Jet Energy Correlations and the Identification of New Light Resonances

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Jet Substructure

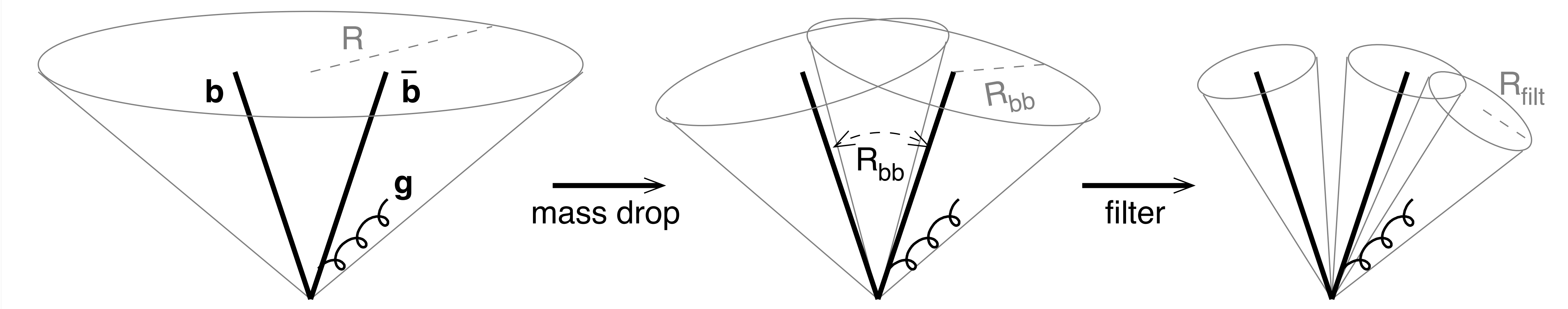
Substructures help background reduction + classification of jets

Classic Example $H \to b\bar{b}$

"BDRS" 0802.4280,

Find local subclusters of energy within a jet

$$R_{b\bar{b}} \simeq \frac{1}{\sqrt{z(1-z)}} \frac{m_{\rm H}}{p_T}$$



Step through clustering history to identify a hard splitting

Remove UE/Pile up contamination through pruning/filtering

Related ideas

N-Subjettiness -> Quasi-minimization of N-point sub-structure

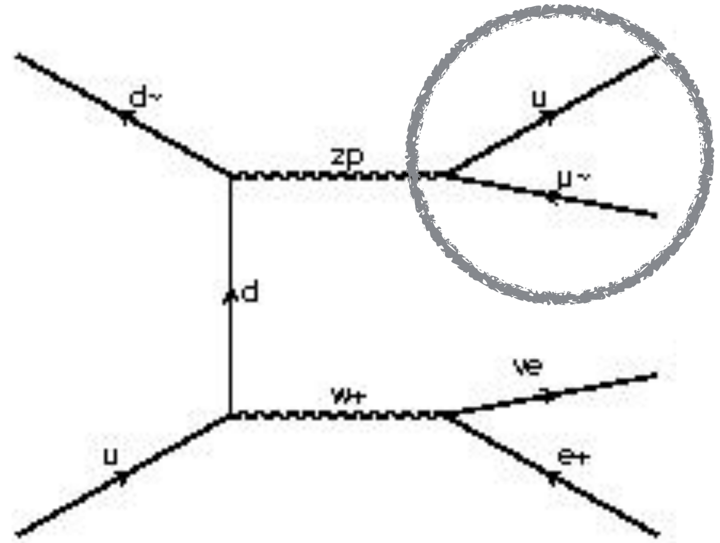
Q-Jets -> Tree based substructure to reduce fluctuations in the pruned jet mass

Thaler, Van Tilburg, Ellis, Schwartz, Krohn, Horning, Roy

Jet Substructure for "light" leptophobic V' resonances

Leptophobic Z' $\frac{g_B}{6} Z'_{B\mu} \bar{q} \gamma^\mu q$ $\Gamma(Z'_B \to jj) = \frac{5\alpha_B}{36} M_{Z'_B} \left(1 + \frac{\alpha_s}{\pi}\right)$

Look at leptonic mode



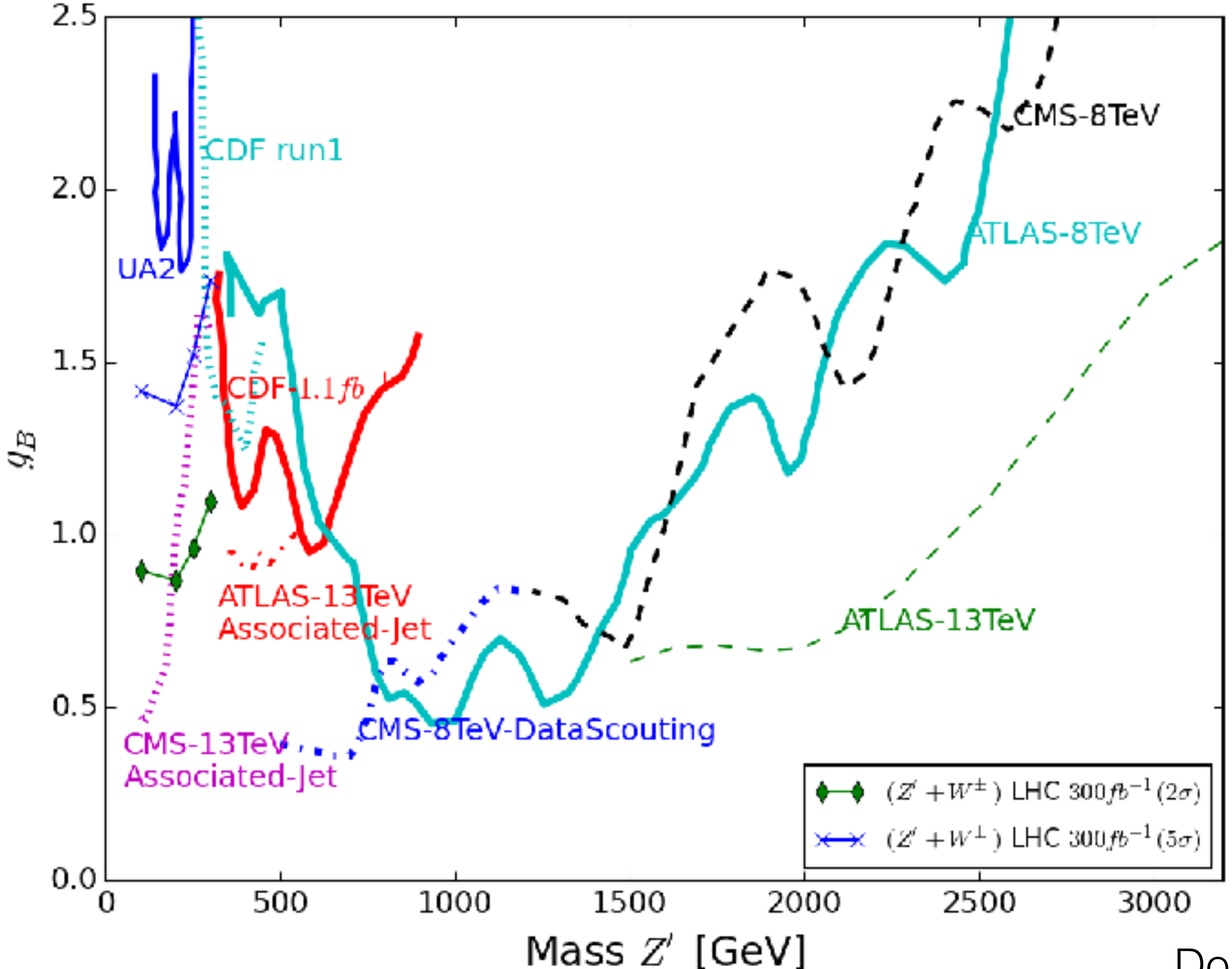
Use BDRS to reconstruct Z'
R=1.5 , Pt > 100 GeV

Principle backgrounds : W/Z + jets/ tt + jets,WW, ZZ,WZ

Analysis cuts

- A single lepton and is selected with a p_T threshold of 10 GeV and isolated with respect to tracks within a cone of 0.1.
- A b-jet veto to discriminate against the $t\bar{t}$ background.
- $\not{p}_{\mathrm{T}} \geq 100$ GeV.
- $\cos\theta(\mathrm{jj}, \mathrm{l}\not{p}_{\mathrm{T}}) < 0$.
- $\mathrm{H_T} = \Sigma \mathrm{p_T} + \mathrm{l} + \not{p}_{\mathrm{T}} > 500$ GeV.
- An invariant mass cut on the fat jet. This depends on the mass of the Z'. We choose a cut of $\mathrm{M_{Z'}} \pm 20$ GeV.

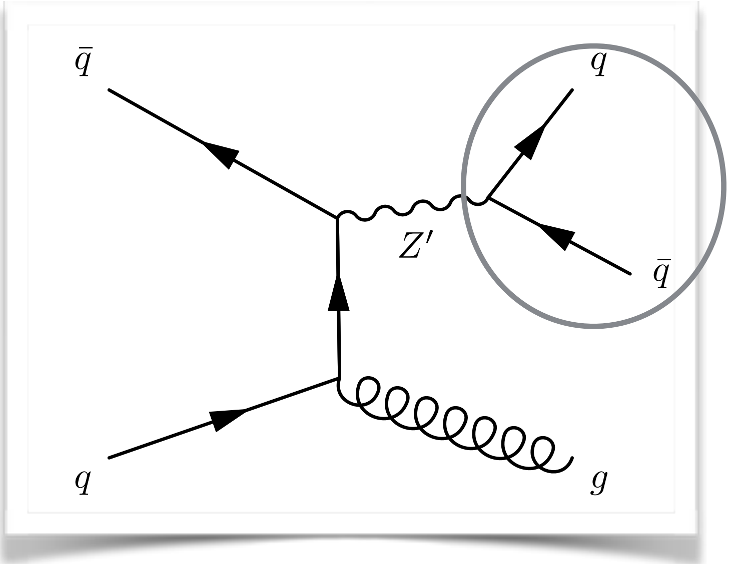
Z’ Resonance Limits - Dijet and Associated Production

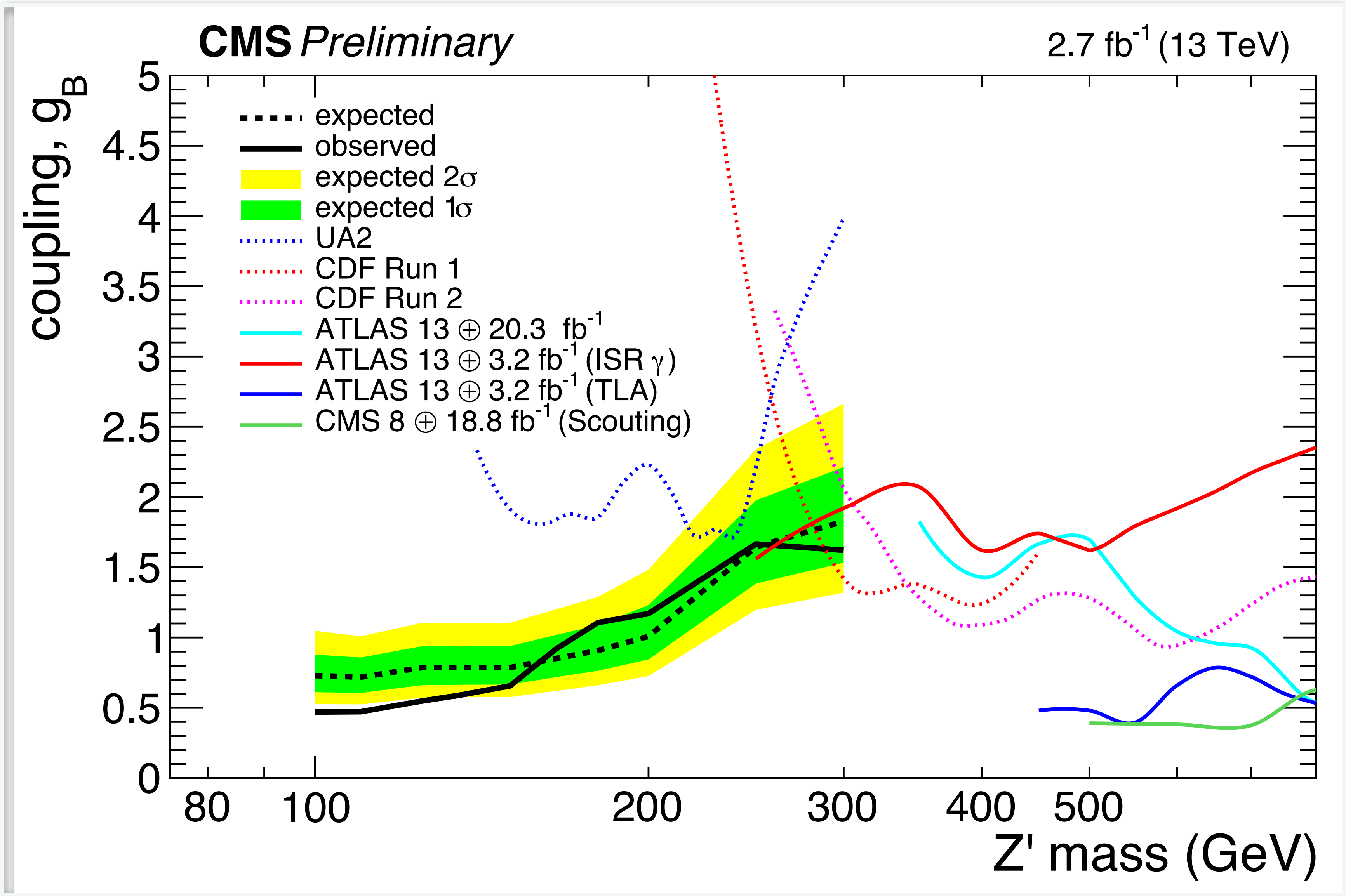


See Dobrescu and Yu PRD 2013

Jet Substructure for Light Z' resonances

- However the Z' + jet channel is more effective due larger cross section.
- Use of substructure by CMS has already yielded impressive bounds in the low mass region





Expect significant improvement at high luminosity

From Jet substructures to Energy Correlators

- Energy Correlation functions are an alternative measure of jet substructure
- No need to identify “subjet” regions individually
- Better probes of soft and collinear features - radiation

Jet Energy Correlators : Definition, part I

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

$$\mathrm{ECF}(0,\beta) \equiv 1$$

$$\mathrm{ECF}(1,\beta) = \sum_i E_i$$

$$ECF(2,\beta) = \sum_{ij} E_i E_j \theta_{ij}^{\beta}$$

$$ECF(3,\beta) = \sum_{ijk} E_i E_j E_k (\theta_{ij}\theta_{jk}\theta_{ik})^{\beta}$$

→ Vanish in the soft and collinear limit (alternative definition in transverse momentum)

For an "N-jet" event, ECF(N,β) maximal

Defined for entire event or, in our case, for a "fat" jet

Larkoski, Salam, Thaler :1305.0007

Jet Energy Correlators : Definition, 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> $C_N^{(\beta)}$

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

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

Cumulative distribution between quarks and gluons $$\Sigma_g(C_1^{(\beta)}) = \left(\Sigma_q(C_1^{(\beta)})\right)^{C_A/C_F}$$

Discriminant $$\mathrm{disc}(x) = x^{C_A/C_F} = x^{9/4}$$ Independent of the angular exponent

Larkoski, Salam, Thaler :1305.0007

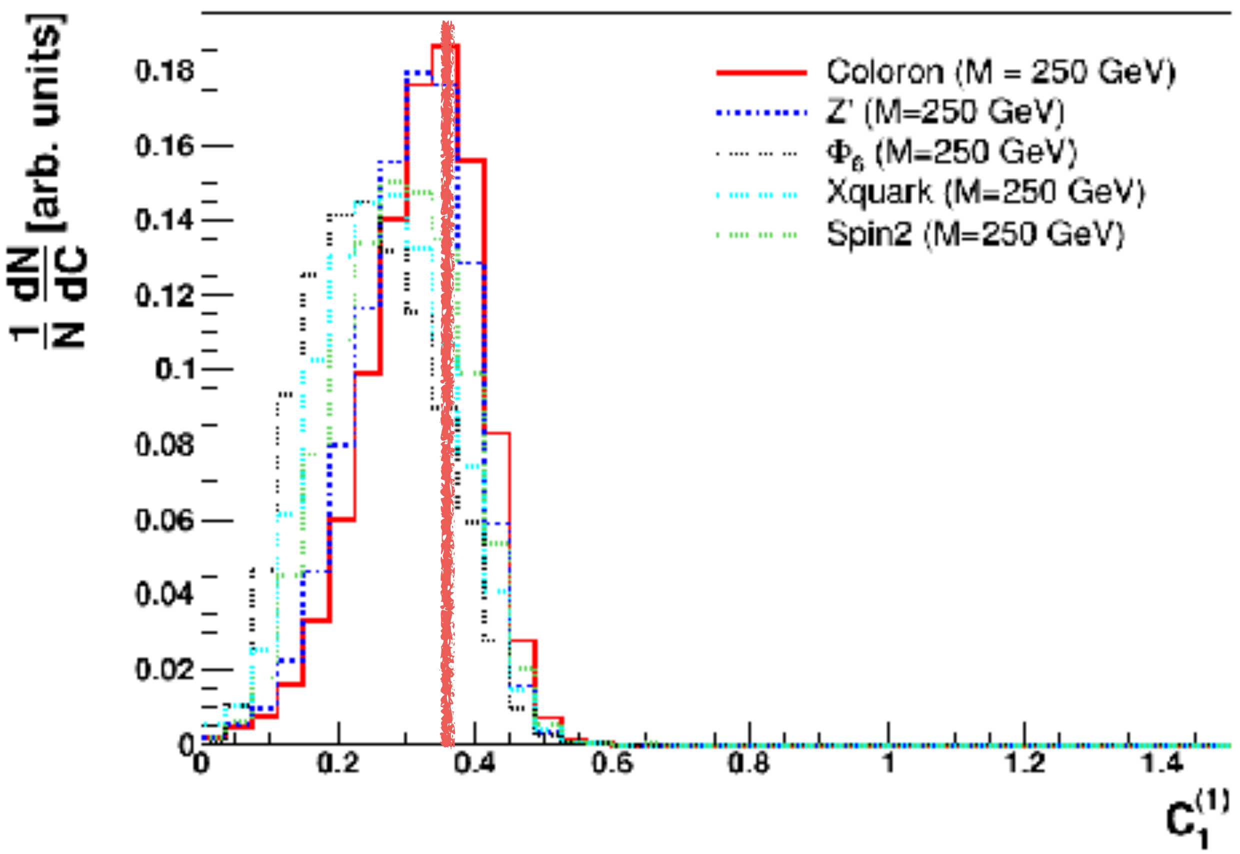
Quark jets peaked at smaller values of $C_1^{(\beta)}$ than gluons, because the radiate less.

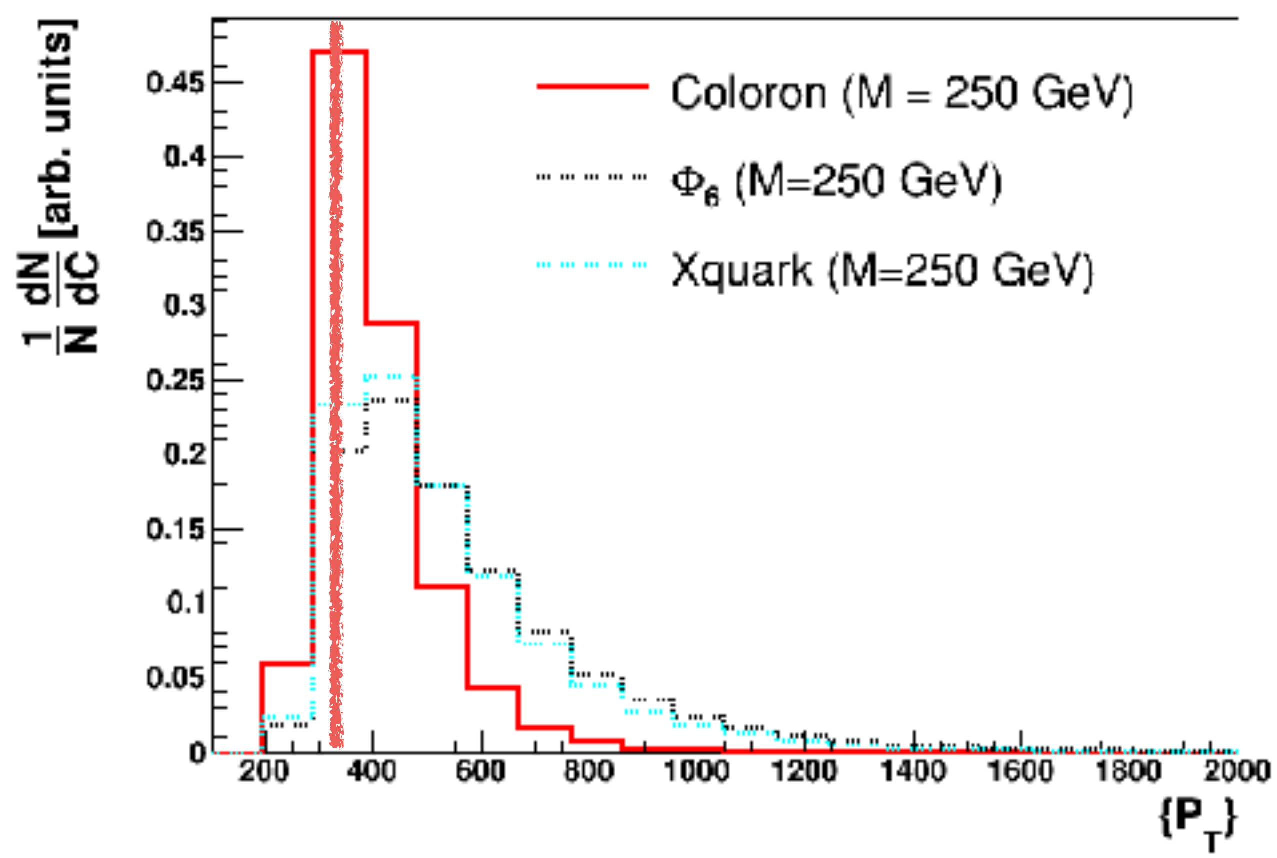
Jet Energy Correlators : Identifying Light Resonances

- Given a signal we would like to classify the resonance.
- Apart from direct spin measurements, radiation patterns provide valuable clue.
- Color octets, sextets and singlets can be distinguished by how it radiates.
- Jet energy correlations can be an efficient handle in this case.

Jet Energy Corelators - pT Information

$$C_1^{(\beta)} = \frac{\sum_{ij} E_i E_j \theta_{ij}^{\beta}}{(\sum_i E_i)^2} \propto \left(\frac{m_R}{p_T}\right)^{\beta}$$





40K events, signal only
Boosted "fat jets" with R=1.5
(which pass mass-drop criteria)
β=2, Pythia tune 4c

PRELIMINARY

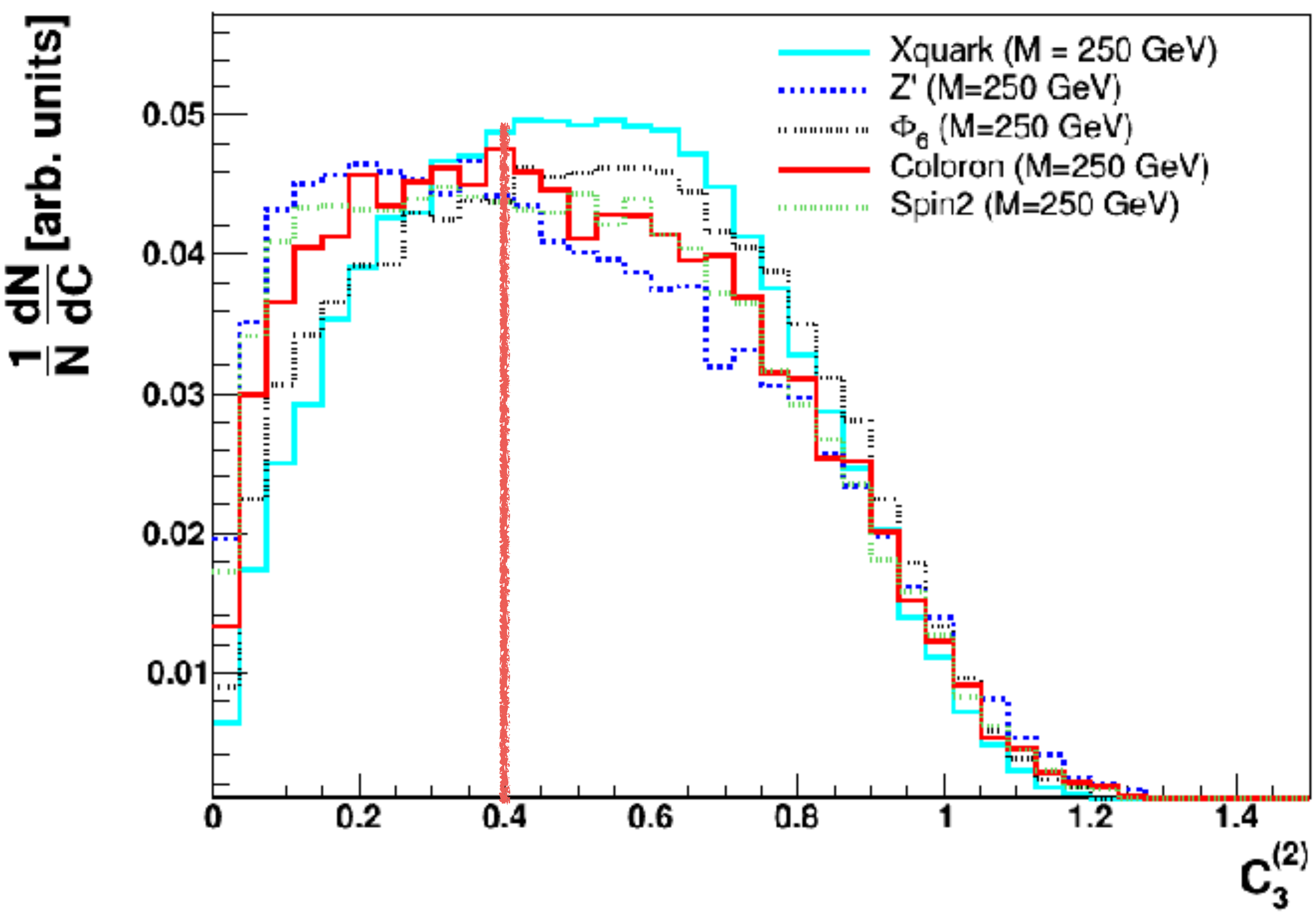
Jet Energy Correlators : Distinguishing resonances

Discriminating with higher point moments

$$C_3^{(\beta)} = \frac{\mathrm{ECF}(4,\beta)\mathrm{ECF}(2,\beta)}{\mathrm{ECF}(3,\beta)^2}$$

$C_3^{(\beta)}$ also depends strongly on what type of radiation contributes to the jet

- Color octets have more wide angle radiation compared to color singlets.
- Larger jet radius improves discrimination power.
- Larger value of the angular exponent -> More weight to wide angle emissions.



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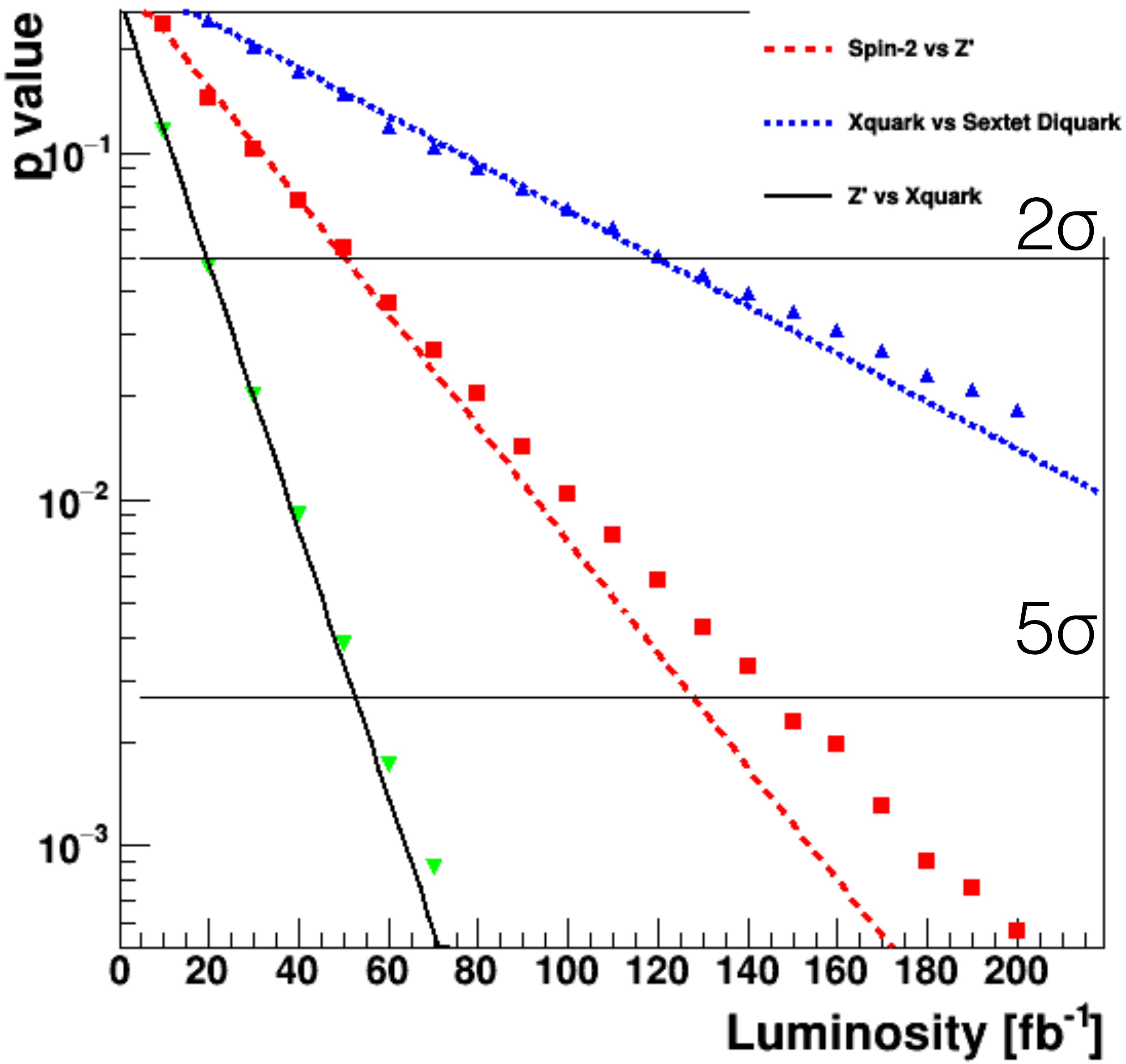
PRELIMINARY

Jet Energy Correlators : Significance



2D binned log likelihood in two-point and four-point correlation

Assumption : 0.4 fb after all cuts and background free

PRELIMINARY

Conclusions

- Jet Energy Correlators can be used to characterize jet substructure
- Correlators are sensitive to spin and color structure of light resonances
- … and can therefore be used to characterize light boosted resonances.