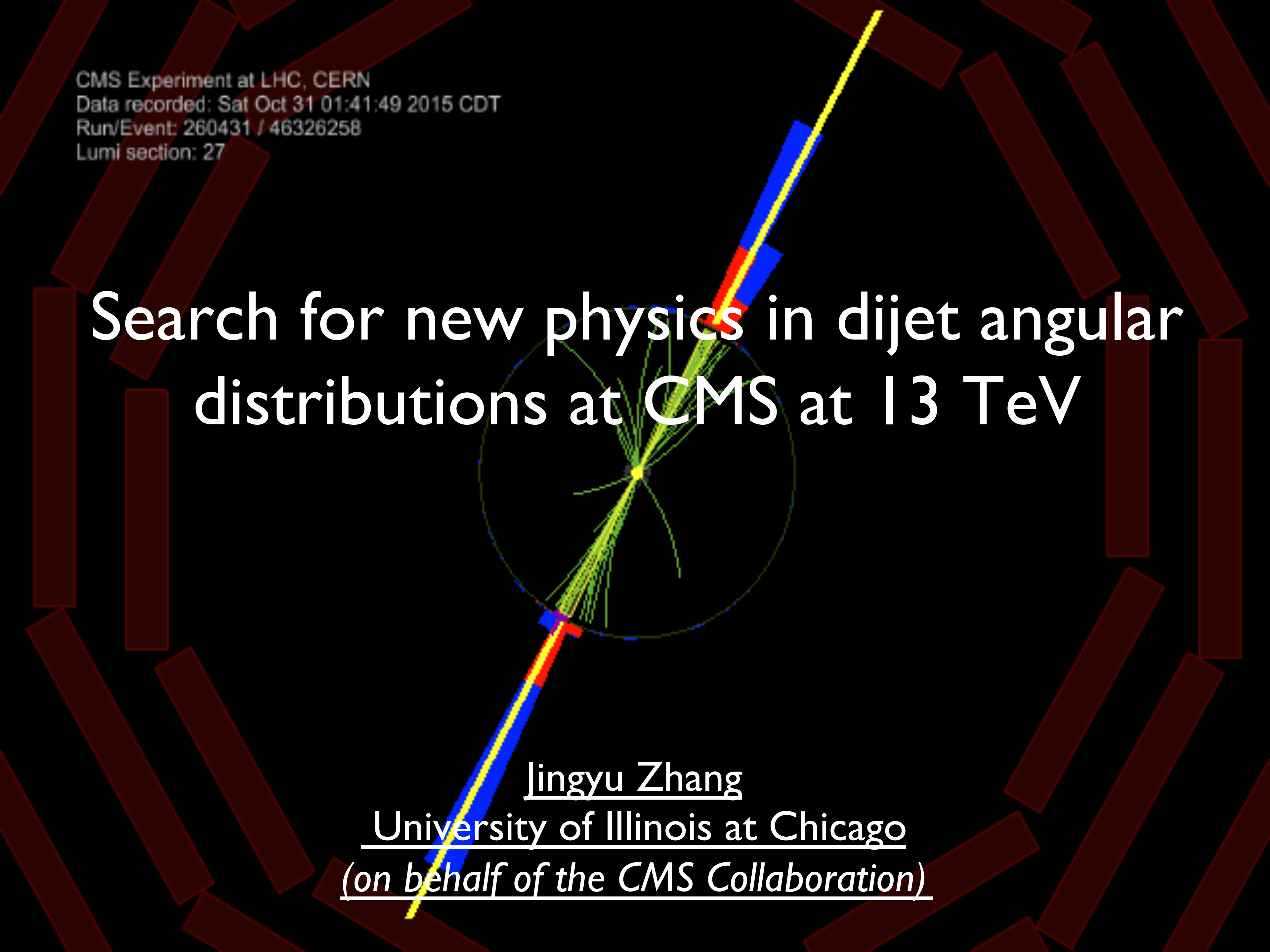

Search for new physics in dijet angular distributions at CMS at 13 TeV

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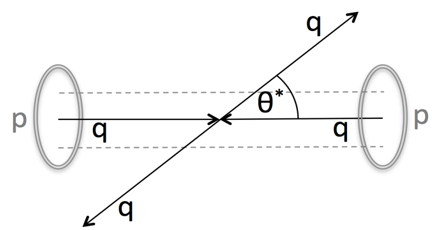
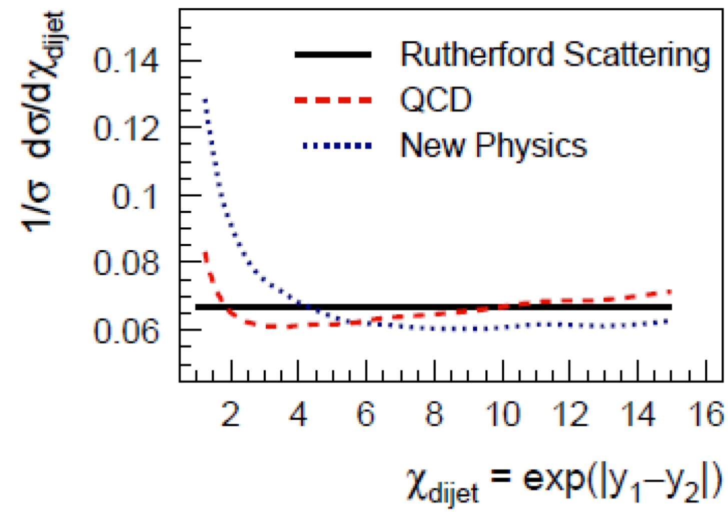
(on behalf of the CMS Collaboration)

Dijet Angular Distribution

- Probe parton-parton scattering angle

$$\chi_{dijet} = e^{|y_1-y_2|} \sim \frac{1+|\cos\theta^*|}{1-|\cos\theta^*|}$$

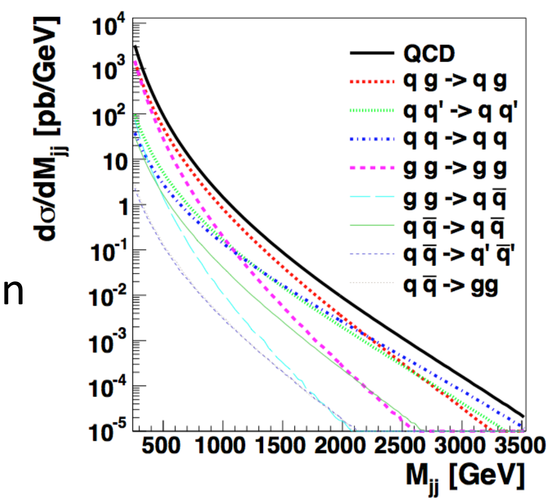


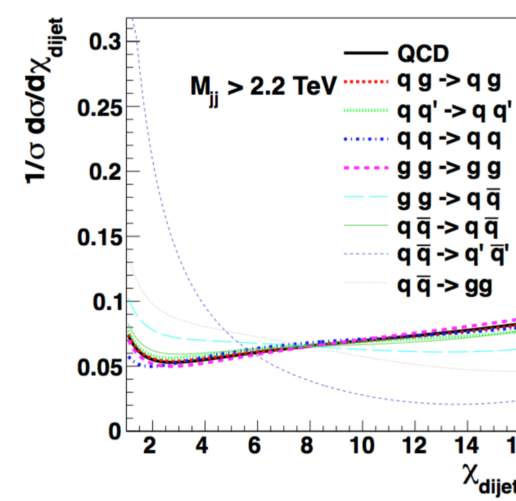


- New Physics will change the χ_{dijet} distribution at low χ_{dijet} at high M_{jj}

- χ_{dijet} is relatively flat for Leading QCD process (qg->qg, qq'->qq',gg->gg)
  - Small sensitivity to PDF uncertainties

- Observable: $1/\sigma d\sigma / d\chi_{dijets}$
  - Measure normalized distribution in bins of dijet mass
  - Reduced sensitivity to detector effects



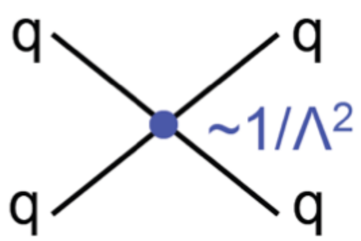


New Physics with Dijet Angular Distribution

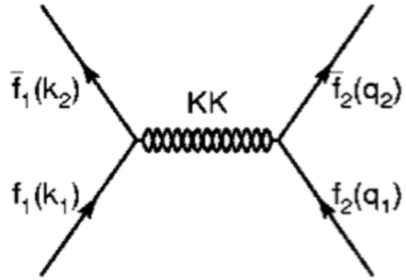
- Quark Contact Interactions
  - For √s << Λ, the quark compositeness interaction can be represented as contact interactions (CI) terms **Eichten, Lane, Peskin, Phys.Rev.Lett. 50 (1983) 811**:

$$L_{qq} = \pm \frac{g^2}{2\Lambda^2} (\bar{q}_L \gamma^\mu q_L)(\bar{q}_L \gamma_\mu q_L)$$

  - Λ=∞ -> point like quark
  - Λ=finite -> substructure of mass scale Λ



- Large Extra Spatial Dimension
  - **N.Arkani-Hamed, S.Dimopoulos, G.R.Dvali, (ADD) Model**
  - Problem of large hierarchy between electroweak scale and gravity scale solved
  - Standard model particles are confined in 3+1 dimensional subspace and gravity propagate in all dimensions
  - Virtual Kaluza-Klein graviton exchange processes modify χ_{dijet} distribution
  - Two parameterizations: GRW (Giudice, Rattazzi, Wells) and HLZ (Han, Lykken, Zhang)



Run1 Results

4.2 TeV

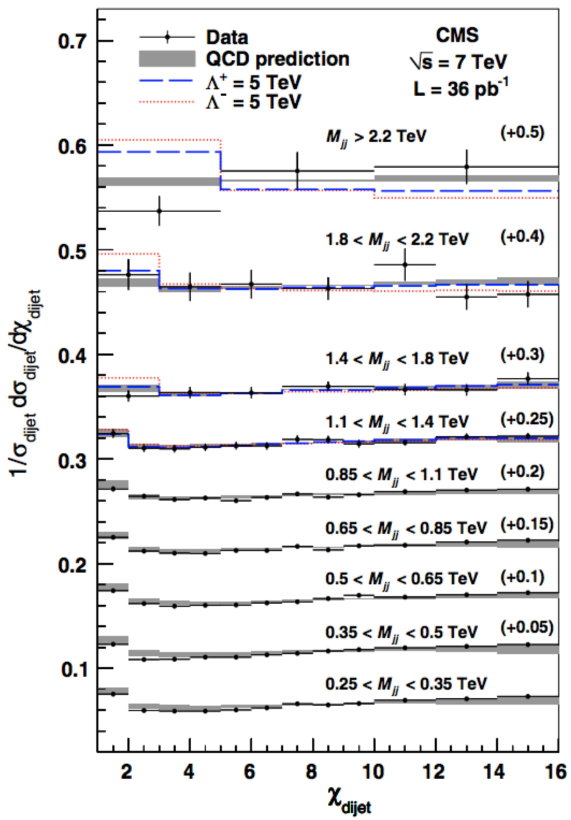
M_{jj}

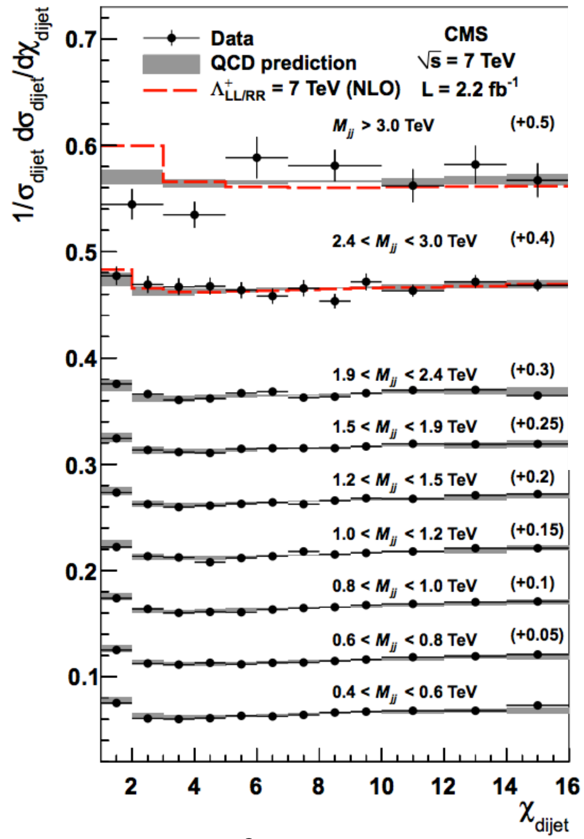
0.25 TeV

Limits on CI for at LO

PhysRevLett.106(2011)201804

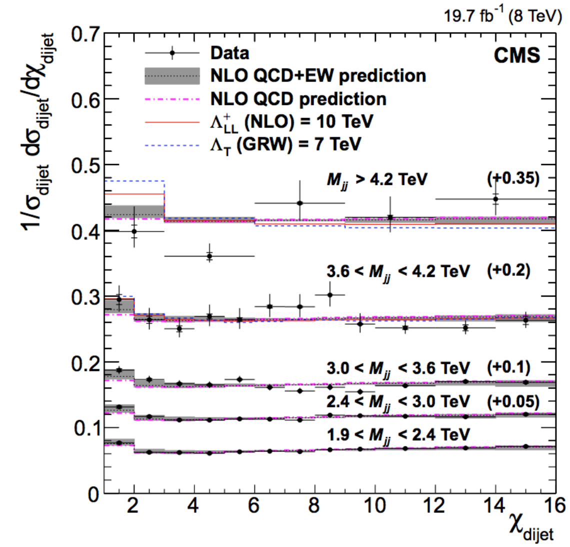
- Λ+: 5.6 TeV
- Λ-: 6.7 TeV





Limits for CI at NLO (JHEP05(2012)055)

- Λ+: 7.5 TeV
- Λ-: 10.5 TeV

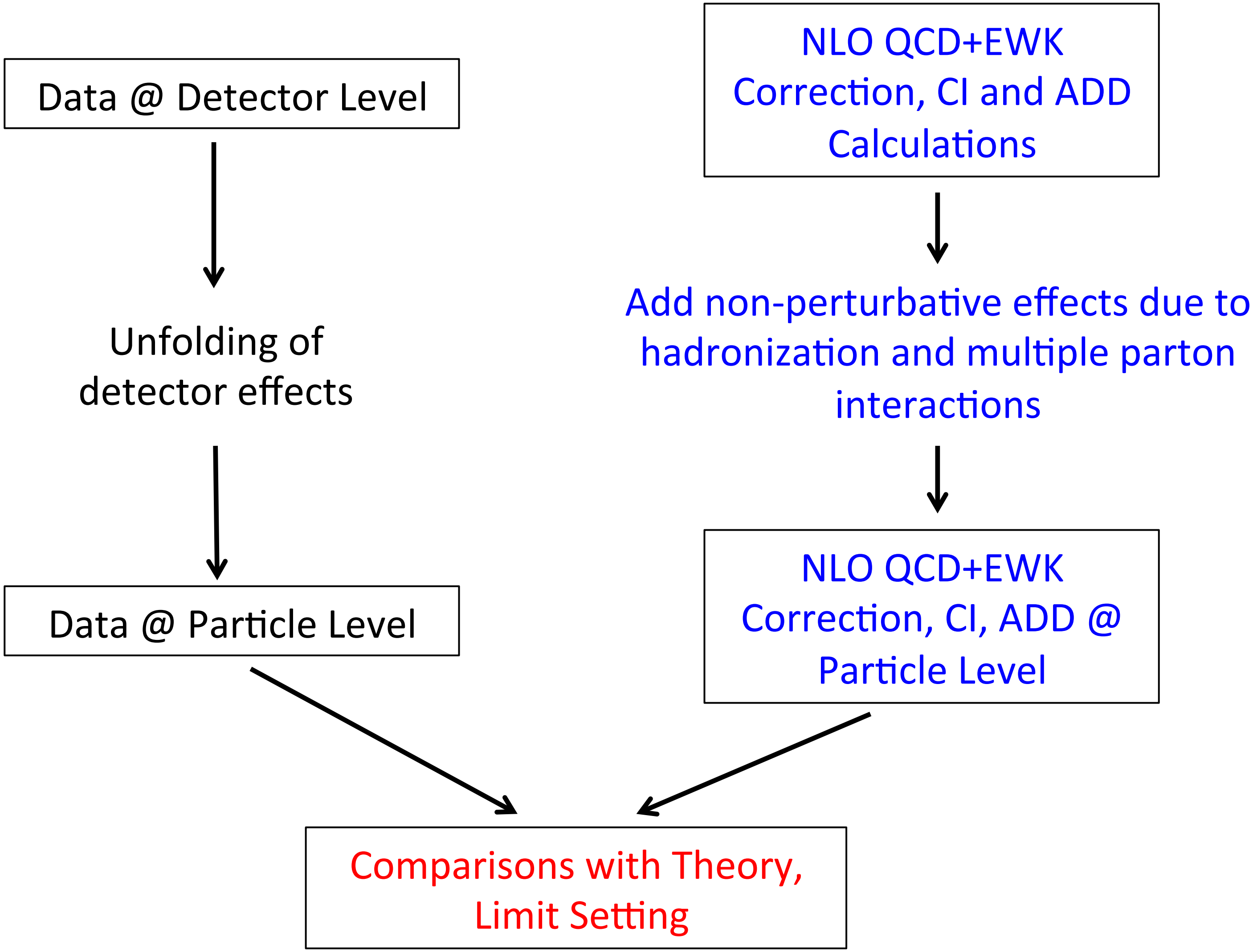


Limits on CI at NLO and ADD

Phys.Lett.B746(2015)79

- Λ+: 9.0 TeV
- Λ- : 11.7 TeV
- ADD (GWR): 7.1 TeV
- ADD (HLZ): 5.0 TeV (n_{ED}=6)

Analysis Strategy

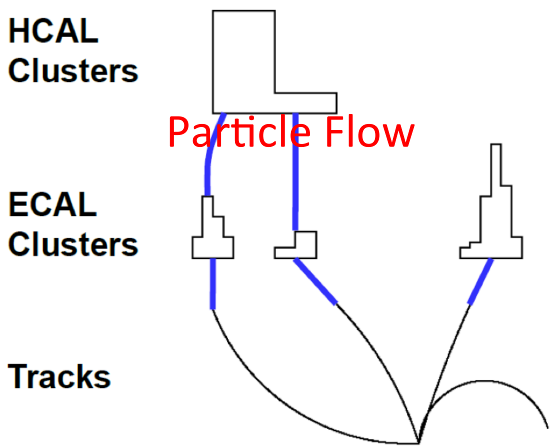


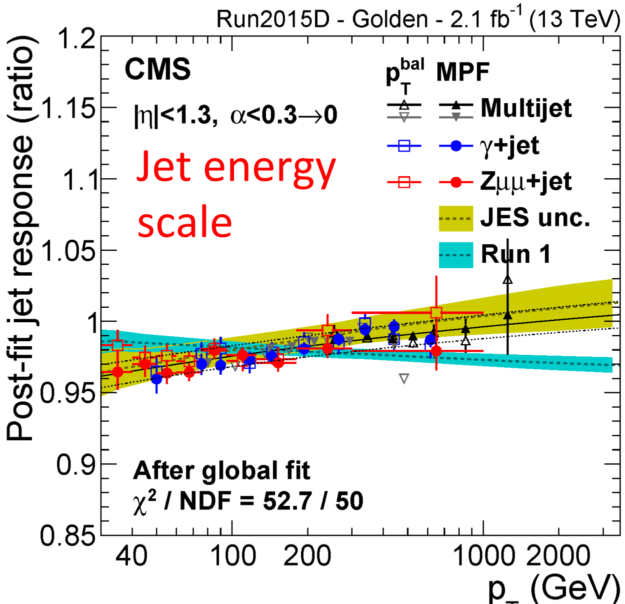
Analysis Phase Space

- Online Selection
  - Trigger path based upon the scalar sum of the transverse momenta of the jets reconstructed by CMS Trigger system. The selection threshold is 800 GeV at High Level Trigger
  - Trigger selection is 100% efficient above 1.9 TeV in M_{jj}
- Offline Selection
  - Good primary vertex
    - reconstructed primary vertex near the interaction point
  - At least two jets with p_T > 30 GeV
  - Well understood calorimeter region: y < |2.5|
  - $y_{boost} = \frac{1}{2}(y_1 + y_2) < 1.11,\ y^* = \frac{1}{2}|y_1 - y_2| < 1.39$
  - $1 < \chi_{dijet} < 16$
  - χ_{dijet} is calculated in different dijet mass regions: [1.9,2.4],[2.4,3],[3,3.6],[3.6,4.2],[4.2,4.8],[4.8,13] (TeV)

Jet Reconstruction and Jet Energy Correction

- Use "anti-k_T" clustering algorithm with cone size 0.4
- Jets are reconstructed and identified using particle flow technique, which utilize an optimal combination of all information of CMS sub-detectors
- Jet Energies are well calibrated and corrected with a multilevel approach:
  - Offset: correct for pile up and detector electronic noise
  - Relative: correct for eta dependency of jet response
  - Absolute: correct the p_T for measured jet to match particle level jet p_T





Overall jet energy correction uncertainty varies between 2% and 3%

Unfolding

- Data are unfolded to particle level using a 2D Bayes method implemented in RooUnfold
  - Correct the effect of event migrating between M_{jj} and χ_{dijet} bins due to finite jet p_T resolution
  - Correction determined from a 2D response matrix that maps particle level M_{jj} and χ_{dijet} to detector level ones
- 2D response matrix derived from particle level Pythia8 that were smeared using double-sided Crystal Ball parameterization of the response that takes into account full jet energy resolution
- 1% correction for lowest mass bin, 5 % correction for highest mass bin
- Almost no effect on the shape of the dijet angular distribution

Theory Predictions

- 13 TeV AK4 NLO QCD calculation with EWK correction
  - Generated with NLOJET++ 2.0.1
  - QCD scale uncertainty from 6 variations of μ_r and μ_f
    - 8% effect at lowest mass bin and 13% effect at highest mass bin
  - PDF uncertainty from CT14 PDF Set
    - 0.15% effect at lowest mass bin and 0.4% effect at highest mass bin
  - EWK correction is 5% in highest mass bin **S.Dittmaier, A.Huss and C.Speckner, JHEP 06 (2010) 038**

- Leading order CI + leading order CI and QCD interference predictions from Pythia8

- Leading order ADD + leading order ADD and QCD interference predictions in GWR and HLZ conventions from Pythia8

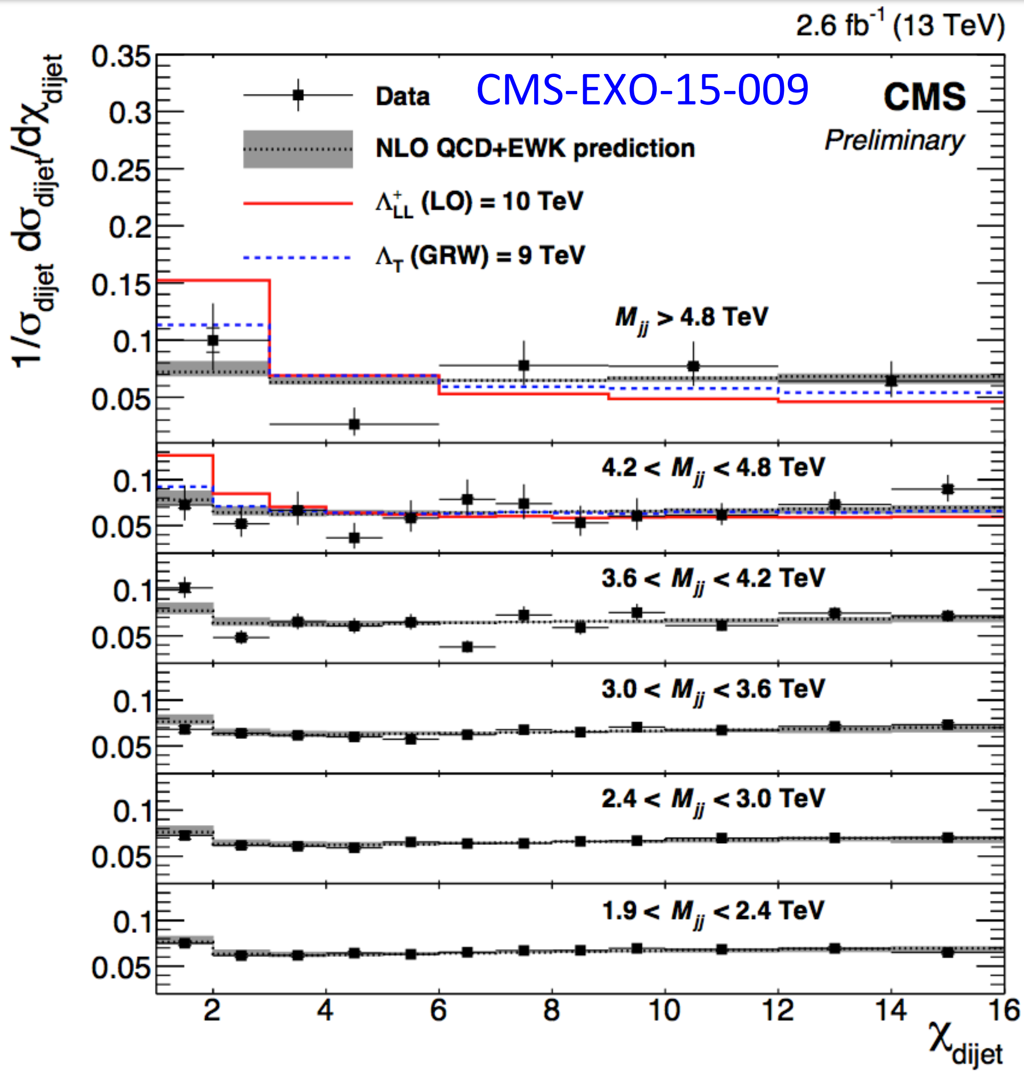
- $\sigma^{QCD+NewPhysics} = \sigma^{QCD}_{NLO} - \sigma^{QCD}_{LO} + \sigma^{QCD+NewPhysics}_{LO}$

Uncertainties

Uncertainty	$1.9 < M_{jj} < 2.4$ TeV	$M_{jj} > 4.8$ TeV
Statistical	1.6%	49%
Jet energy scale	3.0%	9.5%
Jet energy resolution (core)	<1%	2.0%
Jet energy resolution (tails)	<1%	2.5%
Unfolding, MC modeling	<1%	<1%
Unfolding, detector simulation	1.0%	3.0%
Pileup	<1%	<1%
Total experimental	9.7%	50%
NLO scale (6 variations of μ_R and μ_F)	$^{+7.9\%}_{-2.8\%}$	$^{+13\%}_{-4.9\%}$
PDF (CT14 eigenvectors)	0.15%	0.4%
Non-perturbative corrections (Pythia8 vs. Herwig++)	<1%	<1%
Total theoretical	7.9%	13%

- Statistical uncertainty dominates at high M_{jj}
- Main experimental uncertainty is from jet energy scale uncertainty
- Main theoretical uncertainties are from μ_r and μ_f scale variations

Results



- Unfolded data in good agreement with QCD+EW theory prediction

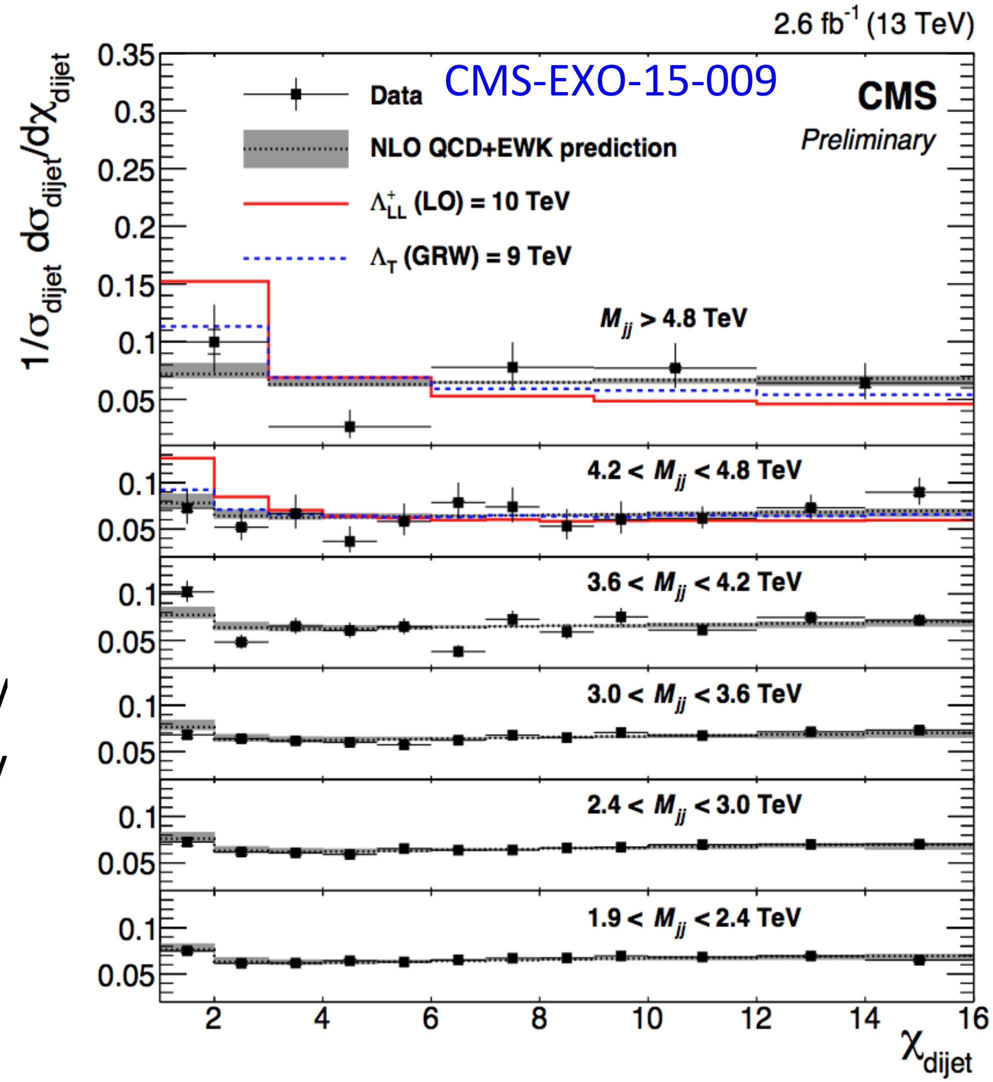
Limit Extraction

- Testing QCD against QCD+NewPhysics
- Limits extracted using CLs
  - CLs calculated using toy-MC experiments
  - Shape uncertainties taken into account by varying them as nuisance parameters in toy-MC experiments
  - Statistical uncertainty treated as Poisson distribution around number of observed events in toy-MC experiments
- Surpass Run1 sensitivity with 2.6 fb^{-1}

	Observed lower limit (TeV)	Expected lower limit (TeV)
$\Lambda^{+}_{LL/RR}$ (LO)	12.1	12.0 ± 1.1
$\Lambda^{-}_{LL/RR}$ (LO)	16.3	15.3 ± 2.4
ADD Λ_T (GRW)	9.1	9.0 ± 0.7
ADD M_S (HLZ) $n_{ED} = 2$	9.7	9.6 ± 0.7
ADD M_S (HLZ) $n_{ED} = 3$	10.8	10.7 ± 0.8
ADD M_S (HLZ) $n_{ED} = 4$	9.2	9.0 ± 0.7
ADD M_S (HLZ) $n_{ED} = 5$	8.3	8.1 ± 0.6
ADD M_S (HLZ) $n_{ED} = 6$	7.7	7.6 ± 0.6

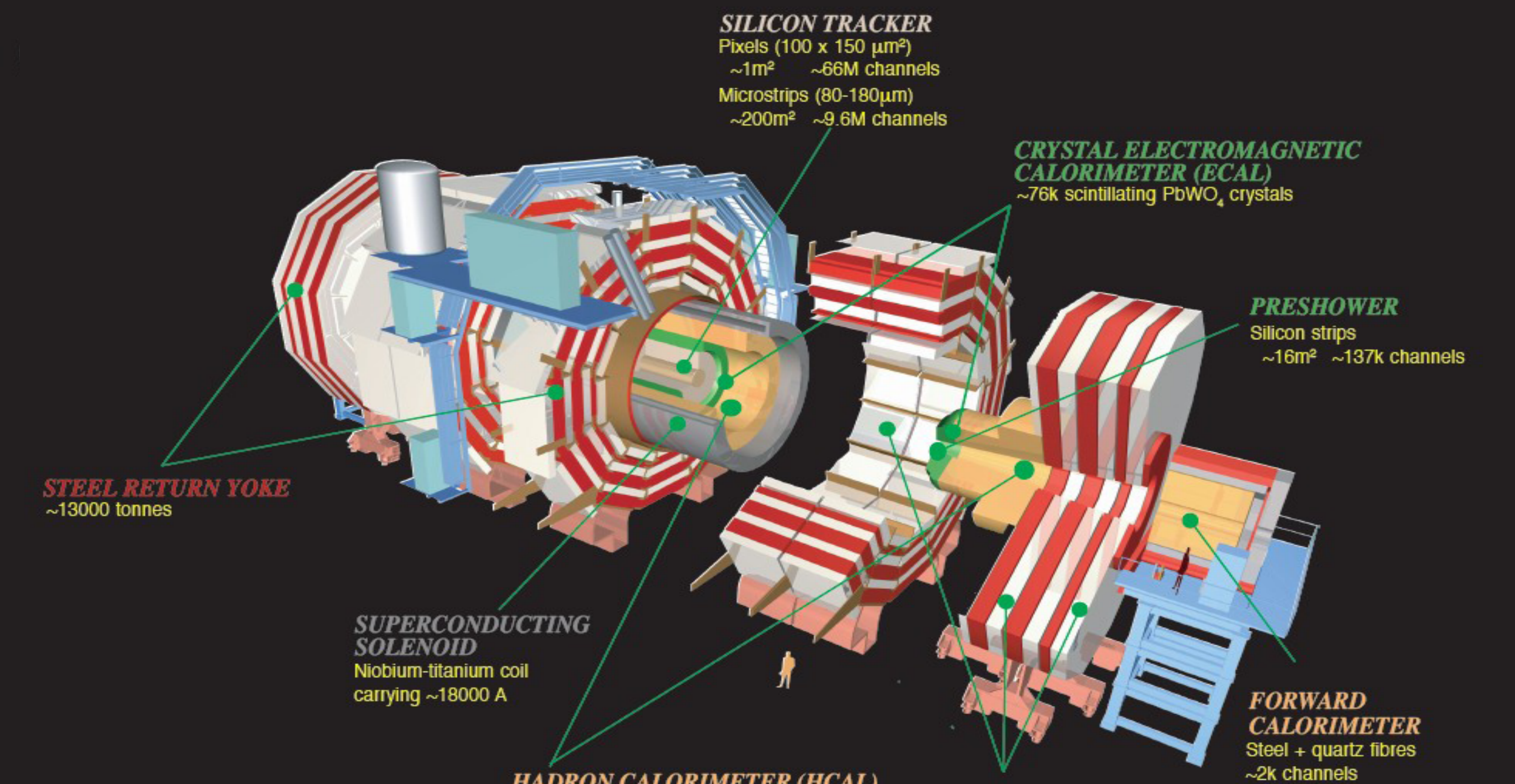
Summary

- Measurements of dijet angular distributions are presented
- Results are in good agreement with QCD prediction
- Limits for CI and ADD models are extracted
  - Λ_{LL}+ (LO): 12.1 TeV
  - Λ_{LL}- (LO): 16.3 TeV
  - Limit on ADD Λ_T (GRW): 9.1 TeV
  - Limit on ADD M_S (HLZ): 7.7 TeV (for n_{ED}=6)
- Search for new physics with more data @ LHC Run2



Back Up

CMS Detector



Total weight	: 14000 tonnes
Overall diameter	: 15.0 m
Overall length	: 28.7 m
Magnetic field	: 3.8 T

ATLAS 13 TeV Results

√s = 13 TeV, 3.6/fb

- arXiv:1512.01530

Limits on CI

- Λ+ (NLO): 12 TeV
- Λ- (NLO): 17 TeV

Limits on Quantum Black Hole

- ADD QBH: 8.3 TeV
- RS QBH: 5.3 TeV