Search for Nonresonant Exotic Physics in Final States with Leptons, Photons and Jets at CMS

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On behalf of the CMS Collaboration

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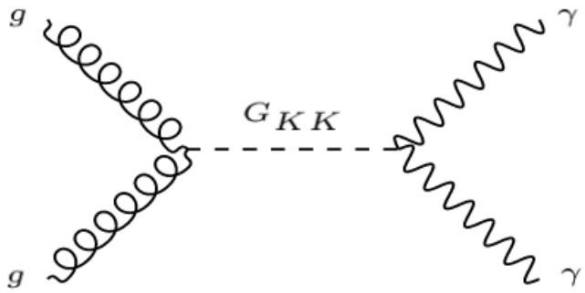
Outline

- Recent CMS results will be presented:
  - Search for microscopic black holes
  - High-mass diphoton nonresonant excess search
  - High-mass dijet angular distribution analysis

- Not covered: CMS searches for Dark Matter with mono-X signatures
  - See talk by Darien Wood

Nonresonant Exotic Physics Scenarios

- Contact Interactions:
  - If quarks/leptons are composite, at collision energies below the mass scale Λ of the new interaction, there is an effective 4-fermion contact interaction
- Large Extra Dimensions:
  - Modify gravity to solve Hierarchy Problem
  - Virtual graviton exchange between SM particles - small spacing of Kaluza-Klein states leads to nonresonant enhancement over SM



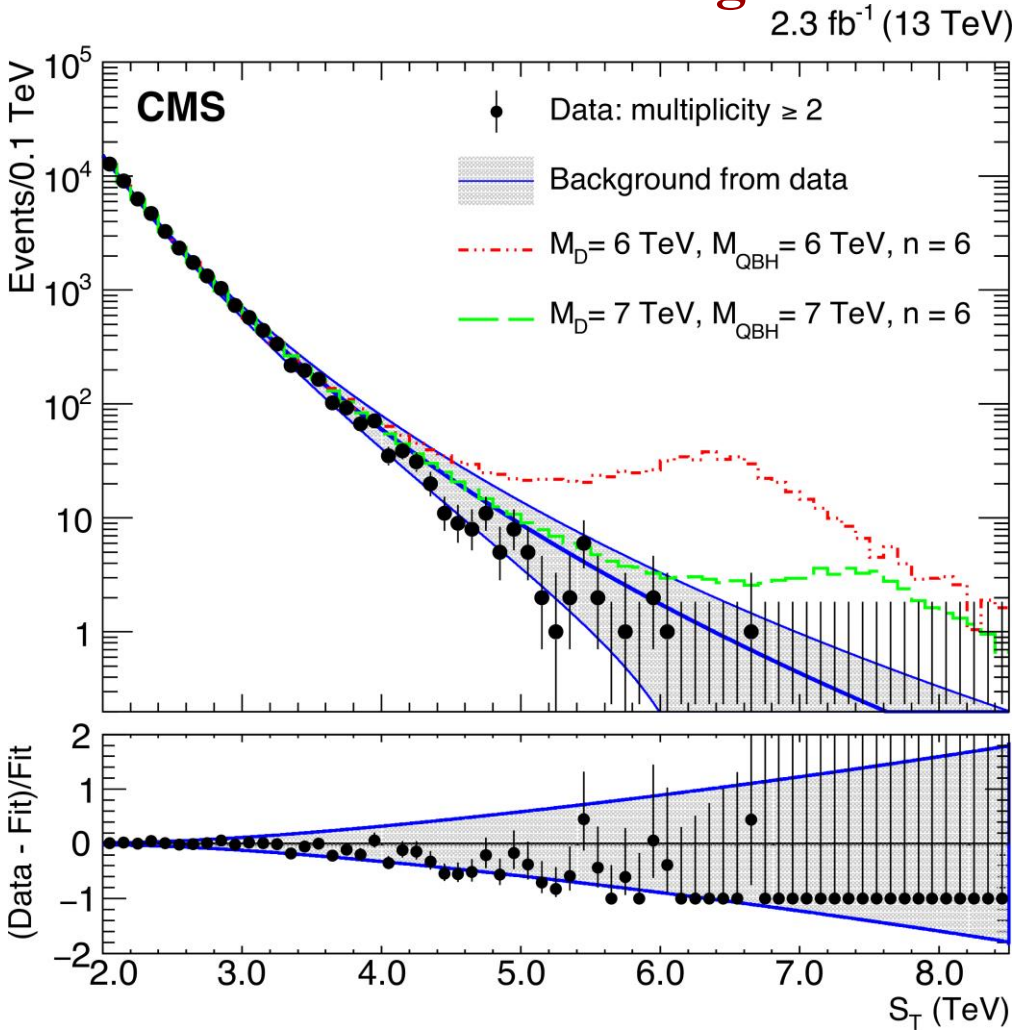
- Microscopic Black Holes:
  - If fundamental scale of modified gravity M_D < LHC collision energy, then micro Black Holes can be produced
  - Can decay (Hawking radiation) to large multiplicity of particles

Search for Microscopic Black Holes

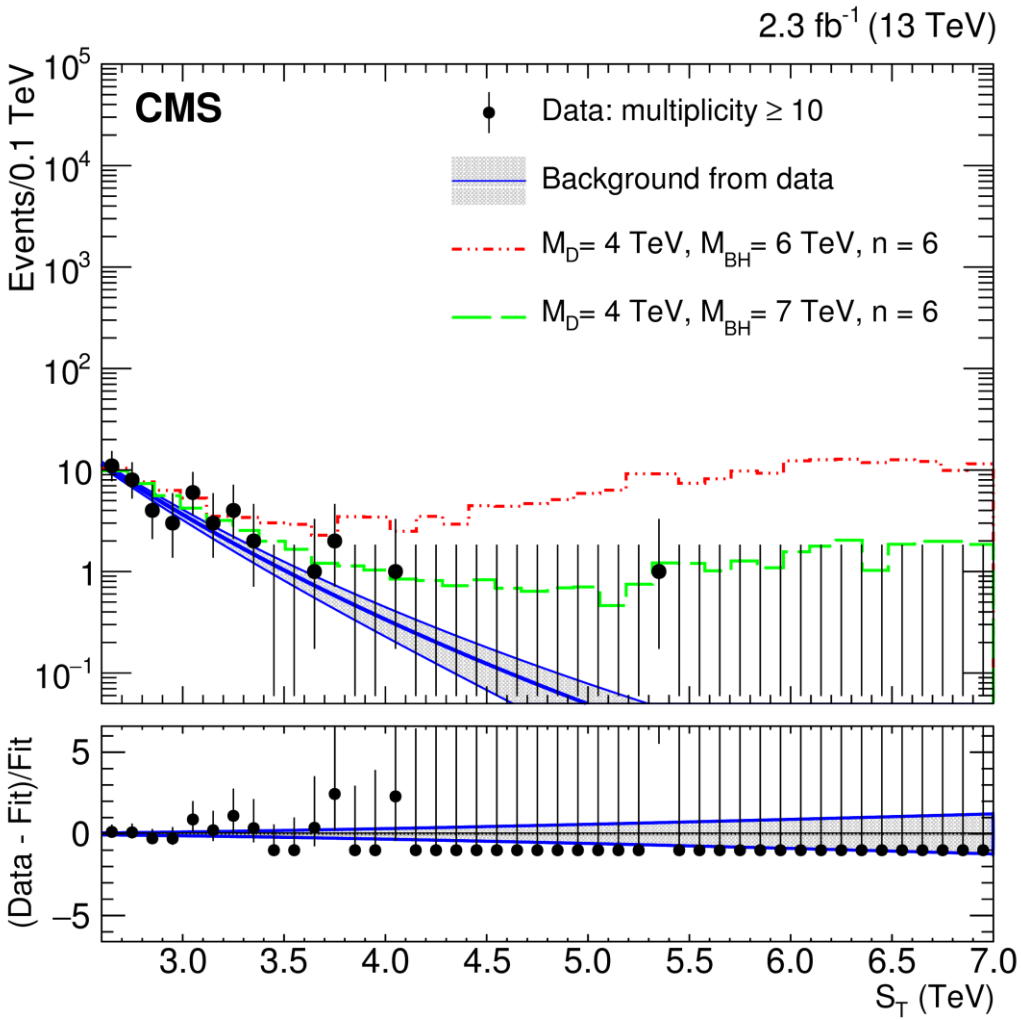
- Search at large S_T (sum of E_T of all objects in event) for nonresonant signatures of:
  - Semi-classical BH ($M_{BH} >> M_D$) → large multiplicity of objects produced
  - Also Quantum BH (QBH) with $M_{BH} \sim M_D$
- How to predict QCD background at large S_T and high object multiplicity?
- Answer: QCD S_T spectrum ~independent of object multiplicity N, so measure S_T distribution for N=2 events in data, then use as bkg prediction for larger N events

Black Holes Search: S_T Distributions

N=2 → Model SM Bkg



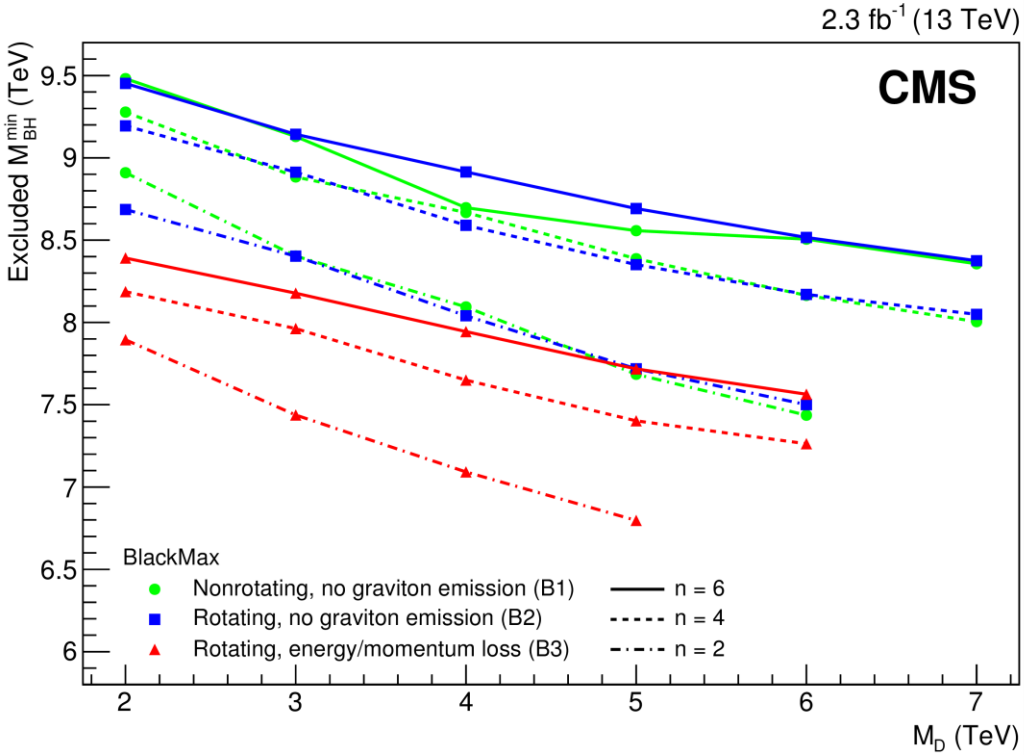
N>10 → Signal Region

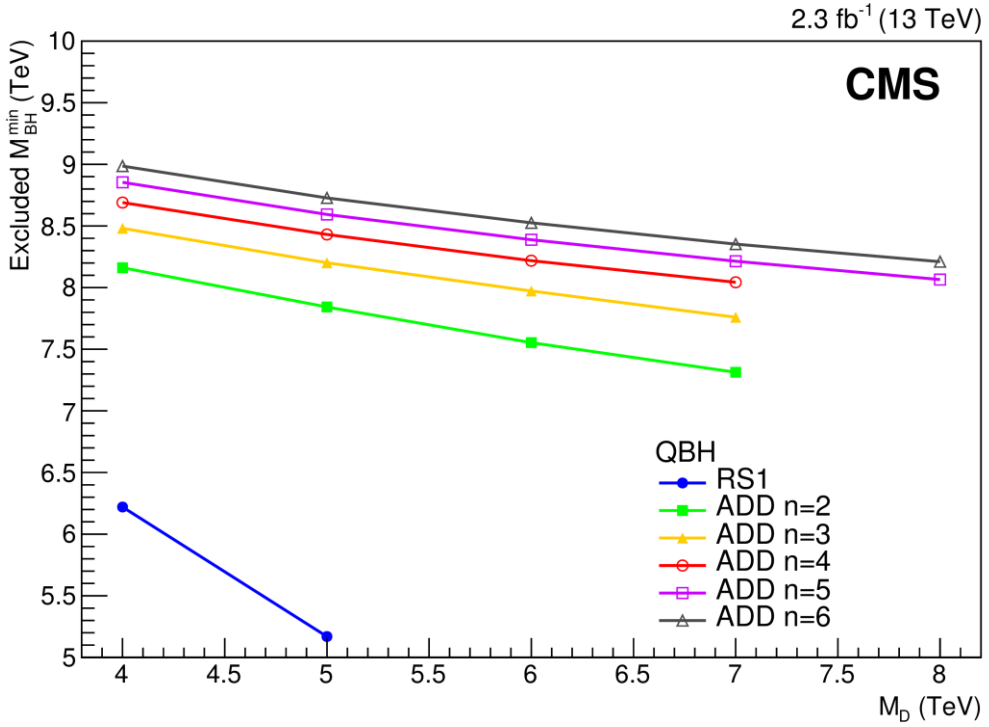


- Data agree with predictions

arXiv:1705.01403
Phys. Lett. B 774 (2017) 279

Black Holes Search: Limits



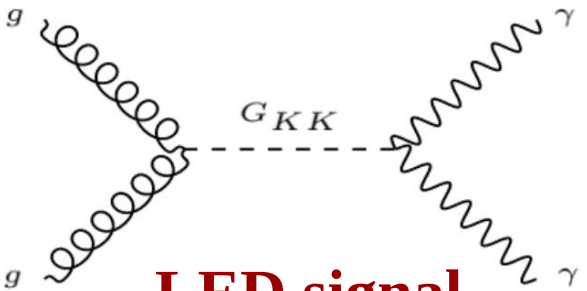


- Semiclassical (left) and Quantum (right) BH limits on min BH mass vs. M_D
- Limits generally in range 7-9 TeV, depending on M_D and BH decay models

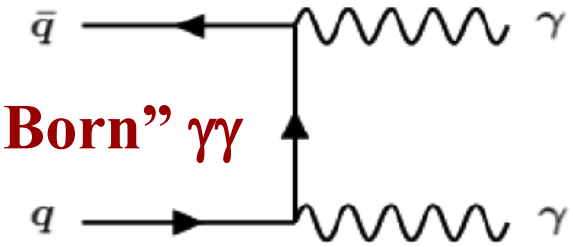
arXiv:1705.01403
Phys. Lett. B 774 (2017) 279

Nonresonant Diphoton Search

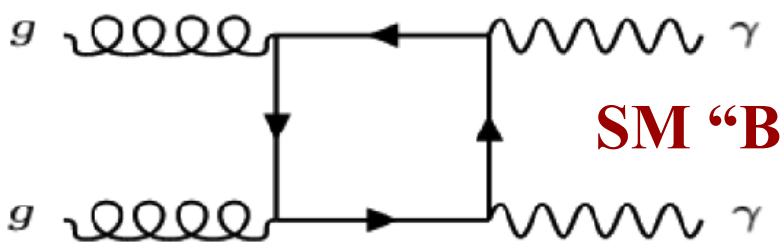
- A nonresonant excess in the high-mass diphoton spectrum could be signature of Large Extra Dimensions (LED), through virtual graviton exchange (sum over closely spaced KK graviton modes)
- SM $\gamma\gamma$ background prediction:
  - Real SM diphoton production NNLO (using MCFM)
  - Data-based estimate of misidentified photon contribution from jets



LED signal



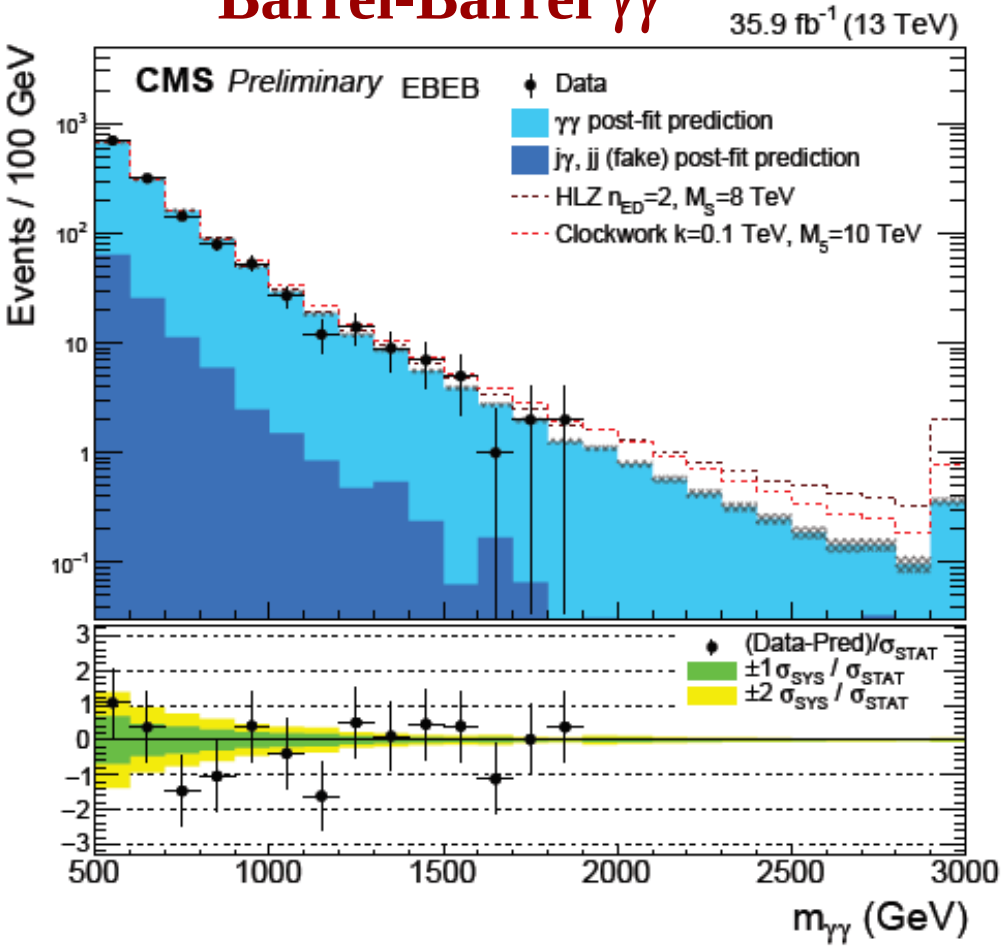
SM "Born" γγ



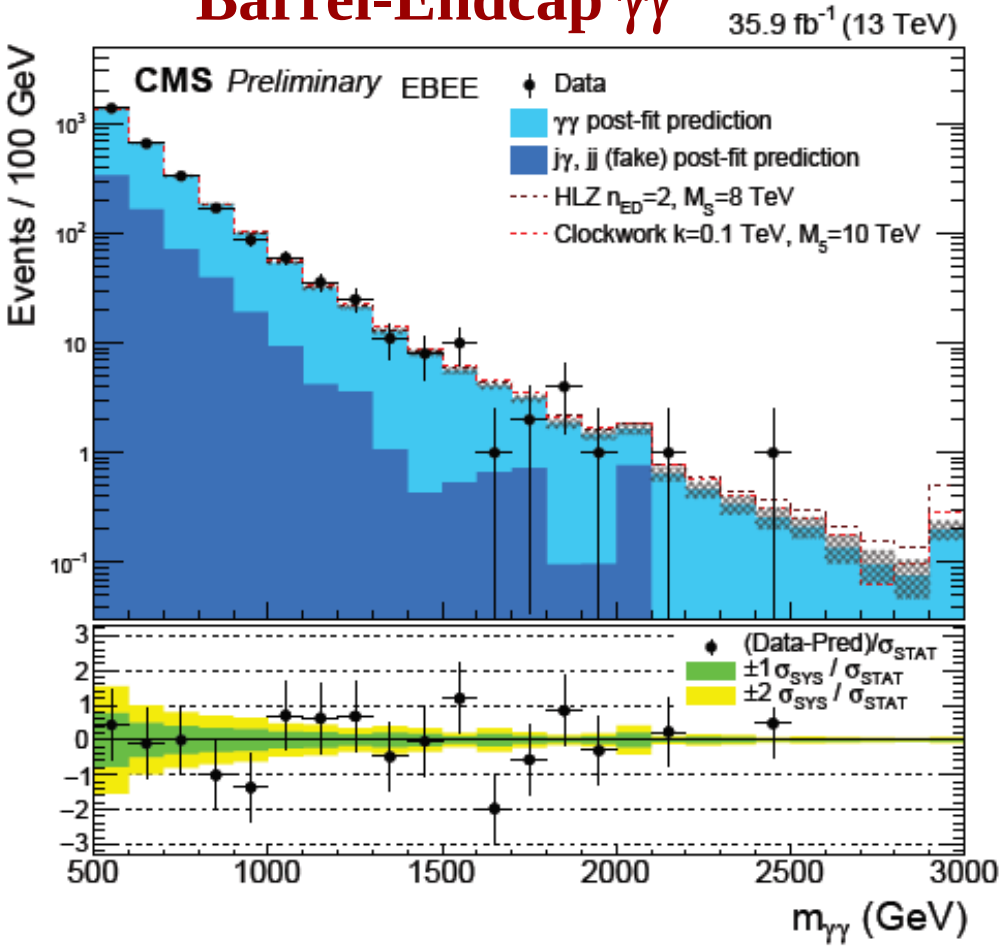
SM "Box" γγ

Nonresonant Diphoton Search: Results

Barrel-Barrel γγ



Barrel-Endcap γγ



- Diphoton mass spectrum agrees with SM predictions

CMS Physics Analysis Summary EXO-17-017 (May 2018)
CERN Doc Server: https://cds.cern.ch/record/2316245

Nonresonant Diphoton Search: Limits

- Exclusion lower limits on mass scale M_S (units of TeV) for various LED conventions:

Signal:	GRW	Hewett		HLZ					
		negative	positive	n_{ED}=2	n_{ED}=3	n_{ED}=4	n_{ED}=5	n_{ED}=6	n_{ED}=7
Expected:	$7.1^{+0.7}_{-0.5}$	$5.5^{+0.1}_{-0.3}$	$6.3^{+0.6}_{-0.4}$	$8.4^{+1.3}_{-1.1}$	$8.4^{+0.8}_{-0.6}$	$7.1^{+0.7}_{-0.5}$	$6.4^{+0.6}_{-0.5}$	$6.0^{+0.6}_{-0.4}$	$5.6^{+0.6}_{-0.4}$
Observed:	7.8	5.6	7.0	9.7	9.3	7.8	7.0	6.6	6.2

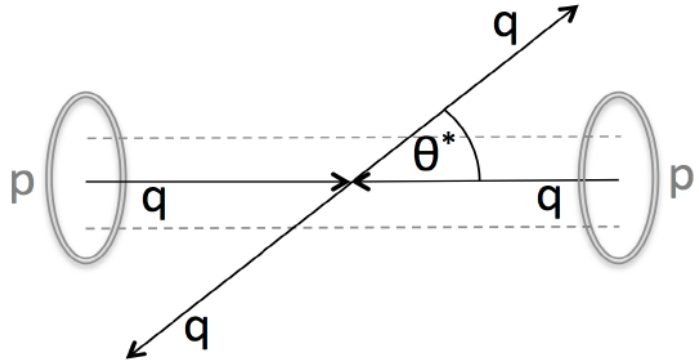
- First limits on Clockwork model: exclude fundamental scale $M_5 < 5$ TeV for 'spring' parameter k in range 2×10^{-4} – 2 TeV

CMS Physics Analysis Summary EXO-17-017 (May 2018)
CERN Doc Server: https://cds.cern.ch/record/2316245

Dijet Angular Distribution Analysis

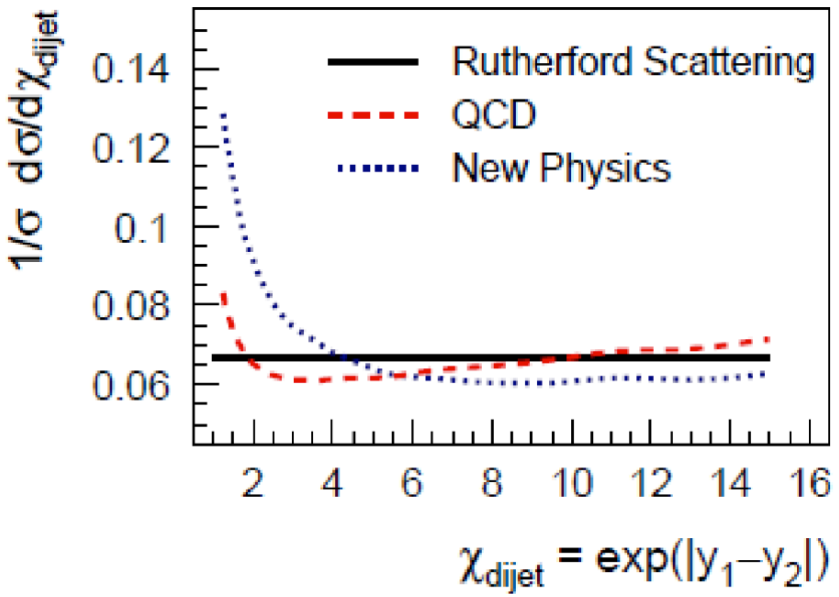
- Study distribution of dijet angular variable:

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

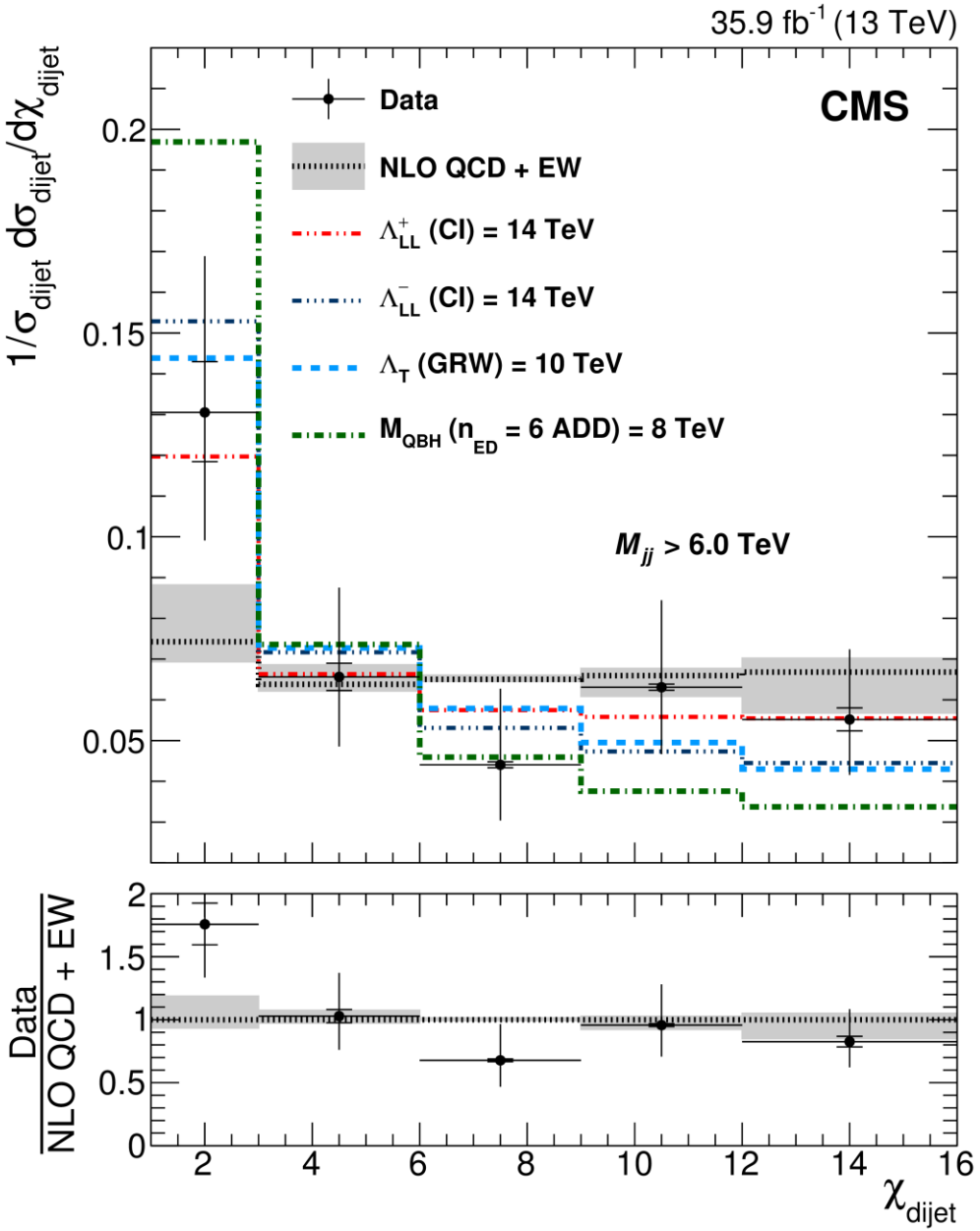


- QCD relatively flat in χ_{dijet} while new physics (NP) tends to populate low χ_{dijet}

→ good NP discriminator



Dijet Angular Distribution Results



- χ_{dijet} distribution in highest mass bin (M_{jj}>6 TeV)
- SM bkg is QCD at NLO
- Angular distributions in all mass bins found to be in agreement with SM predictions

arXiv:1803.08030
Submitted to Eur. J. Phys. C

Dijet Angular Distribution Limits

	Model	Observed lower limit (TeV)	Expected lower limit (TeV)
CI	$\Lambda^{+}_{\mathrm{LL/RR}}$	12.8	14.6 ± 0.8
	$\Lambda^{-}_{\mathrm{LL/RR}}$	17.5	23.5 ± 3.0
	$\Lambda^{+}_{\mathrm{VV}}$	14.6	16.4 ± 0.8
	$\Lambda^{-}_{\mathrm{VV}}$	22.4	30.7 ± 3.7
	$\Lambda^{+}_{\mathrm{AA}}$	14.7	16.5 ± 0.8
	$\Lambda^{-}_{\mathrm{AA}}$	22.3	30.6 ± 3.8
	$\Lambda^{+}_{(\mathrm{V-A})}$	9.2	11.5 ± 1.0
	$\Lambda^{-}_{(\mathrm{V-A})}$	9.3	11.8 ± 1.1
ADD	Λ_{T} (GRW)	10.1	11.4 ± 0.9
	M_{S} (HLZ) $n_{\mathrm{ED}} = 2$	10.7	12.4 ± 1.0
	M_{S} (HLZ) $n_{\mathrm{ED}} = 3$	12.0	13.6 ± 1.1
	M_{S} (HLZ) $n_{\mathrm{ED}} = 4$	10.1	11.4 ± 0.9
	M_{S} (HLZ) $n_{\mathrm{ED}} = 5$	9.1	10.3 ± 0.8
	M_{S} (HLZ) $n_{\mathrm{ED}} = 6$	8.5	9.6 ± 0.8
QBH	M_{QBH} (ADD $n_{\mathrm{ED}} = 6$)	8.2	8.5 ± 0.4
	M_{QBH} (RS $n_{\mathrm{ED}} = 1$)	5.9	6.3 ± 0.7
DM	Vector/Axial-vector M_{Med}	2.0–4.6	2.0–5.5

arXiv:1803.08030

Submitted to Eur. J. Phys. C

Summary

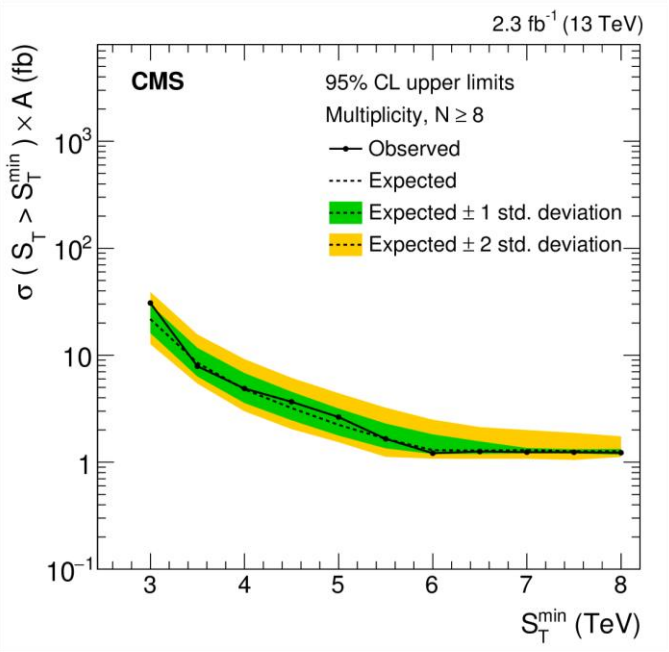
- Recent CMS results on searches for nonresonant new physics in 13 TeV pp collisions have been presented:
  - Search for microscopic Black Holes
  - Search for nonresonant diphoton excess at high mass
  - Study of dijet angular distributions at high mass
- So far, all data found to be consistent with SM predictions, but with LHC Run 2 data, we are generally starting to probe new physics mass scales ~ 10 TeV
- More results expected soon!

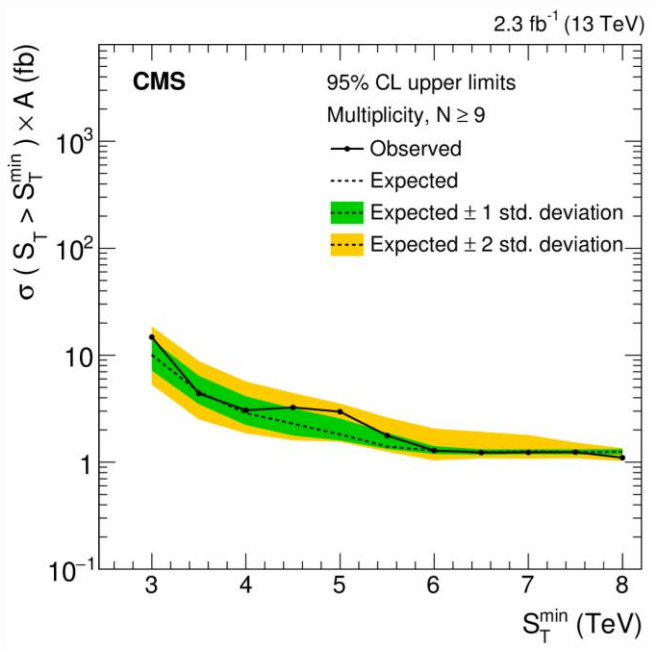
Backup

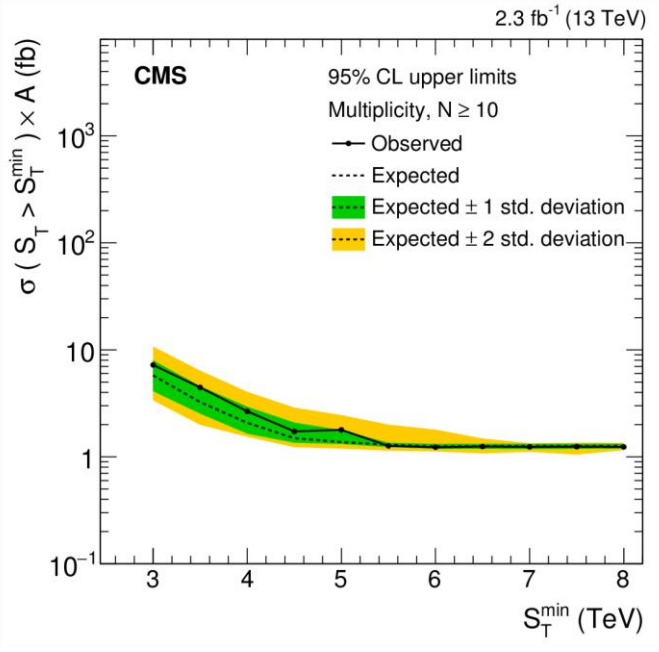
Black Holes: Syst. Uncertainties

Uncertainty	Effect on signal acceptance	Effect on background estimate
JES	±5%	—
JER	±4%	—
PDF	±6%	—
FSR	±1.2%	—
Integrated luminosity	±2.7%	—
Background normalization	—	±(0.5–5.2)%
Background shape	—	±(1–200)%,
Potential S_T noninvariance	—	±5%

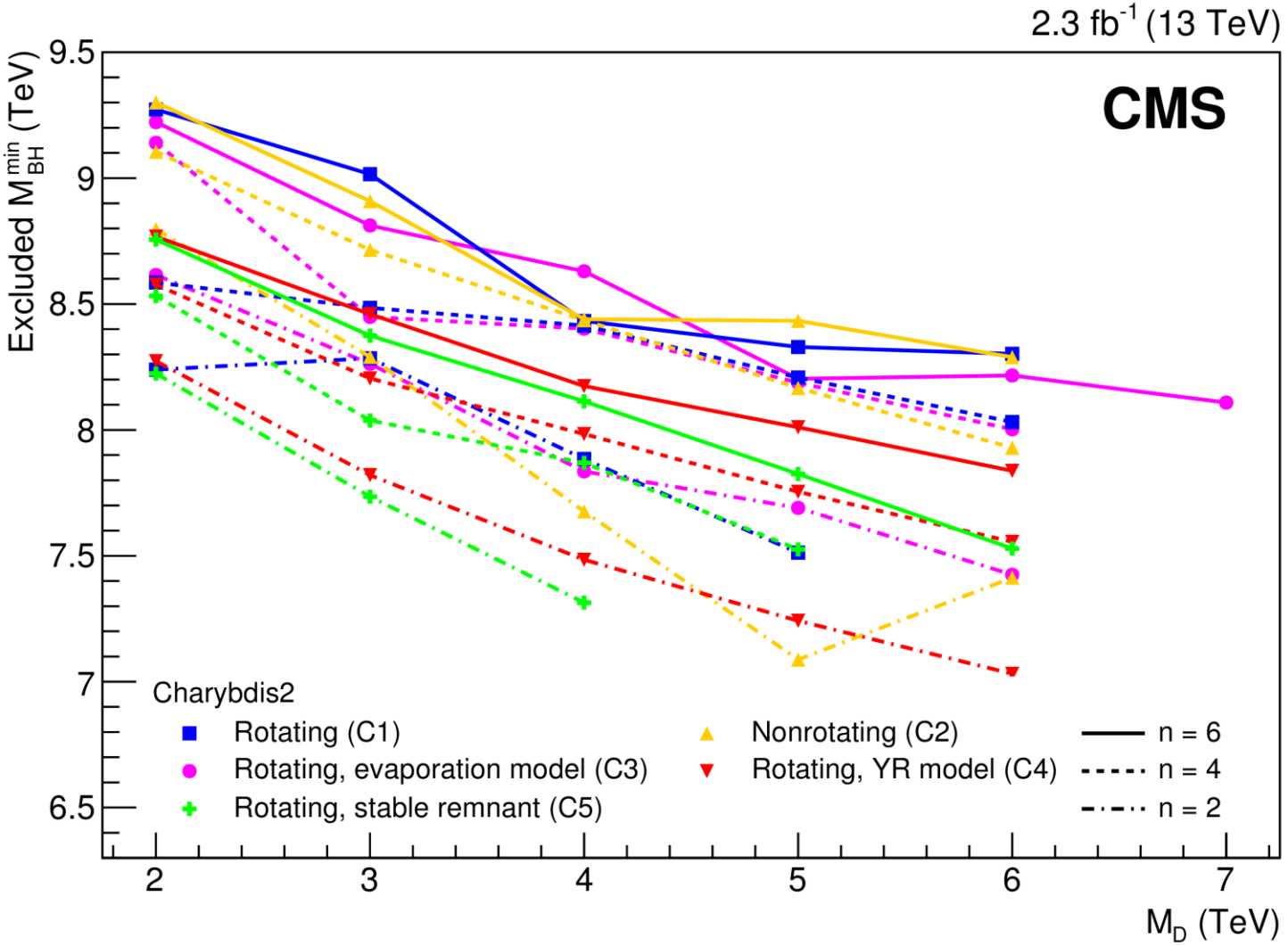
Black Holes: Model-Independent Limits



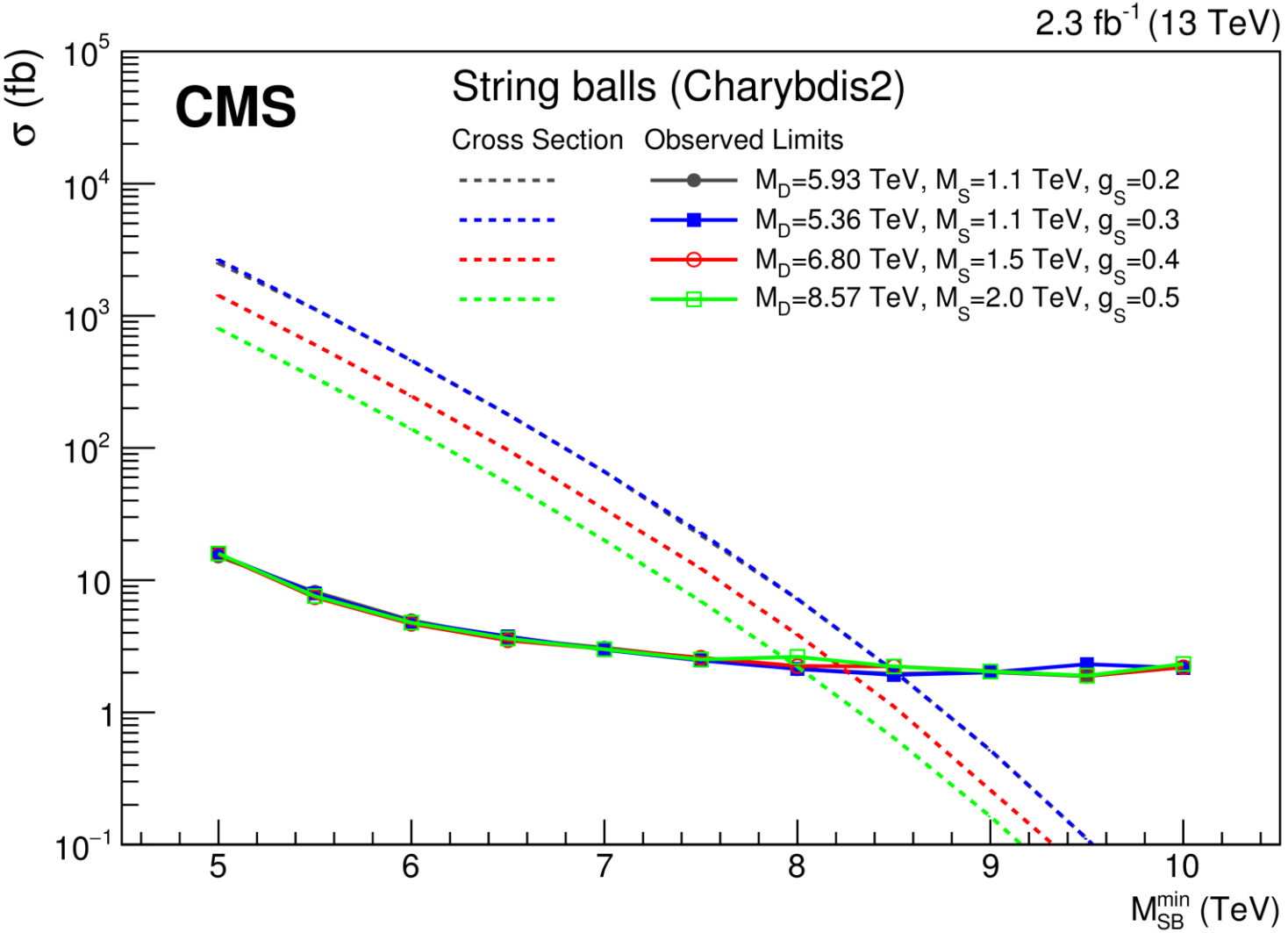




Black Holes: Semiclassical BH Limits



Black Holes: String Balls Limits

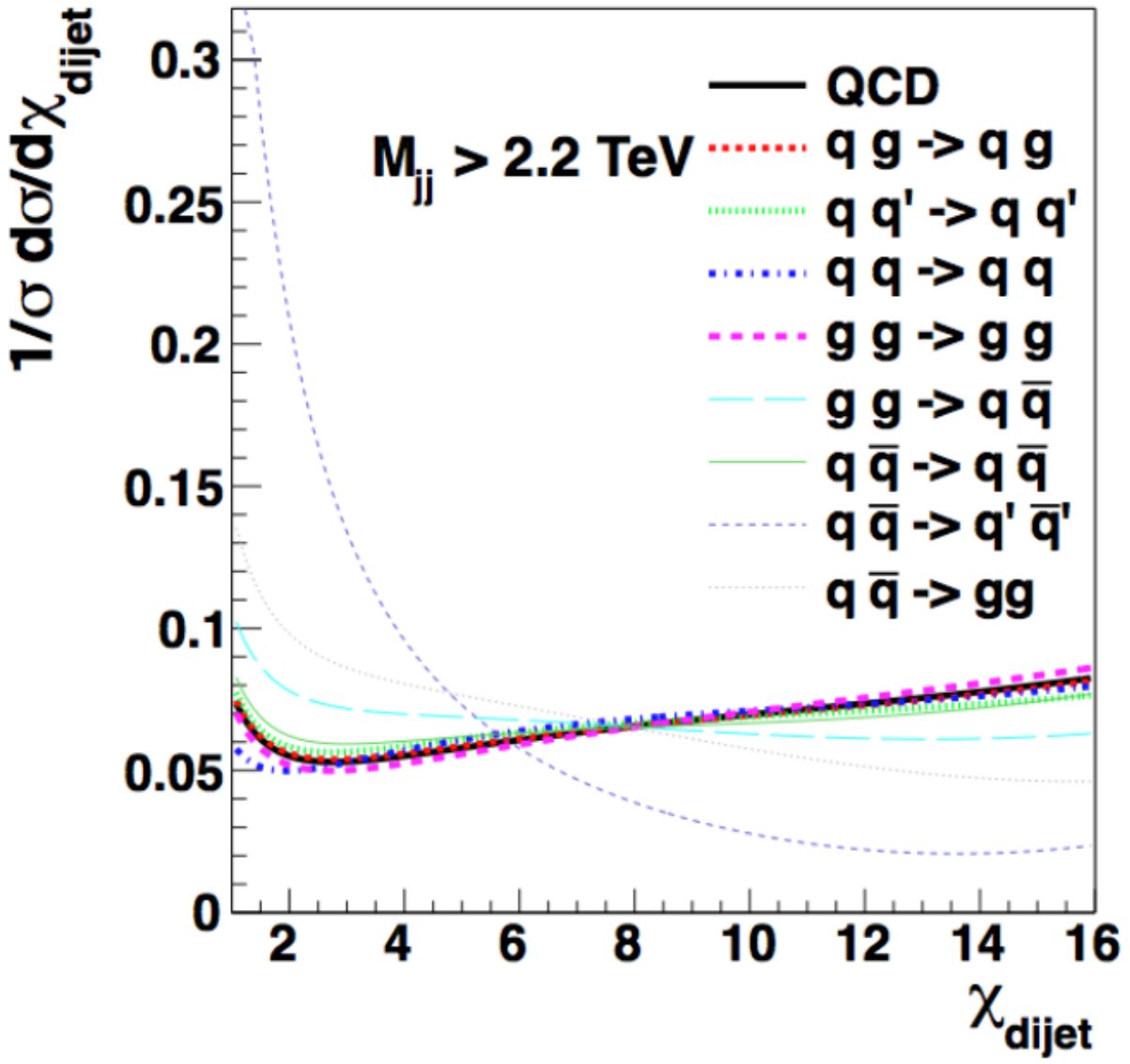


Dijet Angular Distributions: Analysis

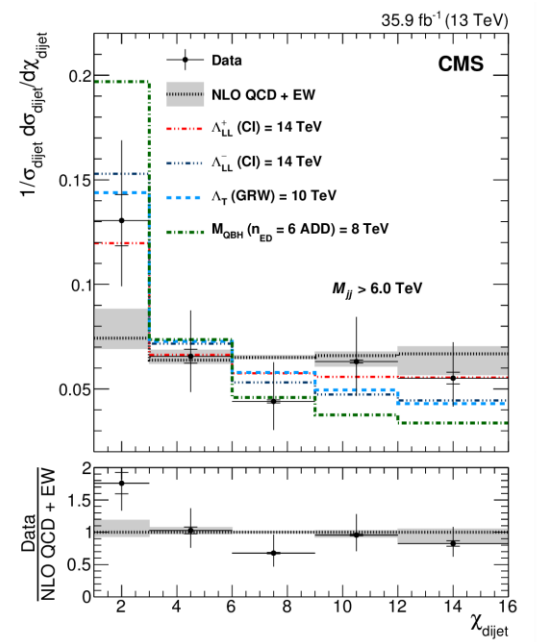
- Trigger: jet p_T>450 GeV, OR H_T> 900 GeV
- Offline: jet |y|<2.5; jet p_T>200 GeV; M_{jj}>2.4 TeV
- QCD Bkg: NLOjet++ 4.1.3
- Signal simulations:
  - DM: MADDM
  - Contact Interactions: CIJET 1.0
  - Large Extra Dimensions: Pythia 8
  - Quantum Black Holes: QBH 3.0

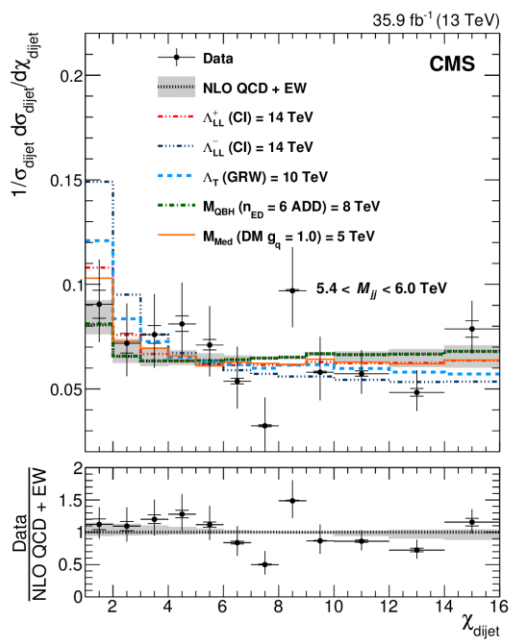
Dijet Angular Distributions: QCD Bkg

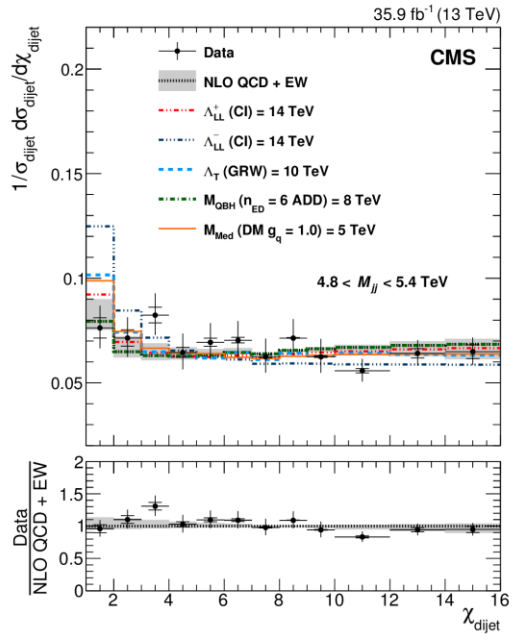
- Dominant QCD processes relatively flat in χ_{dijet}
- Makes the variable less sensitive to PDFs



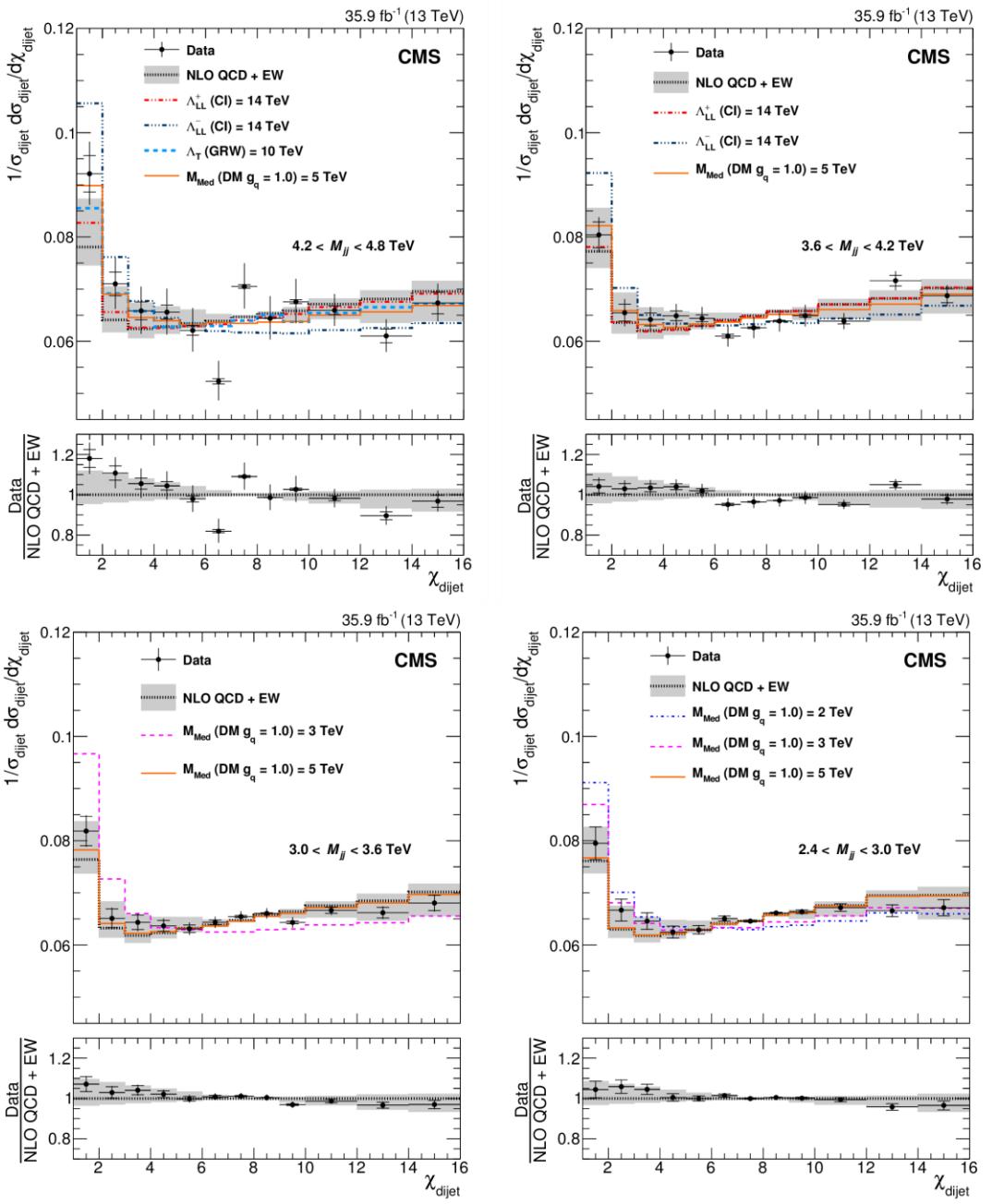
Dijet Angular Distributions: All M bins







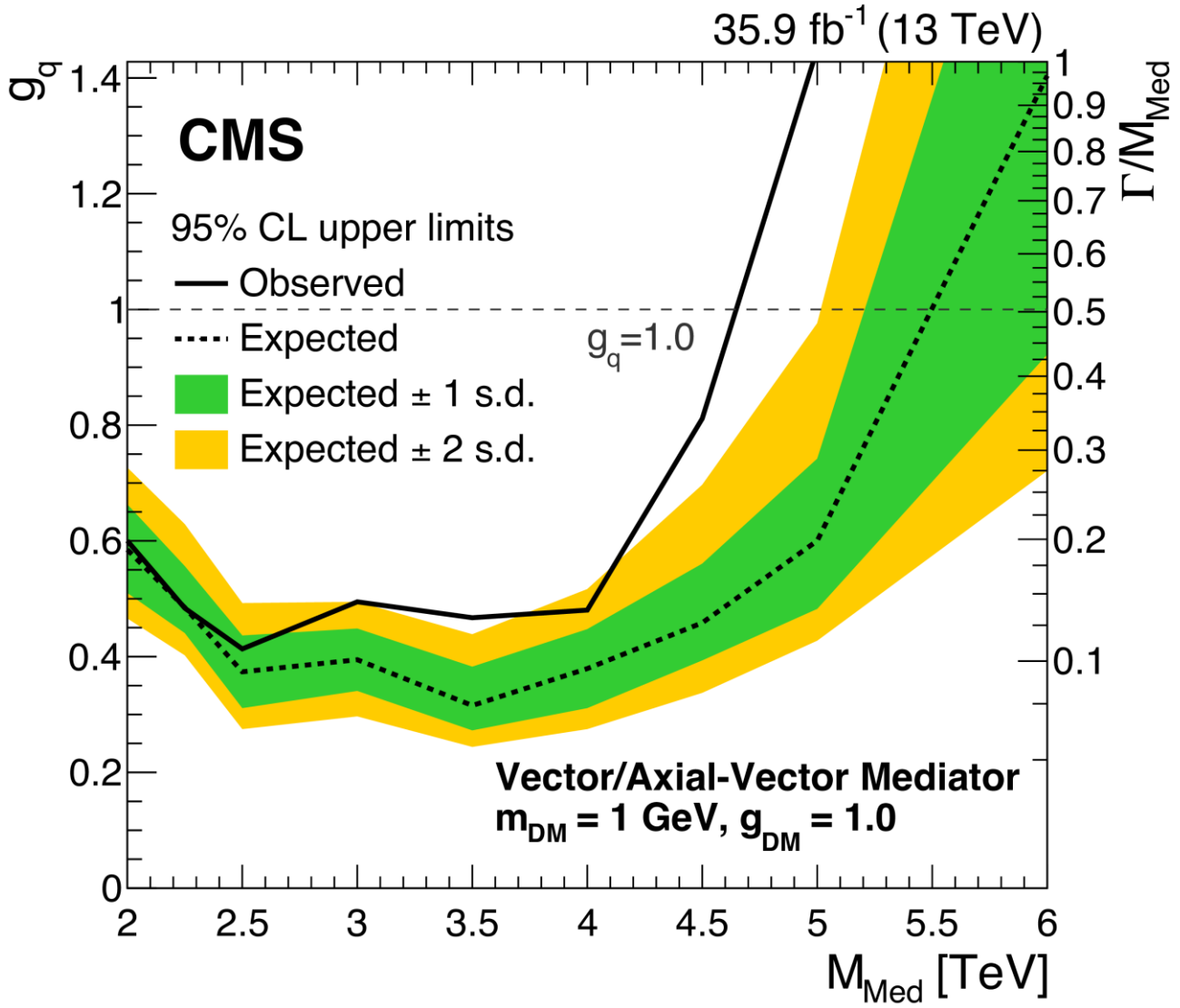
Dijet Angular Distributions: All M bins



Dijet Angular Distributions: Syst. Uncertainties

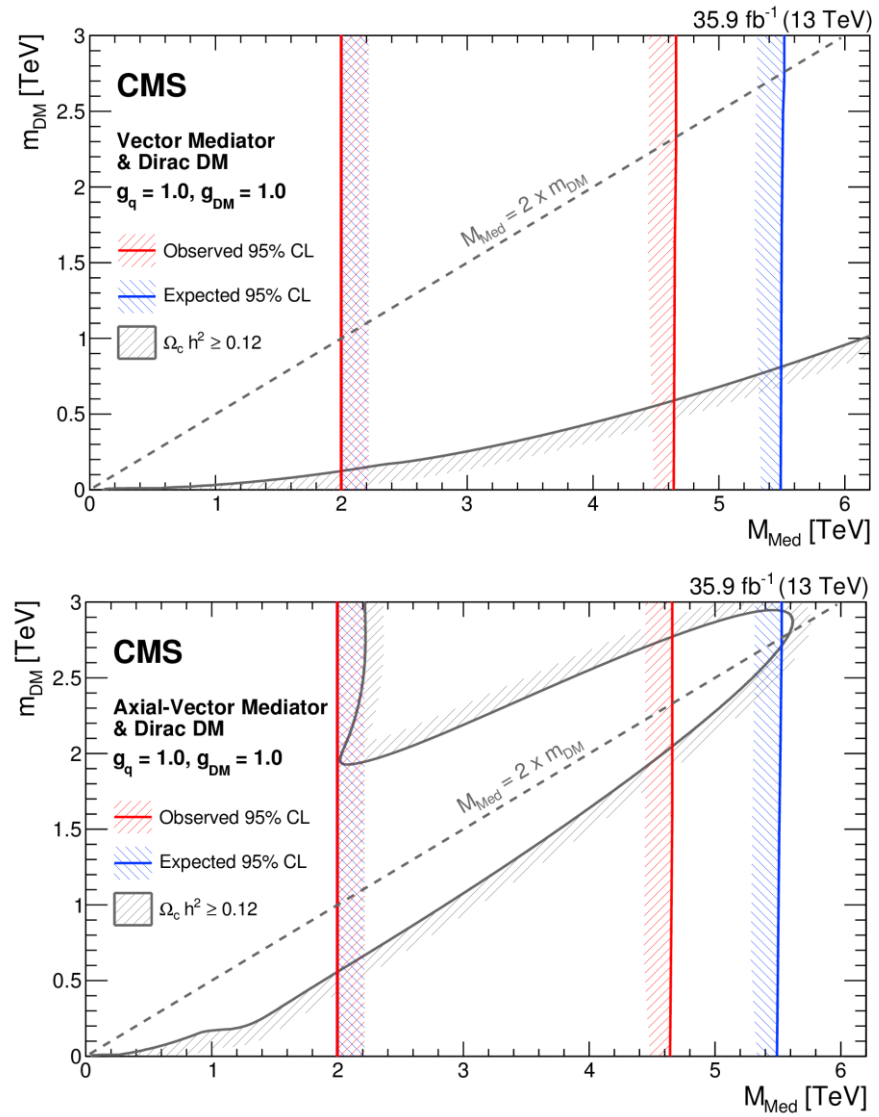
Source of uncertainty	$2.4 < M_{jj} < 3.0\,\text{TeV}$	$M_{jj} > 6.0\,\text{TeV}$
Statistical	0.7	27
JES	3.6	9.2
Jet p_T resolution (core)	1.0	1.0
Jet p_T resolution (tails)	1.0	1.5
Unfolding, modeling	0.2	1.5
Unfolding, detector simulation	0.5	1.0
Total experimental	4.1	29
QCD NLO scale (6 changes in μ_r and μ_f)	$^{+8.5}_{-3.0}$	$^{+19}_{-5.8}$
PDF (CT14 eigenvectors)	0.2	0.6
Total theoretical	8.5	19

Dijet Angular Distributions: DM Limits



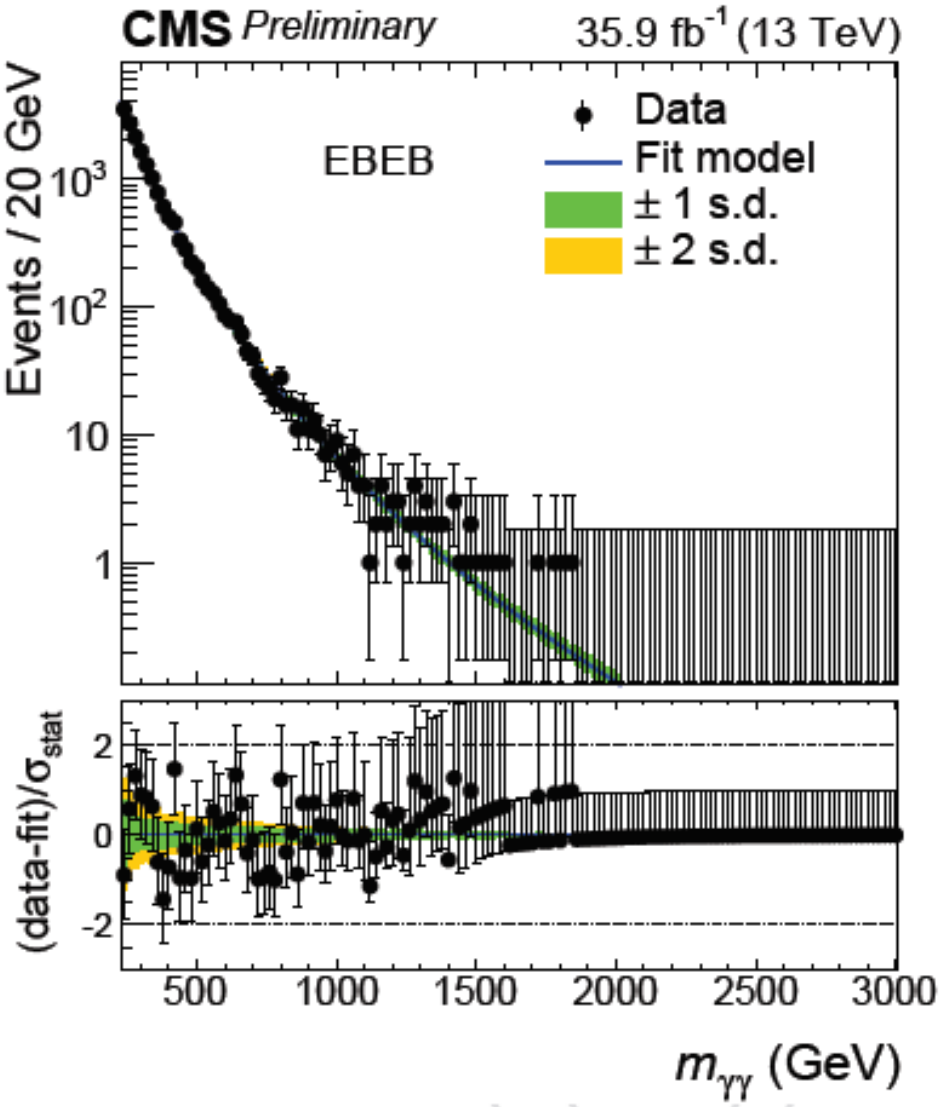
Limits on quark coupling as function of mass for axial-vector or vector DM mediator

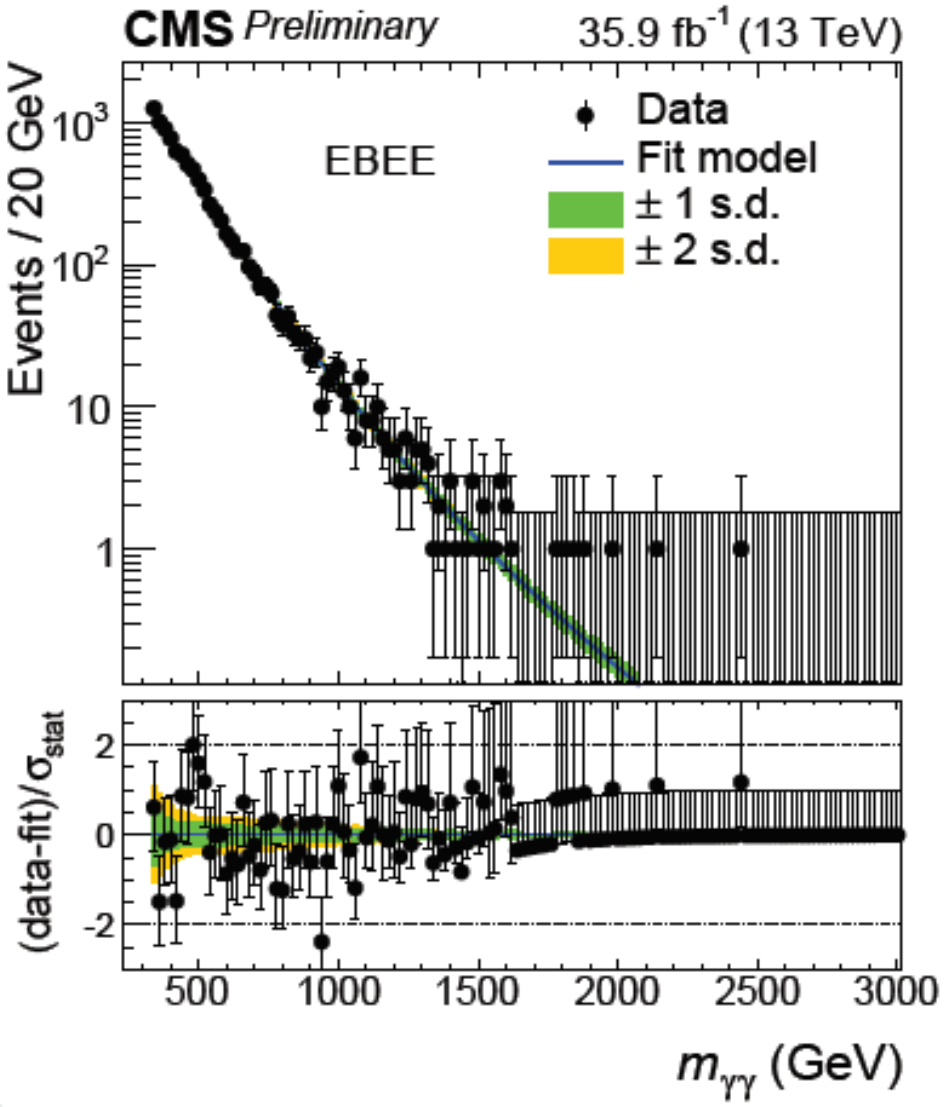
Dijet Angular Distributions: DM Limits



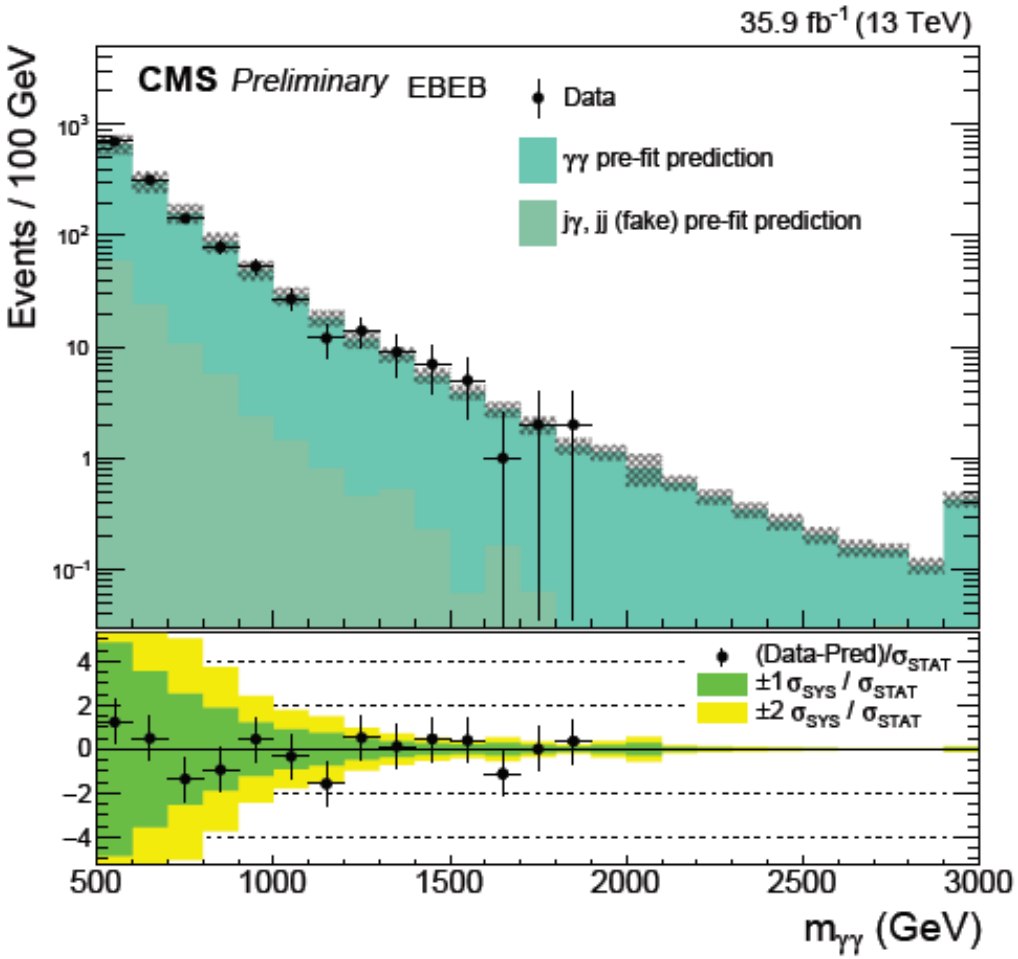
Exclusion regions in plane of $m_{DM} - M_{Med}$.

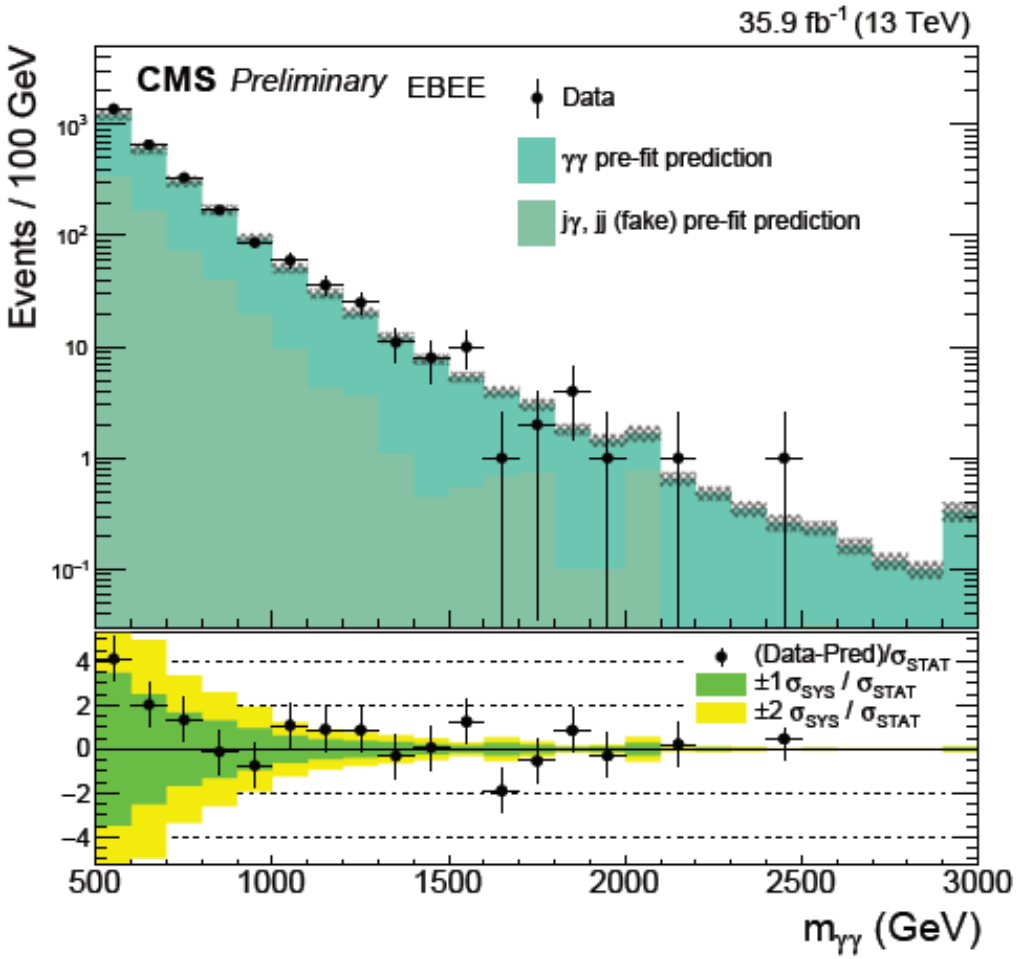
Resonant Diphoton Spectrum





Nonresonant Diphotons: Pre-fit Spectrum





Nonresonant Diphoton: Clockwork Limits