# Search for Contact Interactions Using Inclusive Jet $p_T$ Spectrum

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Exotica Jets+X Working Group Meeting

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# Outline

1. Overview
2. Analysis
3. Preliminary Results
4. Plans

# Overview

## Goal

- Search for new QCD-like interactions that can be modeled as contact interactions (CI) at LHC energies. Look for deviations in the inclusive jet $p_T$ spectrum at high $p_T$.
- Preliminary results by end of August 2016 using SMP-15-007 inclusive jet cross section measurement.
- Publishable result by the end of calendar year 2016.

## Manpower

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

# Overview

Previous results at 7 and 8 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)

**CMS AN-13-351**

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Search for contact interactions using the inclusive jet $p_T$ spectrum in pp collisions at $\sqrt{s} = 8$ TeV

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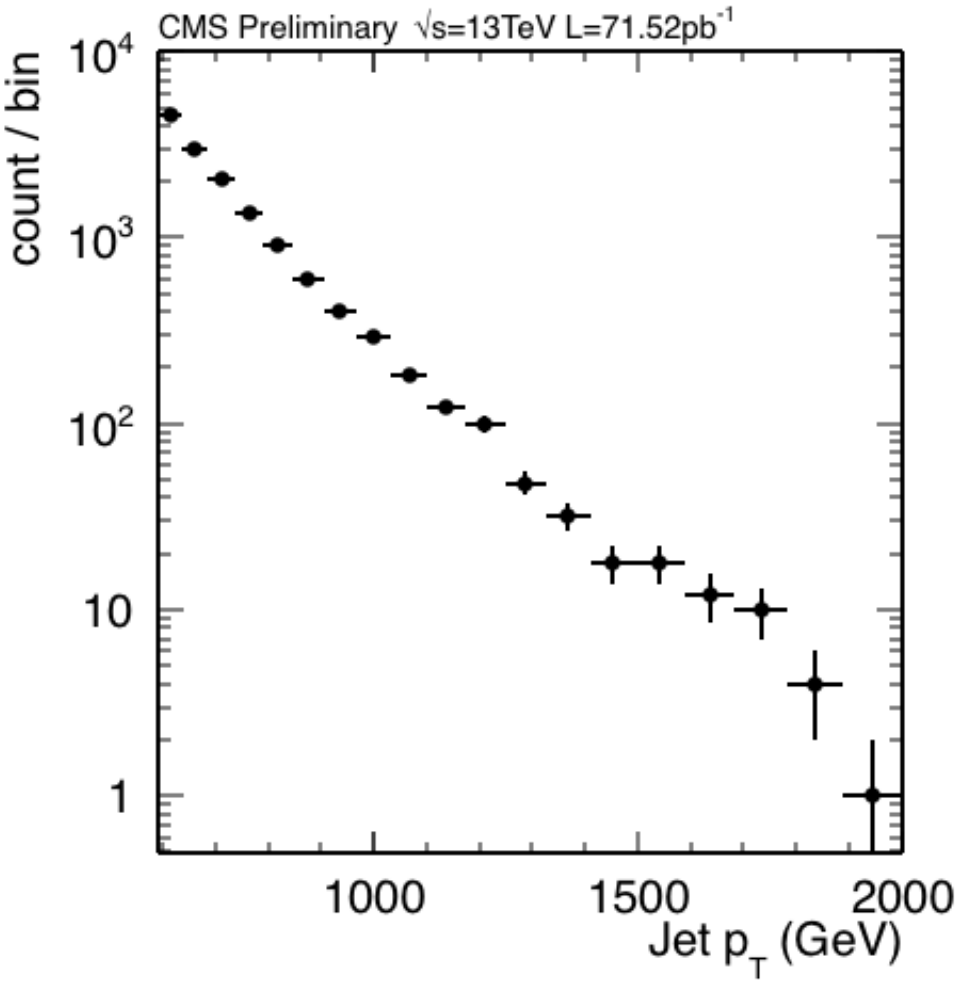
# Overview

## Experimental Input

- Inclusive jet $p_T$ spectrum in
  $|y| < 0.5$,
  $638 \leq p_T \leq 2000$ GeV,
  $L = 71.5$/pb
- Use AK7 jets
- Jet response function (JRF)
- Jet energy correction (JEC) uncertainty
- Jet energy resolution (JER) uncertainty

# Data: $L$ = 71.5 $pb^{-1}$



# Overview

## Theoretical Input

- PDFs (LHAPDF-6.1.5)

  CT14nlo, MMHT2014nlo68cl, NNPDF30_nlo

- QCD predictions at NLO

  fastnlo_toolkit-2.3.1pre-2163
  InclusiveNJets_fnl5332g_v23_fix.tab

- CI predictions at NLO

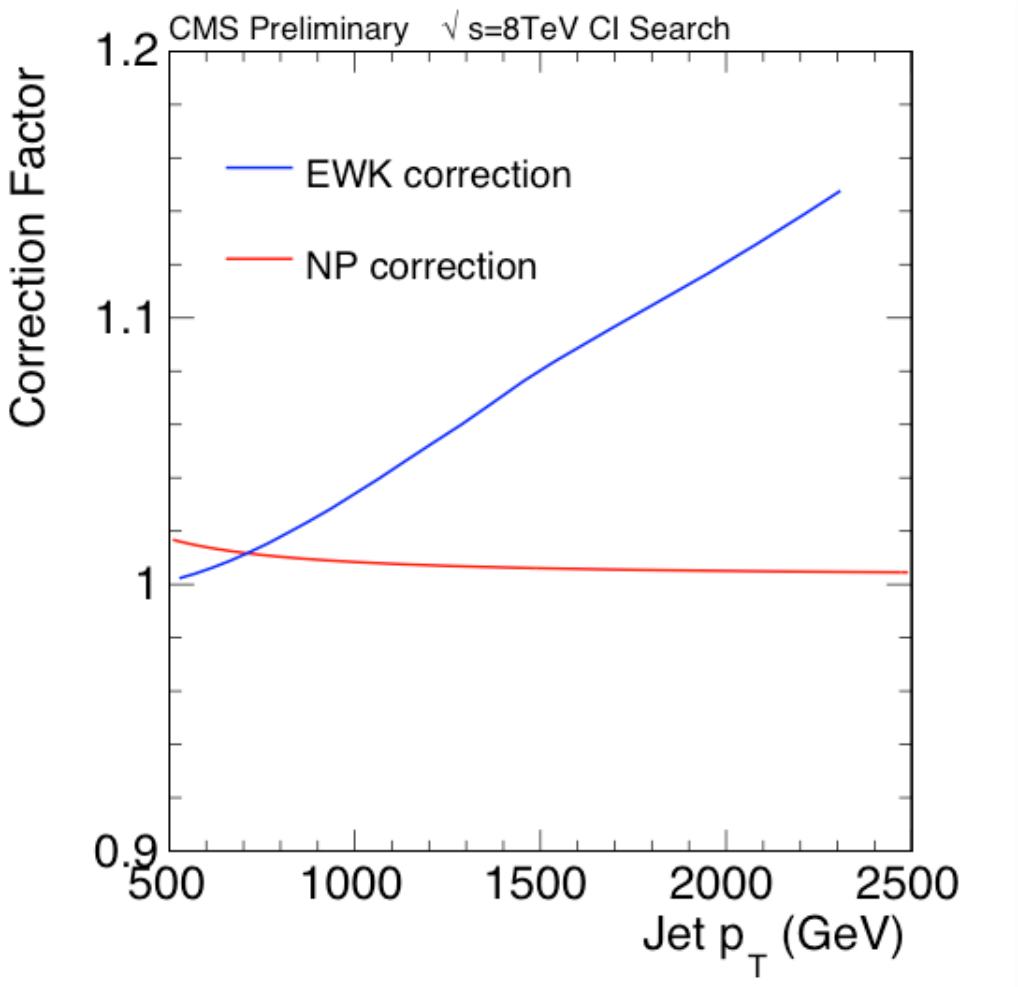
  CIJET-1.1

- Non-perturbative corrections

- Electroweak corrections

# Overview: NP & EWK Corrections

This will be updated.



# Overview: Models

New QCD-like interactions described using the effective Lagrangian

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

where $\Lambda$ is a mass scale, $\kappa_i$ 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

This yields a QCD+CI cross section per $p_T$ bin of the form

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

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

and

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

where $g = -\ln(\mu_0 \sqrt{k})$

$\lambda = 1/\Lambda^2$

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

The CI term comprises

57

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

coefficients

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

# Overview: Models

The parameters $\kappa_1 \ldots \kappa_6$ are free, but we consider only the following discrete set of values:

| Model | $\eta_{LL}$ | $\eta_{RL}$ | $\eta_{RR}$ | |
|---|---|---|---|---|
| LL | $\pm 1$ | 0 | 0 | Left-Left |
| RR | 0 | 0 | $\pm 1$ | Right-Right |
| VV | $\pm 1$ | $\pm 1$ | $\pm 1$ | Vector-Vector |
| AA | $\pm 1$ | $\mp 1$ | $\pm 1$ | Axial Vector |
| V-A | 0 | $\pm 1$ | 0 | Vector – Axial Vector |

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

# Outline

1. Overview
2. **Analysis**
3. Preliminary Results
4. Plans

# Analysis: Roadmap

Analysis Steps

1. For each PDF set (except for NNPDF for which sample exists), 200 sets of PDFs are *randomly* sampled using the hessian2replicas tool in LHAPDF6.1.5.

2. For each of these PDF sets, and 7 combinations of the renormalization and factorization scales, compute the QCD inclusive jet $p_T$ spectrum using fastNLO. This yields an ensemble of 3x200x7 = 4200 spectra.

3. Do the same for the 57 differential coefficients needed to compute the CI spectra for *arbitrary* values of $\kappa$ and $\Lambda$.

# Analysis: Roadmap

## Analysis Steps

4. Each spectrum, $f(p_T) = d^2F/dp_T dy$, (either QCD or the 57 CI differential coefficients) is smeared

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

with the jet response function $R$. We also randomly sample the jet energy correction (JEC) and jet energy resolution (JER), taking care to maintain the correlations across all bins and all spectra.

# Analysis: Roadmap

## Analysis Steps

5. Next, compute the likelihood

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

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

where $D$ denotes the counts per bin and $\nu$ denotes the JEC, JER, and PDF nuisance parameters. Since there is no evidence of a significant deviation from QCD, we set limits on $\Lambda$ for different choices of $\kappa$. The three PDF sets are given equal weight. The likelihood and data are stored in a RooStats Workspace.

# Analysis: Status

1. QCD and CI spectra for all PDFs have been calculated.

2. All spectra have been smeared. However, we are still using the 8 TeV jet response function and jet energy correction uncertainties. We plan to migrate to the Summer15_50ns uncertainties over the next week or so.

3. Corrections: Non-perturbative corrections have been implemented as well as the far more significant electroweak corrections (thanks to Paolo Gunnellini).

4. The workspace has been built and preliminary expected limits have been calculated for all models.

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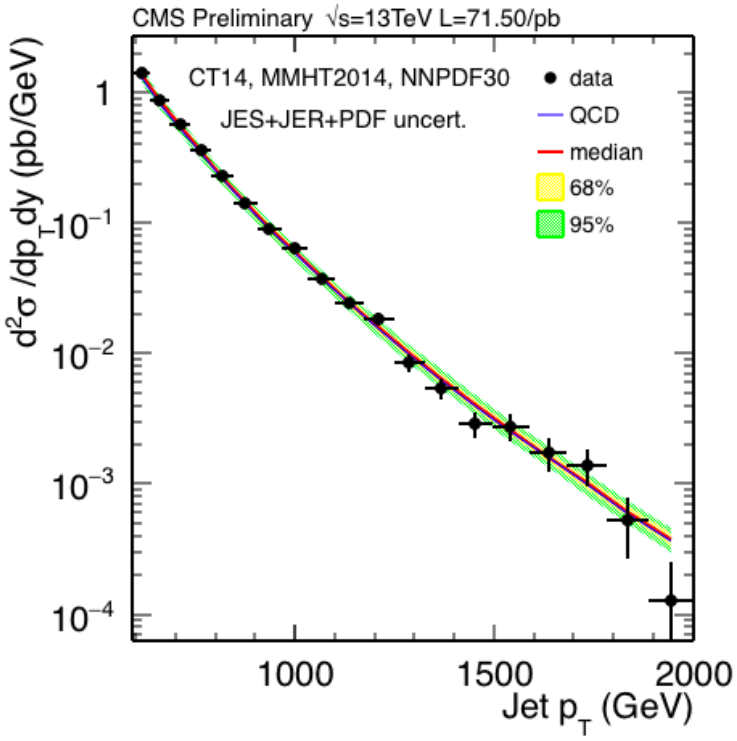
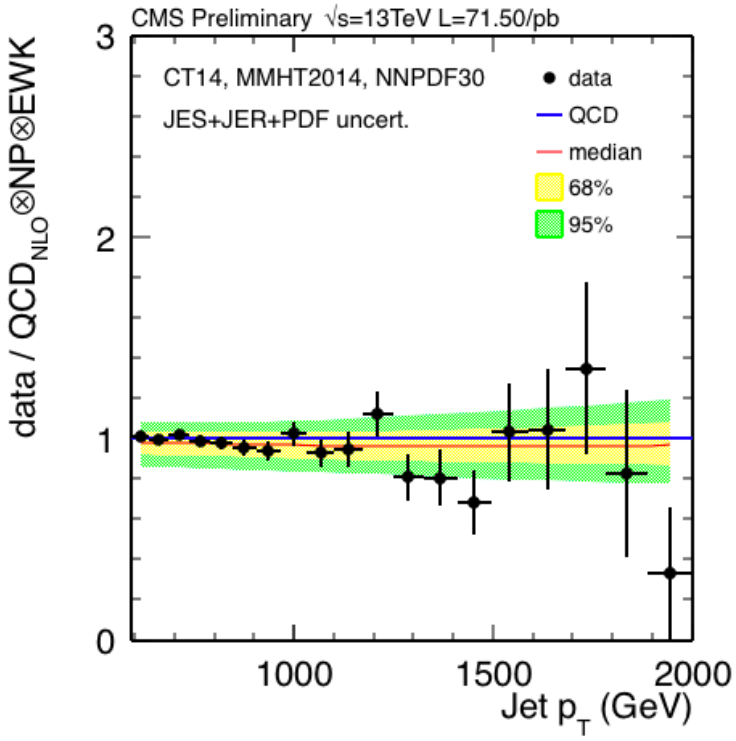
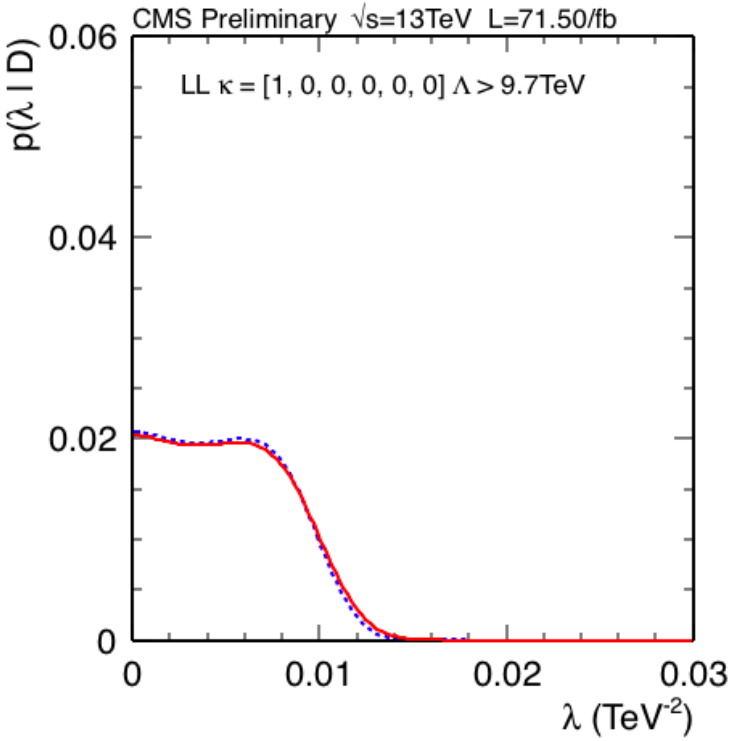
# Data / QCD Comparison

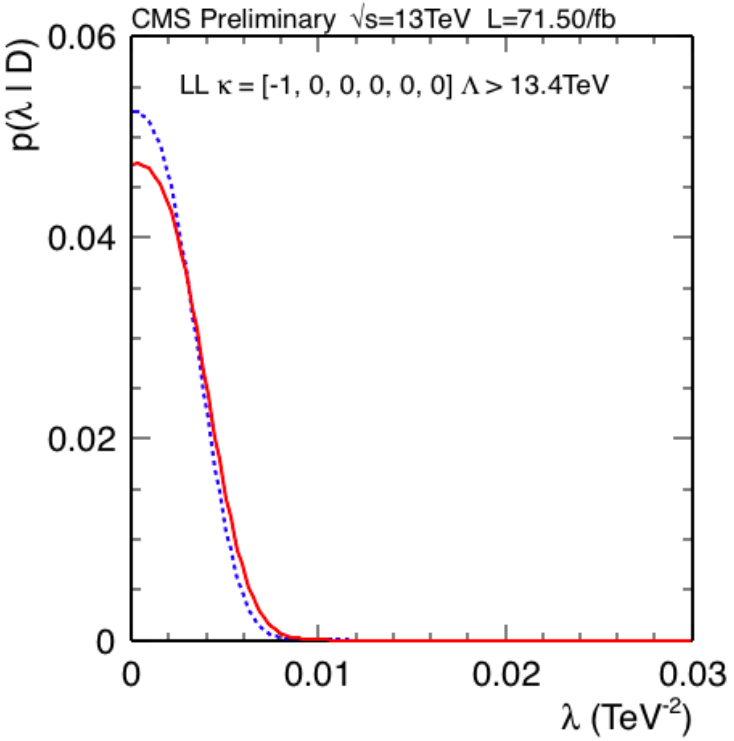


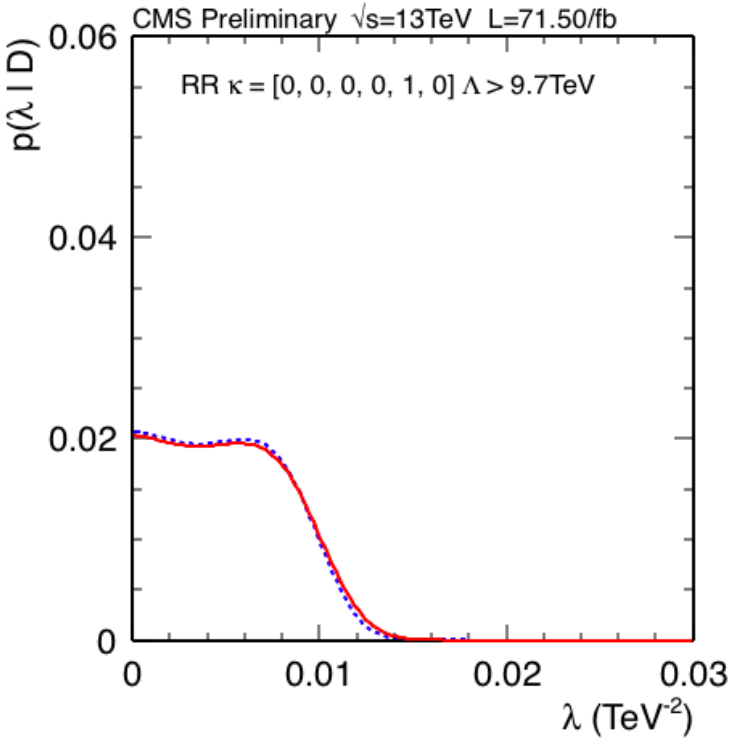

No evidence of a significant deviation from Standard Model.

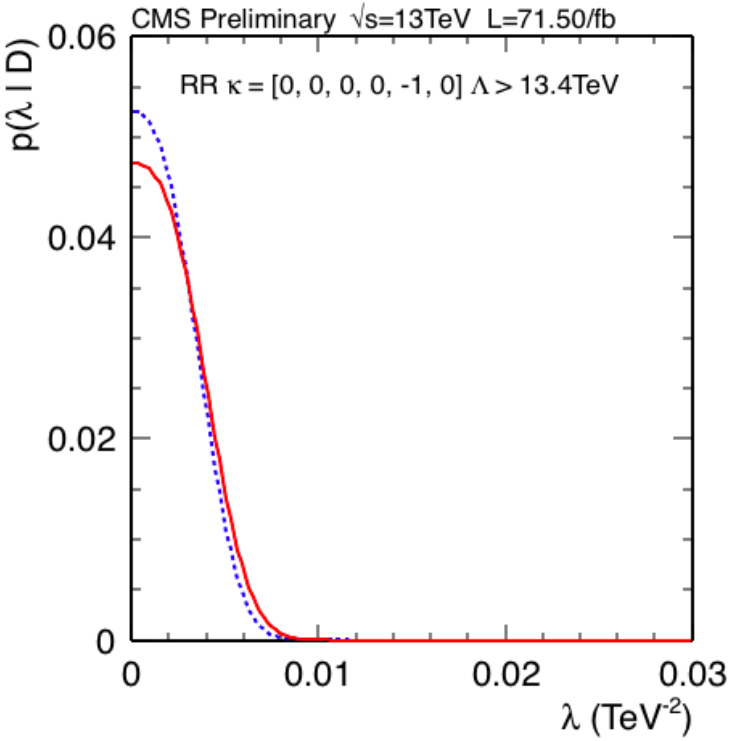
# Expected Limits – LL



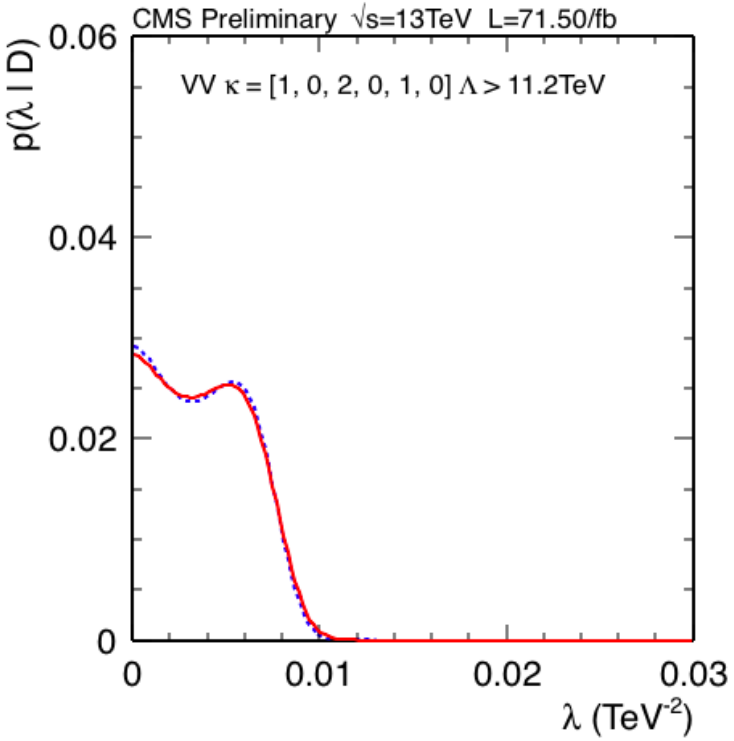



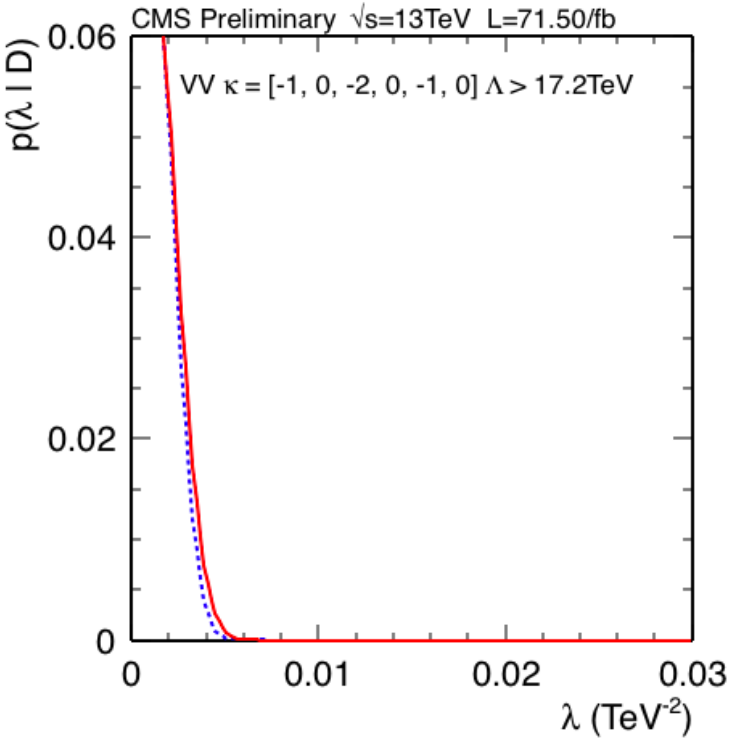
# Expected Limits – RR



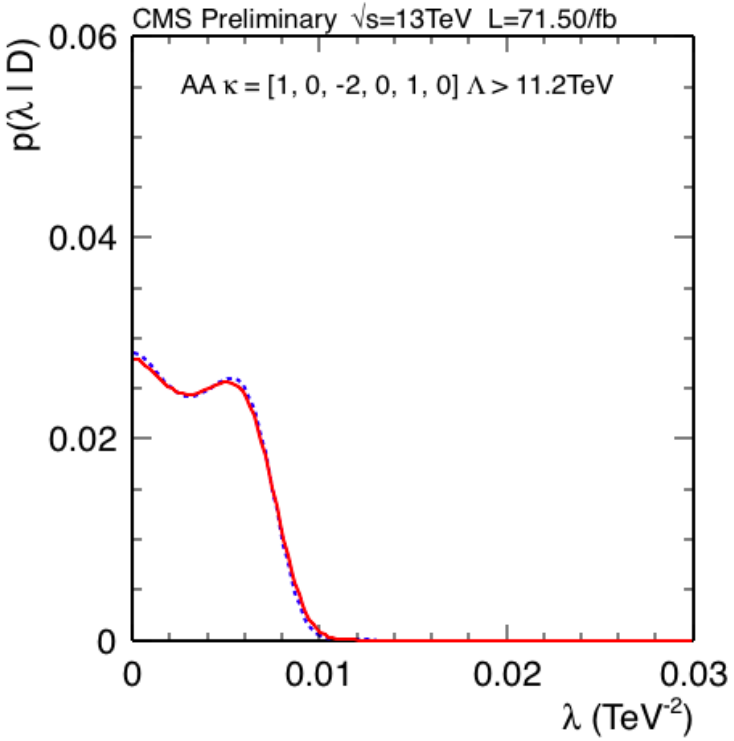



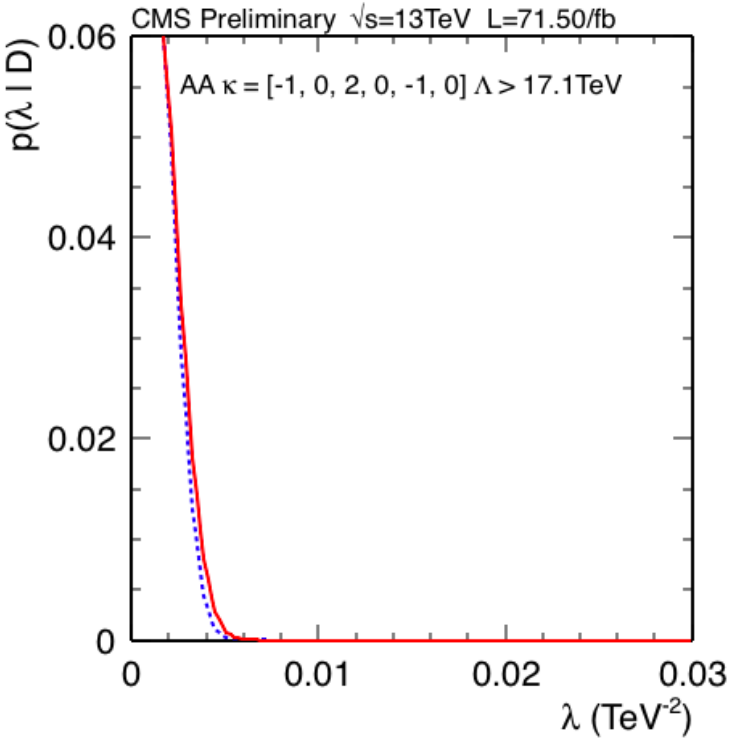
# Expected Limits – VV



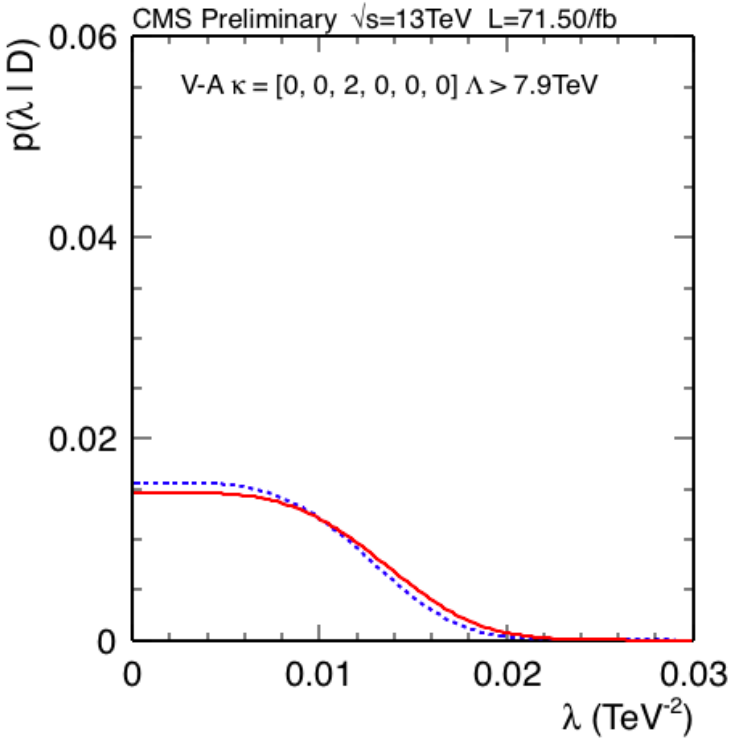



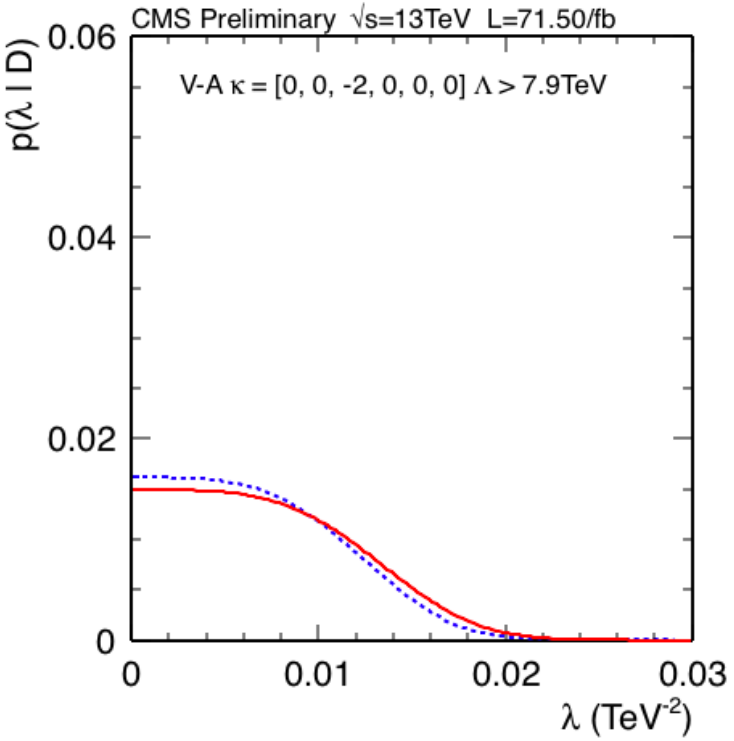
# Expected Limits – AA



# Expected Limits – V - A



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# Near Term Plans

1. Re-smear all spectra using the same jet response function as used in SMP-15-007 and use the Summer15_50ns jet energy correction uncertainties.

2. Re-compute expected limits.

1. Check stability of expected limits by repeating calculations with increasing thresholds on minimum jet $p_T$. Also, repeat calculations with different (bootstrap) samples of spectra and study distribution of limits to check that they behave sensibly.

# Near Term Plans

4. Compute observed limits for all models.

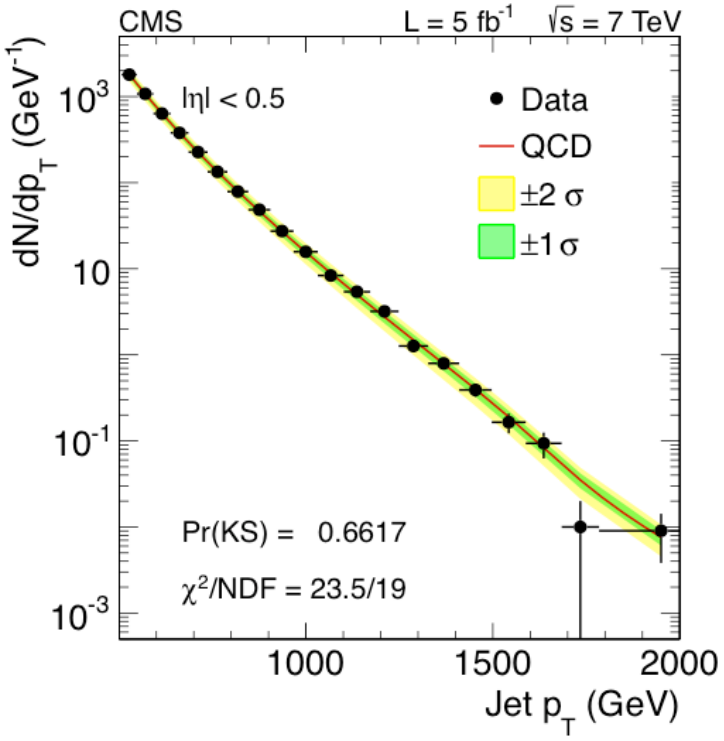
5. Complete 13TeV Analysis Note.

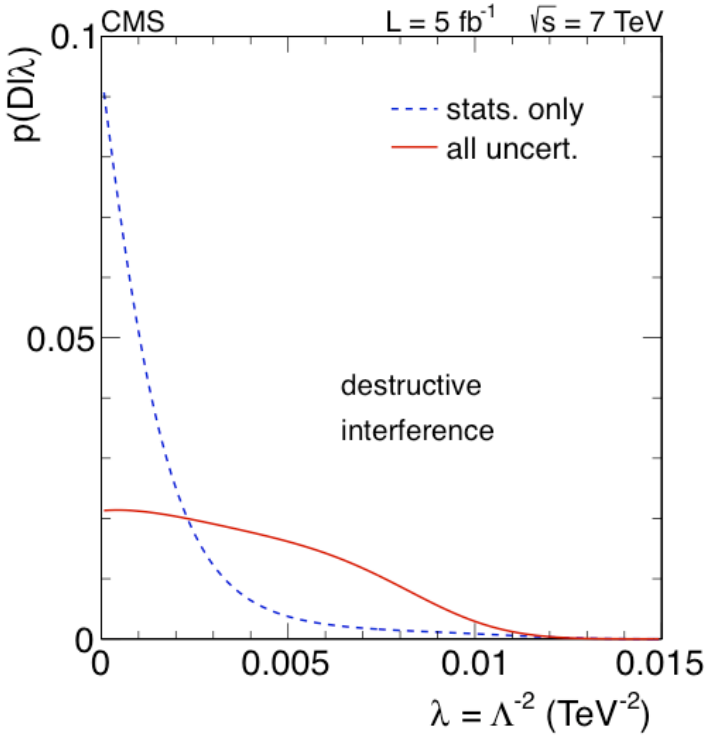
6. Subject analysis to ARC review and write paper.

# BACKUP

# CI Cross Section Coefficients (8 TeV)

# Contact Interaction Search @ 7 TeV

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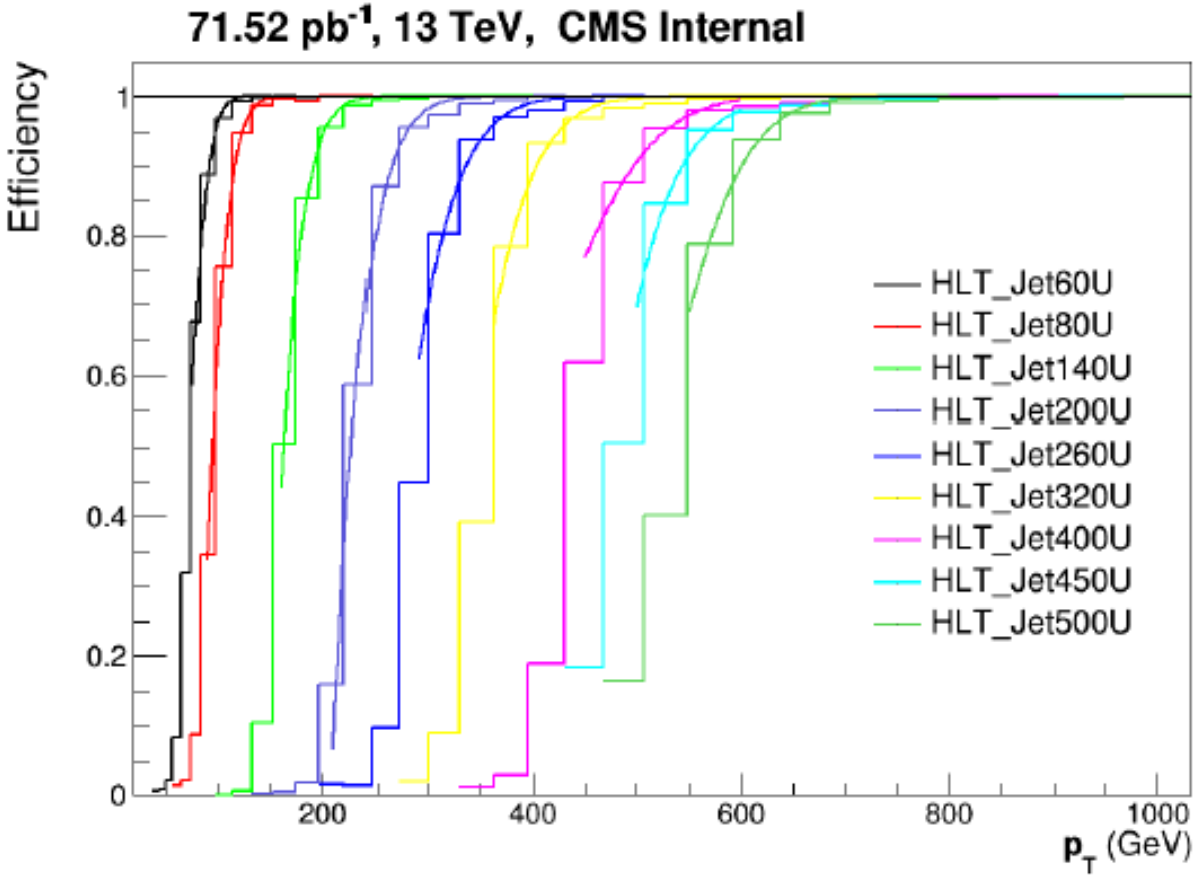
# Overview: Triggers




SMP-15-007

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 |