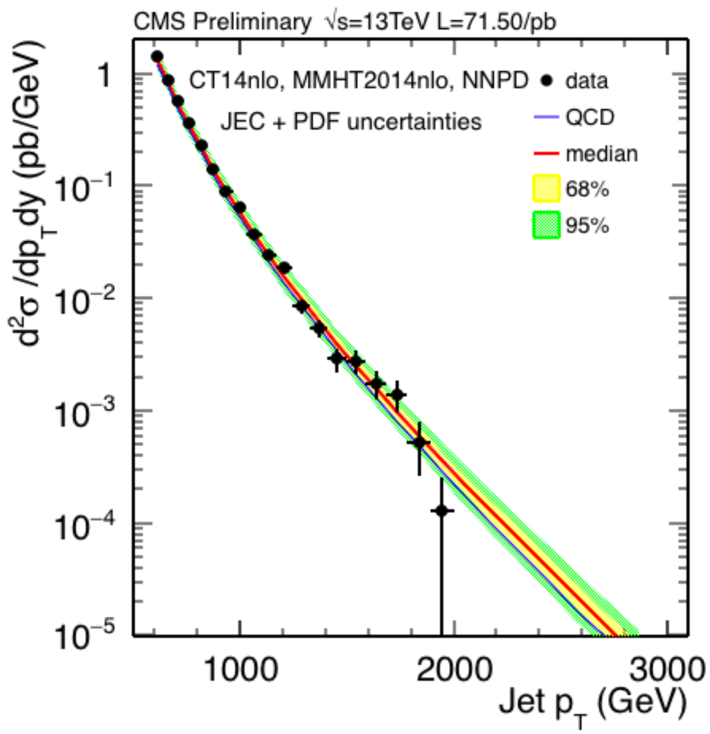
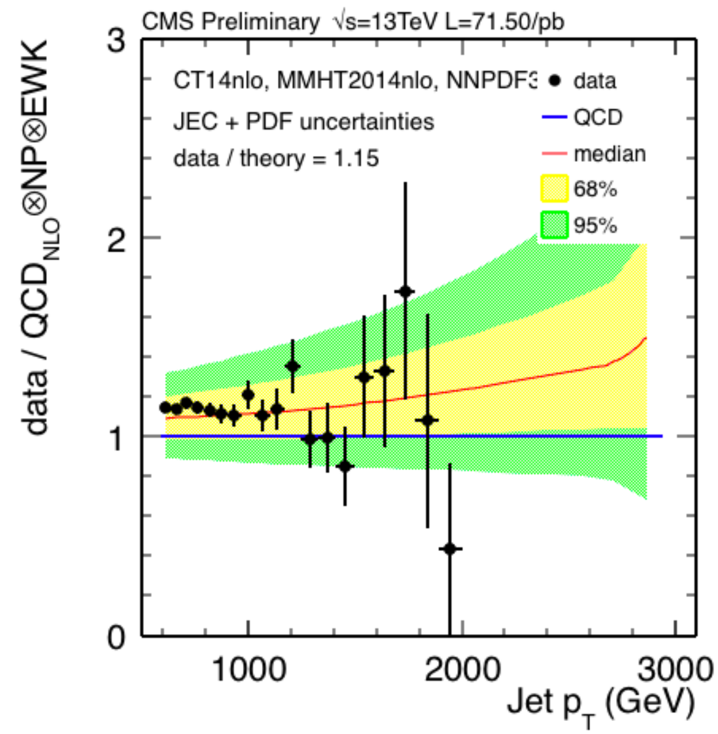
Data: 71.52 pb^{-1} @ 13TeV



Data vs. QCD

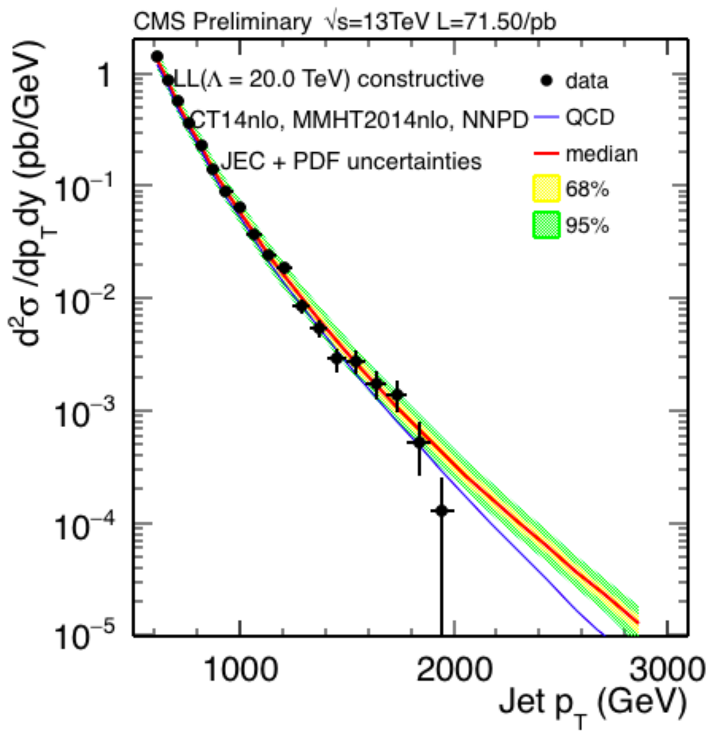
PDF + JES + JER (Summer15 V5) uncertainties

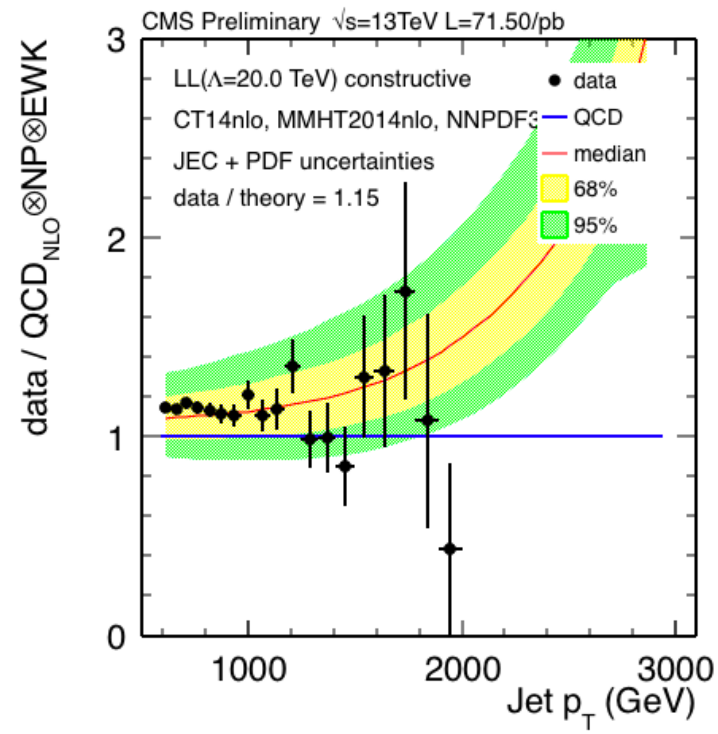




Data vs. LL Model (Λ=20TeV)

PDF + JES + JER (Summer15 V5) uncertainties

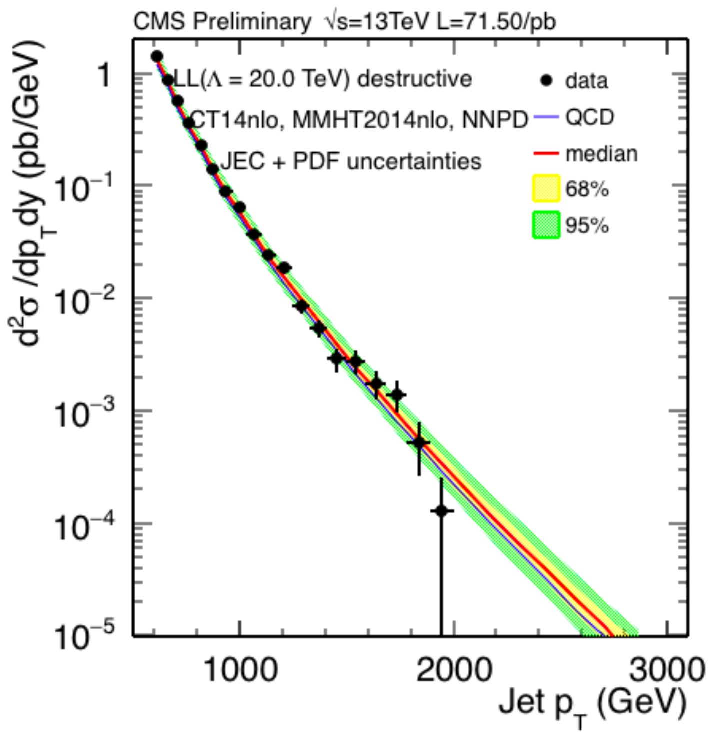


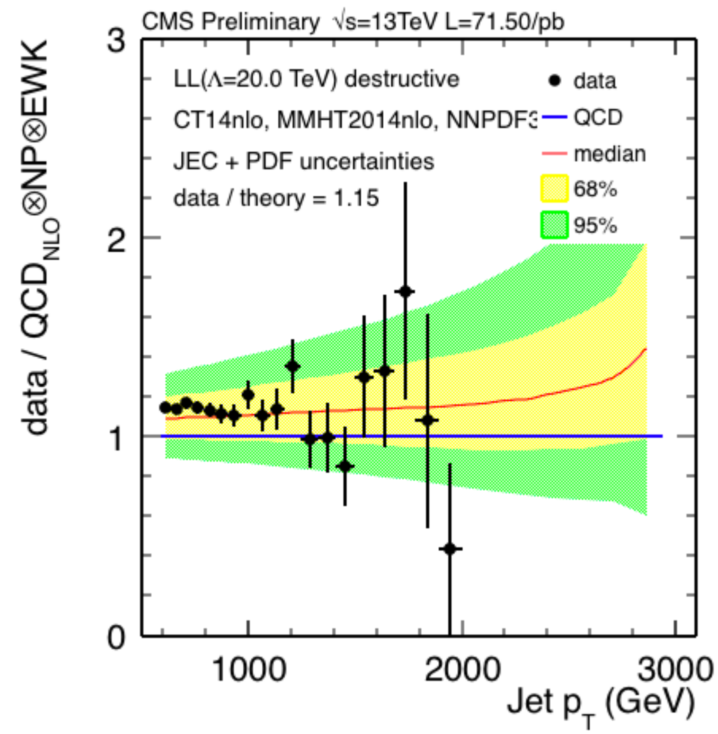


Constructive

Data vs. LL Model (Λ=20TeV)

PDF + JES + JER (Summer15 V5) uncertainties

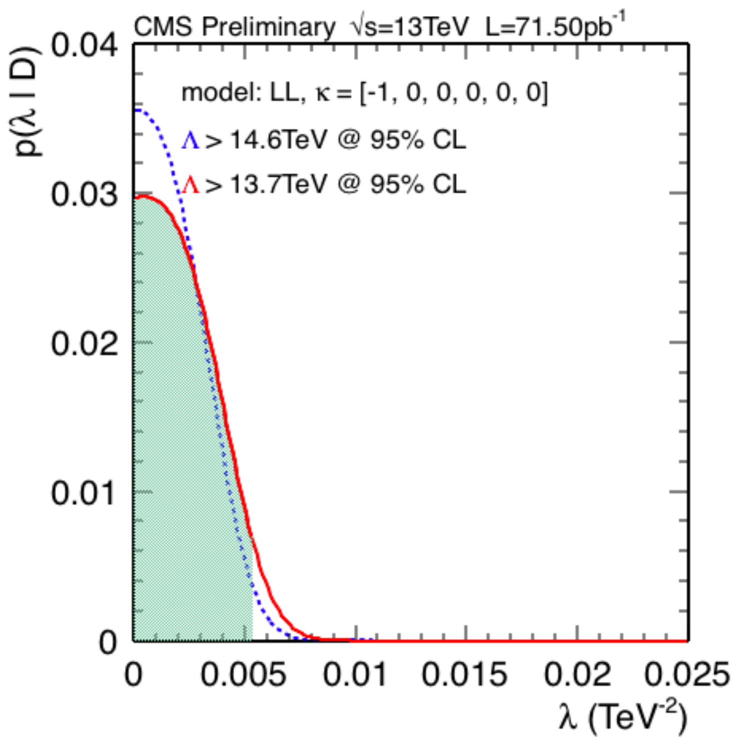


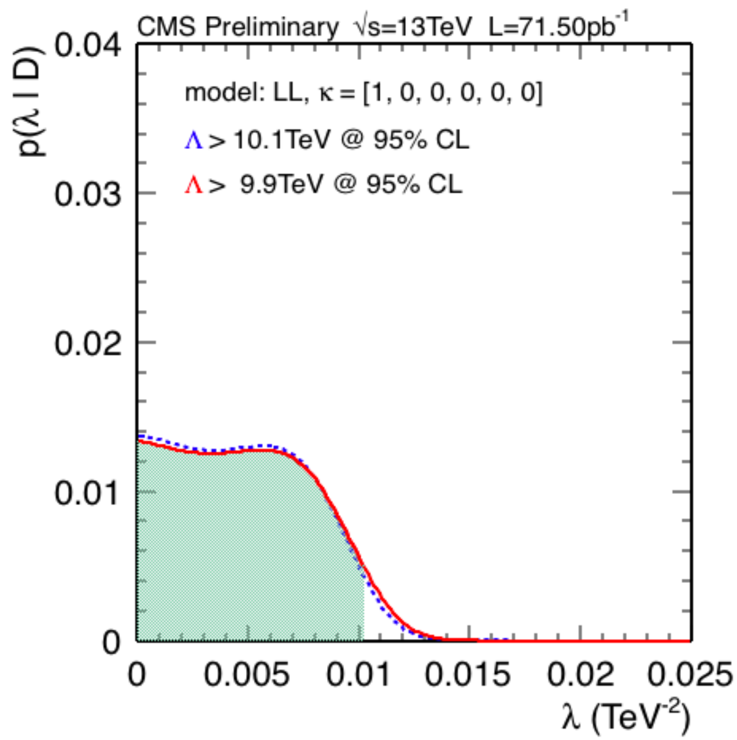


Destructive

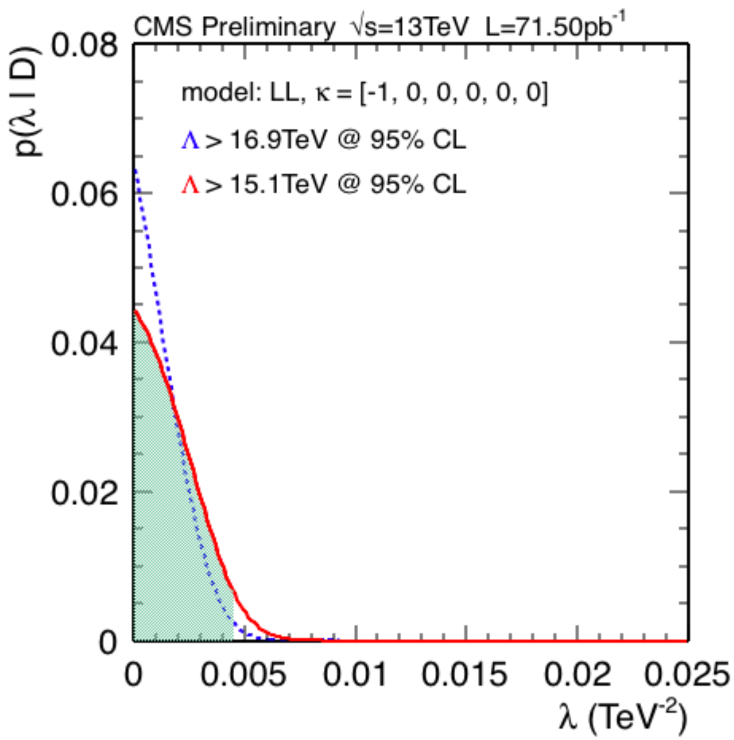
LIMITS

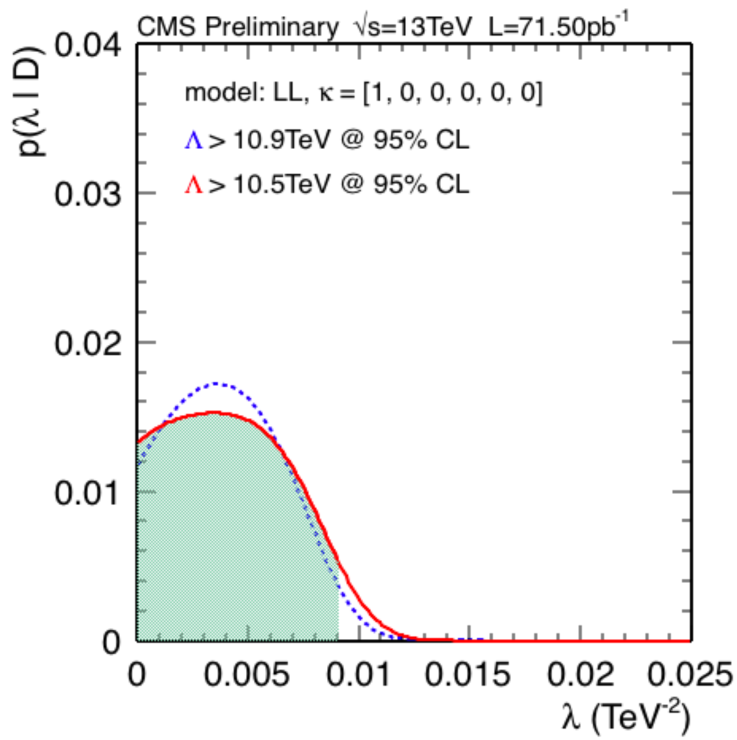
LL Limits @ 95% CL: Expected





LL Limits @ 95% CL: Observed





Limits @ 95% CL

		L = 0.072 fb^{-1} AN-16-338	L = 2.6 fb^{-1} AN-15-245*
Model	**Observed (TeV)**	**Expected (TeV)**	**Expected (TeV)**
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*.

Plans for 2016 Data

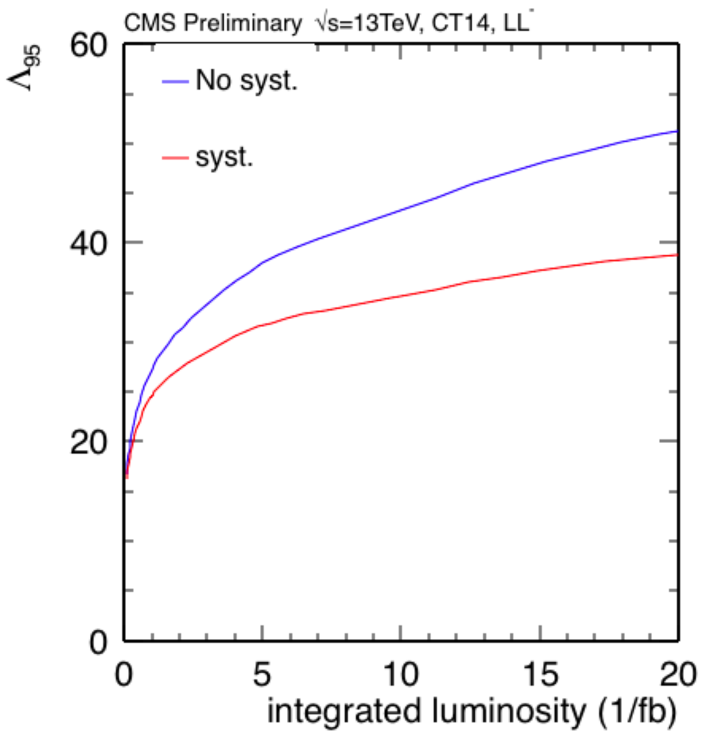
We would like to work on a publishable result using the 2016 data set.

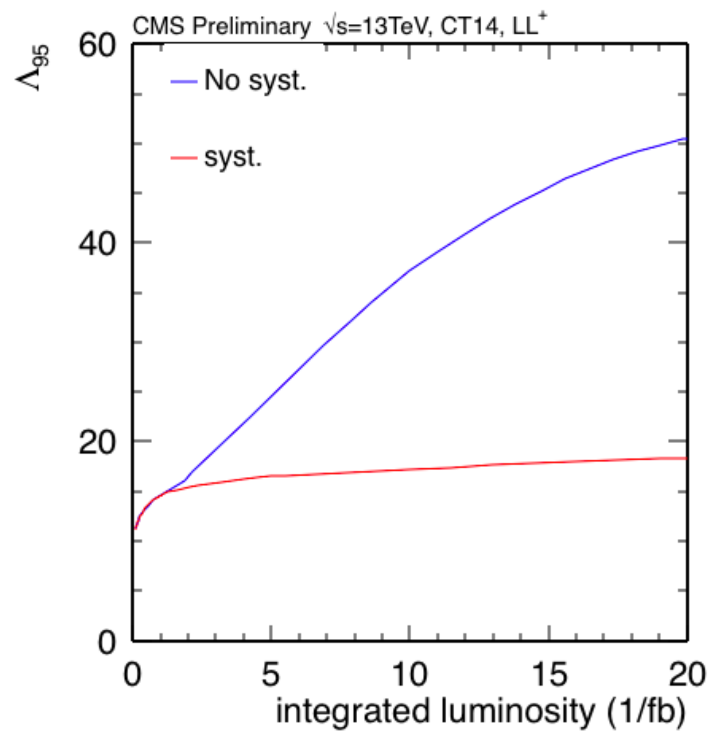
However, this only makes sense if the analysis is not severely limited by systematic uncertainties.

We've made a rough estimate for the LL model (assuming JEC uncertainties become << PDF uncertainties) using CT14.

Plans for 2016 Data: Λ^{95} vs Lumi

These plots suggest that we can use up to ~2.0/fb for destructive





interference models and up to ~20/fb for constructive interference models with 2014 PDFs.

Plans for 2016 Data

1. Work with inclusive jet group on ongoing measurement of inclusive jet p_T spectrum using 2016 data.

2. Repeat analysis using 2016 measurement. Extend cross section predictions beyond 2TeV.

3. Write AN/paper.

Timescale ~ 6 – 8 months.

Immediate plans: complete current AN, then write a PAS.

BACKUP

Analysis

Steps

1. For each PDF generate 200 *randomly* sampled PDF sets using hessian2replicas in LHAPDF6.1.6, except for NNPDF30_nlo for which the sample already exists.

2. For each sampled PDF set and 7 combinations of the renormalization and factorization scales, compute the QCD inclusive jet p_{T} spectrum (yielding 4200 spectra).

3. Repeat 2., but instead use CIJET to compute the 57 differential coefficients needed to compute the CI spectra for *arbitrary* values of κ and Λ (57×4200 spectra).

CI Differential Coefficients (CT14, 0)

Analysis

Steps

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

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

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

Analysis

Steps

5. Compute the marginal likelihood

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

$$\simeq \frac{1}{K} \sum_{i=1}^{K=4200} \text{multinomial}(D \mid \lambda, \kappa, \nu_i)$$

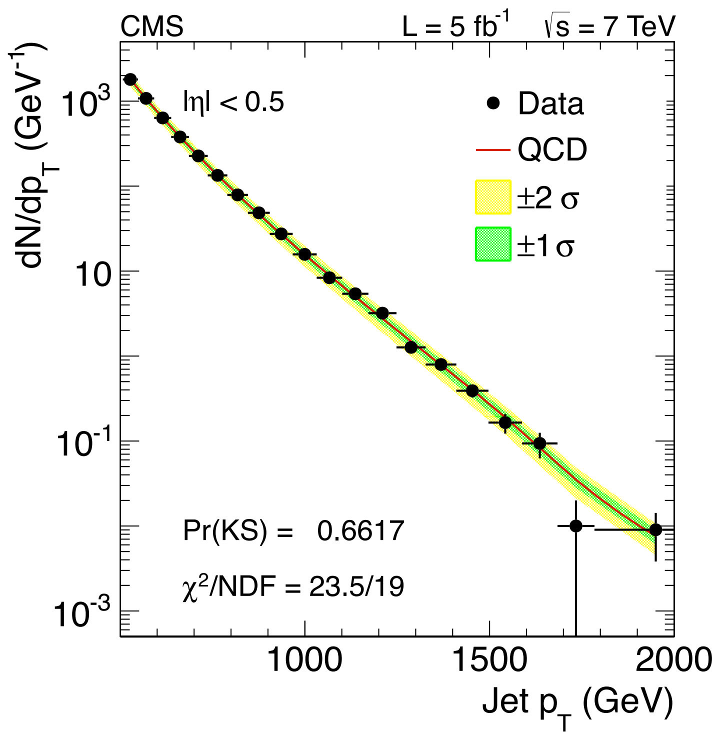
where D denotes the counts per bin, and ν denotes the JES, JER, and PDF nuisance parameters.

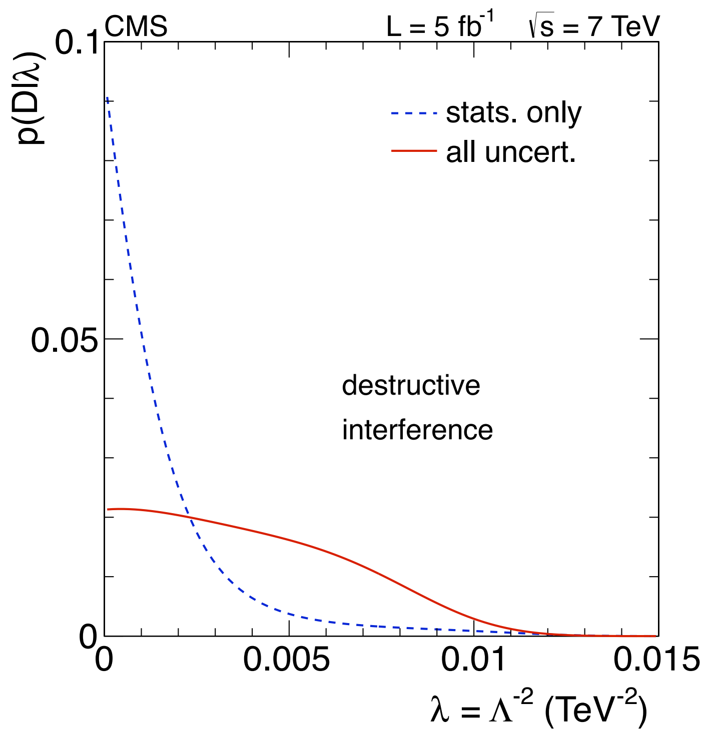
6. Compute upper limit on λ by solving

$$\int_0^{\lambda^{UP}} p(\lambda \mid D, \kappa)\, d\lambda = 0.95,$$

where $p(\lambda \mid D, \kappa) = p(D \mid \lambda, \kappa)\, p(\lambda) / p(D, \kappa)$

Contact Interaction Search @ 7 TeV



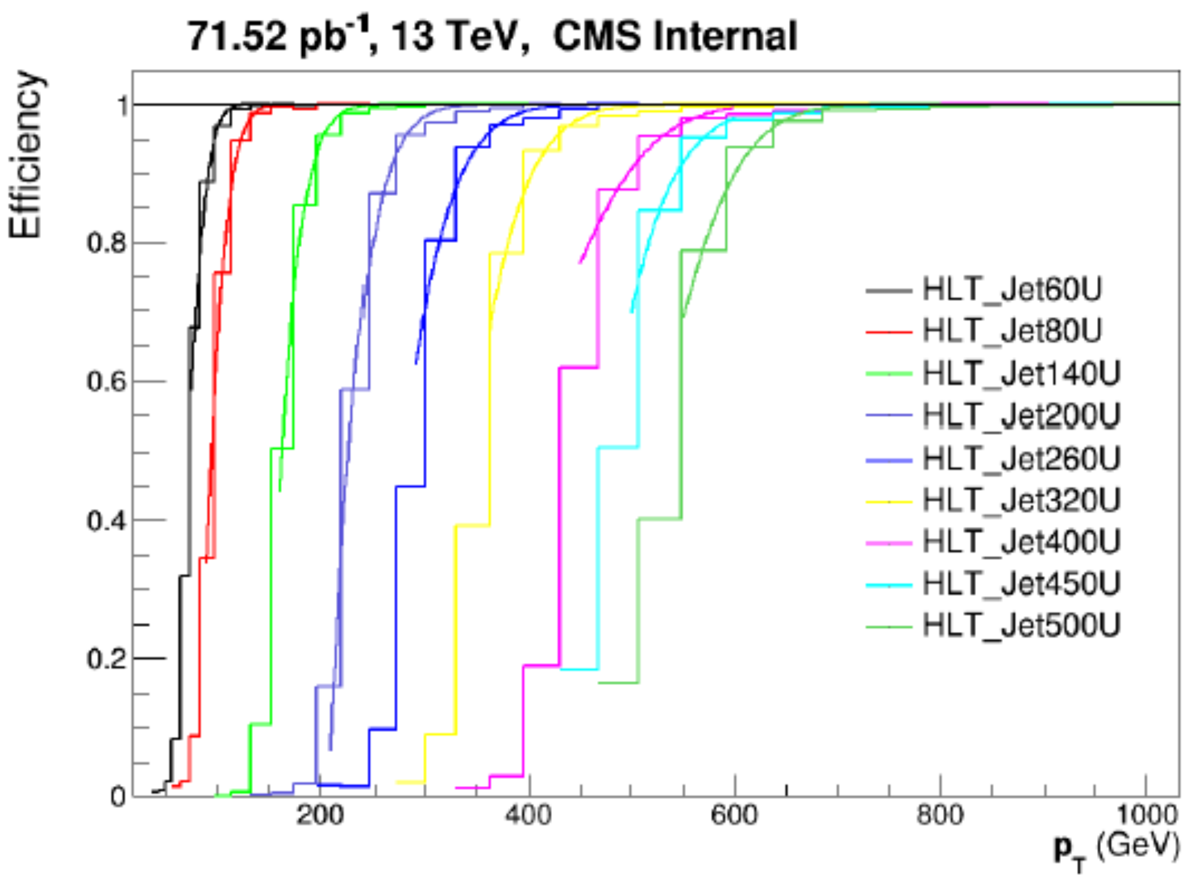


PHYSICAL REVIEW D **87,** 052017 (2013)

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: Triggers



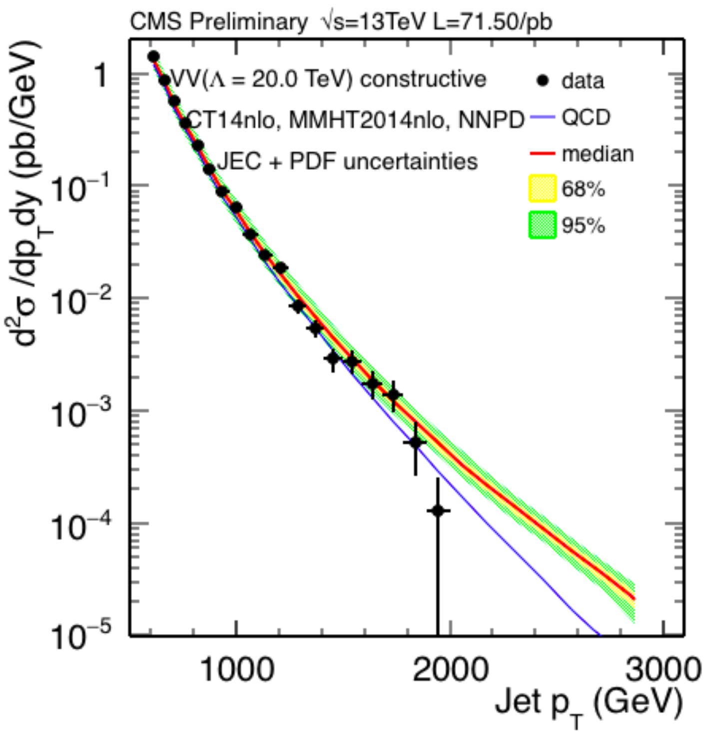
Requirement of ak7chs jet in $|\eta| < 4.7$

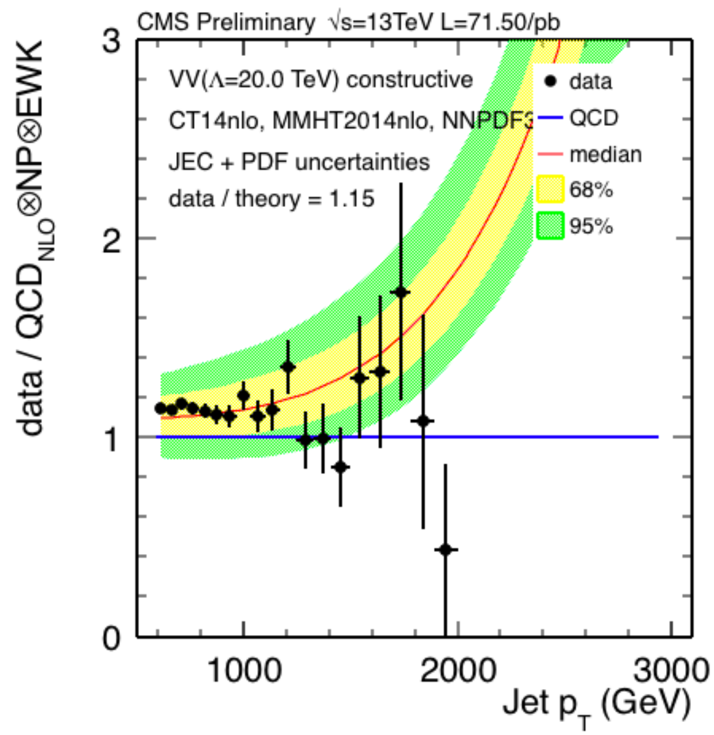
Trigger	Turnon
HLT60	105
HLT80	132
HLT140	220.6
HLT200	315.7
HLT260	399.8
HLT320	505.6
HLT400	602.1
HLT450	632.5

SMP-15-007
Constructive

Data vs. VV Model (Λ=20TeV)

PDF + JES + JER (Summer15 V5) uncertainties





Constructive