Effects of background driven resolutions on jet substructure measurements

Kaya Tatar
Massachusetts Institute of Technology

The Definition of Jets in a Large Background, BNL, Upton, USA
June 26, 2018
γ-tagged jet substructure at CMS

Photon-tagged jet fragmentation function (FF) and jet shape (JS) results from CMS

Background (Bkg) sources

- **Photons** from neutral meson decays
  - → Subtracted based on shower shape
- **Tracks** and **jets** from PbPb UE
  - → Subtracted via event mixing

Photon-tagged jet fragmentation function (FF) and jet shape (JS) results from CMS

- Supplementary
  - \( p_T^\gamma > 60 \text{ GeV/c} \)
  - \( \text{anti-}k_T \text{ jet } R = 0.3 \)
  - \( p_T^{\text{jet}} > 30 \text{ GeV/c} \)
  - \( \Delta\phi_{\gamma j} > \frac{7\pi}{8} \)

- Preliminary
  - \( p_T^\gamma > 60 \text{ GeV/c} \)
  - \( \text{anti-}k_T \text{ jet } R = 0.3 \)
  - \( p_T^{\text{jet}} > 30 \text{ GeV/c} \)
  - \( \Delta\phi_{\gamma j} > \frac{7\pi}{8} \)

excess (depletion) of low-pT (high-pT) particles

larger fraction of jet energy carried at large distances
Background subtraction for tracks

isolated-photon+jet event

Raw tracks inside jet cone

MB event

Bkg tracks inside jet cone

Raw – Bkg (Bkg track subtracted)

CMS Supplementary

$\sqrt{s_{NN}} = 5.02 \text{ TeV}$

PbPb Data

$\gamma$+jet events

Cent. 0-10%

$N_{\text{jet}}$ distributions

$1 \frac{dN_{\text{trk}}}{dN_{\text{jet}}}$

$\xi_{\text{jet}} = \ln \frac{|p_{\text{jet}}|^2}{p_{\text{trk}} \cdot p_{\text{jet}}}$

Large $\xi$ $\rightarrow$ low $p_T$ particle

Kaya Tatar

June 26, 2018

arXiv:1801.04895
Size of background

- Interesting region is also the one with largest bkg
  - Large bkg $\Rightarrow$ Large unc
- What type of observables are good?
  - Interesting region does not suffer large bkg/uninteresting things
  - No large slopes, not steeply falling
    - FF is good in this, JS not good

$S/B \approx 30\%$
$S/B \approx 15\%$
$S/B \approx 75\%$
Background subtraction methods

η-reflection
- No need to find matching events
- Statistics limited to one event
  - Cannot subtract jets
- Loss of analysis phase space
  - e.g. Exclude $|\eta| < 0.3$
- Self subtraction?

Event mixing
- Need to match event characteristics
  - Centrality, vertex, collision geometry
- High statistics

---


η-reflection for inclusive jet shapes

Event mixing for $Z+$jet correlations
Start with baseline

A lot of things happen already in pp

MPI

Initial-state radiation (ISR)

Final-state radiation (FSR)

...

and

Beam Remnants (BR)
MC Exercise

- Pythia 8.2, pp collisions, $\sqrt{s} = 5.02$ TeV
- Process = photon + jet
- LO process
- No detector effects

Processes in pp collisions: MPI, ISR, FSR
Happen the same way in pp and AA? Considered as background? Impact on jet substructure?

Left (Right) tail from FSR (ISR)
**FF and JS in $\gamma$+jet MC**

Observables constructed using charged particles with $p_T > 1$ GeV/c

\[ r = \sqrt{(\eta_{\text{track}} - \eta_{\text{jet}})^2 + (\phi_{\text{track}} - \phi_{\text{jet}})^2} \]

\[ \rho(r) = \frac{1}{\delta r} \sum_{\text{jets}} \sum_{\text{trk} \in [r_a, r_b]} \left( \frac{p_{T\text{trk}}}{p_{T\text{jet}}} \right) \]
Sensitivity To Hadronization

Pythia 8.2
γ + jet

$p_T^\gamma > 60$ GeV/c
$p_T^{\text{jet}} > 30$ GeV/c

Anti-$k_T$ jet $R = 0.3$

$\frac{1}{N_{\text{jet}}} \frac{dN_{\text{particle}}}{d\xi_{\text{jet}}}$

$\xi_{\text{jet}} = \ln \left( \frac{p_T^{\text{jet}}}{p_T^\gamma} \cdot \frac{p_T^\gamma}{p_T^{\text{jet}}} \right)$

$\rho(r)$

Ratio
MPI, ISR, FSR effects

**MPI effect of ~10% at $\xi \sim 4$**

**ISR effect of ~20% at $r=0.2-0.3$**
Hard parton radiates to large angles

Fraction of energy radiated at angle $\Delta R$

Fraction of energy inside $\Delta R$

Radiation up to large angles ($\Delta R \sim 1.5$)

- Does $\eta$-reflection self-subtract?

Hard → parton produced at hard scattering
Final → daughters of “hard” partons right before hadronization
Add toys on top of baseline

We ~know how to correct/subtract some things
e.g. energy, multiplicity
Generally --> scalar quantities – > along 1D, direction of change is known

What about vector quantities ?
e.g. direction in 2D plane
Might estimate the **magnitude** of the change
But what about **direction** ?
Embedding Toy PbPb

1. Sample toy particles from PbPb Hydjet
2. Shoot them into Pythia event
3. Cluster jets using all (Pythia+toy) particles
   Correct jet energy by subtracting energy of toy particles → JES/JER factored out
4. Construct observables using Pythia particles only
Embedding Toy PbPb

A lot of particles

Mostly low energy
FF and JS in toy PbPb MC

No large change

~20% change at small r

== > Toy particles pull the jet axis
Higher-pt jets much less affected
• What is distorted here is the jet axis, a vector
  - Direction of change ambiguous
• Correlated with the position of particles
  - Not reproduced by random smearing
• Need to redefine jet angle?

\[ \text{~20\% change at small } r \]
\[ \Rightarrow \text{Toy particles pull the jet axis} \]
JS using WTA jet axis

- Standard jet axis determined via E-scheme
  - sum of 4-vec
- Winner-Take-All recombination scheme
  - In particular WTA-pt-scheme
  - Recombination $p_r$ of $p_i$ and $p_j$ where

\[
p_{t,r} = p_{t,i} + p_{t,j},
\]
\[
\phi_r = \left( \frac{w_i \phi_i + w_j \phi_j}{w_i + w_j} \right),
\]
\[
y_r = \left( \frac{w_i y_i + w_j y_j}{w_i + w_j} \right),
\]
\[
w_i = \frac{p_{t,i}^n}{n \rightarrow \infty}
\]

== >
The new axis coincides with that of the harder of 2 components

Ref. FastJet v3.2.2 Doc
JS using WTA jet axis

- Standard jet axis determined via E-scheme
  - sum of 4-vec
- Winner-Take-All recombination scheme
  - In particular WTA-pt-scheme
  - Recombination $p_r$ of $p_i$ and $p_j$ where

$$p_{t,r} = p_{t,i} + p_{t,j},$$

$$\phi_r = \frac{(w_i \phi_i + w_j \phi_j)}{(w_i + w_j)},$$

$$y_r = \frac{(w_i y_i + w_j y_j)}{(w_i + w_j)},$$

$$w_i = \frac{p_t^n}{n \to \infty}$$

Ref. FastJet v3.2.2 Doc

$\Rightarrow$

The new axis coincides with that of the harder of 2 components

Soft particles slightly removed
**WTA axis in Toy PbPb MC**

- Pythia 8.2
- $\gamma + \text{jet}$
- $p_T^\gamma > 60 \text{ GeV/c}$
- $p_T^{\text{jet}} > 30 \text{ GeV/c}$
- anti-$k_T$ jet $R = 0.3$
- particle-level
- WTA jet axis

**JS much more robust with WTA**
Summary

• If want to subtract bkg,
  – Then consider the bkg size and how it distorts observable
  – Rethink / identify suitable observables
• There are things for which we can ~remove bkg effects
  – Where we know the direction of change and estimate its magnitude
    • e.g. energy, particle yields
• Things for which we cannot undo bkg effects
  – The direction of change not known and things happen in a correlated way
  – Studied effects using gen-level Pythia and toy PbPb
  – The case of JS
    • UE particles pull jet axis
    • One way to overcome – > change axis definition to WTA.
    • This effect distorts JS, but maybe it is an observable by itself

Acknowledgements: The MIT group’s work was supported by US DOE-NP.
BACKUP
Hard parton radiates to large angles

Fraction of energy radiated at angle $\Delta R$

Hard $\rightarrow$ parton produced at hard scattering
Final $\rightarrow$ daughters of “hard” partons right before hadronization

Radiation up to large angles ($\Delta R \sim 1.5$)

$\rightarrow$ Does $\eta$-reflection self-subtract?
Embedding Toy PbPb

PbPb Hydjet
Cent:0-10%
$|\eta| < 2.5$

charged particles
neutral particles
FF and JS in toy PbPb MC – high-pt

$\sqrt{s} = 5.02$ TeV

$\gamma + \text{jet}$

$|p_T^\gamma| > 60$ GeV/c

$|p_T^{\text{jet}}| > 90$ GeV/c

anti-$k_T$ jet $R = 0.3$

particle-level

Ratio

Pythia 8.2

+ Jet

Pythia + Toy PbPb

$p_T^{\gamma}$

$p_T^{\text{jet}}$

anti-$k_T$ jet $R = 0.3$

particle-level

$\zeta = \ln \left( \frac{|p_T^{\text{jet}}|^2}{|p_T^{\text{final}}|^2} \right)$
JS using WTA axis: q vs g

**quark jets**

- **pp, $\sqrt{s} = 5.02$ TeV**
- Pythia 8.2
- $\gamma +$ jet
- $p_{T}^{\gamma} > 60$ GeV/c
- $p_{T}^{jet} > 30$ GeV/c
- anti-$k_T$ jet $R = 0.3$
- particle-level

- standard jet axis (E scheme)
- WTA jet axis

**gluon jets**

- **pp, $\sqrt{s} = 5.02$ TeV**
- Pythia 8.2
- $\gamma +$ jet
- $p_{T}^{\gamma} > 60$ GeV/c
- $p_{T}^{jet} > 30$ GeV/c
- anti-$k_T$ jet $R = 0.3$
- particle-level

- standard jet axis (E scheme)
- WTA jet axis
JS out of cone

standard

pp, $\sqrt{s} = 5.02$ TeV

Pythia 8.2

$\gamma + \text{jet}$

$p_{T}^\gamma > 60$ GeV/c

$p_{T}^{\text{jet}} > 30$ GeV/c

anti-$k_T$ jet $R = 0.3$

particle-level

- inclusive
- quark
- gluon

WTA

pp, $\sqrt{s} = 5.02$ TeV

Pythia 8.2

$\gamma + \text{jet}$

$p_{T}^\gamma > 60$ GeV/c

$p_{T}^{\text{jet}} > 30$ GeV/c

anti-$k_T$ jet $R = 0.3$

particle-level

WTA jet axis

- inclusive
- quark
- gluon
Isolated photon+jet

\[ LHC, \, pp \rightarrow \gamma_{\text{isol}} + X @ \sqrt{s} = 14 \text{ TeV}, \, y = 0 \]

\( R_{\text{isol}} = 0.4, \, E_{\text{T}}^{\text{had}} < 4 \text{ GeV} \)

\begin{align*}
\text{Compton: } & q \, g \rightarrow \gamma \, q \\
\text{Annihilation: } & q \, \bar{q} \rightarrow \gamma \, g \\
\text{Fragmentation: } & \gamma \rightarrow q \, q
\end{align*}

\( \text{JETPHOX NLO (NNPDF2.1, } \mu_{F} = E_{T}^{\gamma} \)
Bkg subtraction for jets and tracks

- MB event mixing technique
  - Estimate the bkg from fake jets and bkg tracks by constructing the observable using jets and tracks in matching MB events
- For each signal event find MB events with very close
  - centrality bin
  - vertex position in z-direction
  - event plane angle
Analysis steps: bkg tracks

isolated-photon+jet event

MB event

RAW jets
RAW-BKG tracks

BKG tracks

MB event mixing technique

How to estimate the bkg from jets/tracks?
– construct the observable using jets/tracks in matching MB events
Analysis steps – bkg jets

isolated-photon+jet event

MB event

\( \gamma \)

 RAW tracks

 RAW-BKG jets

RAW tracks

N RAW jets – N BKG jets

RAW-BKG jets

RAW-BKG tracks
Bkg subtraction: tracks and jets

Raw tracks inside jet cone
- Bkg tracks inside jet cone
= Raw – Bkg
(bkg track subtracted)

Raw jets
- Bkg jets
= Raw – Bkg
(bkg track and bkg jet subtracted)
Bkg subtraction for jets

Raw jets (bkg track subtracted)

Bkg jets (bkg track subtracted)

Raw – Bkg (bkg track and bkg jet subtracted)
In general the mapping depends on $\eta_{\text{jet}}$, $\eta_{\text{trk}}$ and $\Delta R (\text{jet, trk})$. The solid and dashed lines are the extreme cases for a given $\eta_{\text{jet}}$. 

\[ \xi_{\text{jet}} = \ln \frac{|p_{T_{\text{jet}}}|^2}{p_{T_{\text{trk}}} p_{T_{\text{jet}}}} \]
If $\Delta R \text{ (jet, trk)} = 0$, then the mapping becomes $\eta$-indep.
For $50 < p_T^{\text{jet}} < 300$ GeV range,
- there are 8-13 ch. with $p_T^{\text{trk}} > 0.5$ GeV
- there are 5-10 ch. with $p_T^{\text{trk}} > 2$ GeV inside the jet.