Precision Jet Substructure

Ilya Feige

Cargèse 2012

Harvard University

August 21, 2012

work done in collaboration with:
Matthew D. Schwartz, Iain W. Stewart and Jesse Thaler

arXiv: 1204.3898

Jet Substructure

why substructure?

we want to be able to distinguish between

 and 

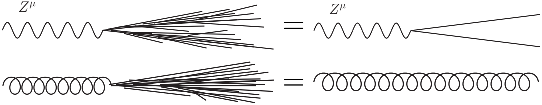
Jet Substructure

why substructure?

we want to be able to distinguish between

 and 

that is, we want to be able to say



+ splitting/hadronisation

+ splitting/hadronisation

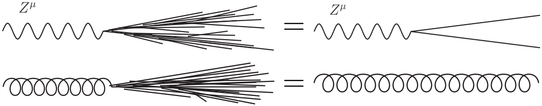
Jet Substructure

why substructure?

we want to be able to distinguish between

and

that is, we want to be able to say



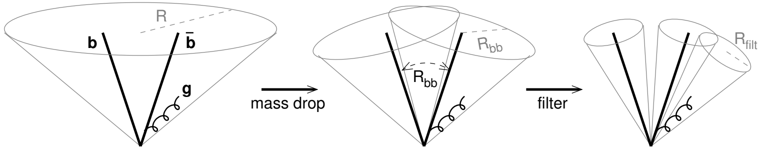
+ splitting/hadronisation

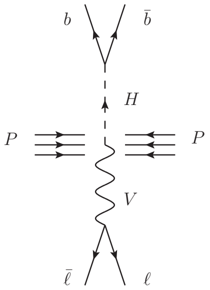
+ splitting/hadronisation

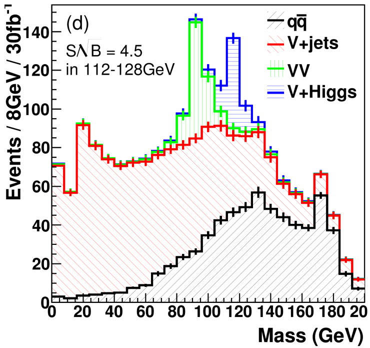
this significantly improves searches involving heavy boosted objects

Jet Substructure

case study: the Higgs [Butterworth, Davison, Rubin, Salam]





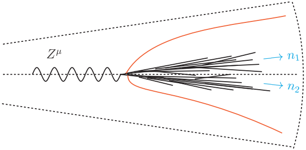


N-subjettiness

definition

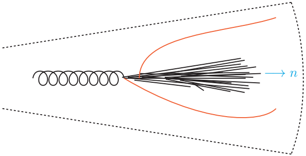
$$\mathcal{T}_N \equiv \min_{n_1,\ldots,n_N} \sum_{j\in J} \min\{n_1 \cdot p_j, \ldots, n_N \cdot p_j\}.$$

Example



$$\Longrightarrow \quad \mathcal{T}_2 \ll \mathcal{T}_1 \implies \mathcal{T}_2/\mathcal{T}_1 \ll 1$$

$$\left(\mathcal{T}_2 \approx \frac{m_1^2}{2E_1} + \frac{m_2^2}{2E_2}\right)$$



$$\Longrightarrow \quad \mathcal{T}_2 \approx \mathcal{T}_1 \implies \mathcal{T}_2/\mathcal{T}_1 \approx 1$$

$$\left(\mathcal{T}_1 \approx \frac{m_J^2}{2E_J}\right)$$

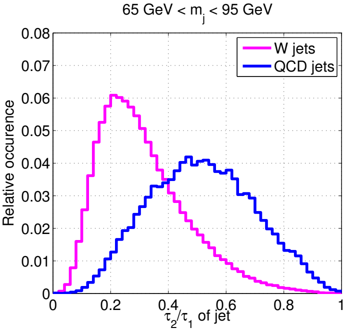
N-subjettiness

definition

$$\mathcal{T}_N \equiv \min_{n_1,\ldots,n_N} \sum_{j\in J} \min\{n_1 \cdot p_j, \ldots, n_N \cdot p_j\}.$$

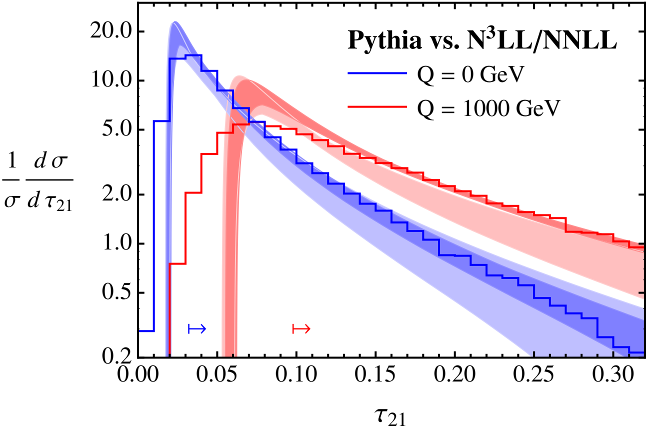
how it's used [Thaler, Van Tilburg]

- $\mathcal{T}_N \ll 1 \implies$ jet with $\leq N$ subjets
- $\mathcal{T}_N \gg 0 \implies$ jet with $> N$ subjets
- $\mathcal{T}_{N/N-1} \equiv \mathcal{T}_N / \mathcal{T}_{N-1}$ good for identifying boosted heavy objects



Results

$$\frac{d\sigma}{d\mathcal{T}_{2/1}} \text{ for a boosted } Z \text{ with } p_Z = (\sqrt{Q^2 + m_Z^2}, 0, 0, Q):$$



Thank you!

Corrections

can we apply this calculation to LHC scenarios?

in real life:

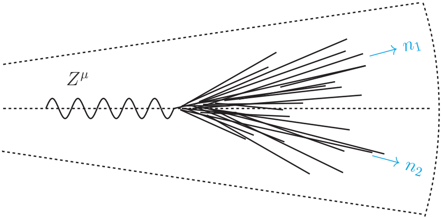
- we put cones around our jets
- initial states can radiate (ISR)
- complicated interactions happen when protons collide (UE)
- final states radiate into our jet (FSR)

we will show that these effects can be dealt with in the large Q limit

Corrections: Cone Effects

cone effects $\sim 1/Q$

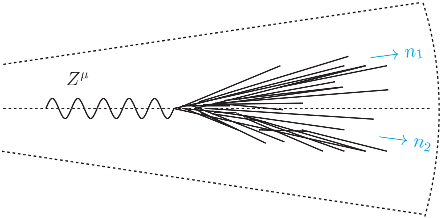
effects of cone get suppressed in large Q limit



Corrections: Cone Effects

cone effects $\sim 1/Q$

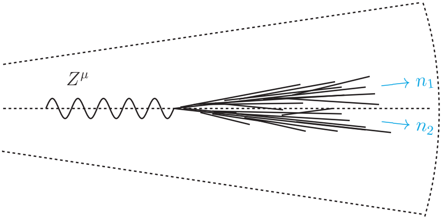
effects of cone get suppressed in large Q limit



Corrections: Cone Effects

cone effects $\sim 1/Q$

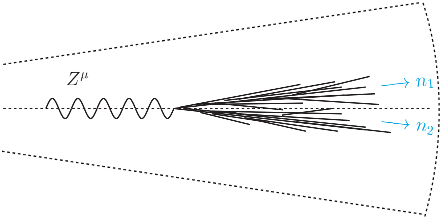
effects of cone get suppressed in large Q limit



Corrections: Cone Effects

cone effects $\sim 1/Q$

effects of cone get suppressed in large Q limit



so cone effects are dealt with

Corrections: ISR/UE/FSR

radiation not from the Z (ISR/UE/FSR)

$$Q \to \infty \implies n^\mu_{1,2} = n^\mu + \mathcal{O}\left(\frac{m_Z}{Q}\right) \implies (\mathcal{T}_2 - \mathcal{T}_1)_{ISR/\ldots} \sim 1/Q\, \mathcal{T}_2$$

Corrections: ISR/UE/FSR

radiation not from the Z (ISR/UE/FSR)

$$Q \to \infty \implies n^\mu_{1,2} = n^\mu + \mathcal{O}\Big(\frac{m_Z}{Q}\Big) \implies (\mathcal{T}_2 - \mathcal{T}_1)_{ISR/\ldots} \sim 1/Q\, \mathcal{T}_2$$

1-subjettiness

$$\mathcal{T}_1 = \min_n \sum_{j \in J} p_j \cdot n = n \cdot P_J$$

if no UE/ISR/FSR

$$\widehat{\mathcal{T}}_1 = n \cdot P_Z = \sqrt{Q^2 + m_Z^2} - Q$$

so $\Delta\tau \equiv \mathcal{T}_1 - \widehat{\mathcal{T}}_1$ measures amount of jet contamination

Corrections: ISR/UE/FSR

radiation not from the Z (ISR/UE/FSR)

$$Q \to \infty \implies n^\mu_{1,2} = n^\mu + \mathcal{O}\Big(\frac{m_Z}{Q}\Big) \implies (\mathcal{T}_2 - \mathcal{T}_1)_{ISR/\dots} \sim 1/Q\,\mathcal{T}_2$$

1-subjettiness

$$\mathcal{T}_1 = \min_n \sum_{j \in J} p_j \cdot n = n \cdot P_J$$

if no UE/ISR/FSR

$$\widehat{\mathcal{T}}_1 = n \cdot P_Z = \sqrt{Q^2 + m_Z^2} - Q$$

so $\Delta\tau \equiv \mathcal{T}_1 - \widehat{\mathcal{T}}_1$ measures amount of jet contamination

define a new observable

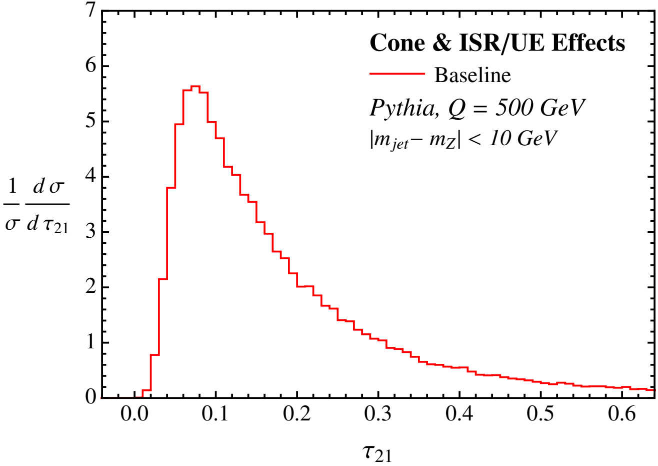
$$\tau_{21} \equiv \frac{\mathcal{T}_2 - \mathcal{T}_1 + \widehat{\mathcal{T}}_1}{\mathcal{T}_1 - \mathcal{T}_1 + \widehat{\mathcal{T}}_1} = \frac{\mathcal{T}_2 - \Delta\tau}{\mathcal{T}_1 - \Delta\tau} \quad \implies \quad (\tau_{21})_{ISR/UE} \sim 1/Q$$

Results II

how well does τ_{21} work?

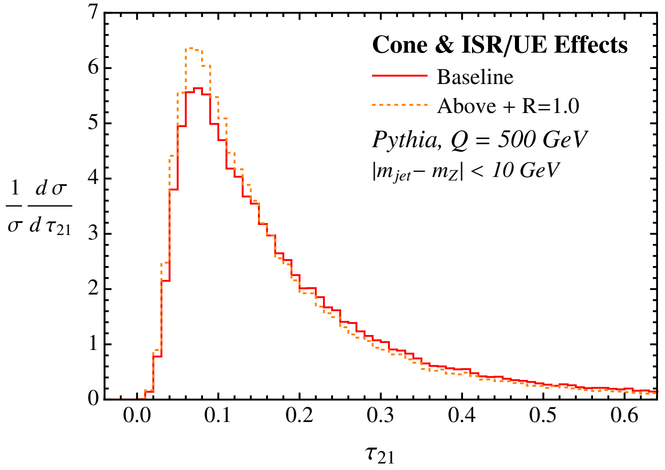
Results II

how well does τ_{21} work?



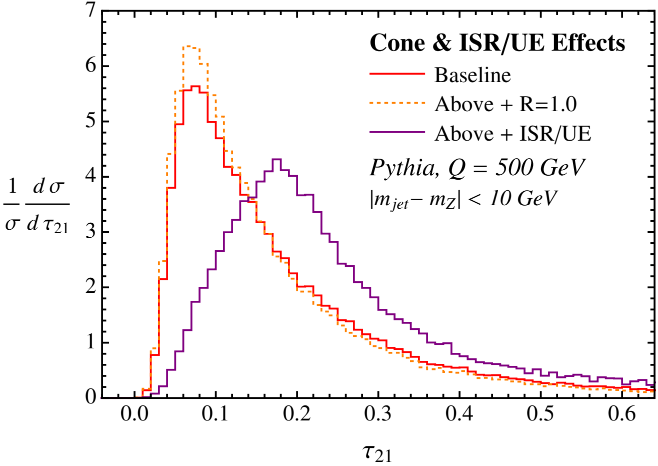
Results II

how well does τ_{21} work?



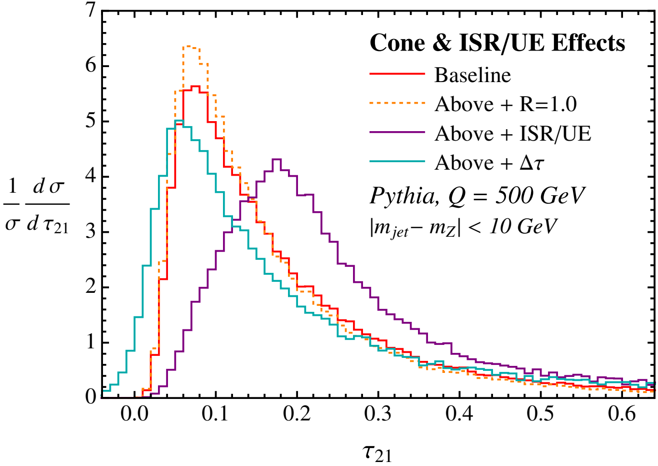
Results II

how well does τ_{21} work?



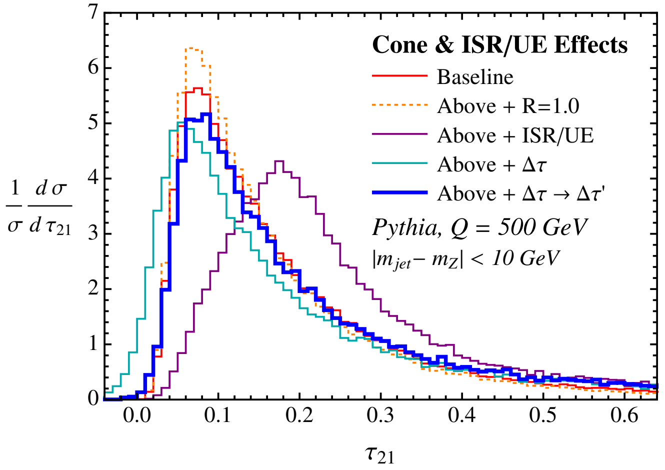
Results II

how well does τ_{21} work?



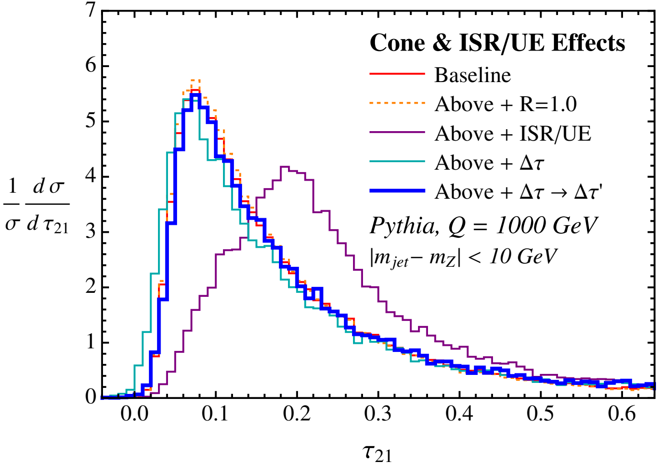
Results II

how well does τ_{21} work?



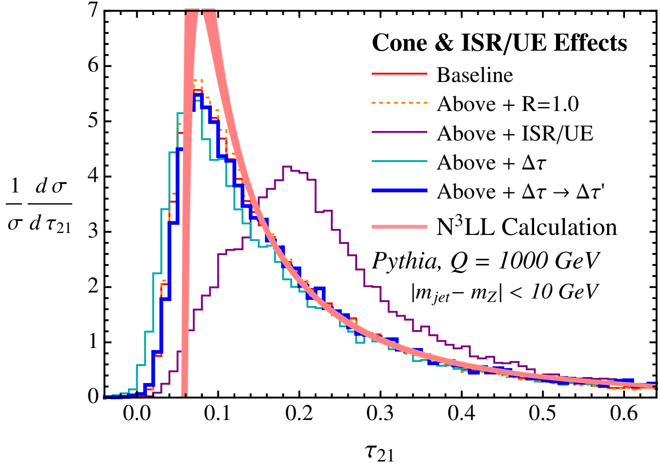
Results II

how well does τ_{21} work?



Results II

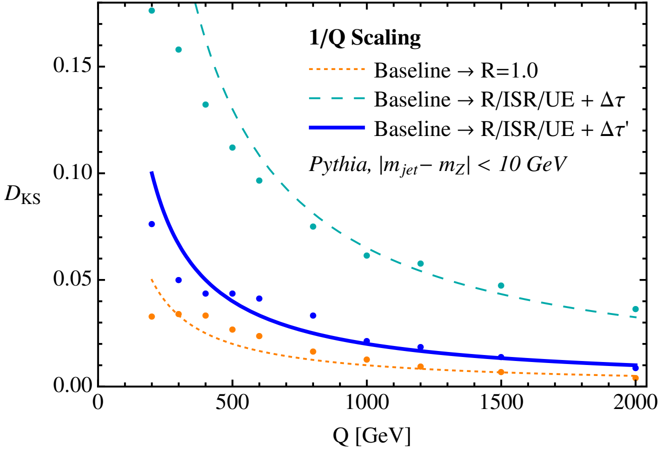
how well does τ_{21} work?



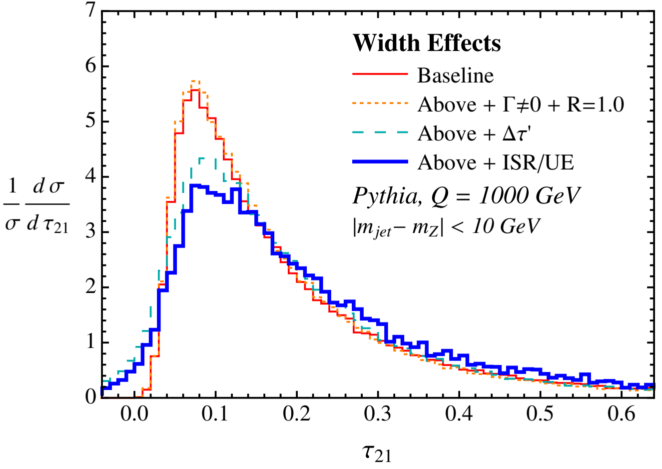
Thank you!

Q Scaling

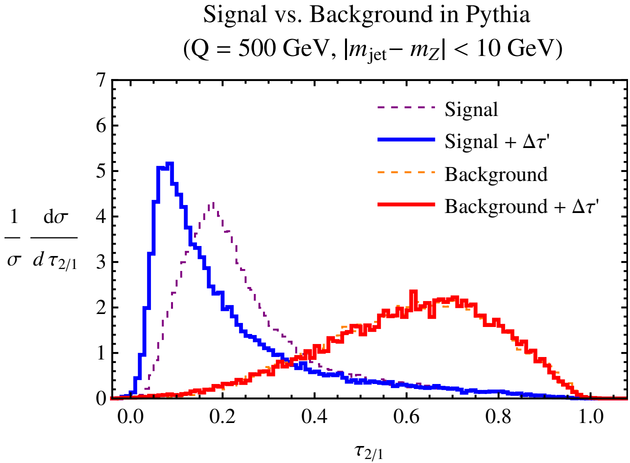
effect of adding ISR/UE with $\Delta\tau$ correction go like $1/Q$



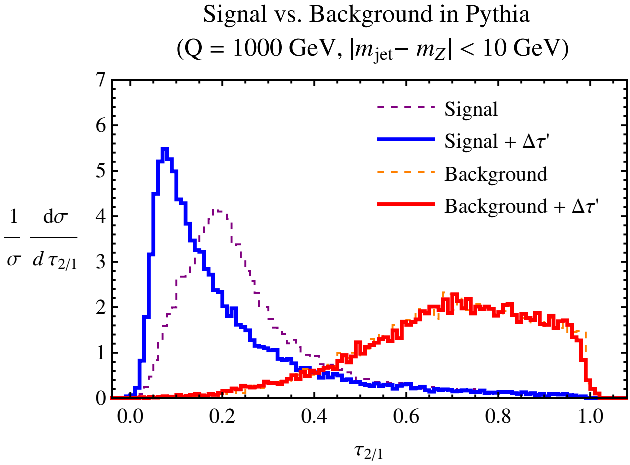
Finite Width Effect



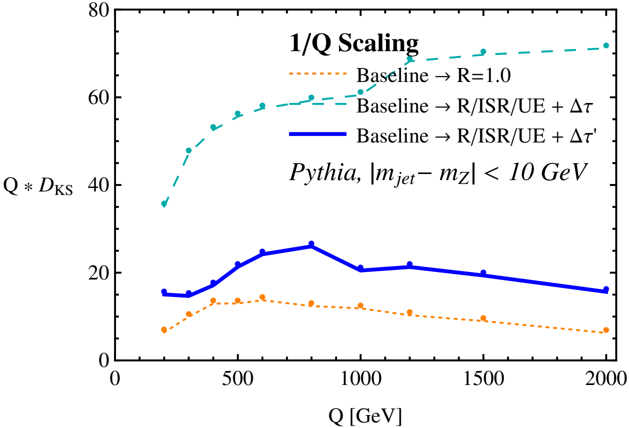
Signal vs. Background



Signal vs. Background



Q-scaling



1/Q Scaling
Baseline → R=1.0
Baseline → R/ISR/UE + Δτ
Baseline → R/ISR/UE + Δτ'
Pythia, |m_jet − m_Z| < 10 GeV
Q ∗ D_KS
Q [GeV]
0
20
40
60
80
0
500
1000
1500
2000

non-perturbative shift from thrust