Characterizing boosted dijet resonances with Jet Energy Correlators

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arXiv: 1710.04661

Exotica searches at the LHC

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: July 2017

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 37.0)\ \mathrm{fb}^{-1}$ $\sqrt{s}$ = 8, 13 TeV

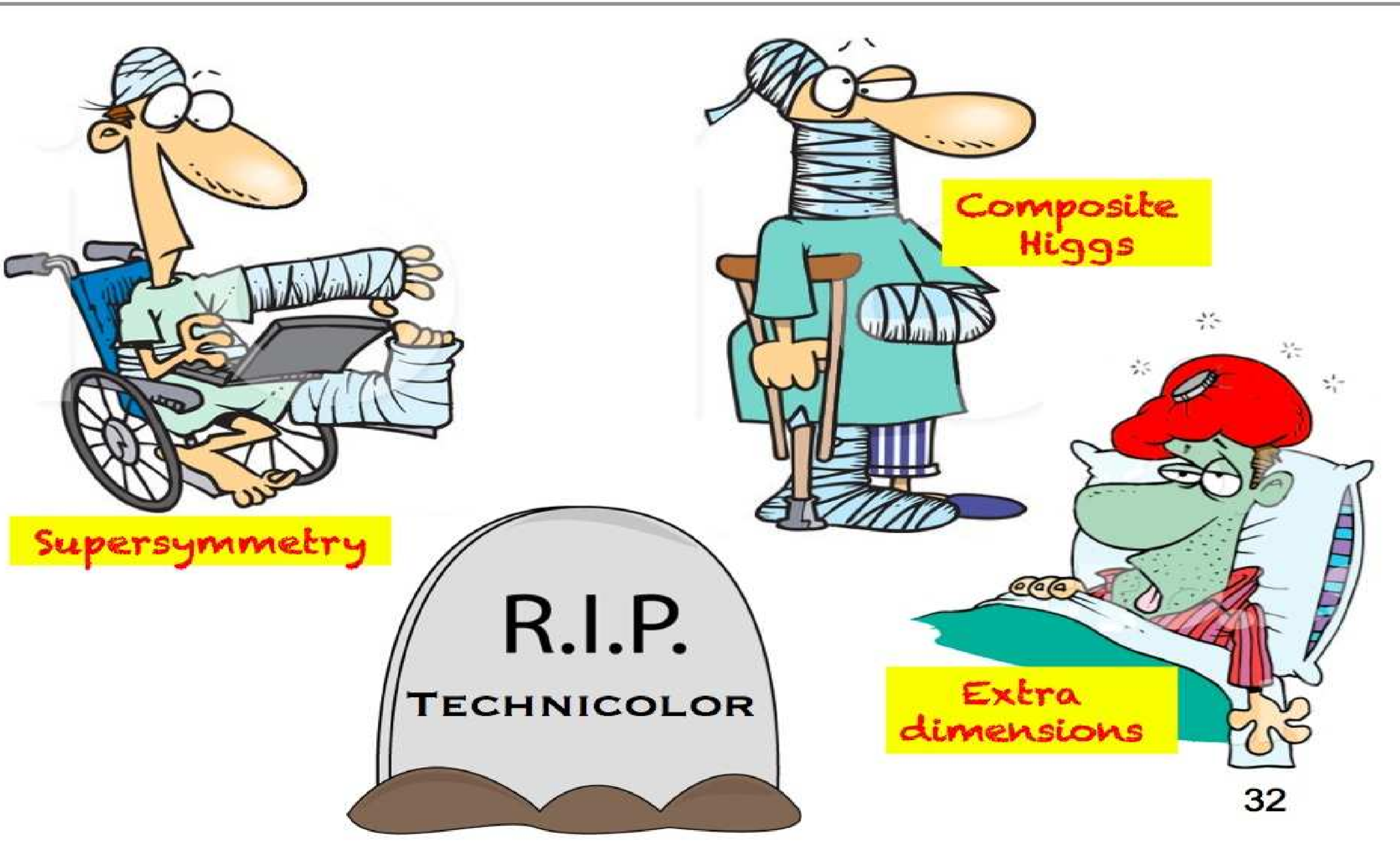
	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\, dt[\mathrm{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	0 e, μ	$1-4$ j	Yes	36.1	M_D 7.75 TeV	$n=2$	ATLAS-CONF-2017-060
	ADD non-resonant $\gamma\gamma$	2 γ	–	–	36.7	M_S 8.6 TeV	$n=3$ HLZ NLO	CERN-EP-2017-132
	ADD QBH	–	2 j	–	37.0	M_{th} 8.9 TeV	$n=6$	1703.09217
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n=6$, $M_D=3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n=6$, $M_D=3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \gamma\gamma$	2 γ	–	–	36.7	G_{KK} mass 4.1 TeV	$k/\overline{M}_{Pl}=0.1$	CERN-EP-2017-132
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	1 e, μ	1 J	Yes	36.1	G_{KK} mass 1.75 TeV	$k/\overline{M}_{Pl}=1.0$	ATLAS-CONF-2017-051
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 3 j	Yes	13.2	KK mass 1.6 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \to tt)=1$	ATLAS-CONF-2016-104
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	36.1	Z' mass 4.5 TeV		ATLAS-CONF-2017-027
	SSM $Z' \to \tau\tau$	2 τ	–	–	36.1	Z' mass 2.4 TeV		ATLAS-CONF-2017-050
	Leptophobic $Z' \to bb$	–	2 b	–	3.2	Z' mass 1.5 TeV		1603.08791
	Leptophobic $Z' \to tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	3.2	Z' mass 2.0 TeV	$\Gamma/m=3\%$	ATLAS-CONF-2016-014
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	36.1	W' mass 5.1 TeV		1706.04786
	HVT $V' \to WV \to qqqq$ model B	0 e, μ	2 J	–	36.7	V' mass 3.5 TeV	$g_V=3$	CERN-EP-2017-147
	HVT $V' \to WH/ZH$ model B	multi-channel			36.1	V' mass 2.93 TeV	$g_V=3$	ATLAS-CONF-2017-055
	LRSM $W'_R \to tb$	1 e, μ	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \to tb$	0 e, μ	≥ 1 b, 1 J	–	20.3	W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	37.0	Λ 21.8 TeV η^-_{LL}		1703.09217
	CI $\ell\ell qq$	2 e, μ	–	–	36.1	Λ 40.1 TeV η^-_{LL}		ATLAS-CONF-2017-027
	CI $uutt$	2(SS)/$\geq$3 e, μ	$\geq$1 b, $\geq$1 j	Yes	20.3	Λ 4.9 TeV	$\lvert C_{RR}\rvert=1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	0 e, μ	$1-4$ j	Yes	36.1	m_{med} 1.5 TeV	g_q=0.25, g_χ=1.0, $m(\chi)$ < 400 GeV	ATLAS-CONF-2017-060
	Vector mediator (Dirac DM)	0 e, μ, 1 γ	≤ 1 j	Yes	36.1	m_{med} 1.2 TeV	g_q=0.25, g_χ=1.0, $m(\chi)$ < 480 GeV	1704.03848
	$VV\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	M_* 700 GeV	$m(\chi)$ < 150 GeV	1608.02372
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	3.2	LQ mass 1.1 TeV	$\beta=1$	1605.06035
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	3.2	LQ mass 1.05 TeV	$\beta=1$	1605.06035
	Scalar LQ 3rd gen	1 e, μ	$\geq$1 b, $\geq$3 j	Yes	20.3	LQ mass 640 GeV	$\beta=0$	1508.04735
Heavy quarks	VLQ $TT \to Ht + X$	0 or 1 e, μ	≥ 2 b, ≥ 3 j	Yes	13.2	T mass 1.2 TeV	$\mathcal{B}(T \to Ht)=1$	ATLAS-CONF-2016-104
	VLQ $TT \to Zt + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	36.1	T mass 1.16 TeV	$\mathcal{B}(T \to Zt)=1$	1705.10751
	VLQ $TT \to Wb + X$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	T mass 1.35 TeV	$\mathcal{B}(T \to Wb)=1$	CERN-EP-2017-094
	VLQ $BB \to Hb + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	B mass 700 GeV	$\mathcal{B}(B \to Hb)=1$	1505.04306
	VLQ $BB \to Zb + X$	2/$\geq$3 e, μ	$\geq$2/$\geq$1 b	–	20.3	B mass 790 GeV	$\mathcal{B}(B \to Zb)=1$	1409.5500
	VLQ $BB \to Wt + X$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	36.1	B mass 1.25 TeV	$\mathcal{B}(B \to Wt)=1$	CERN-EP-2017-094
	VLQ $QQ \to WqWq$	1 e, μ	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
Excited fermions	Excited quark $q^* \to qg$	–	2 j	–	37.0	q* mass 6.0 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1703.09127
	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	36.7	q* mass 5.3 TeV	only u^* and d^*, $\Lambda = m(q^*)$	CERN-EP-2017-148
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	13.3	b* mass 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^* \to Wt$	1 or 2 e, μ	1 b, 2-0 j	Yes	20.3	b* mass 1.5 TeV	$f_g = f_L = f_R = 1$	1510.02664
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	ℓ^* mass 3.0 TeV	Λ = 3.0 TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	ν^* mass 1.6 TeV	Λ = 1.6 TeV	1411.2921
Other	LRSM Majorana ν	2 e, μ	2 j	–	20.3	N^0 mass 2.0 TeV	$m(W_R)$ = 2.4 TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2,3,4 e, μ (SS)	–	–	36.1	$H^{\pm\pm}$ mass 870 GeV	DY production	ATLAS-CONF-2017-053
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	3 e, μ, τ	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $\mathcal{B}(H^{\pm\pm}_L \to \ell\tau)=1$	1411.2921
	Monotop (non-res prod)	1 e, μ	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{\text{non-res}}=0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	multi-charged particle mass 785 GeV	DY production, $\lvert q\rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	monopole mass 1.34 TeV	DY production, $\lvert g\rvert = 1g_D$, spin 1/2	1509.08059

$\sqrt{s}$ = 8 TeV $\sqrt{s}$ = 13 TeV

10^{-1} 1   10   **Mass scale [TeV]**

*Only a selection of the available mass limits on new states or phenomena is shown.

†Small-radius (large-radius) jets are denoted by the letter j (J).



In such a scenario the Higgs boson has assumed the

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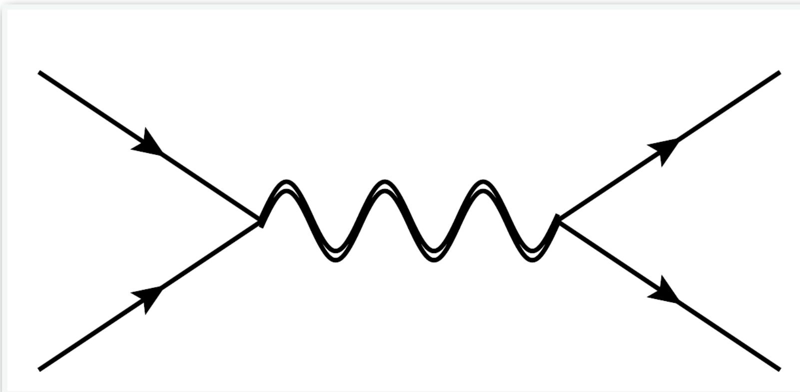
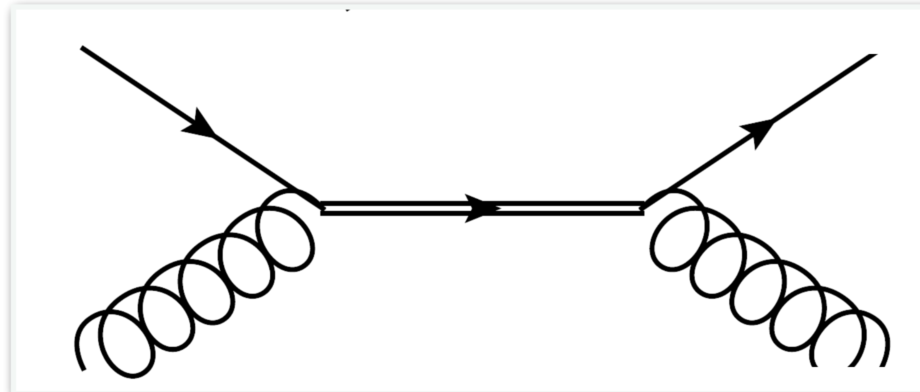
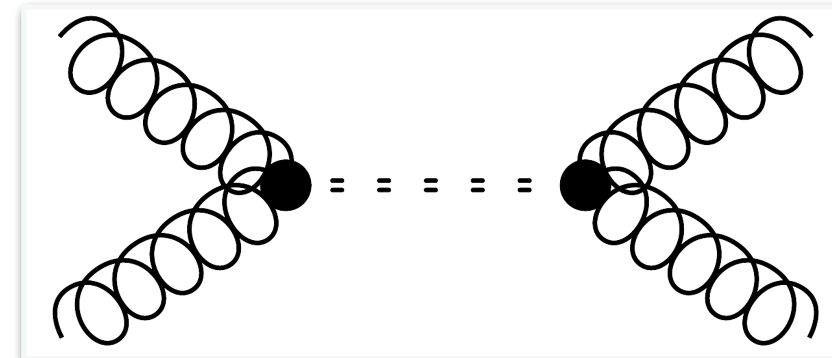
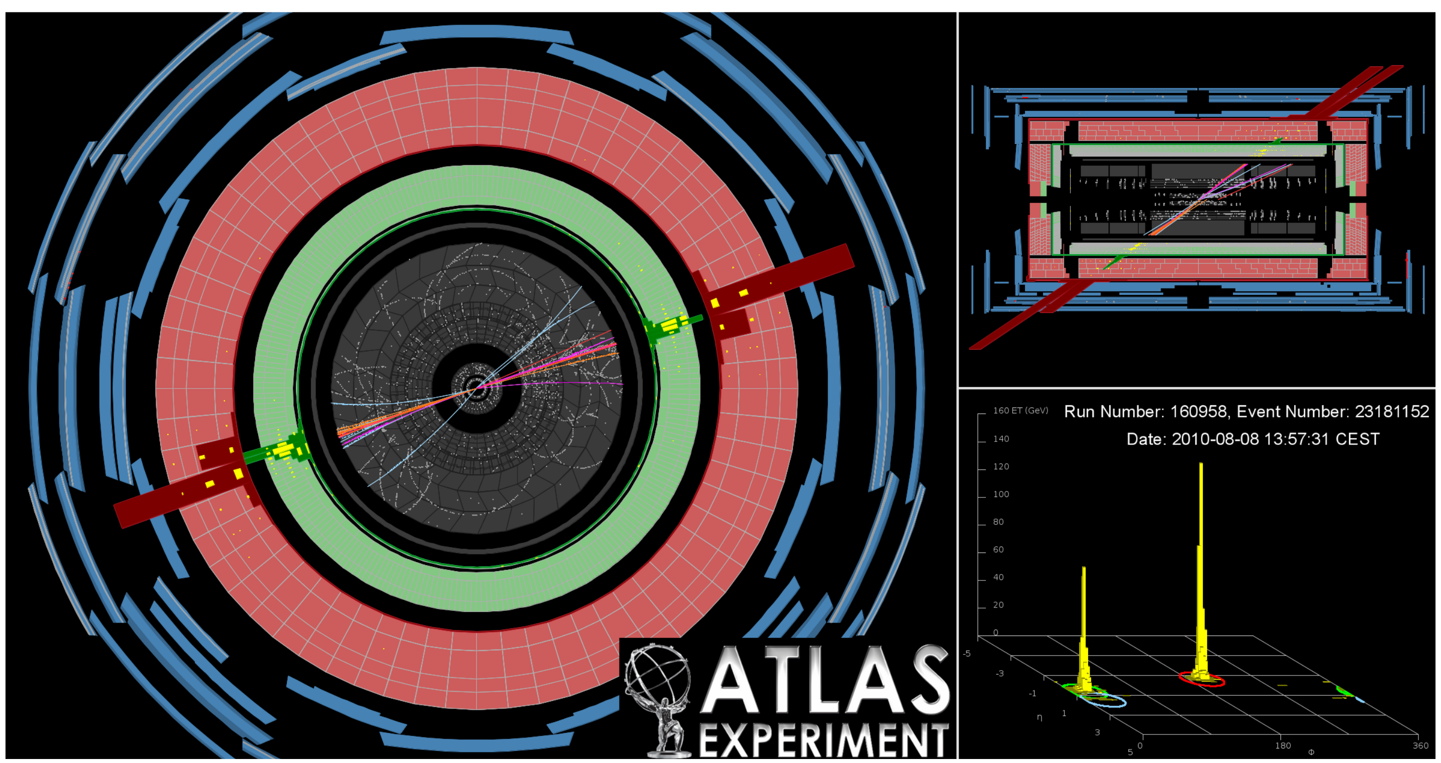
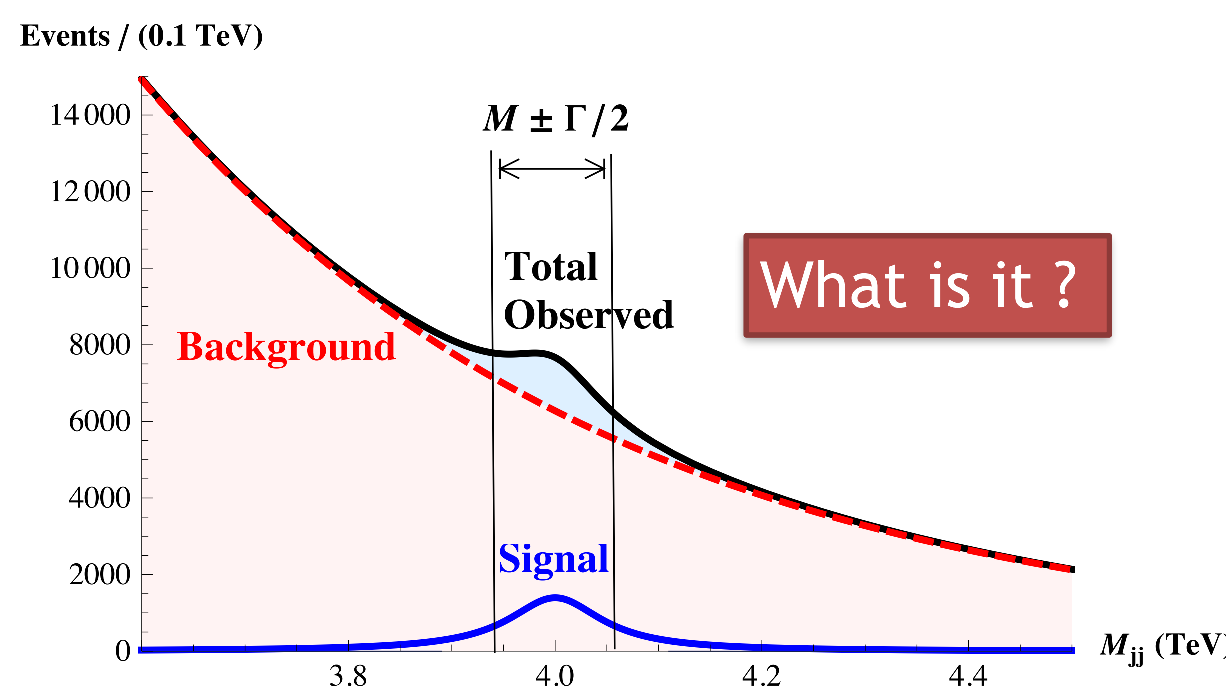






- Dijet resonances: simple and powerful probe of many different scenarios of new physics at the LHC.





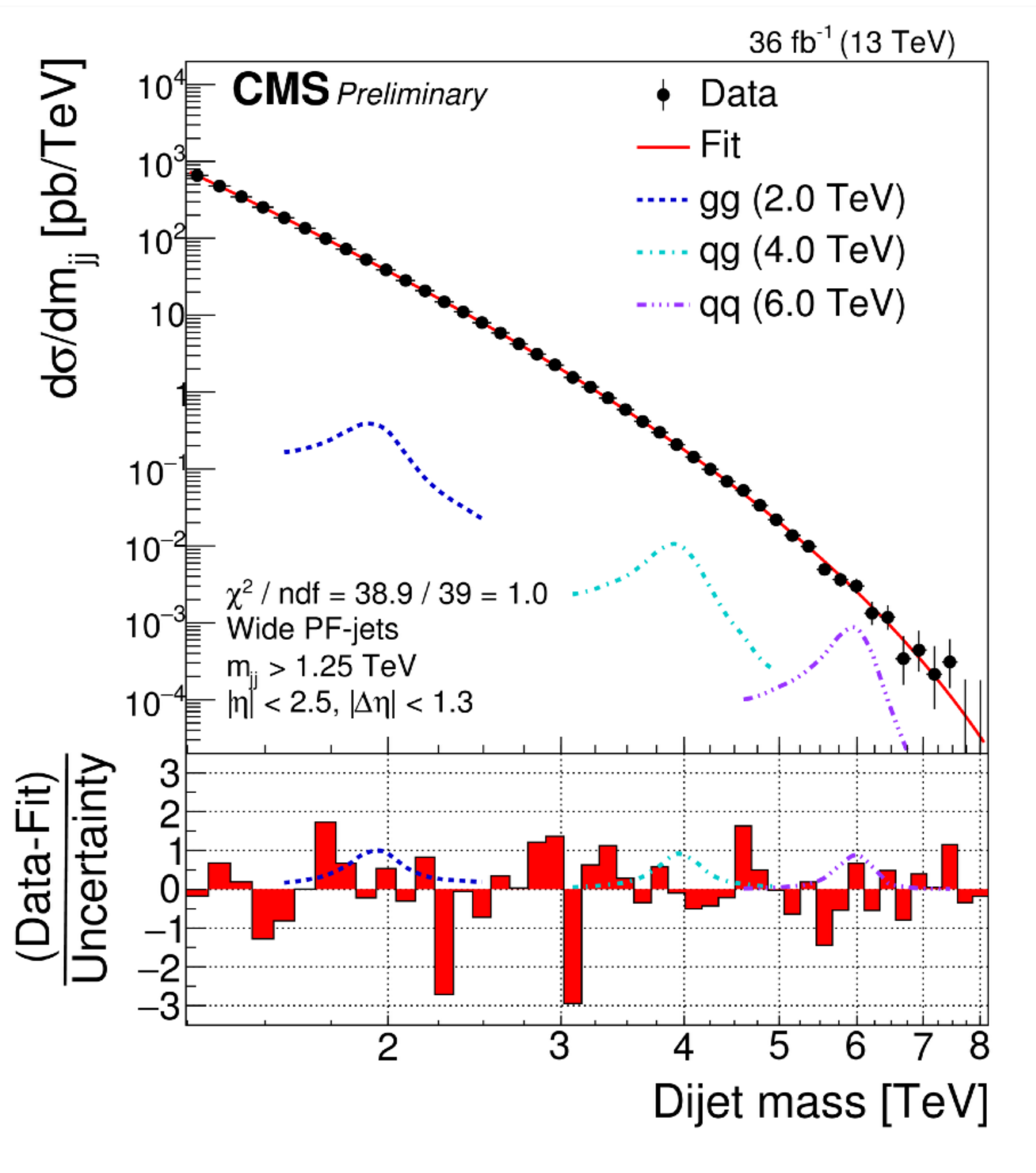
Outline

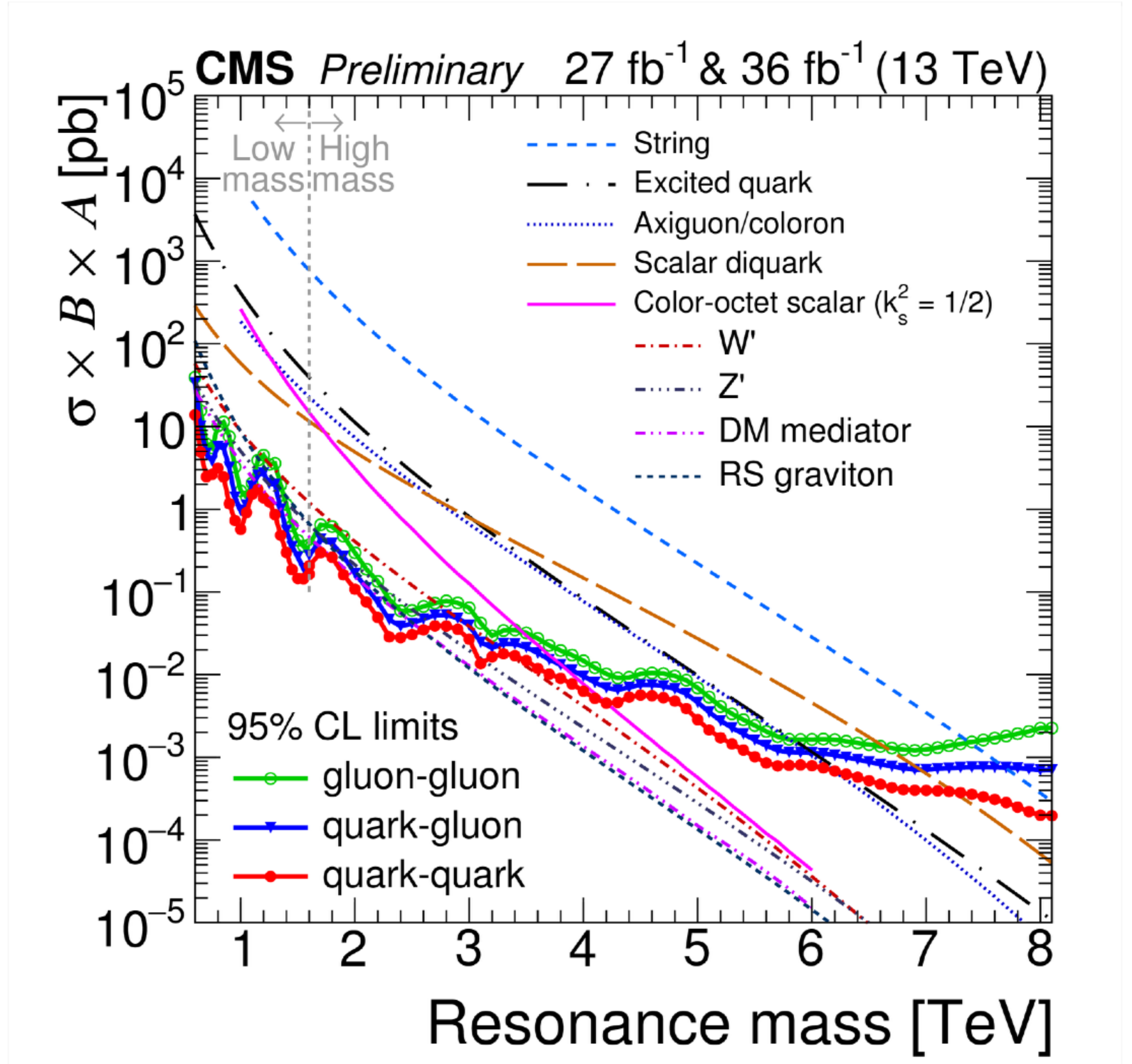
- Q. How to Characterize dijet resonances?
- Introduce benchmark models
- Color discriminant variable (Broader resonances)
- Jet Energy Profiles
- Jet Energy Correlators

Benchmark Models

Resonance	Interaction	J	$SU(3)_C$	$\|Q_e\|$	Dominant decay
Leptophobic Z'	$\frac{g_B}{6}\bar{q}\gamma^\mu q Z'_\mu$	1	**0**	0	$\bar{q}q$
Coloron C_μ	$g_s \tan\theta\ \bar{q}\ T^a\gamma^\mu q C^a_\mu$	1	**8**	0	$\bar{q}q$
Octet Scalar S_8	$\frac{g_s d_{ABC} k_s}{\Lambda} S_8^A G^B_{\mu\nu} G^{C,\mu\nu}$	1	**8**	0	gg
Sextet diquark Φ_6	$\sqrt{2}(\bar{K}_6)^{ab}_\gamma \lambda_\Phi \Phi_6^\gamma \bar{u}^c_{Ra} u_{Lb}$	0	**6**	4/3	qq
Excited quark q^*	$\frac{1}{2\Lambda}\bar{q}^*_R\sigma^{\mu\nu}[g_S f_S \frac{\lambda^a}{2} G^a_{\mu\nu}]q_L$	1/2	**3**	2/3	qg
Spin-2 $X^{\mu\nu}$	$\frac{1}{\Lambda}X^{\mu\nu}T_{\mu\nu}$	2	**0**	0	$gg+qq$

Constraints from LHC





Color Discriminant Variable

Resonance	Interaction	J	$SU(3)_C$	$\lvert Q_e \rvert$	Dominant decay
Leptophobic Z'	$\frac{g_B}{6}\bar{q}\gamma^\mu q Z'_\mu$	1	$\mathbf{0}$	0	$\bar{q}q$
Coloron C_μ	$g_s \tan\theta\ \bar{q}\ T^a \gamma^\mu q C^a_\mu$	1	$\mathbf{8}$	0	$\bar{q}q$
Octet Scalar S_8	$\frac{g_s d_{ABC} k_s}{\Lambda} S_8^A G^B_{\mu\nu} G^{C,\mu\nu}$	1	$\mathbf{8}$	0	gg
Sextet diquark Φ_6	$\sqrt{2}(\bar{K}_6)^{ab}_\gamma \lambda_\Phi \Phi_6^\gamma \bar{u}^c_{Ra} u_{Lb}$	0	$\mathbf{6}$	4/3	qq
Excited quark q^*	$\frac{1}{2\Lambda}\bar{q}^*_R \sigma^{\mu\nu}[g_S f_S \frac{\lambda^a}{2} G^a_{\mu\nu}] q_L$	1/2	$\mathbf{3}$	2/3	qg
Spin-2 $X^{\mu\nu}$	$\frac{1}{\Lambda} X^{\mu\nu} T_{\mu\nu}$	2	$\mathbf{0}$	0	$gg + qq$

Identifying Dijet Resonances

Suppose a new dijet resonance of mass M and cross-section σ_{jj} is found. **Is it a coloron or a leptophobic Z'?** Assume its quark couplings are **flavor universal** to start.

$$\sigma^{C}_{jj} = \frac{8}{9}\frac{\Gamma_C}{M_C^3}\sum_q W_q(M_C) Br(C \to jj)$$

must be equal

$$\sigma^{Z'}_{jj} = \frac{1}{9}\frac{\Gamma_{Z'}}{M_{Z'}^3}\sum_q W_q(M_{Z'}) Br(Z' \to jj)$$

$$W_q(M_V) = 2\pi^2 \frac{M_V^2}{s}\int_{M_V^2/s}^{1}\frac{dx}{x}\left[f_q\left(x,Q^2\right) f_{\bar{q}}\left(\frac{M_V^2}{sx},Q^2\right) + f_{\bar{q}}\left(x,Q^2\right) f_q\left(\frac{M_V^2}{sx},Q^2\right)\right]$$

Color Discriminant Variable

$$\sigma^{C}_{jj} = \frac{8}{9}\frac{\Gamma_C}{M_C^3}\sum_q W_q(M_C)Br(C \to jj)$$

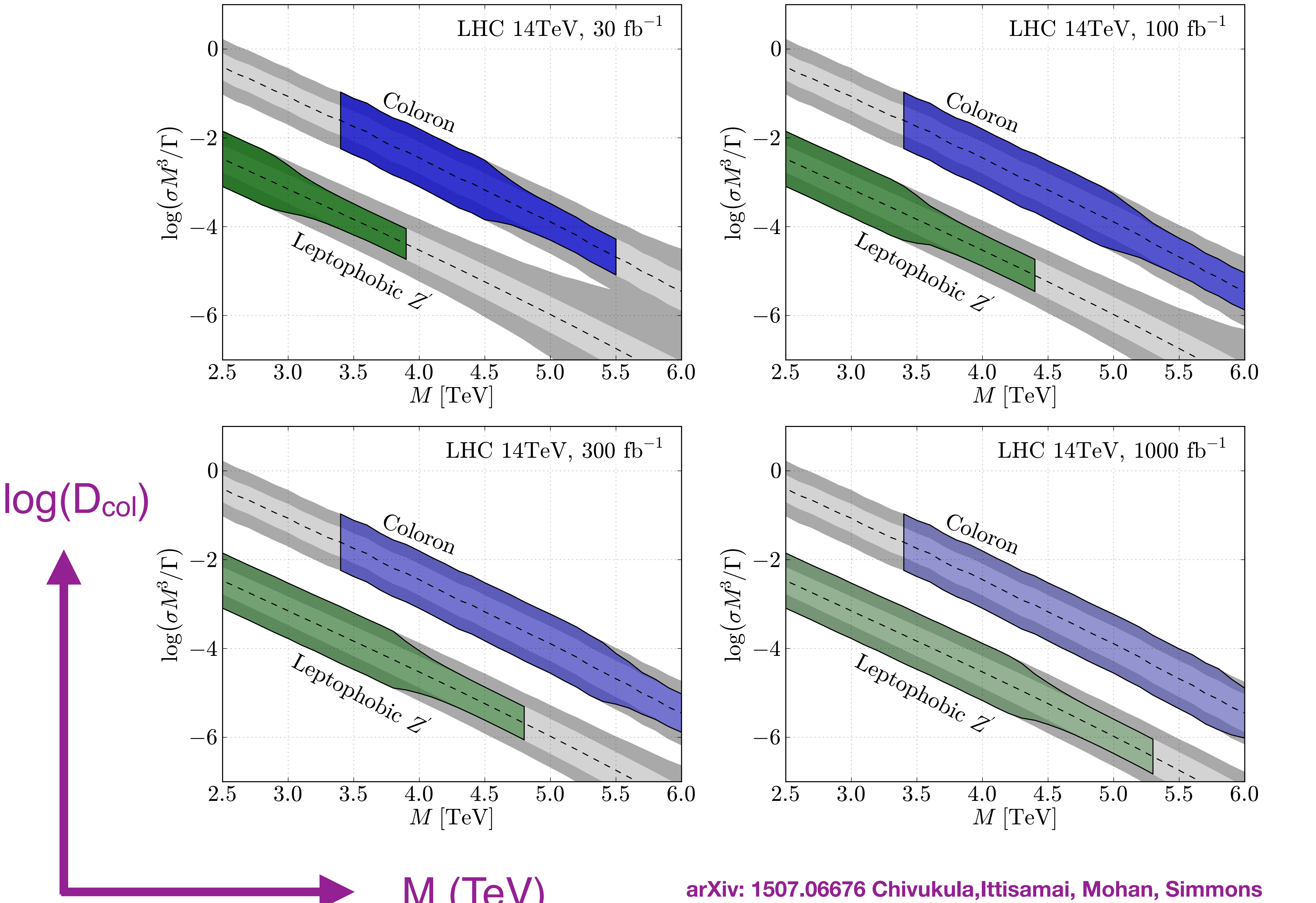
must be equal

$$\sigma^{Z'}_{jj} = \frac{1}{9}\frac{\Gamma_{Z'}}{M_{Z'}^3}\sum_q W_q(M_{Z'})Br(Z' \to jj)$$

Define a color discriminant variable: $D_{\rm col} \equiv \frac{M^3}{\Gamma}\sigma_{jj}$

- based on standard observables
- useful whenever width is measurable
- distinguishes color structure of resonance

log(D_{col}) Separates Coloron from Z'

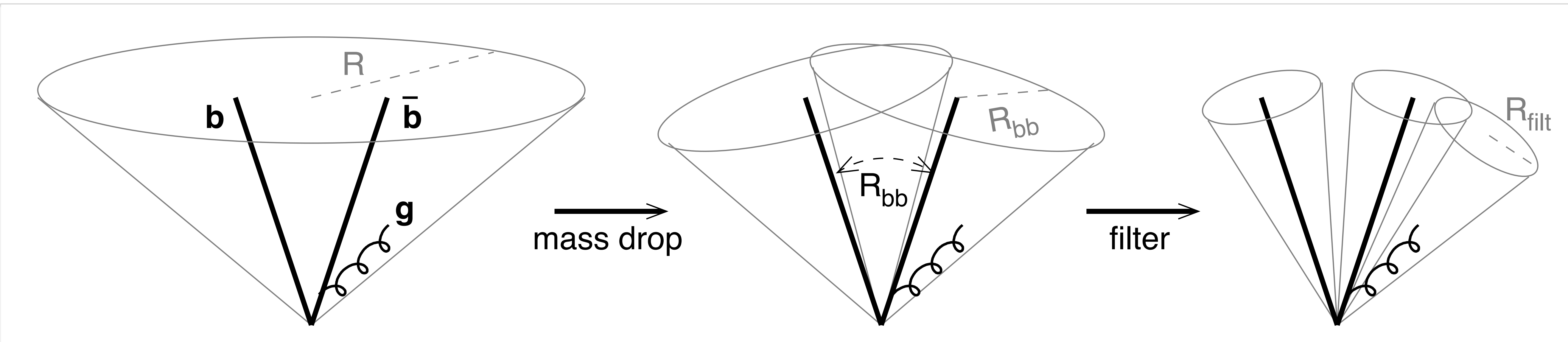


arXiv: 1507.06676 Chivukula,Ittisamai, Mohan, Simmons

Jet Substructure

Substructures help background reduction + classification of jets

Find local subclusters of energy within a jet



Step through clustering history to identify a hard splitting

$$\Delta R_{ij} \sim \frac{m}{p_T} \frac{1}{\sqrt{z(1-z)}} \sim \frac{2m}{p_T}$$

Radiation

$$\langle m^2 \rangle \approx p_{T,P}^2 \int_0^{R^2} \frac{d\theta^2}{\theta^2} \int dz\, z(1-z)\theta^2 \frac{\alpha_s}{2\pi} \mathcal{P}(z).$$

$$\langle m^2 \rangle \approx \frac{\alpha_s}{\pi} \frac{3}{8} C_F\, p_T^2 R^2.$$

$$\langle m^2 \rangle \approx \frac{\alpha_s}{\pi} \frac{1}{20} C_A\, p_T^2 R^2$$

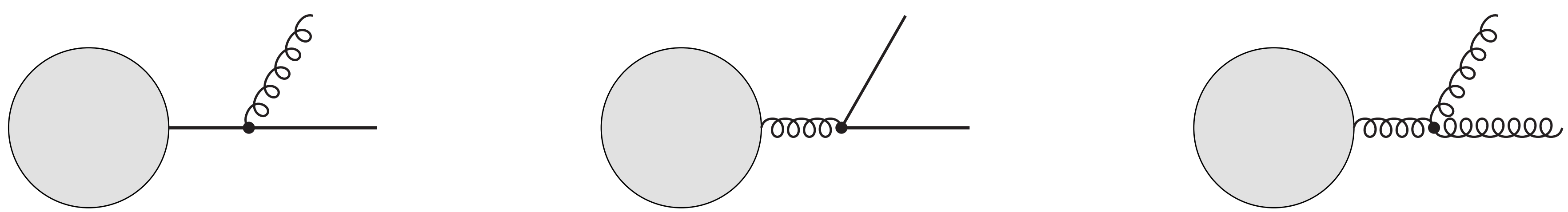
Jet substructure to probe resonance properties

- Jets: Highly collimated objects that contain most of the energy of the hard process.
- Have measurable macroscopic properties (jet shapes): Mass, Transverse momentum, R, rapidity …
- These provide information about the nature of the hard process
- Jet substructure: infrared safe jet observables that can tell us more about the hard parton

Radiation cascade

$$d\sigma_{n+1} \approx d\sigma_n \, dz \, \frac{dt}{t} \, \frac{\alpha_s}{2\pi} \, \mathcal{P}(z)$$

$$P_{qq} = C_F \frac{1+z^2}{1-z} \qquad P_{qg} = T_R[z^2 + (1-z)^2] \qquad P_{gg} = C_A \frac{(1-z(1-z))^2}{z(1-z)}$$

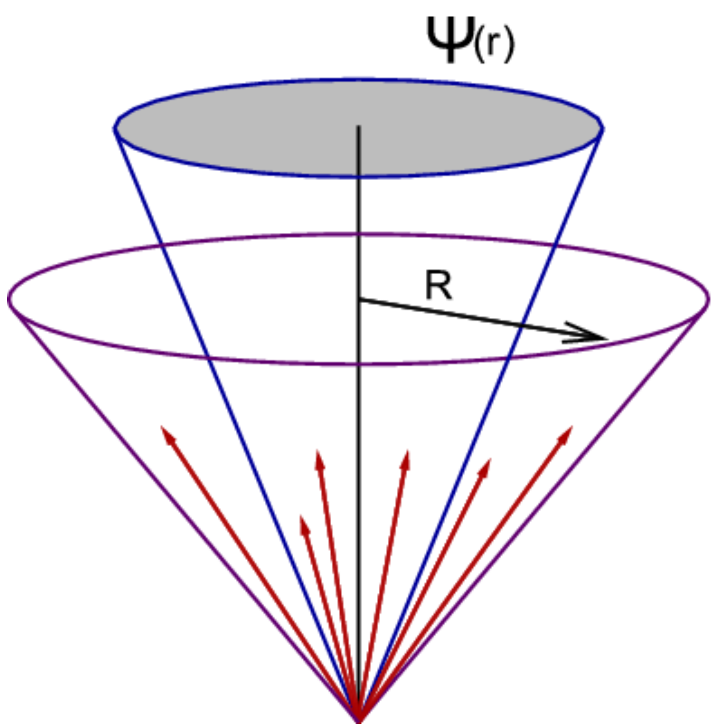


$$\Delta(t) = \exp\left[-\int_{t_0}^{t} \frac{dt'}{t'} \, dz \frac{\alpha_s}{2\pi} \mathcal{P}(z)\right]$$

Since $C_F(=4/3) < C_A(=3)$, gluon jets radiate more and at wider angles.

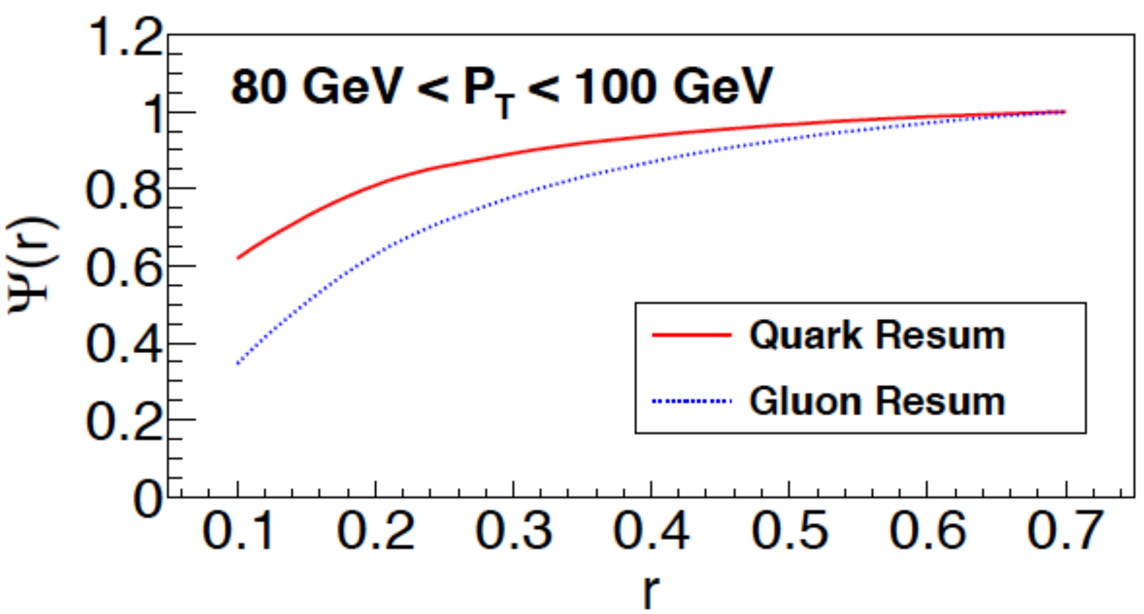
Emission probability from the Sudakov factor.

Jet Energy Profile



Average fraction of jet pT lying within a sub-cone of radius r

$$\psi(r) = \frac{1}{N_j} \sum_j \frac{p_T(0,r)}{p_T(0,R)}$$



Quarks C_F=4/3   Gluons: C_A=3

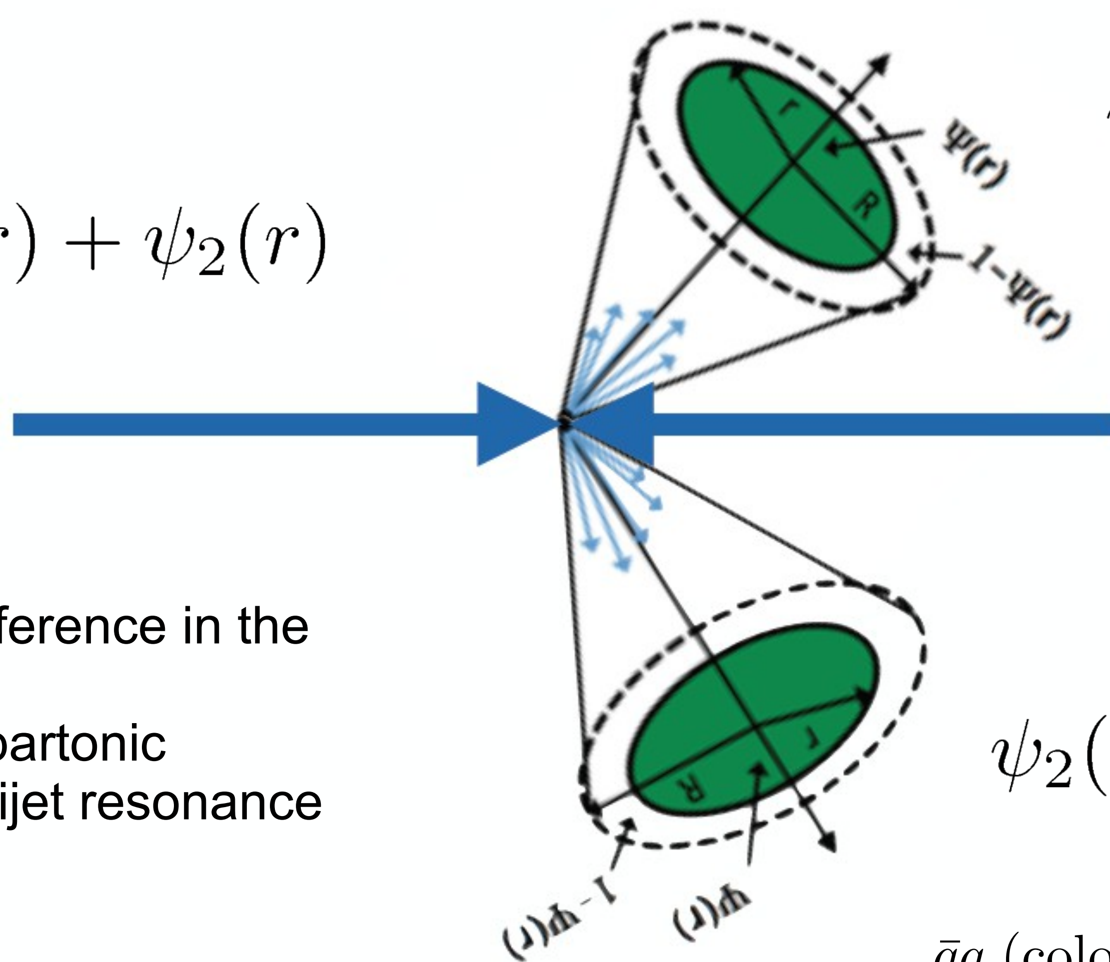
Gluon-jets irradiate more, slowly rising JEP
Quark-jets irradiate less, fast rising JEP

H. Li, Z. Li, C.-P. Yuan
PRD 87 (2013) 074025

New Physics in dijet resonance searches

Dijet energy profile

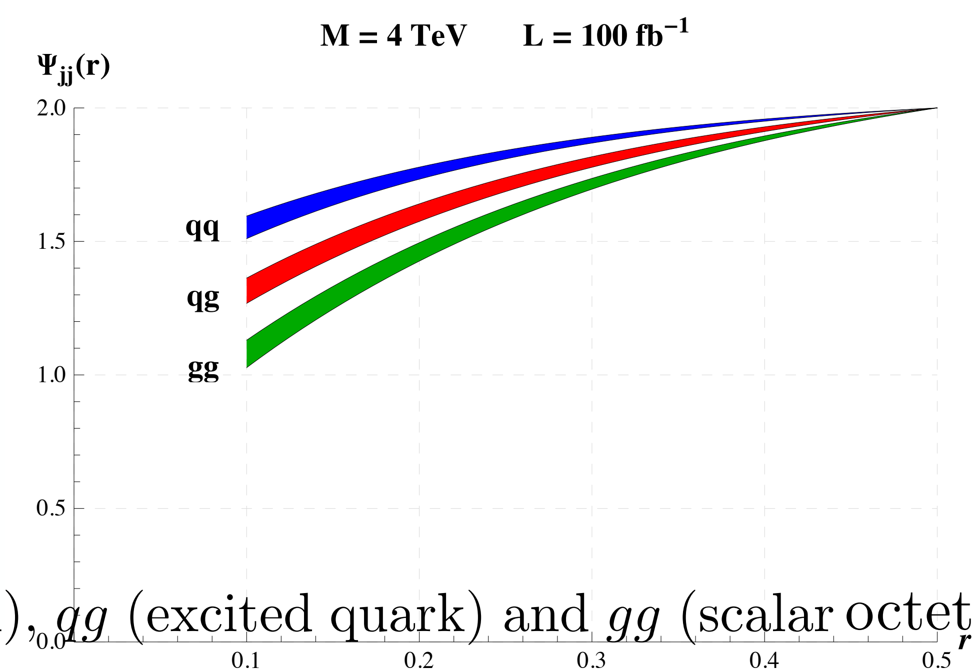
$$\psi_{jj}(r) = \psi_1(r) + \psi_2(r)$$



$\psi_1(r)$

$\psi_2(r)$

We will use the difference in the quark/gluon JEP
to distinguish the partonic composition of a dijet resonance



$\bar{q}q$ (coloron), qg (excited quark) and gg (scalar octet)

Similar technique recently applied to distinguish Higgs production mechanisms [Rentala *et al.* PRD88 (2013) 7, 073007] and Dark matter interactions [Agrawal, Rentala, JHEP 1405 (2014) 098]

Resonance	Interaction	J	$SU(3)_C$	$\lvert Q_e \rvert$	Dominant decay
Leptophobic Z'	$\frac{g_B}{6}\bar{q}\gamma^\mu q Z'_\mu$	1	**0**	0	$\bar{q}q$
Coloron C_μ	$g_s \tan\theta\ \bar{q}\ T^a \gamma^\mu q C^a_\mu$	1	**8**	0	$\bar{q}q$
Octet Scalar S_8	$\frac{g_s d_{ABC} k_s}{\Lambda} S^A_8 G^B_{\mu\nu} G^{C,\mu\nu}$	1	**8**	0	gg
Sextet diquark Φ_6	$\sqrt{2}(\bar{K}_6)^{ab}_\gamma \lambda_\Phi \Phi^\gamma_6 \bar{u}^c_{Ra} u_{Lb}$	0	**6**	4/3	qq
Excited quark q^*	$\frac{1}{2\Lambda}\bar{q}^*_R \sigma^{\mu\nu}[g_S f_S \frac{\lambda^a}{2} G^a_{\mu\nu}] q_L$	1/2	**3**	2/3	qg
Spin-2 $X^{\mu\nu}$	$\frac{1}{\Lambda} X^{\mu\nu} T_{\mu\nu}$	2	**0**	0	$gg + qq$

New Physics in dijet resonance searches

Light Dijet resonances

Resonance	Interaction	J	$SU(3)_C$	$\lvert Q_e \rvert$	Dominant decay
Leptophobic Z'	$\frac{g_B}{6}\bar{q}\gamma^\mu q Z'_\mu$	1	**0**	0	$\bar{q}q$
Coloron C_μ	$g_s \tan\theta \; \bar{q} \; T^a \gamma^\mu q C^a_\mu$	1	**8**	0	$\bar{q}q$
Octet Scalar S_8	$\frac{g_s d_{ABC} k_s}{\Lambda} S_8^A G^B_{\mu\nu} G^{C,\mu\nu}$	1	**8**	0	gg
Sextet diquark Φ_6	$\sqrt{2}(\bar{K}_6)^{ab}_\gamma \lambda_\Phi \Phi_6^\gamma \bar{u}^c_{Ra} u_{Lb}$	0	**6**	4/3	qq
Excited quark q^*	$\frac{1}{2\Lambda}\bar{q}^*_R \sigma^{\mu\nu}[g_S f_S \frac{\lambda^a}{2} G^a_{\mu\nu}] q_L$	1/2	**3**	2/3	qg
Spin-2 $X^{\mu\nu}$	$\frac{1}{\Lambda} X^{\mu\nu} T_{\mu\nu}$	2	**0**	0	$gg + qq$

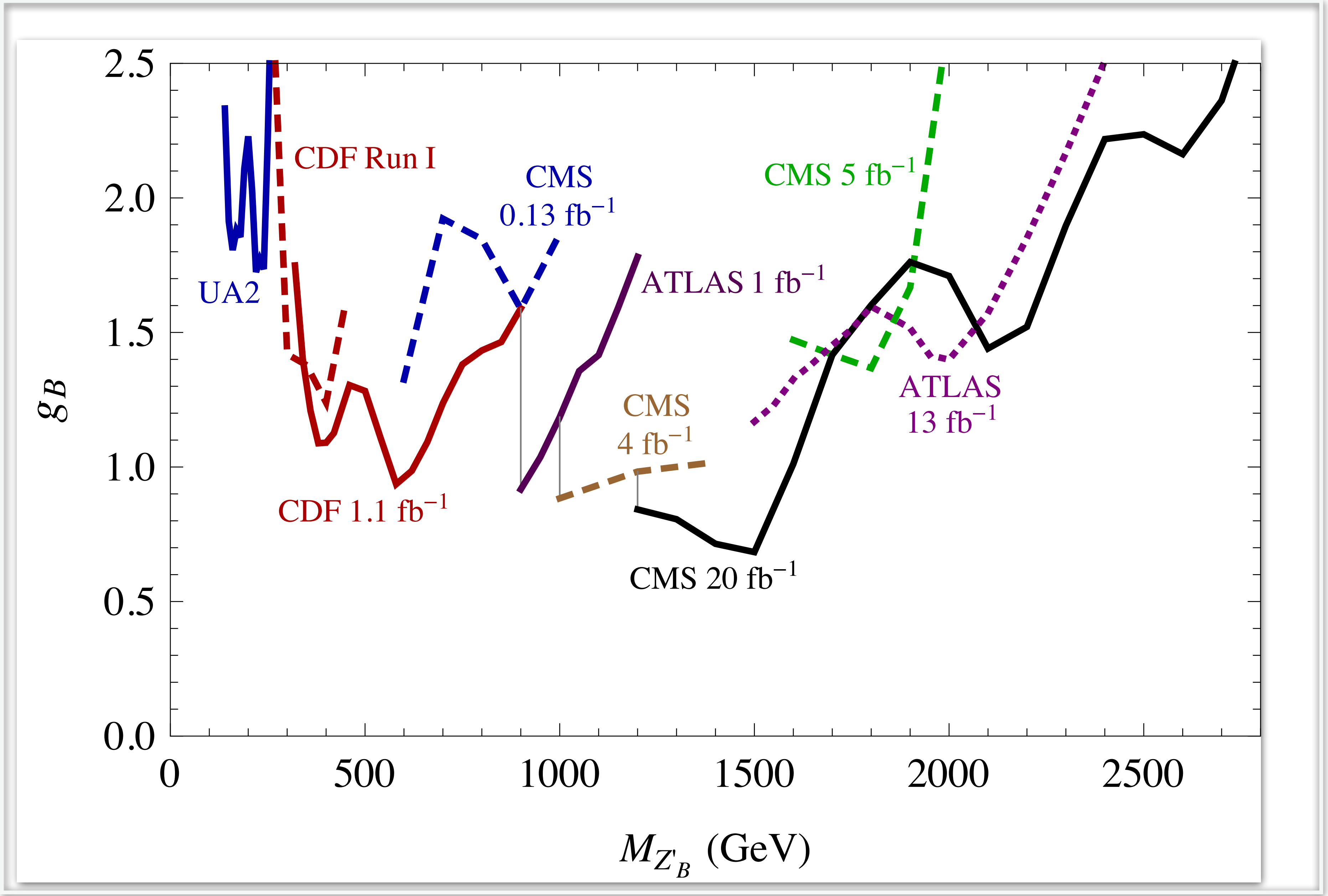
Q. Can we use color, transverse momentum and production/decay mechanism to distinguish resonances ?

New Physics in dijet resonance searches

Experimental constraints in the Mass-coupling plane

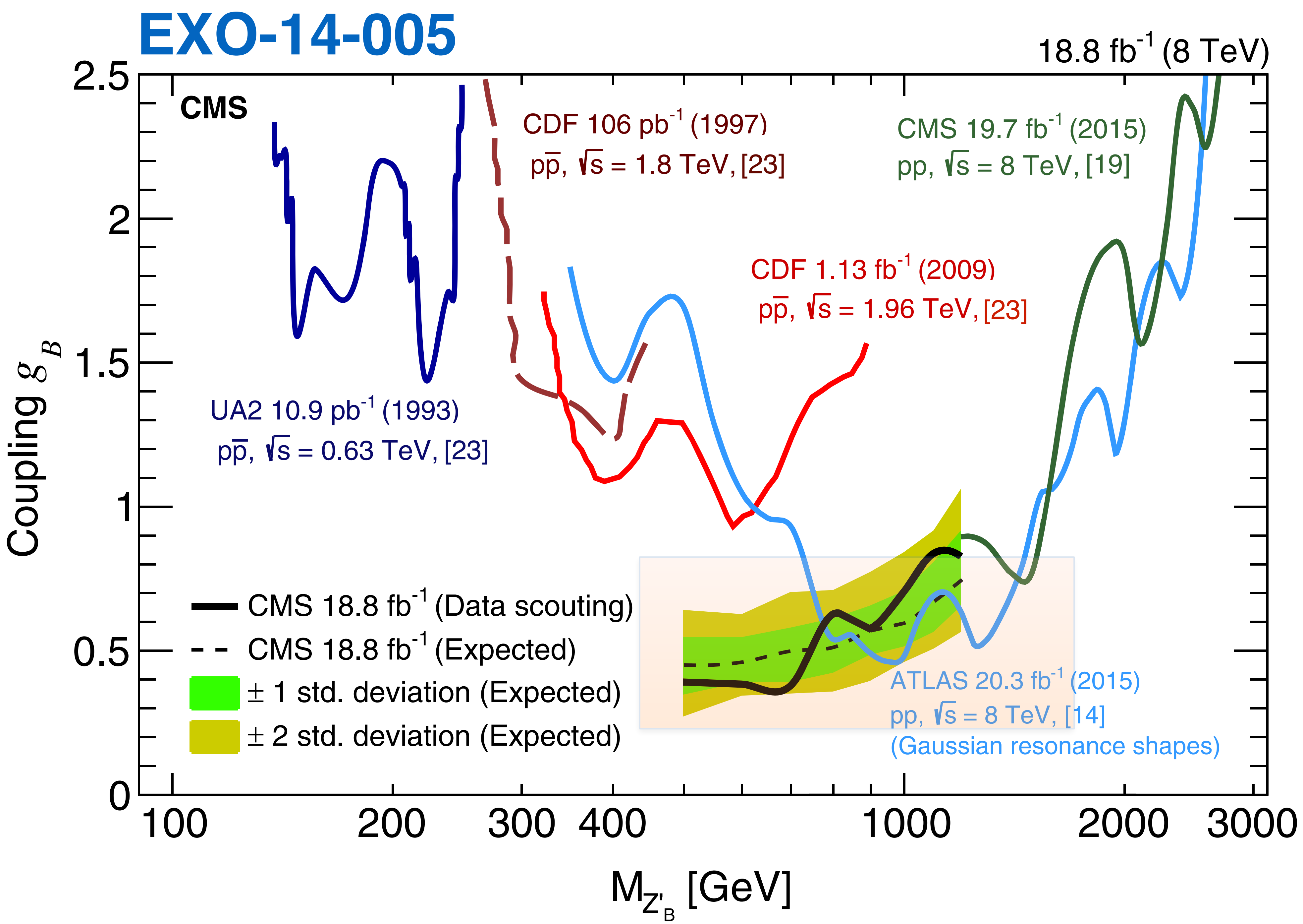
Increasing collider energy reduces sensitivity to low mass because backgrounds are large.

What new strategies can be used to probe this region at LHC?



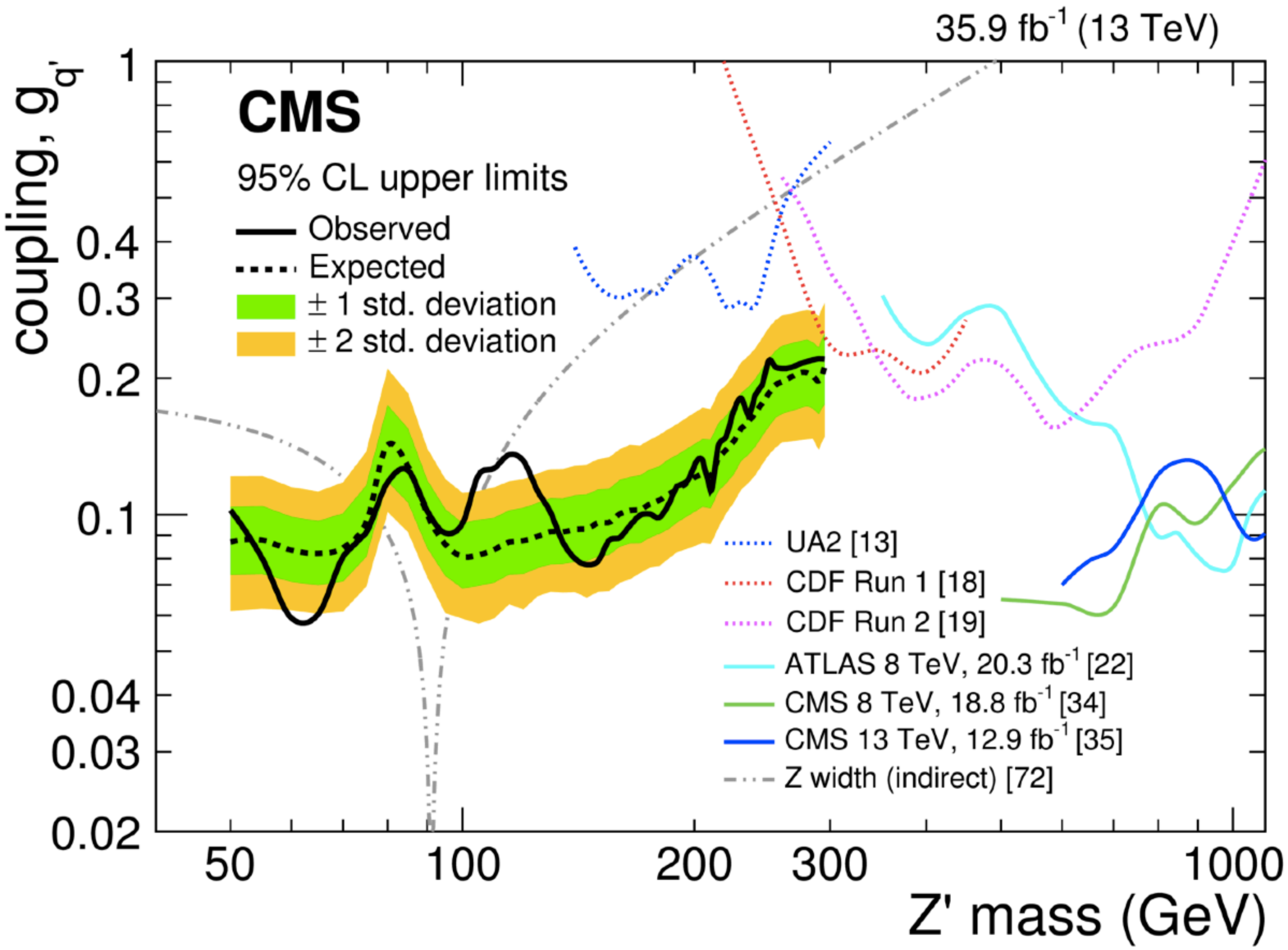
New Physics in dijet resonance searches

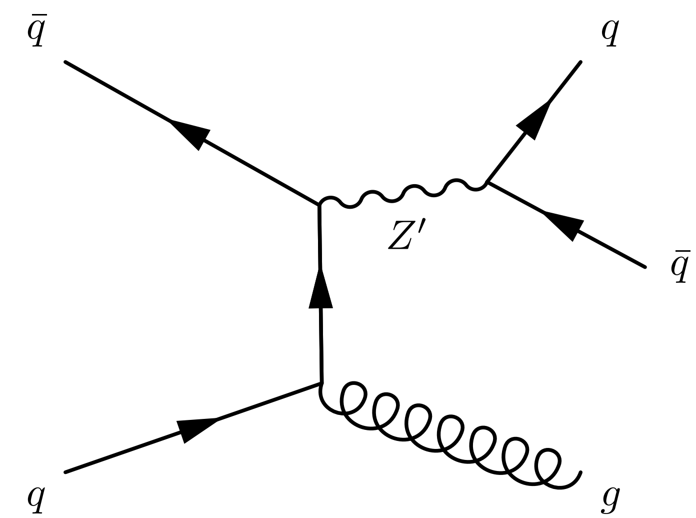
Strategy 1: Data Scouting



New Physics in dijet resonance searches

Strategy 2: Check for production of resonance in association with another SM particle





1. $\sum H_T > 900$ GeV
2. $R^{\text{fat-jet}}_{\text{anti-kt}} = 0.8$
3. $p_T^{\text{fat-jet}} > 500$ GeV

New Physics in dijet resonance searches

Identifying light dijet resonances

- Given a signal we would like to classify the resonance
- Apart from direct spin measurements, radiation patterns provide a valuable clue
- Color octets, sextets, singlets can be identified by how they radiate as well as how their decay products radiate (quark vs gluon).
- Jet Energy Correlators (JEC) can provide an efficient handle.

New Physics in dijet resonance searches

Jet Energy Correlators: Part-I

$$\mathrm{ECF}(N,\beta) = \sum_{i_1<i_2<\ldots<i_N\in J} \left(\prod_{a=1}^{N} E_{i_a}\right)\left(\prod_{b=1}^{N-1}\prod_{c=b+1}^{N}\theta_{i_b i_c}\right)^{\beta}$$

Vanish in the soft and collinear limit.

Or when there are fewer than N (sub-)jets
In the system.

$$\mathrm{ECF}(0,\beta) = 1,$$
$$\mathrm{ECF}(1,\beta) = \sum_{i\in J} p_{T\,i},$$
$$\mathrm{ECF}(2,\beta) = \sum_{i<j\in J} p_{T\,i}\, p_{T\,j} (R_{ij})^{\beta},$$
$$\mathrm{ECF}(3,\beta) = \sum_{i<j<k\in J} p_{T\,i}\, p_{T\,j}\, p_{T\,k} \left(R_{ij}R_{ik}R_{jk}\right)^{\beta},$$
$$\mathrm{ECF}(4,\beta) = \sum_{i<j<k<\ell\in J} p_{T\,i}\, p_{T\,j}\, p_{T\,k}\, p_{T\,\ell} \left(R_{ij}R_{ik}R_{i\ell}R_{jk}R_{j\ell}R_{k\ell}\right)^{\beta}.$$

Can be applied to entire event
or in our case
to the subjets of fat-jet.

Larkoski, Salam, Thaler :1305.0007

New Physics in dijet resonance searches

Jet Energy Correlators: Part-II

First, define the ratio

$$r_N^{(\beta)} \equiv \frac{\mathrm{ECF}(N+1,\beta)}{\mathrm{ECF}(N,\beta)}$$

$r_N^{(\beta)}$ (small) determines if an N-pronged decay has N-subjets

Finally, define the <u>dimensionless</u> double ratio :

$$C_N^{(\beta)} \equiv \frac{r_N^{(\beta)}}{r_{N-1}^{(\beta)}} = \frac{\mathrm{ECF}(N+1,\beta)\,\mathrm{ECF}(N-1,\beta)}{\mathrm{ECF}(N,\beta)^2}$$

For example: $C_1^{(\beta)} = \frac{\sum_{ij} E_i E_j \theta_{ij}^{\beta}}{(\sum_i E_i)^2}$

<u>Radiation from N-jets increases the value of</u> $C_N^{(\beta)}$

New Physics in dijet resonance searches

Jet Energy Correlators : LL Quark Gluon Discrimination

$$\hat{C}_1^{(\beta)} = z(1-z)\theta^{\beta}$$

Dominated by the splitting angle and energy of the softer particle

Resummed distribution

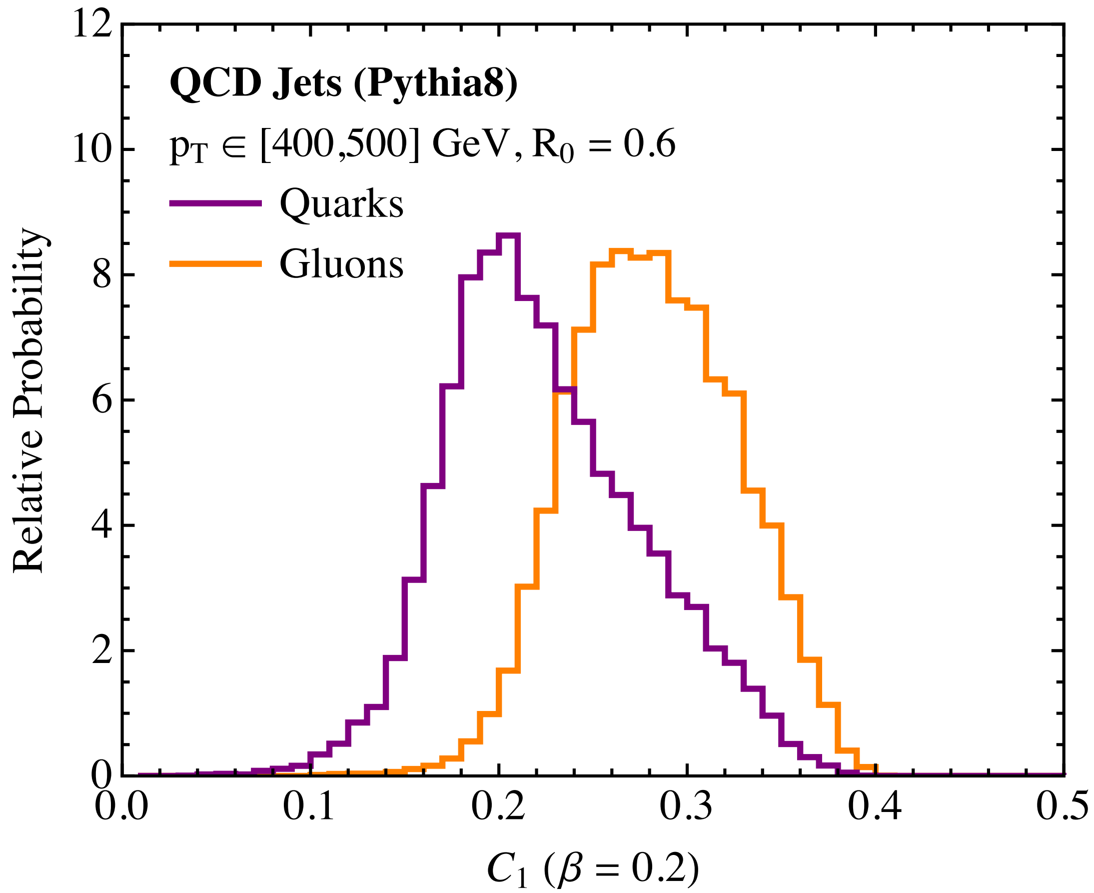
$$\frac{1}{\sigma}\frac{d\sigma^{\text{LL}}}{dC_1^{(\beta)}} = \frac{2\alpha_s}{\pi}\frac{C}{\beta}\frac{L}{C_1^{(\beta)}}e^{-\frac{\alpha_s}{\pi}\frac{C}{\beta}L^2} \qquad L \equiv \ln\frac{R_0^{\beta}}{C_1^{(\beta)}}$$

Discriminant

$$\text{disc}(x) = x^{C_A/C_F} = x^{9/4}$$

Independent of the angular exponent

Quark jets peaked at smaller values of $C_1^{(\beta)}$ than gluons, because they radiate less.



(a)

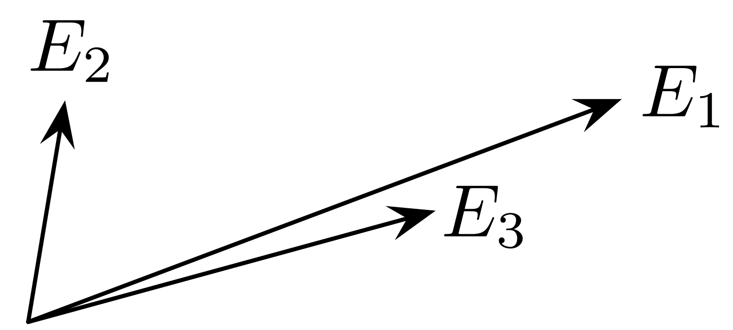
New Physics in dijet resonance searches

Sensitivity to wide angle emission

Jet Energy Correlators

$$\mathrm{ECF}(1,\beta) \simeq E_1, \qquad \mathrm{ECF}(2,\beta) \simeq E_1 \max\left[E_2\,(\theta_{12})^\beta\,,E_3\,(\theta_{13})^\beta\right]$$

$$\mathrm{ECF}(3,\beta) = E_1 E_2 E_3\,(\theta_{12}\theta_{23}\theta_{13})^\beta\,,$$



$$C_2^{(\beta)} = \frac{\mathrm{ECF}(3,\beta)\mathrm{ECF}(1,\beta)}{\mathrm{ECF}(2,\beta)^2} \simeq \frac{E_2 E_3\,(\theta_{12})^{2\beta}\,(\theta_{13})^\beta}{\max\left[E_2\,(\theta_{12})^\beta\,,E_3\,(\theta_{13})^\beta\right]^2}\,.$$

$$E_1 \gg E_2, E_3, \qquad \theta_{13} \ll \theta_{12} \simeq \theta_{23}.$$

N-subjettiness

$$\tau_N^{(\beta)} = \sum_i p_{Ti} \min\left\{R_{1,i}^\beta, R_{2,i}^\beta, \ldots, R_{N,i}^\beta\right\} \qquad \tau_{N,N-1}^{(\beta)} \equiv \frac{\tau_N^{(\beta)}}{\tau_{N-1}^{(\beta)}}\,.$$

$$\tau_1^{(\beta)} \simeq \max\left[E_2(\theta_{12})^\beta, E_3(\theta_{13})^\beta\right], \qquad \tau_2^{(\beta)} \simeq \min\left[E_2(\theta_{12})^\beta, E_3(\theta_{13})^\beta\right]$$

$$\Rightarrow \qquad \tau_{2,1}^{(\beta)} = \frac{\min\left[E_2(\theta_{12})^\beta, E_3(\theta_{13})^\beta\right]}{\max\left[E_2(\theta_{12})^\beta, E_3(\theta_{13})^\beta\right]}\,.$$

$$\boxed{C_2^{(\beta)} \simeq \tau_{2,1}^{(\beta)} \times (\theta_{12})^\beta,}$$

New Physics in dijet resonance searches

Sensitivity to wide angle emission

$$C_2^{(\beta)} \simeq \tau_{2,1}^{(\beta)} \times (\theta_{12})^{\beta},$$

Presence of soft subject at large angle -> C_2 > $\tau_{2,1}^{(\beta)}$

Jet mass squared $\beta = 2$

$$m^2 \simeq E_1 \max\left[E_2\,(\theta_{12})^2\,, E_3\,(\theta_{13})^2\right]$$

$$z = E_2/E_1 \text{ if } E_2\,(\theta_{12})^2 > E_3\,(\theta_{13})^2$$

define z as the energy fraction of the emission that dominates the mass

For C_2, if particle 2 dominates the mass

$$C_2^{(2)} \simeq \tau_{2,1}^{(2)} \times \frac{m^2}{(E_1)^2}\frac{1}{z},$$

C_2 penalizes small values of z

QCD backgrounds peak at small values of z

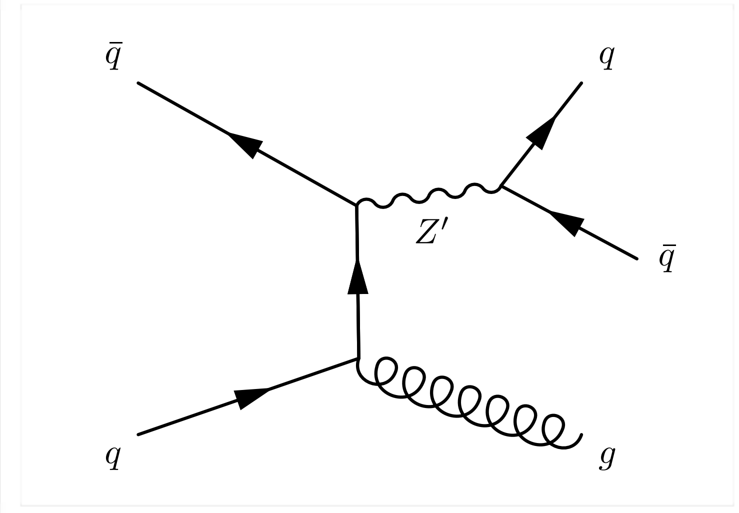
New Physics in dijet resonance searches

Resonance	Interaction	J	$SU(3)_C$	$\|Q_e\|$	Dominant decay
Leptophobic Z'	$\frac{g_B}{6}\bar{q}\gamma^\mu q Z'_\mu$	1	**0**	0	$\bar{q}q$
Coloron C_μ	$g_s \tan\theta\ \bar{q}\ T^a\gamma^\mu q C^a_\mu$	1	**8**	0	$\bar{q}q$
Octet Scalar S_8	$\frac{g_s d_{ABC} k_s}{\Lambda} S_8^A G^B_{\mu\nu} G^{C,\mu\nu}$	1	**8**	0	gg
Sextet diquark Φ_6	$\sqrt{2}(\bar{K}_6)^{ab}_\gamma \lambda_\Phi \Phi_6^\gamma \bar{u}^c_{Ra} u_{Lb}$	0	**6**	$4/3$	qq
Excited quark q^*	$\frac{1}{2\Lambda}\bar{q}^*_R\sigma^{\mu\nu}[g_S f_S \frac{\lambda^a}{2} G^a_{\mu\nu}]q_L$	$1/2$	**3**	$2/3$	qg
Spin-2 $X^{\mu\nu}$	$\frac{1}{\Lambda}X^{\mu\nu}T_{\mu\nu}$	2	**0**	0	$gg+qq$

New Physics in dijet resonance searches

Event simulation

1. $\sum H_T > 900$ GeV
2. $R_{\mathrm{CA}}^{\text{fat-jet}} = 1.0$
3. Mass drop tagger.
4. $p_T^{\text{fat-jet}} > 500$ GeV
5. Recluster $R_{\mathrm{AK}}^{\text{fat-jet}} = 1.0$
6. Find C_N^{β}.

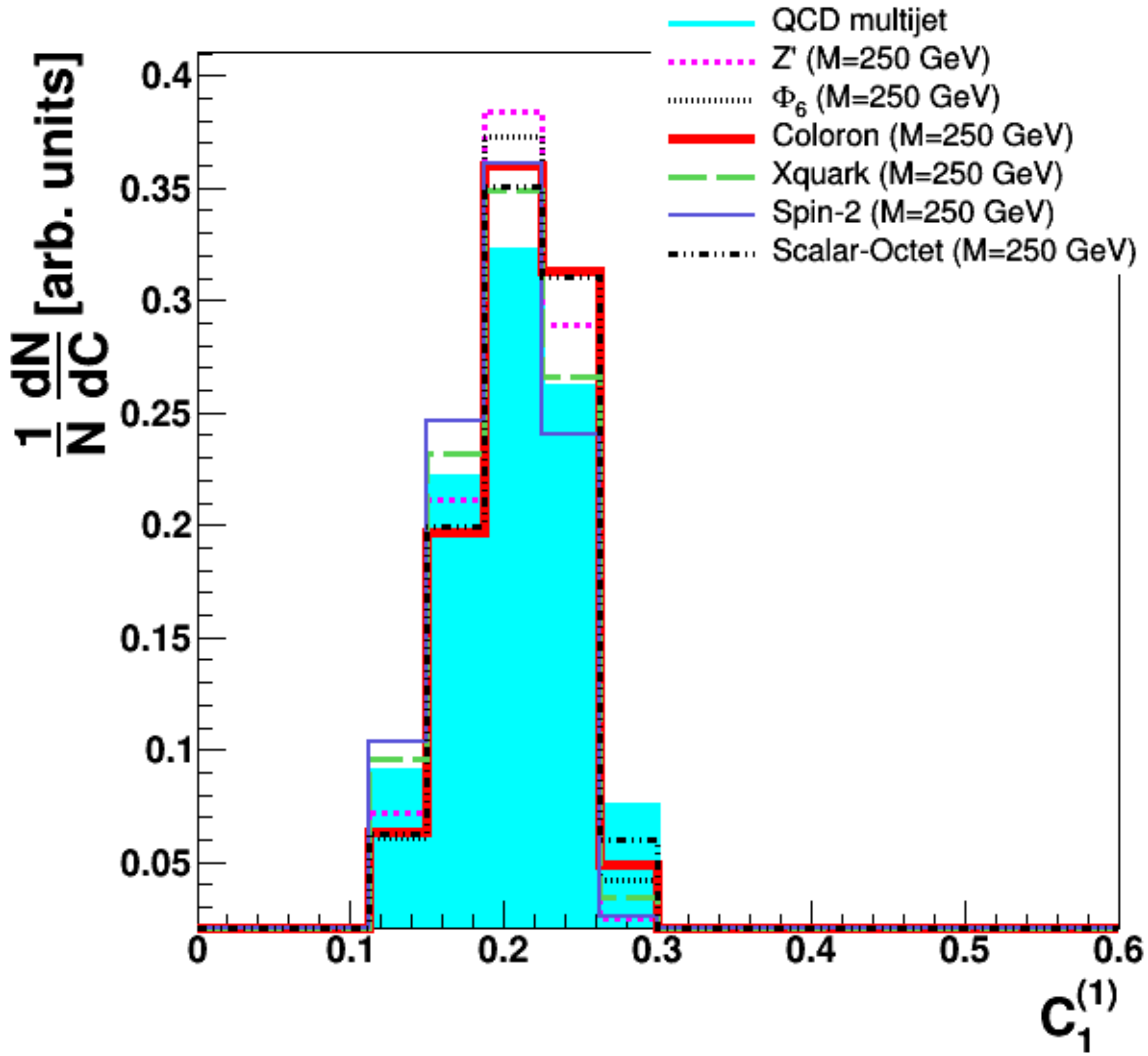


MadGraph, Pythia8, Delphes
MCFM, Powheg, FastJet

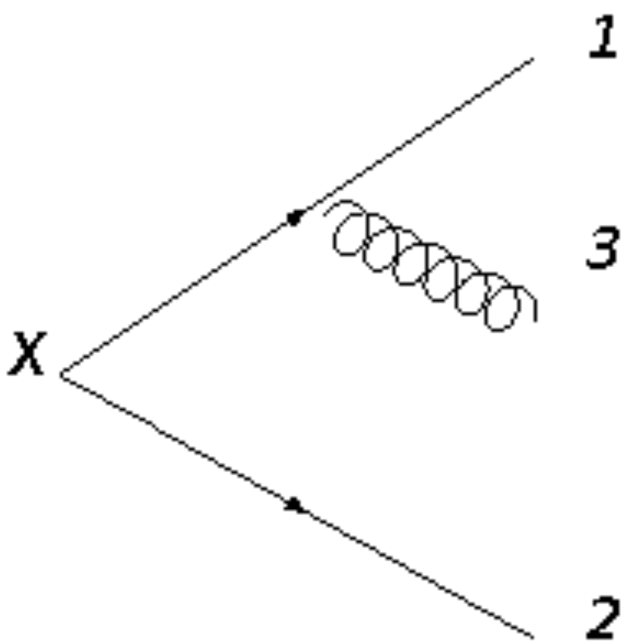
New Physics in dijet resonance searches

$$C_1^{(1)} \simeq \frac{R_{12}}{4} \simeq \frac{m_j}{2p_{T_j}}$$

Slight differences bin by bin between operators depending on the momentum dependence



New Physics in dijet resonance searches

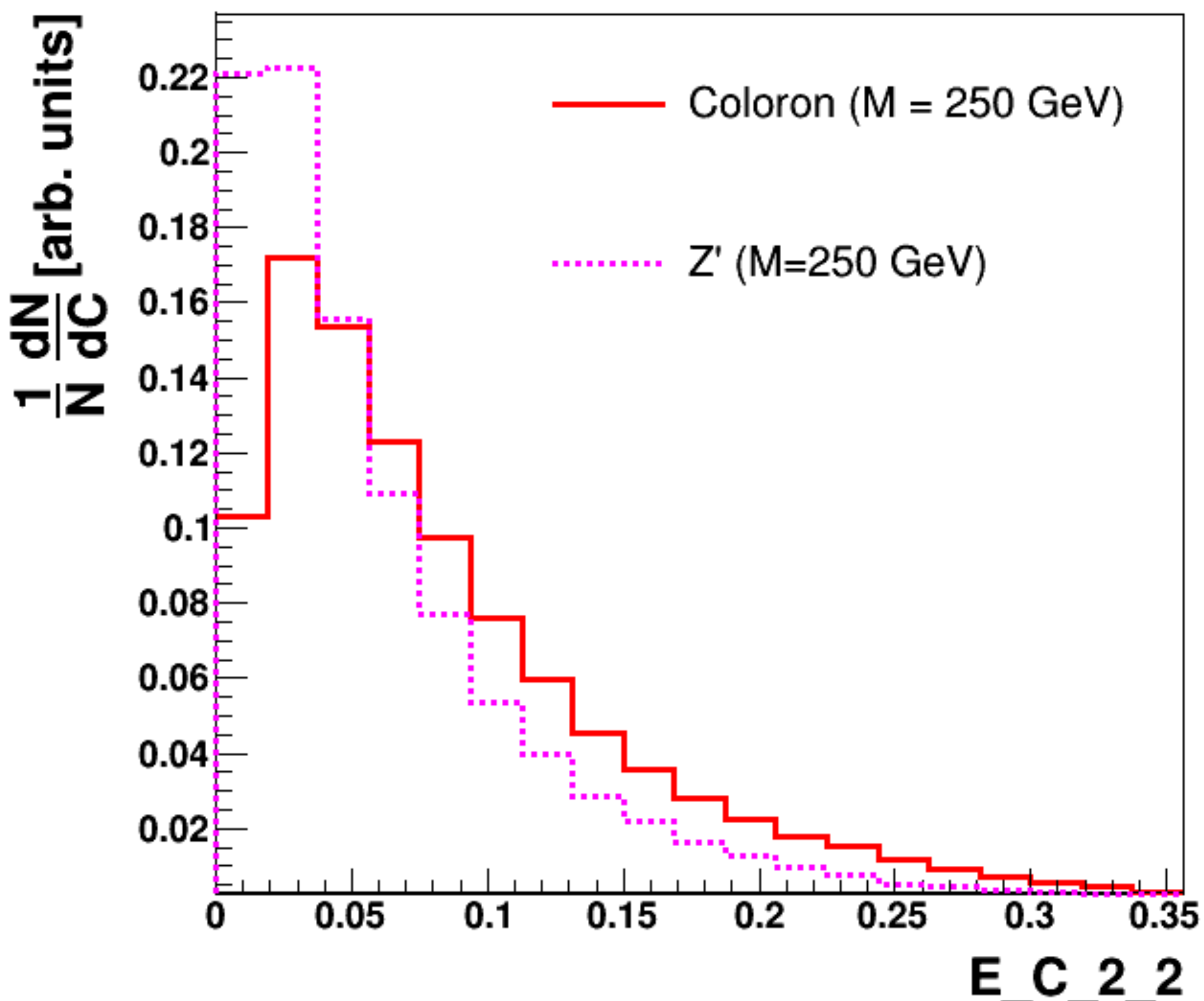


$$C_2^{(\beta)} \simeq \frac{2\varepsilon R_{12}^\beta R_{13}^\beta R_{23}^\beta}{(R_{12}^\beta + \varepsilon R_{13}^\beta + \varepsilon R_{23}^\beta)^2}$$

$$C_3^{(\beta)} \simeq \frac{[(R_{13}R_{14}R_{23}R_{24}R_{34})^\beta}{[(R_{13}R_{23})^\beta + (R_{14}R_{24})^\beta]^2} + \mathcal{O}(\epsilon)$$

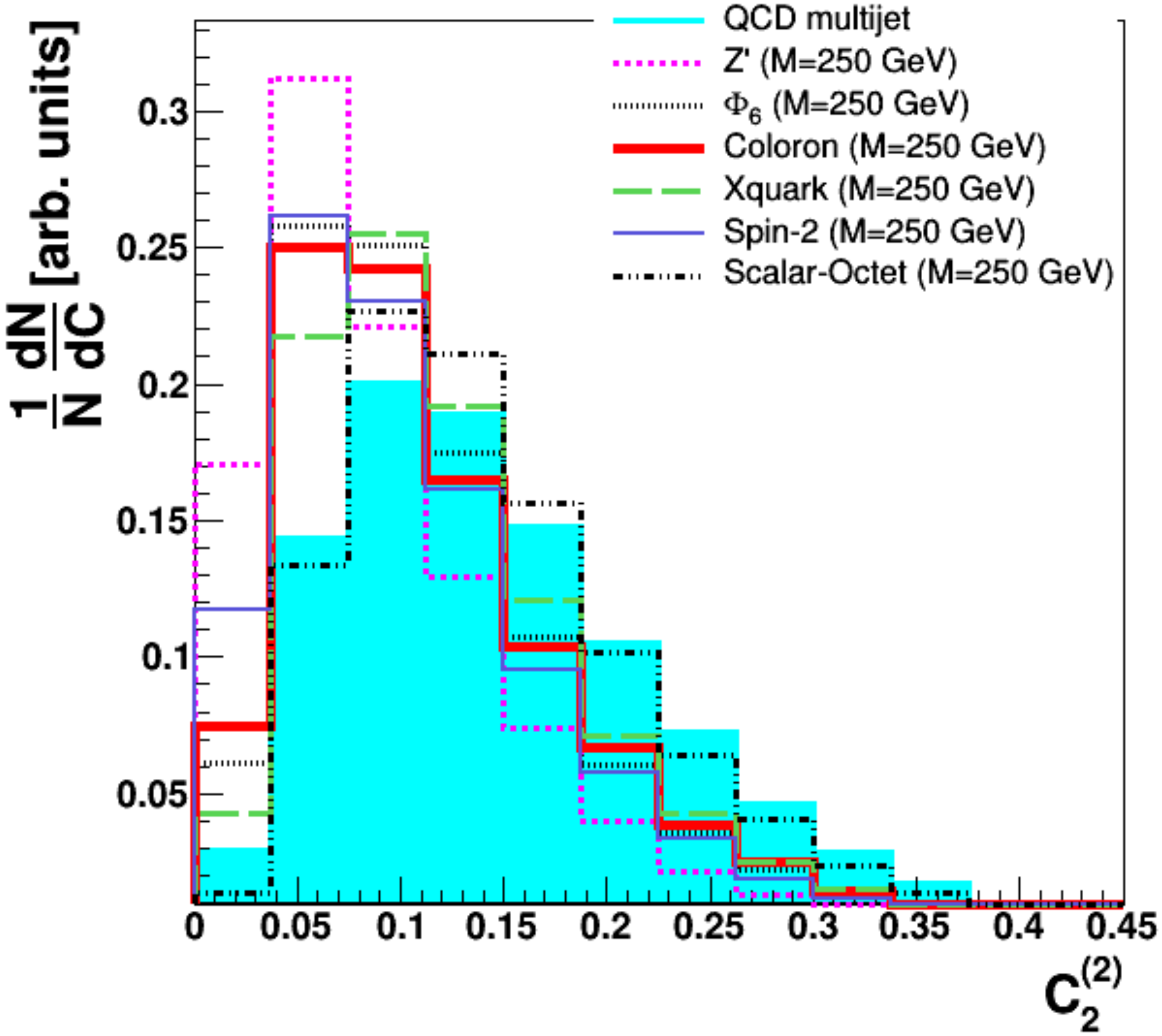
Peaks close to zero.

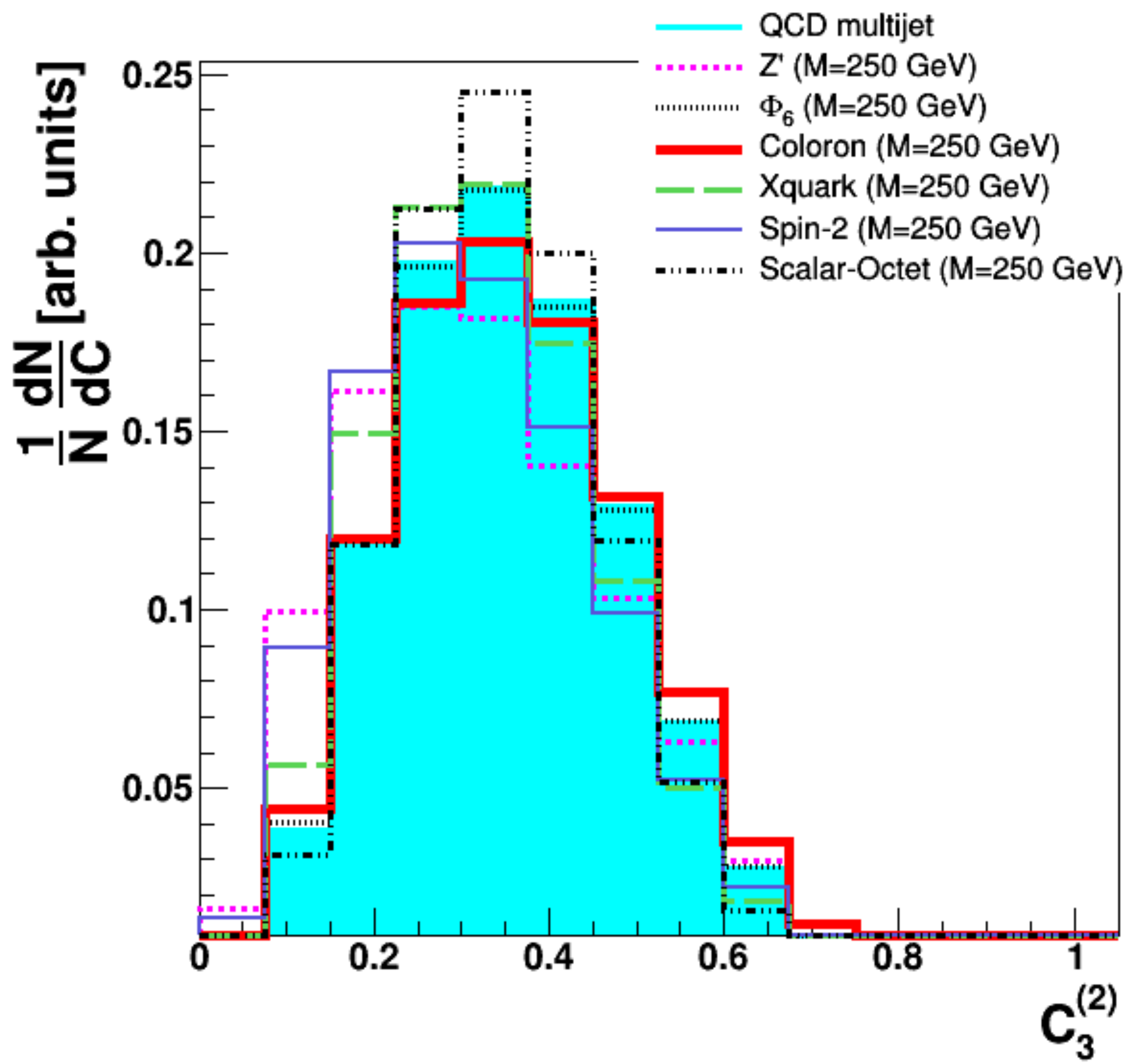
Colored resonances: shifted away from zero



New Physics in dijet resonance searches

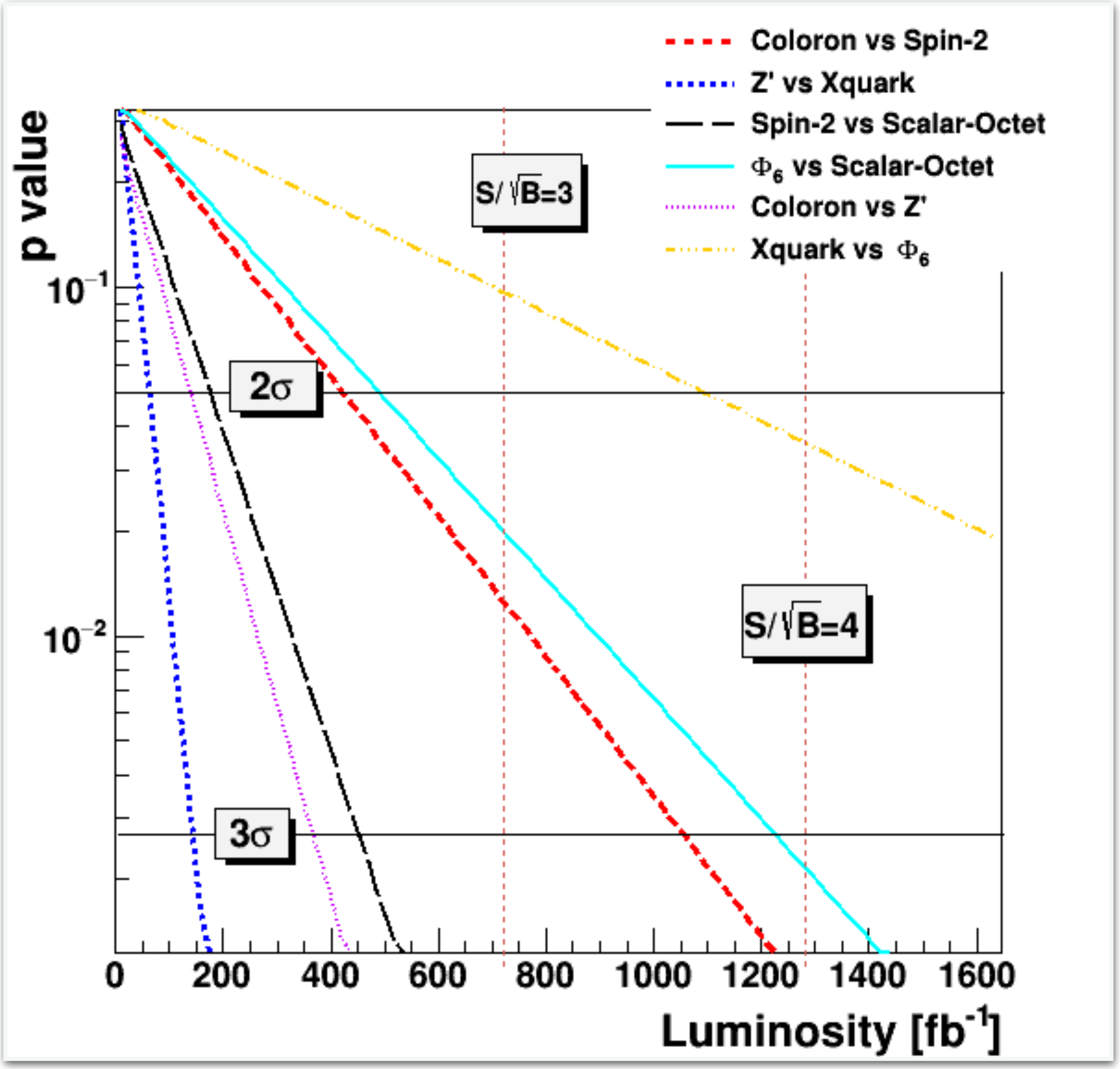
Including Hadronization & Detector effects





New Physics in dijet resonance searches

2D binned likelihood analysis with C_2 and C_3



Current exclusion $g_b \lesssim 1.5$

→ $g_b = 0.6$ C.S : 25 fb

Conclusions

- *Jet Energy Correlators are powerful probes of resonances*
- *Can distinguish resonances based on their color and momentum structures*
- *Powerful tool to suppress SM backgrounds.*

Future plans : Work in progress

- Compare Jet Energy profiles, N-subjettiness, JECs.
- Optimize over the angular exponent.
- Are Jet Imaging techniques useful in this context ?
- Machine learning techniques, unsupervised learning to optimize over a large number of jet observables

Conclusions

- *Jet Energy Corre*
- *Can distinguish r* *um structures*
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Future plans

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Characterizing Boosted Dijet Resonances with Jet Energy Correlators

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We show that Jet Energy Correlation variables can be used effectively to discover and distinguish a wide variety of boosted light dijet resonances at the LHC through sensitivity to their transverse momentum and color structures.

The LHC is actively seeking dijet resonances. However, for a given resonance mass, the ability to probe smaller couplings to quarks and gluons depends on the amount of data collected and how well one can reduce Standard Model (SM) backgrounds. Sensitivity to light dijet resonances at the LHC, in particular, is limited by the presence of large SM backgrounds that accumulate at a rate which is difficult to manage by currently available trigger and data acquisition systems at ATLAS and CMS. Looking for such resonances produced with high transverse momenta in association with a jet, photon, $W^{\pm}$ or Z boson (or even in pair production of the resonances) can reduce both signal and background rates thus avoiding trigger threshold limitations. Additionally, for highly boosted light resonances, jet substructure techniques can be applied to further reduce backgrounds.

Recently, using this search strategy, ATLAS [1] and CMS [2] were able to set limits on narrow light vector resonances (specifically a leptophobic Z' [3]), decaying to a pair of jets, in a coupling and mass range $(100-600)$ GeV that was not accessible to earlier colliders such as UA2 and CDF. However there are a plethora of possible dijet resonances that could exist: colorons [4], sextet and triplet diquarks [5, 6], excited quarks [7, 8], color-octet scalars [9], massive spin-2 particles [10] to name a few. While substructure techniques can unearth new resonances, once a light resonance is discovered the primary task becomes understanding the nature of the resonance itself. In this note we demonstrate how Jet Energy Corelators (JECs) aid in differentiating between these numerous types of resonances [1].

New dijet resonances may be classified

[1] Elsewhere we will consider and compare other jet