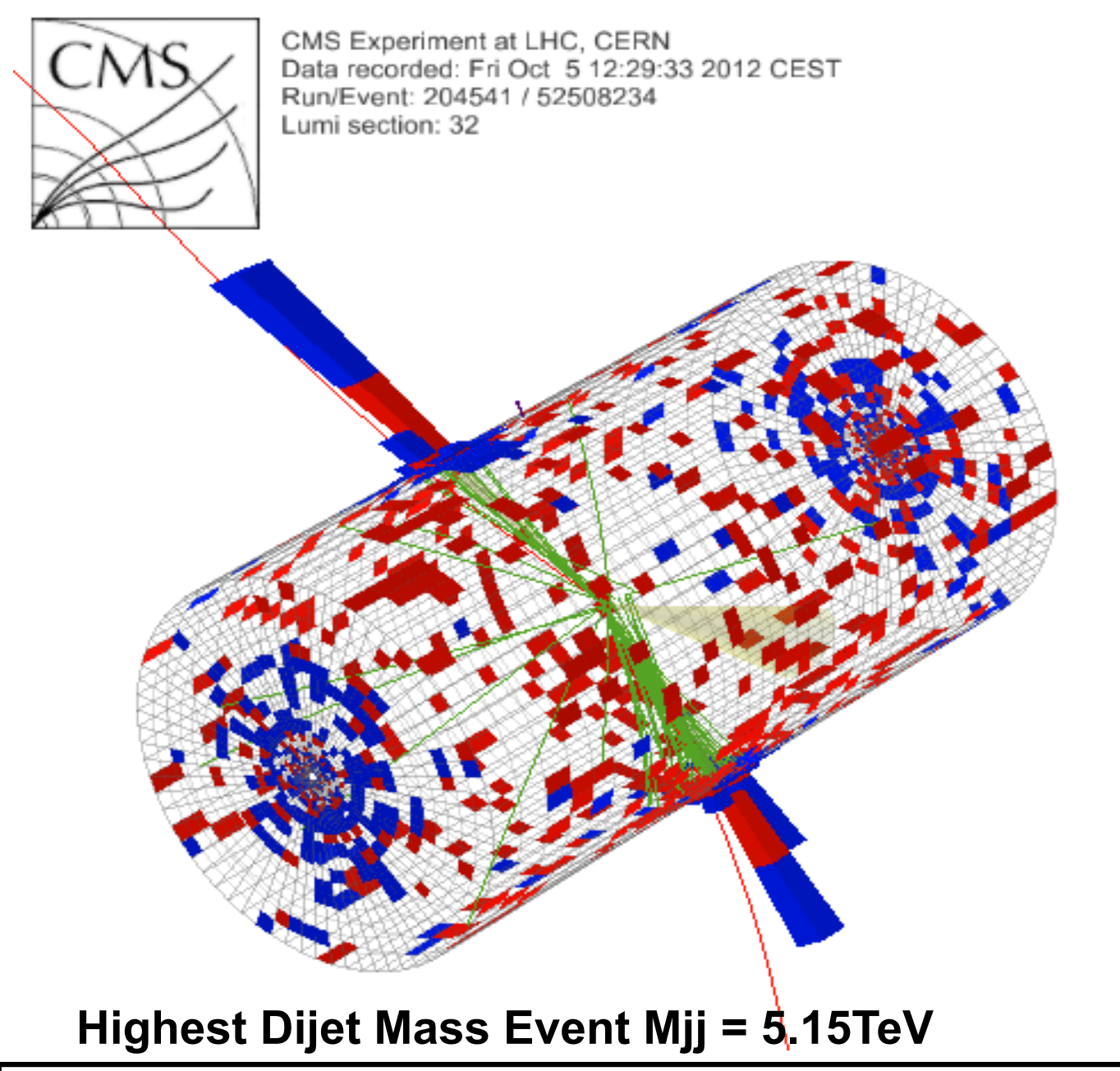

Highest Dijet Mass Event Mjj = 5.15TeV

Search for resonances and quantum black holes using the dijet mass spectrum in pp collisions at √s = 8 TeV

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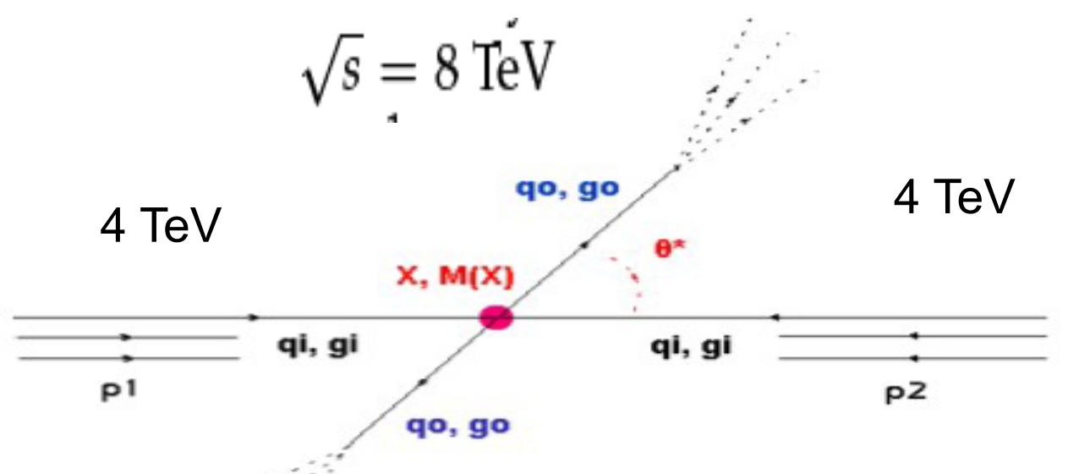
On the behalf of CMS Collaboration

http://arxiv.org/abs/1501.04198

MOTIVATION

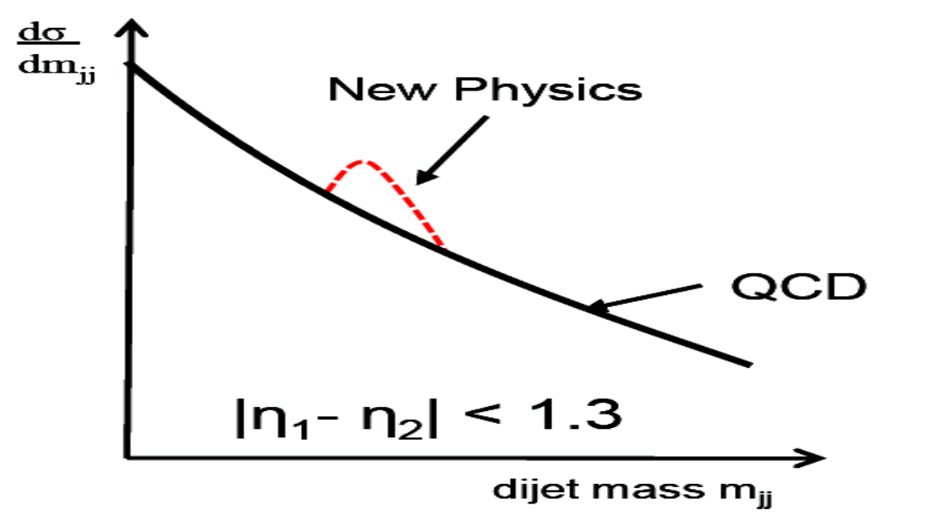
- Search for
  - Narrow dijet resonances decaying to quark-quark(qq), quark-gluon(qg), gluon-gluon(gg) where the resonance width is negligible compared to the experimental dijet mass resolution,
  - Narrow qq and gg resonances using the observed dijet resonance line shape of the RS graviton model for $k/M_{Pl} = 0.1$, which corresponds to a natural width equal to 1.5% of the resonance mass.
  - Narrow resonances decaying to b quarks,
  - Wide dijet resonances that are not narrow compared to the detector resolution, in qq and gg final states,
  - Wide qq and gg resonances using the dijet resonance line shape of the RS graviton model with larger values of k/M_{Pl}, which corresponds to natural widths varying between 5% and 30% of the resonance mass.
  - Quantum black holes decaying to two jets



$$\Delta\eta_{12} = |\eta_{jet1} - \eta_{jet2}| = \ln\frac{1+|\cos\theta^*|}{1-|\cos\theta^*|}$$

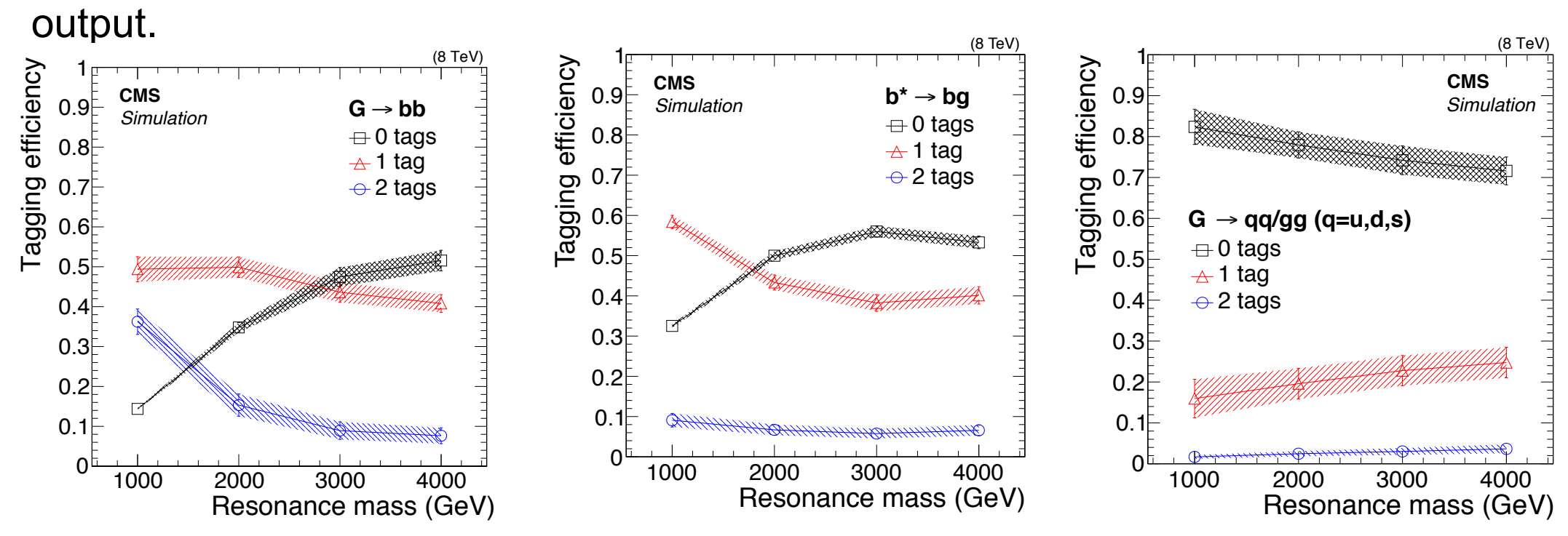
- Several benchmark models of dijet resonances produced via the s channel

Model Name	X	Color	J^P	$\Gamma/(2M)$	Chan
Excited Quark	q*	Triplet	$1/2^+$	0.02	qg
E_6 Diquark	D	Triplet	0^+	0.004	qq
Axigluon	A	Octet	1^+	0.05	$q\bar{q}$
Coloron	C	Octet	1^-	0.05	$q\bar{q}$
RS Graviton	G	Singlet	2^+	0.01	$q\bar{q}$, gg
Heavy W	W'	Singlet	1^-	0.01	$q\bar{q}$
Heavy Z	Z'	Singlet	1^-	0.01	$q\bar{q}$
String	S	mixed	mixed	$0.003-0.037$	$q\bar{q}$, gg and qg

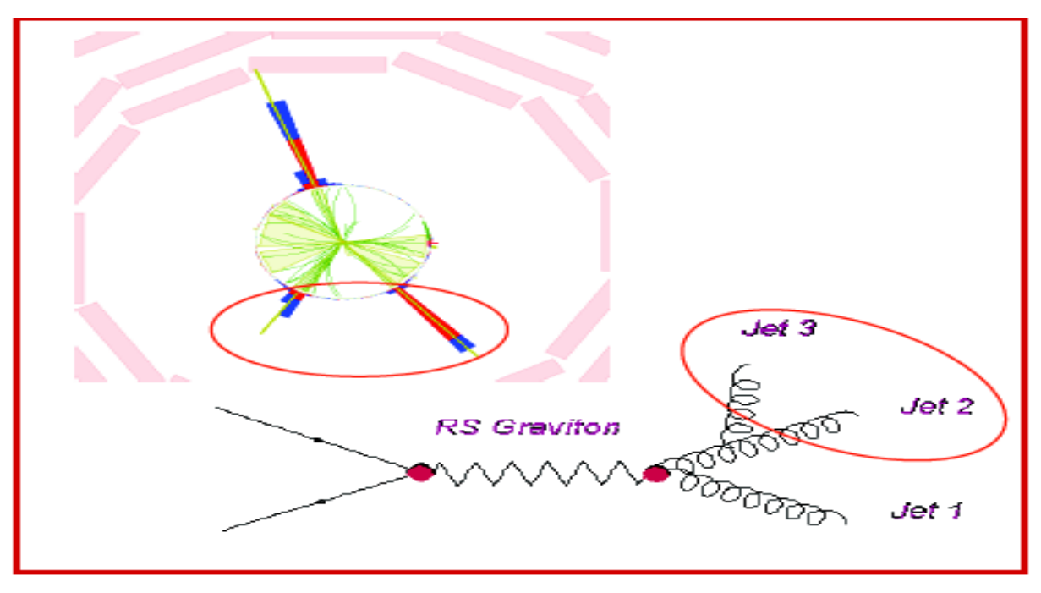


SELECTION STRATEGY AND WIDE JET ALGORITHM

- Dijet system = two leading wide jets which satisfies |Δη|<1.3 and reconstructed in the region |η|<2.5 (suppresses QCD background)
- $m = \sqrt{(E_1 + E_2)^2 - (p_1 + p_2)^2}$
- Events with dijet mass (formed from the two wide jets) > 890 GeV because of 99.7% efficiency of L1 and HLT.
- Applying the loose version of the combined secondary-vertex (CSV) algorithm to the two leading jets to categorized as 0b, 1b, or 2b according to the algorithm output.



Tagging efficiencies for 0, 1, and 2 b tags selections as a function of the resonance mass for bb, bg, and qq/gg (where q=u,d,s) decay modes. The hatched regions represent uncertainties in the tagging efficiencies due to the variation of the b-tag scale factors within their uncertainties.

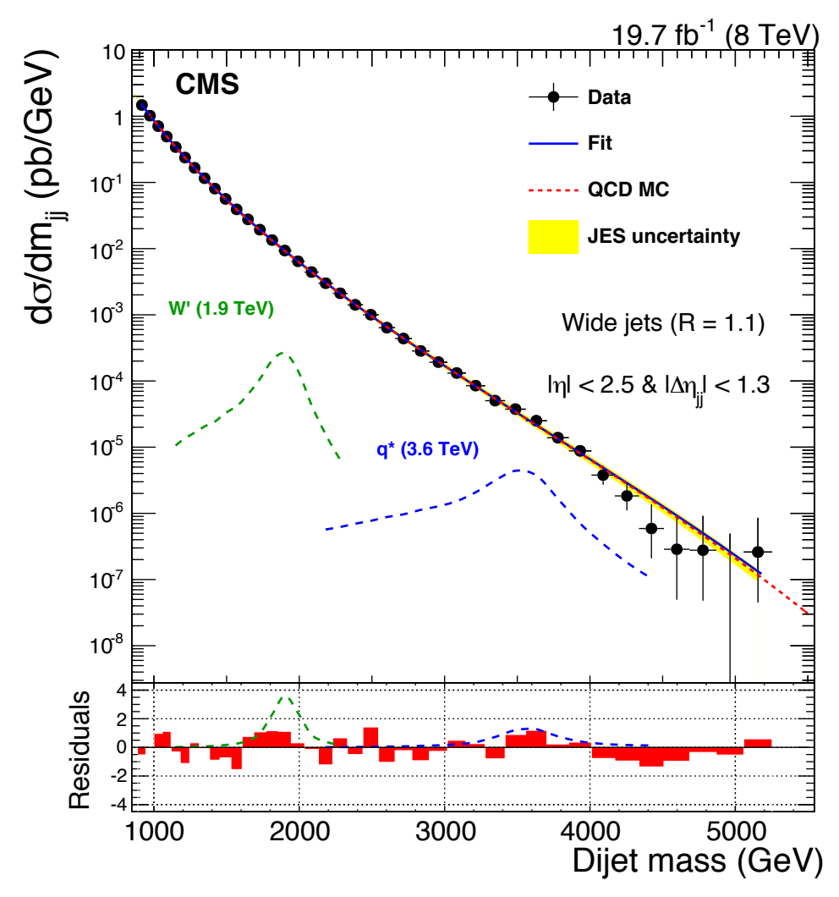


Wide jet algorithm:

Require two leading AK5 PF jets to have pT>30 GeV and |η|<2.5, and to pass tight PF jet ID
All other AK5 PF jets with pT>30 GeV, |η|<2.5, and passing loose PF jet ID added to the closest leading jet if within ΔR<Rwide=1.1

Wide jet algorithm developed to improve the dijet mass resolution for heavy resonances

DIJET MASS SPECTRUM AND FIT

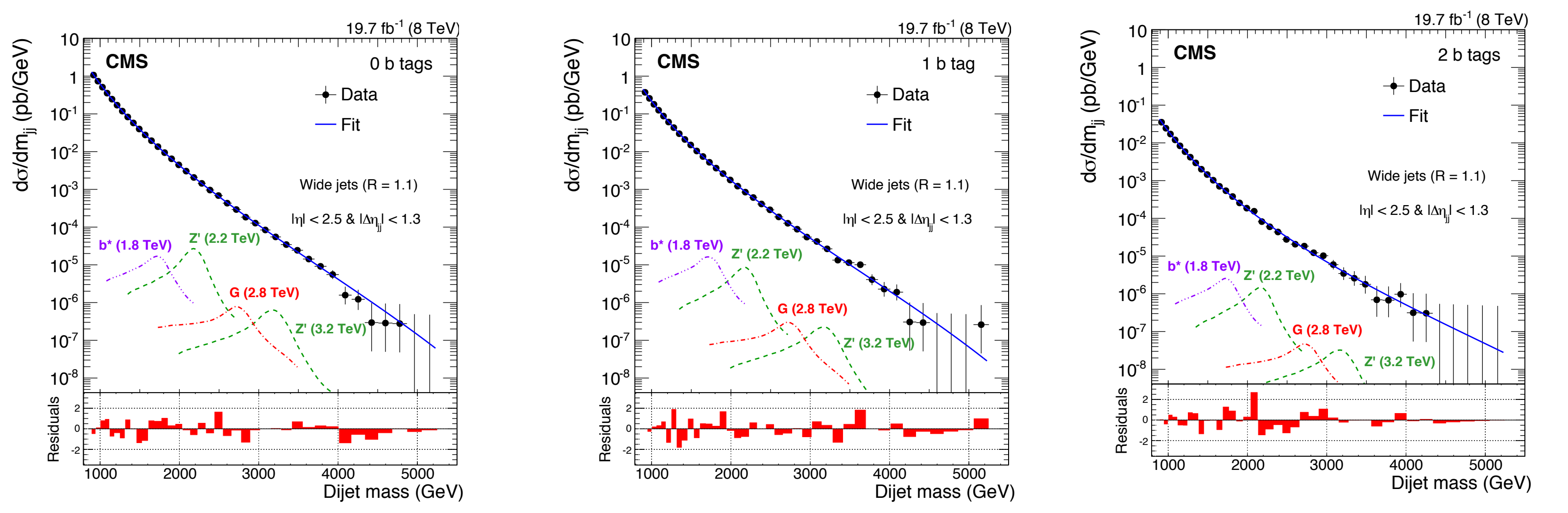


- Fit the following parameterization to the data and compare to QCD prediction using the full CMS simulation and signal resonances.

$$\frac{d\sigma}{dm} = \frac{P_0(1 - m/\sqrt{s})^{P_1}}{(m/\sqrt{s})^{P_2 + P_3 \ln(m/\sqrt{s})}}$$

where m is the dijet mass, four free parameters P_0, P_1, P_2, P_3 and $\sqrt{s} = 8$ TeV .

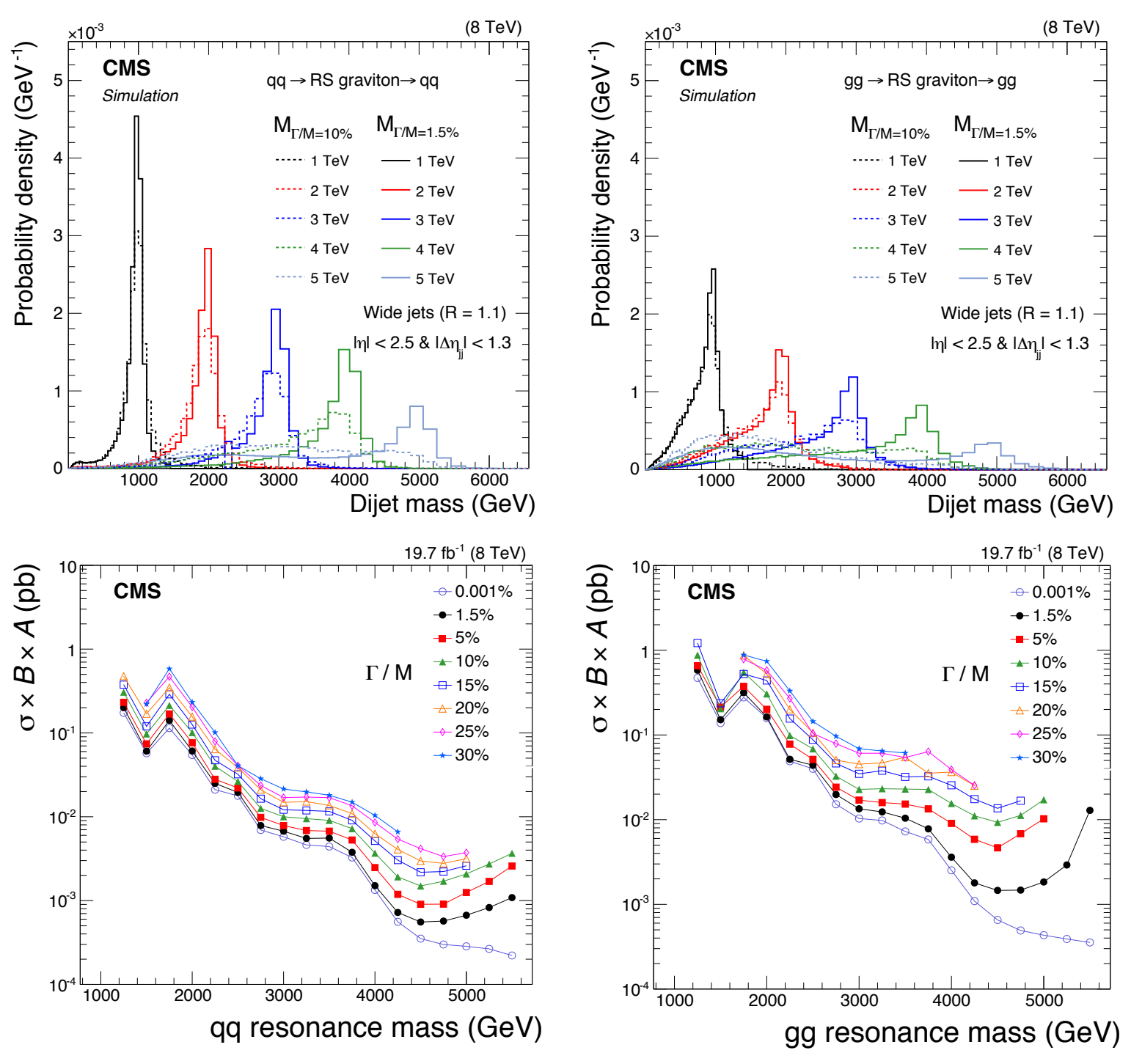
Inclusive dijet mass spectrum from wide jets (points) compared to a fit (solid line) and to predictions including detector simulation of multijet events and signal resonances. The predicted multijet shape has been normalized to the data. The vertical error bars are statistical only and the horizontal error bars are the bin widths. The bin-by-bin fit residuals normalized to the statistical uncertainty of the data, (data-fit)/σ_{data}, are shown.

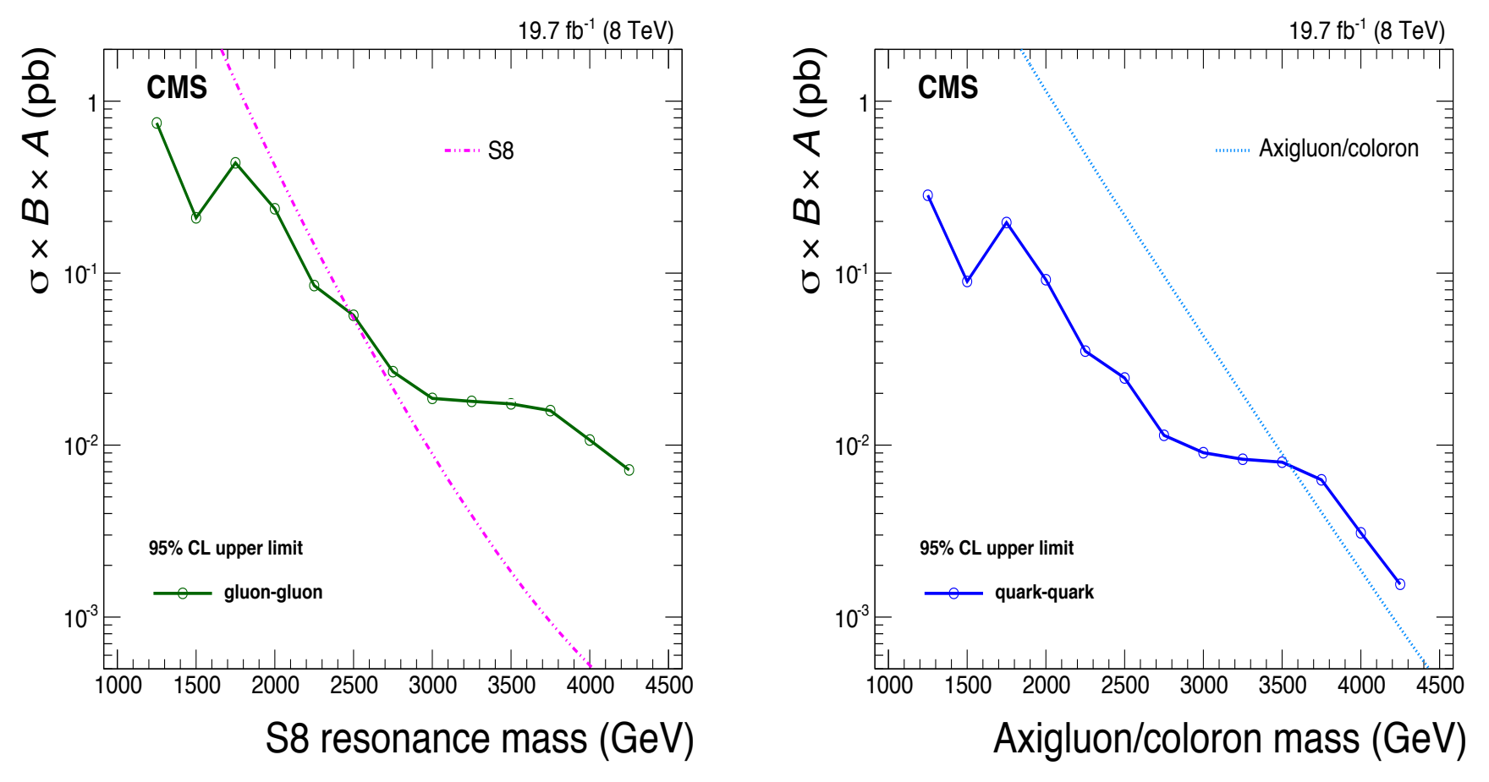


Dijet mass spectra (points) in different b-tag multiplicity bins compared to a fit (solid line). Predictions for RS graviton, Z', and excited b-quark signal spectra are also shown. The vertical error bars are statistical only and the horizontal error bars are the bin widths. The bin-by-bin fit residuals normalized to the statistical uncertainty of the data, (data-fit)/σ_{data}, are shown at the bottom of each plot.

RESULTS FOR WIDE RESONANCES

- Two set of samples:
  qq → G → qq, gg → G → gg, where G is the RS Graviton model implemented in Pythia8
- The relative width of the resonance depend on the k/MPl parameter of the RS Graviton model
- The width-to-mass ratio of the resonance is $\Gamma/M \approx 1.4 \times (k/M\text{Pl})^2$.
- The range of relative widths for the resonances are (Γ/M) of 0.001%, 1.5% (narrow resonance), 5%, 10%, 15%, 20%, 25%, 30%.
- The limits are quoted in a range of masses and widths that satisfies two conditions:
  - at low mass, the core of the signal shape is preserved after the trigger selection mjj > 890 GeV,
  - at high mass, the low-mass tails in the signal shape due to PDFs do not contribute significantly to the limit value (i.e. removing the low-mass tails, by truncating the signal shape at 85% of the nominal resonance mass, changes the expected limit by maximally 30%, corresponding to the typical uncertainty on the expected limits).





Model	Final state	Observed mass exclusion (TeV)	Expected mass exclusion (TeV)
Wide resonance search			
Axigluon (A)/coloron (C)	$q\bar{q}$	[1.3,3.6]	
Color-octet scalar (S8)	gg	[1.3,2.5]	

Observed 95% CL exclusions on the mass of Axigluon/Coloron and Color-Octet Scalar.

- It is no longer appropriate to use the narrow resonance to set limits on Axigluons/Colorons and S8 since They are wide resonances.
- The width of the Axigluon/Coloron is Gamma=alphas_s*M, the S8 resonance is (5/6)*model is alpha_s(M). The width is between %5 and %10.
- We have experimental limits only for 5% and 10% resonance so we perform a linear interpolation between 5% and 10% limits for each mass value.
- We built a new qq experimental limit curve for the axigluon/coloron (such that at each mass value the limit correspond to a relative width equal to alpha_s(M)) and a new gg experimental limit curve for the S8 resonance (such that at each mass value the limit correspond to a relative width equal to 5/6*alpha_s(M))

LIMIT

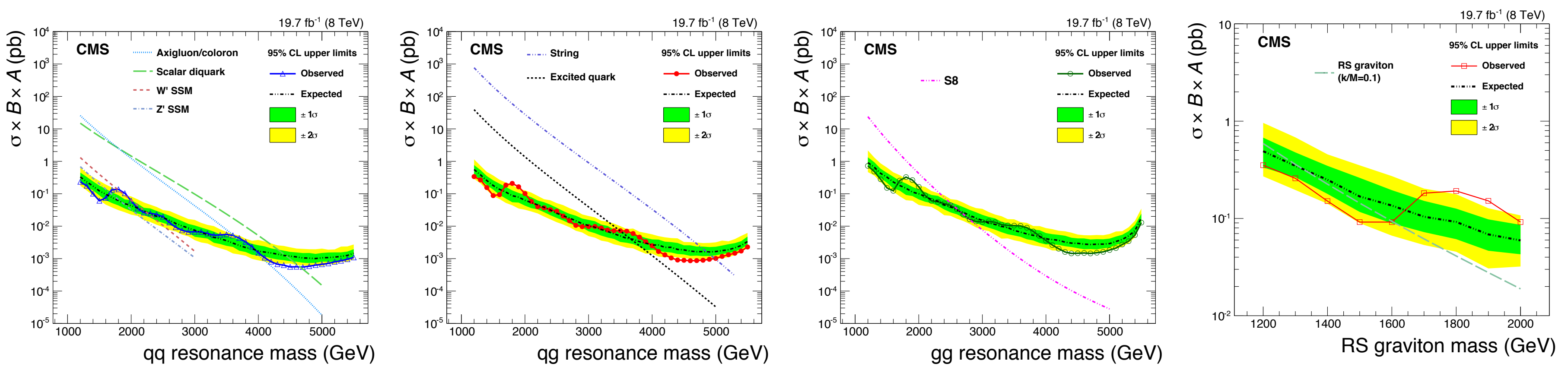
$$L = \prod_i \frac{\lambda_i^{n_i} e^{-\mu_i}}{n_i!} \qquad \lambda_i = \mu N_i(S) + N_i(B),$$

Measured number of events in data

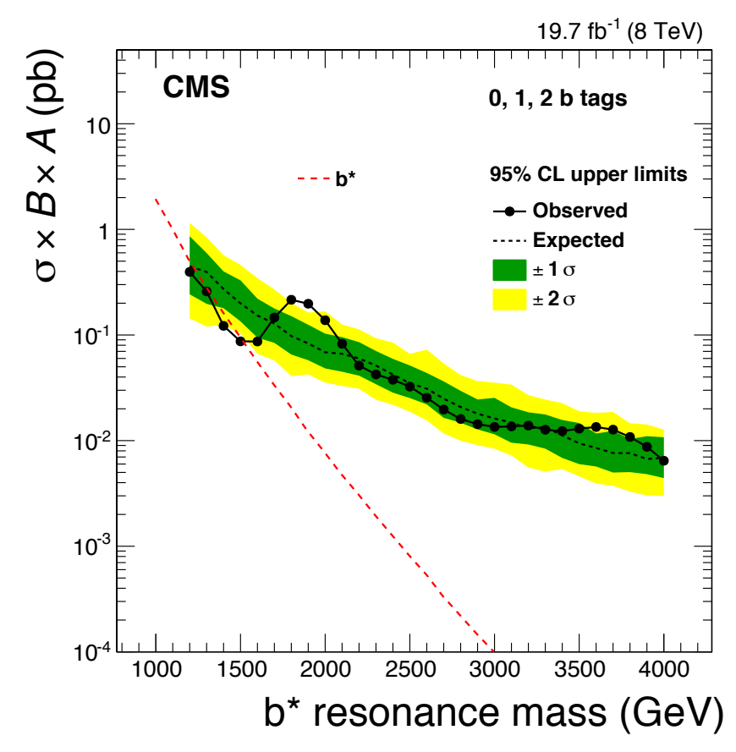
number of events from signal

Expected number of events from background

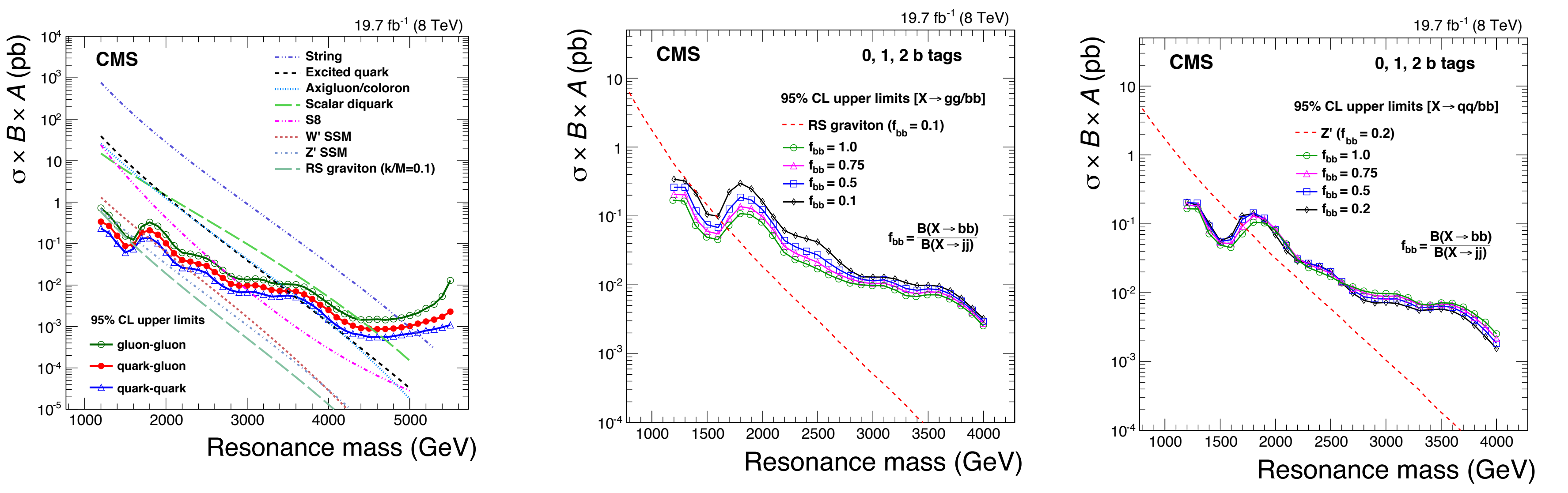
- There is no significant excess in data with respect to the background prediction
- We proceed to set upper limits on the cross section of new resonances.
- Bayesian formalism with a uniform prior is used for the cross section.
  - The signal comes from our dijet resonance shapes
  - Background is fixed to the best
- The systematic uncertainties are included in the limit as nuisance parameters. These are:
  - Jet energy Scale
  - Jet energy resolution
  - Background shape
  - Luminosity
  - b-tagging scale factors (applied only in the b-jet dedicated search)



The observed 95% CL upper limits on σ × B × A for resonances decaying into qq/qg/gg final state (points and solid lines) are compared to the expected limits (dot-dashed dark lines) and their variation at the 1σ and 2σ levels (shaded bands). Predicted cross sections of various narrow resonances are also shown. The signal shape for the RS model is obtained weighting the shapes for qq and gg final states according to LO calculations of the relative branching fractions.



Observed and expected 95% CL upper limits on σBA with systematic uncertainties included, for b* → bg resonances, compared with the LO theoretical cross section for excited b-quark production.



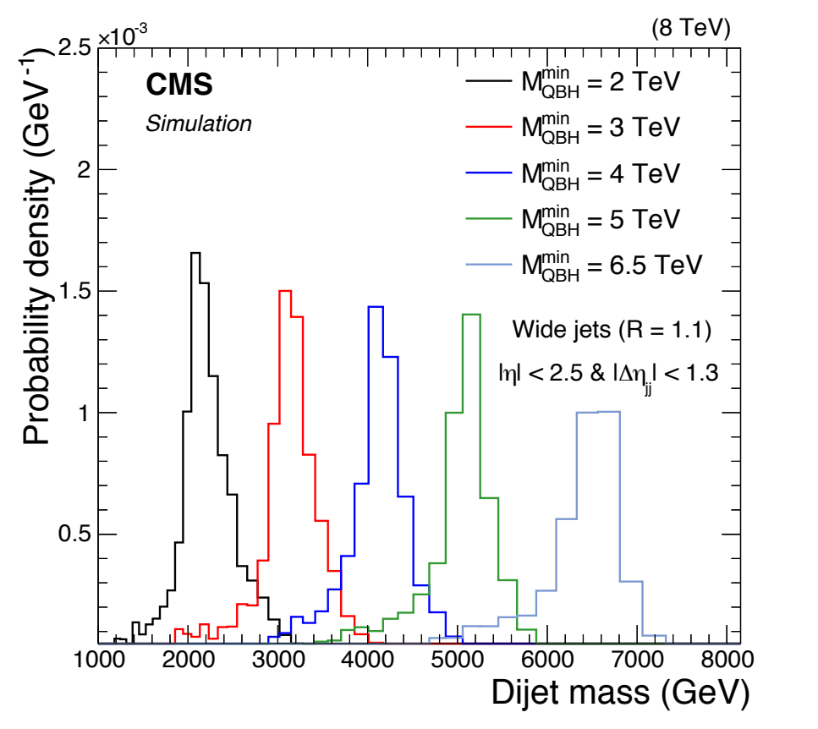
The observed 95% CL upper limits on σBA for narrow dijet resonances. Left: limit on gluon-gluon, quark-gluon, and quark-quark narrow resonances from the inclusive analysis, compared to LO theoretical predictions for string resonances, excited quarks, axigluons, colorons, scalar diquarks, S8 resonances, new SSM gauge bosons W′ and Z′, and RS gravitons. Middle: combined limits on gg/bb resonances for different values of f_b. The theoretical cross section for an RS graviton is shown for comparison. Right: combined limits on qq/bb resonances for different values of f_{bb}. The theoretical cross section for a Z′ is shown for comparison.

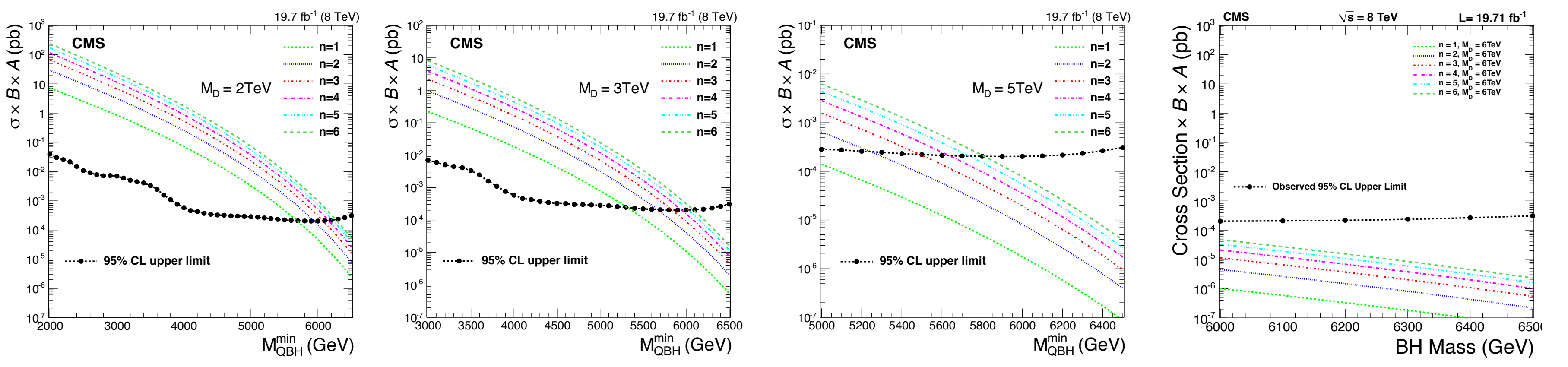
Model	Final state	Observed mass exclusion (TeV)	Expected mass exclusion (TeV)
Inclusive search			
String resonance (S)	qg	[1.2,5.0]	[1.2,4.9]
Excited quark (q*)	qg	[1.2,3.5]	[1.2,3.7]
E_6 diquark (D)	qq	[1.2,4.7]	[1.2,4.4]
W′ boson (W′)	$q\bar{q}$	[1.2,1.9] + [2.0,2.2]	[1.2,2.2]
Z′ boson (Z′)	$q\bar{q}$	[1.2,1.7]	[1.2,1.8]
RS graviton (G), $k/\overline{M}_{Pl} = 0.1$	$q\bar{q} + gg$	[1.2,1.6]	[1.2,1.3]
b-enriched search			
Excited b quark (b*)	bg	[1.2,1.6]	

Observed and expected 95% CL exclusions on the mass of various resonances.

RESULTS FOR QUANTUM BLACK HOLE

- The inclusive dijet search is also sensitive to quantum black holes primarily decaying to pair of jets, can be interpreted in terms of QBH production in models with large (n ≥ 2) or warped (n = 1) dimensions, where n is the number of extra dimensions.
- The peak position is related to the minimum mass of QBHs, Mmin QBH.
- The low-mass dijet tails are due to detector resolution effects.
- The shape is almost independent of the number of extra dimensions n and the fundamental Planck scale MD.
- The cross section limits are presented only for Mmin QBH ≥ MD, for different values of MD.





Observed 95% CL upper limits on σ × B × A as a function of the minimum mass of quantum black holes, compared to theoretical predictions for a quantum gravity scale of M_D = 2 TeV, M_D = 3 TeV, M_D = 4 TeV, and M_D =5 TeV, with the number of extra dimensions n ranging from one to six.

n	M_D (TeV) 2	3	4	5
1	5.7	5.3	5.0	
2	5.9	5.7	5.4	5.2
3	6.1	5.8	5.7	5.5
4	6.2	6.0	5.8	5.6
5	6.2	6.0	5.9	5.7
6	6.3	6.0	5.9	5.8

Observed 95% CL lower limits on the minimum mass values of quantum black holes.

SUMMARY

- Results of a search for dijet resonances and quantum black hole has been presented using inclusive and b-tagged dijet mass spectra.
- No evidence particle is found therefore we set upper limits at 95%CL on the product of the cross section, branching fraction into dijets, and acceptance.
- This results with 8 TeV full data set of pp collisions with CMS detector at LHC (19.7 fb-1) were approved (PAS EXO 2012-059) for Moriond2013 conference; a paper has been produced and accepted by Phys. Rev. D.
  Reference: http://arxiv.org/abs/1501.04198