



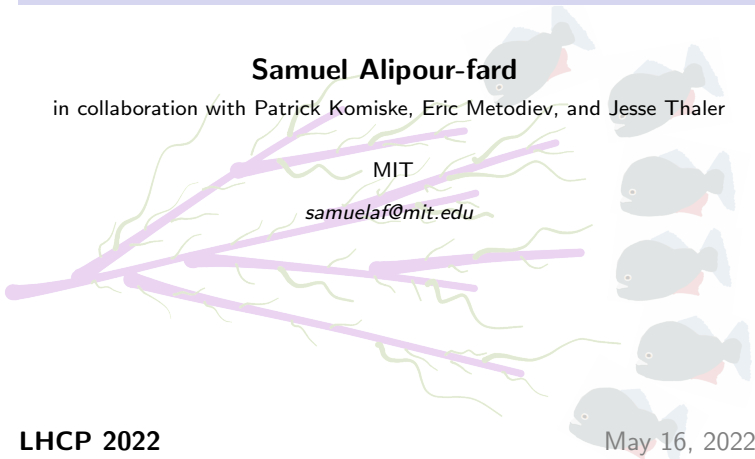
Safely Eating Junk: Pileup and Infrared Radiation AnNiHilAtion (PIRANHA)

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Motivation

PIRANHAs from
Geometry

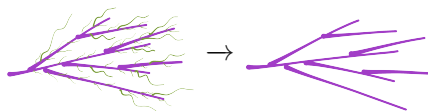
Performance of
PIRANHA

LHCP 2022

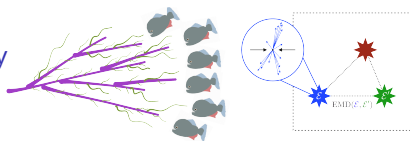
May 16, 2022



Motivation



PIRANHAs from Geometry



Performance of PIRANHA



Motivation

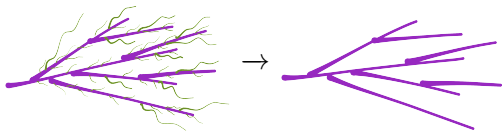
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Grooming:

A systematic procedure for removing contaminating soft radiation from particle collision data.

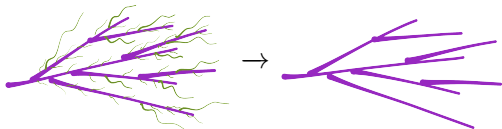


- ▶ Grooming, pileup mitigation, and similar strategies extract high energy information from jets
- ▶ Grooming helps us understand the *high energy* interactions of the microscopic universe (hard process/leading vertex)



Grooming:

A systematic procedure for removing contaminating soft radiation from particle collision data.



This definition groups techniques traditionally separated into

Grooming (see e.g. [1901.10342])

Filtering: [0802.2470], Pruning: [0912.0033], Trimming: [0912.1342]
mMDT/Soft Drop: [1307.0007], [1402.2657]; Dynamical: [1911.00375]

Pile-up Mitigation (see e.g. [1801.09721])

Areas: [0707.1378], [0802.1188], [1111.6097], Charged Hadron Subtraction
Cleansing [1309.4777], SoftKiller [1407.0408], PUPPI [1407.6013], PUMML [1707.08600]

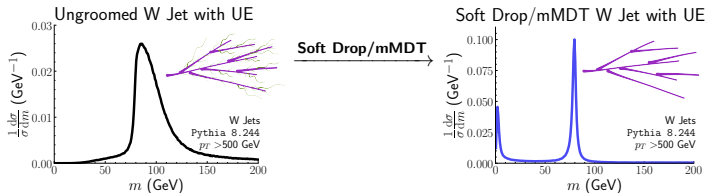


- ▶ **Experiment:** Groomed information is resilient to detector effects, pileup, initial state radiation
ATLAS: [1711.08341], CMS: [1807.05974]
- ▶ **Theory:** Grooming can facilitate precision calculations of jet substructure observables
Frye-Larkoski-Schwartz-Yan: [1603.09338]
Larkoski-Marzani-Soyez-Thaler: [1402.2657]

Motivation

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Performance of PIRANHA



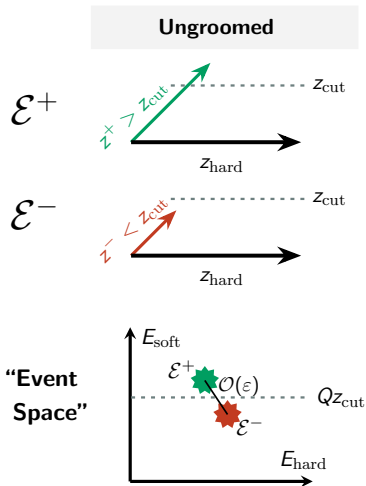
mMDT: Dasgupta-Fregoso-Marzani-Salam: [1307.0007]
Soft Drop: Larkoski-Marzani-Soyez-Thaler: [1402.2657]

- ▶ In this motivating discussion, we will limit ourselves to mMDT, or Soft Drop with $\beta_{SD} = 0$.

Motivation: IRC Sensitivity



Grooming techniques such as Soft Drop/mMDT implement hard cutoffs (z_{cut}), leading to **discontinuous behavior**:



Motivation

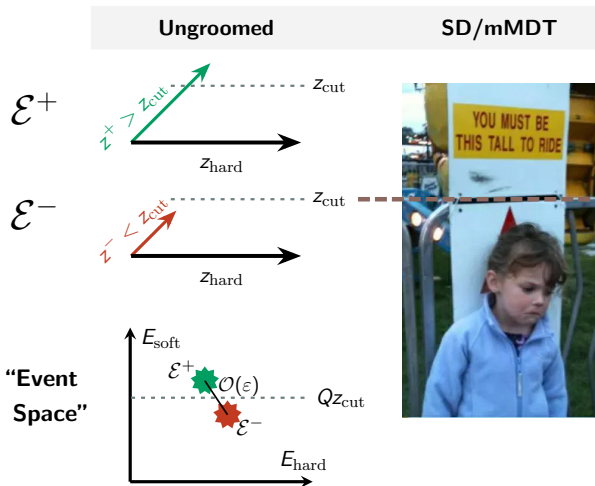
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Motivation: IRC Sensitivity



Grooming techniques such as Soft Drop/mMDT implement hard cutoffs (z_{cut}), leading to **discontinuous behavior**:



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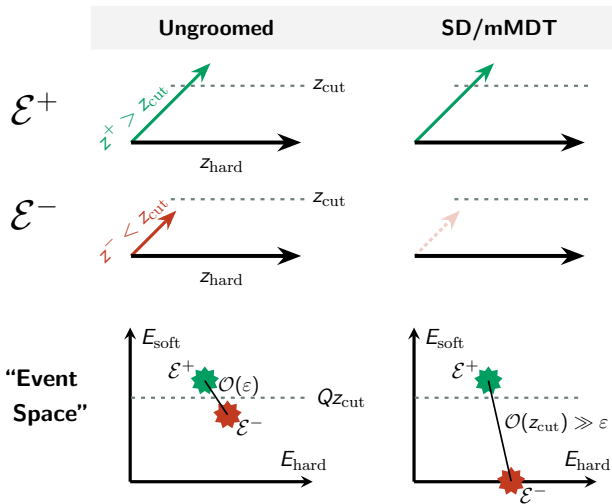
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Performance of PIRANHA

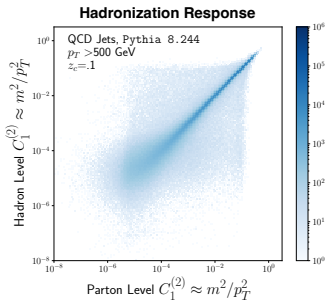
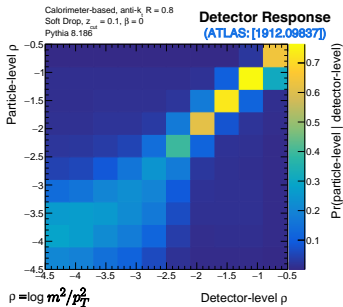


Motivation: IRC Sensitivity

Grooming techniques such as Soft Drop/mMDT implement hard cutoffs (z_{cut}), leading to **discontinuous behavior**.

Consequences:

- ▶ Sensitivity to detector effects [ATLAS: \[PHYS-PUB-2019-027, 1912.09837\]](#)
- ▶ Theoretical complications [Hoang-Mantry-Pathak-Stewart: \[1906.11843\]](#)



Motivation

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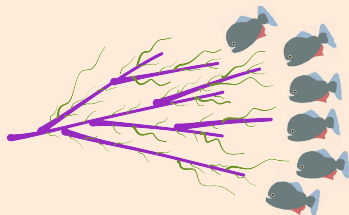
Performance of
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Introducing: PIRANHA Grooming



Grooming: Remove contaminating soft radiation.

PIRANHA: *Continuously* remove contaminating soft radiation (no hard cutoffs)



Motivation

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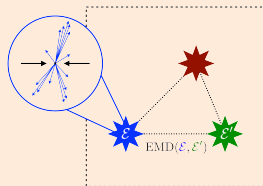
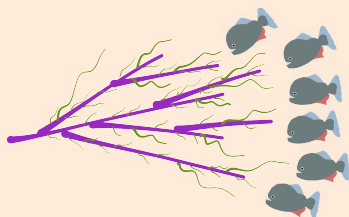
Performance of
PIRANHA

Introducing: PIRANHA Grooming



Grooming: Remove contaminating soft radiation.

PIRANHA: *Continuously* remove contaminating soft radiation (no hard cutoffs) **using geometry.**



► Detail: EMD Definition

Motivation

PIRANHAS from
Geometry

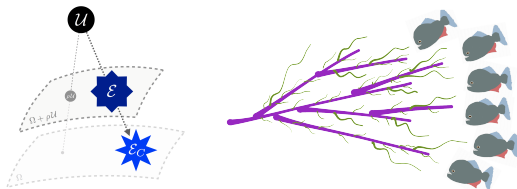
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PIRANHA Grooming



- **PIRANHA** intuitively described as the optimal transport of piranhas hungry for soft radiation

$$\mathcal{E}_{\text{groomed}} = \mathcal{E}_C = \operatorname{argmin}_{\mathcal{E}'} \operatorname{EMD}(\mathcal{E}, \mathcal{E}' + \rho \mathcal{U})$$



Motivation

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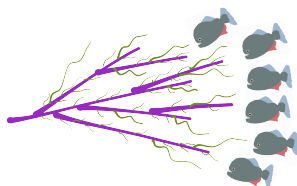
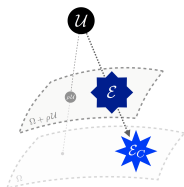
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$$\mathcal{E}_{\text{groomed}} = \mathcal{E}_C = \operatorname{argmin}_{\mathcal{E}} \operatorname{EMD}(\mathcal{E}, \mathcal{E}' + \rho \mathcal{U})$$



- ▶ Optimal transport theory → **Apollonius Subtraction!**



$$p_{T,i}^{\text{groomed}} = p_{T,i} - \rho A_i^{\text{Apoll.}}$$

Komiske-Metodiev-Thaler: [2004.04159]

- ▶ **Weakness:** Computationally expensive

▶ Detail: Runtime Comparison

Motivation

PIRANHAS from
Geometry

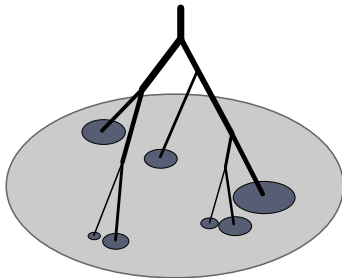
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Introducing: Recursive Safe Subtraction



Motivation for **Recursive Safe Subtraction (P-RSS)**.
Tree-based, efficient, similar to **mMDT/Soft Drop**:

- ▶ Begin with a jet with an angular-ordered tree of emissions (e.g. reclustered with Cambridge-Aachen)
- ▶ Loop through the tree of emissions, widest emission first



- ▶ Energy fraction of an emission: $z_{s,h} = E_{\text{soft,hard}}/E_{\text{total}}$
- ▶ Both use a grooming parameter z_{cut}
- ▶ SD uses a parameter β_{SD} ($\beta_{\text{SD}} = 0$ produces mMDT)

Motivation

PIRANHAs from
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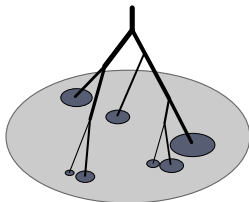
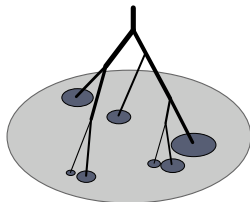
Introducing: Recursive Safe Subtraction



Soft Drop

- ▶ **Check**
 $z_s > z_{\text{cut}} \theta^{\beta_{\text{SD}}}.$
- ▶ **Passed:** Keep remaining jet.
- ▶ **Failed:** Groom softer branch.

P-RSS



Motivation

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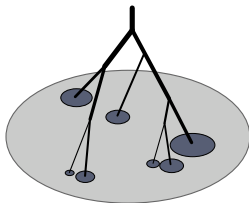
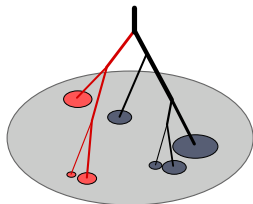
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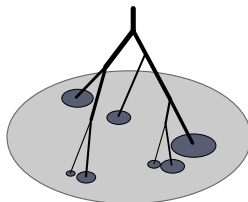
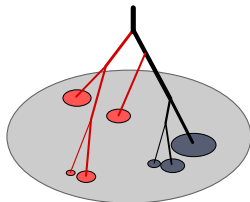
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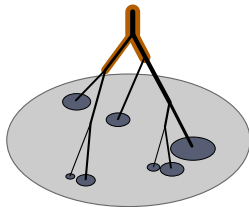
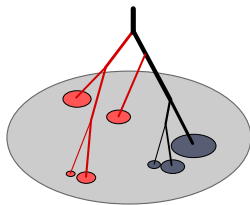


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P-RSS

- ▶ **Check** $z_s > z_{\text{cut}}^{(n)}/2$.
($z_{\text{cut}}^{(0)} = z_{\text{cut}}$)
- ▶ **Passed:** Subtract from (send piranhas) each branch,
 $z_{s,h} \rightarrow z_{s,h} - z_{\text{cut}}^{(n)}/2$.



Motivation

PIRANHAs from Geometry

Performance of PIRANHA

Introducing: Recursive Safe Subtraction

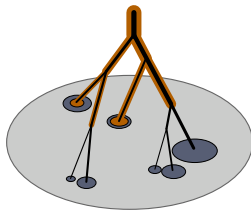
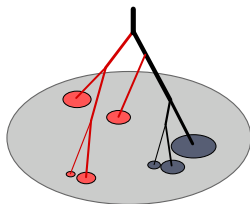


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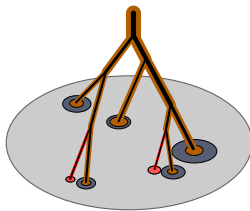
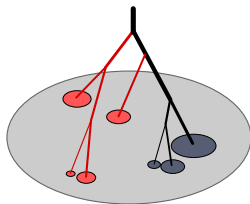
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- ▶ **Passed:** Subtract from (send piranhas) each branch,
 $z_{s,h} \rightarrow z_{s,h} - z_{\text{cut}}^{(n)}/2$.
- ▶ **Failed:** Groom softer, set $z_{\text{cut}}^{(n+1)} = z_{\text{cut}}^{(n)} - z_s$.

▶ Detail: $\text{soft} \neq \text{hard}$, or $f \neq 1/2$



Motivation

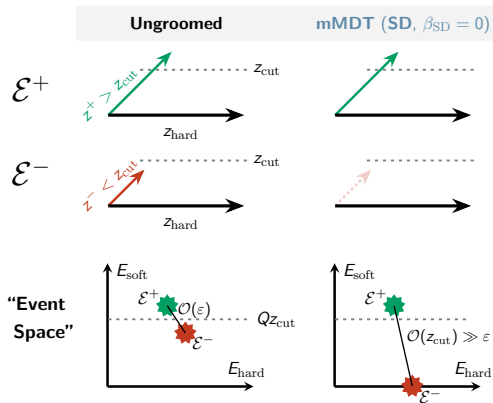
PIRANHAS from Geometry

Performance of PIRANHA

PIRANHA Grooming: Eating up the competition



Let's compare the continuity of **P-RSS** grooming to the discontinuity of **Soft Drop/mMDT**:



Motivation

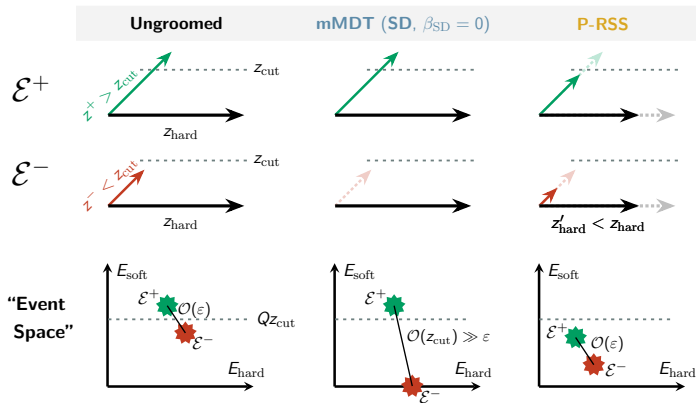
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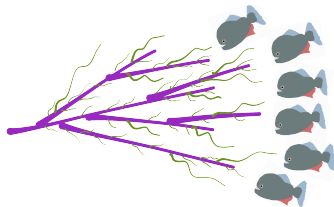
Motivation

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PIRANHA groomers (like P-RSS) are continuous!



Let's study some phenomenological implications in Pythia:

- ▶ **Soft Corrections:** Hadronization (parton level vs. hadron level) ▶ Also: "Detector effects"
- ▶ **Additive Contamination:** Pileup (layered minimum-bias events over dijets) [Soyez: \[1801.09721\]](#) ▶ Also: Underlying Event
- ▶ $z_{\text{cut}} = .1$

Motivation

PIRANHAS from
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PIRANHA Performance: Hadronization

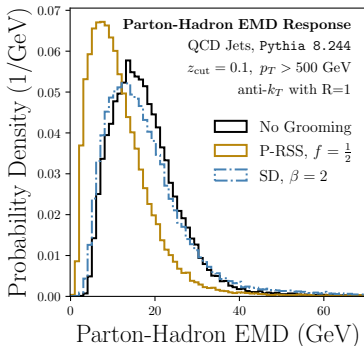


Useful tool: **E**nergy **M**over's **D**istance (**EMD**):

- ▶ Observable independent “distance” between jets
- ▶ EMD bounds changes of a broad class of observables.

[Komiske-Metodiev-Thaler: \[1902.02346\]](#)

How robust are we to soft corrections?



- ▶ **P-RSS**: Small hadronization tweaks \rightarrow smaller changes
- ▶ **Soft Drop** ($\beta_{\text{SD}} = 2$): Small tweaks \rightarrow larger changes

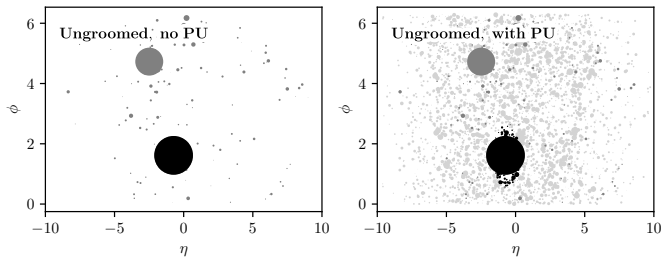
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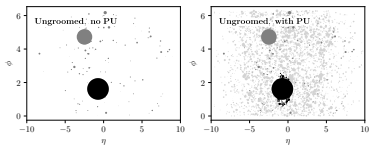
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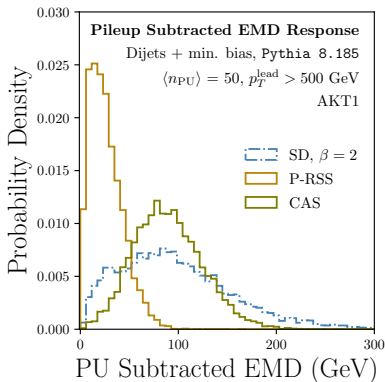
- ▶ Dijets layered with min. bias (light grey), study **leading jet (black)** (subleading jet in dark grey):



- ▶ Grid median bkg. estimation of PU energy density ρ
- ▶ Remove energy: $z_{\text{cut}} p_T = \rho A_{\text{jet}} \approx (p_T)_{\text{PU}}$ in jet
- ▶ Compare to **Constituent Area Subtraction (CAS)**, a pileup mitigation algorithm which influenced PIRANHA



How well can we remove pileup?



Motivation

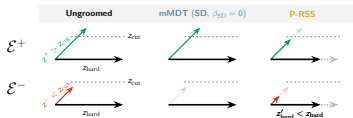
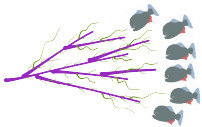
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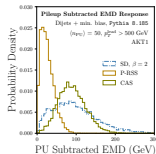
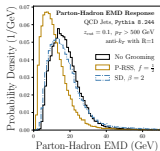
Punchlines!



- ▶ Grooming is an important tool, and traditional groomers have discontinuities which lead to infrared sensitivity.
- ▶ PIRANHA grooming is a continuous strategy for grooming based on geometry and optimal transport.



- ▶ Recursive Safe Subtraction (P-RSS) is a robust technique for the removal of soft radiation.



Motivation

PIRANHAS from Geometry

Performance of PIRANHA



Motivation

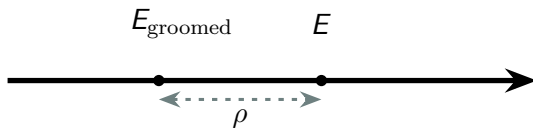
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Subtraction through geometry:

- ▶ **Simple example:** Grooming real numbers



How can we subtract using only the metric?

Motivation

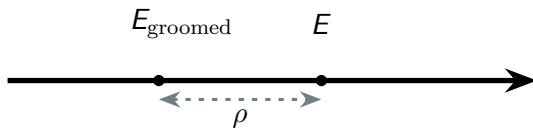
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Subtraction through geometry:

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How can we subtract using only the metric?

$$E_{\text{groomed}} = \operatorname{argmin}_{E'} \|E, E' + \rho\| = E - \rho$$

Motivation

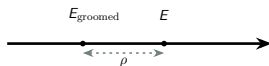
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Subtraction through geometry:

- ▶ **Simple example:** Real line

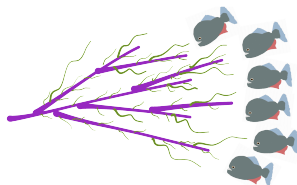
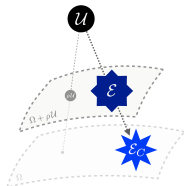


$$E_{\text{groomed}} = \operatorname{argmin}_{E'} \|E, E' + \rho\| = E - \rho$$

- ▶ **PIRANHA:** Grooming jet events

$$\mathcal{E}_{\text{groomed}} = \mathcal{E}_C = \operatorname{argmin}_{\mathcal{E}'} \operatorname{EMD}(\mathcal{E}, \mathcal{E}' + \rho\mathcal{U})$$

where $\rho\mathcal{U}$ is a “uniform event”: underlying event, pileup, etc.



Motivation

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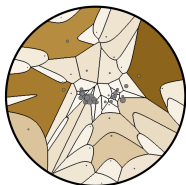
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Introducing: PIRANHA Grooming



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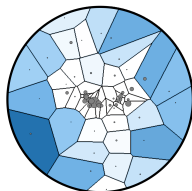
Optimal transport theory \rightarrow **Apollonius Subtraction!**



$$p_{T,i}^{\text{groomed}} = p_{T,i} - \rho A_i^{\text{Apoll.}}$$

Komiske-Metodiev-Thaler: [2004.04159]

Similar to area subtraction pileup mitigation techniques like **Voronoi Area Subtraction.** [▶ Detail: More PIRANHA for PU](#)



$$p_{T,i}^{\text{groomed}} = p_{T,i} - \rho A_i^{\text{Voronoi}}$$

[2004.04159]

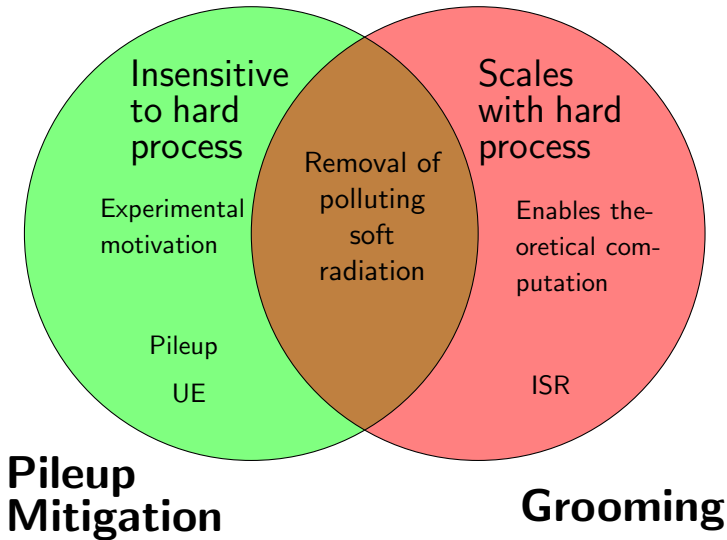
Cacciari-Salam: [0707.1378]; +Soyez: [0802.1188], [1111.6097]

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Grooming vs. Pileup Mitigation



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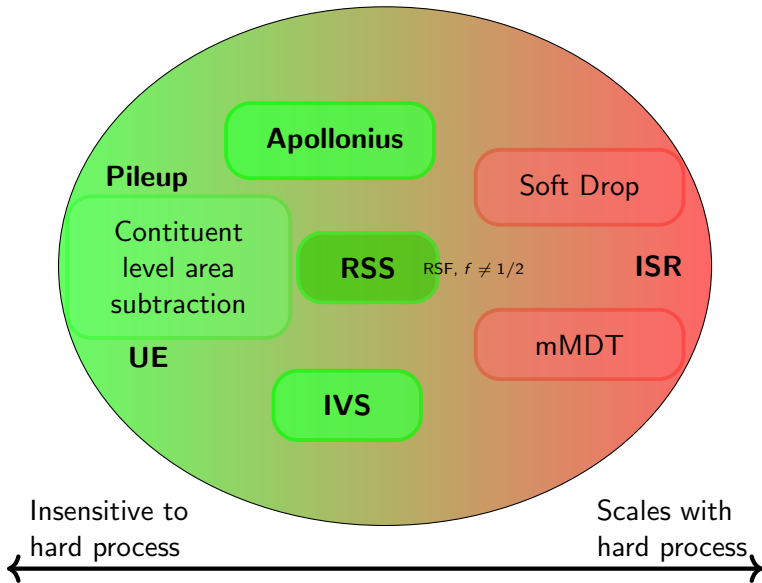
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Performance of PIRANHA

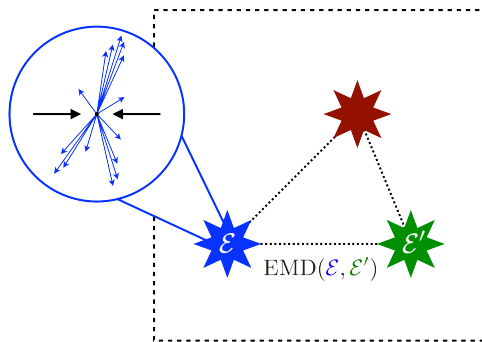


Introducing: Energy Mover's Distance (EMD)



Energy Mover's Distance ("work" to move \mathcal{E} into \mathcal{E}')

⇒ **Geometry** in event space: [▶ Main presentation](#)



$$\text{EMD}(\mathcal{E}, \mathcal{E}') = \min_f \sum_{i \in \mathcal{E}, j \in \mathcal{E}'} f_{ij} \theta_{ij} + |E(\mathcal{E}) - E(\mathcal{E}')|$$

$$f_{ij} \geq 0, \quad \sum_{i \in \mathcal{E}} f_{ij} \leq E_j, \quad \sum_{j \in \mathcal{E}'} f_{ij} \leq E_i, \quad \sum_{i \in \mathcal{E}, j \in \mathcal{E}'} f_{ij} = \min(E(\mathcal{E}), E(\mathcal{E}'))$$

Motivation

PIRANHAs from
Geometry

Performance of
PIRANHA

Introducing: Energy Mover's Distance (EMD)



Common choices for angular metric (“ground metric”):

$$\theta_{ij} = \sqrt{-(n_i - n_j)^2} \quad (1)$$

where n_i^μ is a four vector describing the motion of particle i .

$$n_{i, e^+e^-}^\mu = \frac{p_i^\mu}{E_i} = (1, \mathbf{v}_i)^\mu,$$

$$n_{i, \text{hadronic}}^\mu = \frac{p_i^\mu}{E_{T i}} = (\cosh(y_i), \mathbf{v}_{T i}, \sinh(y_i))^\mu.$$

Komiske-Metodiev-Thaler: [2004.04159]

Motivation

PIRANHAs from
Geometry

Performance of
PIRANHA

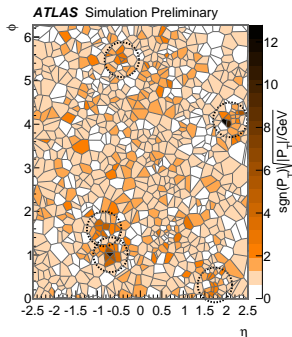


Apollonius Subtraction (AS):



$$p_{T,i}^{\text{groomed}} = p_{T,i} - \rho A_i^{\text{Apoll.}}$$

Similar to pileup mitigation techniques like **Voronoi Area Subtraction**



$$p_{T,i}^{\text{groomed}} = p_{T,i} - \rho A_i^{\text{Voronoi}}$$

Motivation

PIRANHAs from
Geometry

Performance of
PIRANHA

PIRANHA Grooming: The Cast of Characters

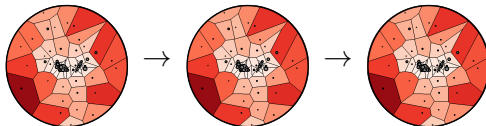


- ▶ **Apollonius grooming:** Closest to optimal transport



$$p_{T,i}^{\text{groomed}} = p_{T,i} - \rho A_i^{\text{Apoll.}}$$

- ▶ **Iterated Voronoi Subtraction:** Efficient variant



$$p_{T,i, n^{\text{th}}\text{step}}^{\text{groomed}} = p_{T,i, n^{\text{th}}\text{step}} - \rho A_{i, n^{\text{th}}\text{step}}^{\text{Voronoi}}$$

- ▶ **Recursive Safe Subtraction:** Closest to traditional grooming methods

▶ Main presentation

Motivation

PIRANHAs from
Geometry

Performance of
PIRANHA



Tweaks to Energy Flow:

- ▶ **Hadronization:** RSS is more robust to the effects of hadronization than Soft Drop/mMDT.
- ▶ **Detector effects:** With a rough analysis, RSS seems more robust to detector effects than Soft Drop/mMDT.
- ▶ Robust for a range of z_{cut} values. ▶ $z_{\text{cut}} \neq .1$

Additive Contamination:

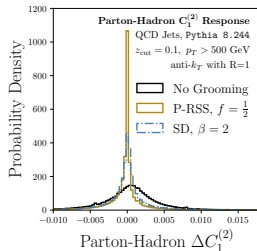
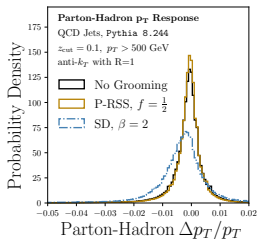
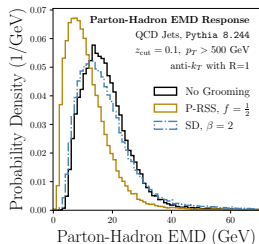
- ▶ **Pileup:** RSS mitigates PU more accurately than Soft Drop and some existing methods. ▶ $\langle n_{\text{PU}} \rangle \neq 50$
- ▶ **UE and Mass Resolution:** RSS leads to slightly worse mass resolution, but comparable acceptance (slightly greater for a simplified tagging scheme). ▶ Top Jets

Motivation

PIRANHAs from
Geometry

Performance of
PIRANHA

PIRANHA Performance: Hadronization

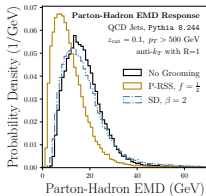


- ▶ **P-RSS:** Small hadronization tweaks \rightarrow smaller changes
- ▶ **Soft Drop:** Small tweaks \rightarrow larger changes

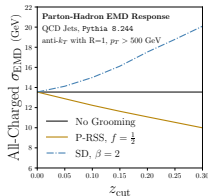
Motivation

PIRANHAs from
Geometry

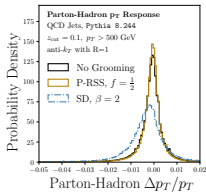
Performance of
PIRANHA



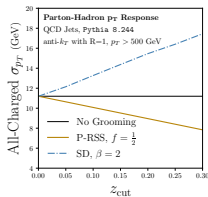
Parton-Hadron EMD (GeV)



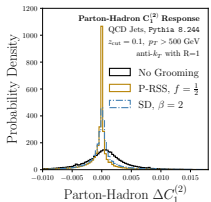
z_{cut}



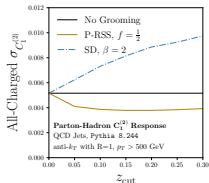
Parton-Hadron $\Delta p_T / p_T$



z_{cut}



Parton-Hadron $\Delta C_1^{(2)}$



z_{cut}

Motivation

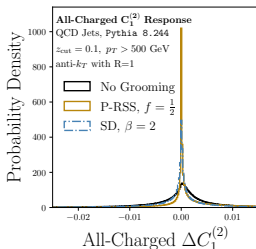
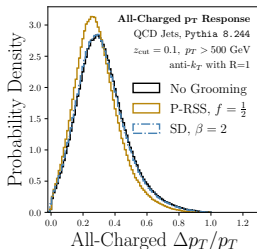
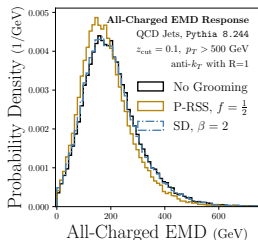
PIRANHAs from
 Geometry

Performance of
 PIRANHA

PIRANHA Performance: Detector Proxy



► Main Presentation



- **P-RSS**: Exclude neutral particles \rightarrow smaller changes
- **Soft Drop**: Exclude neutral particles \rightarrow larger changes

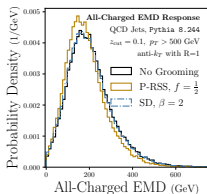
Motivation

PIRANHAs from
Geometry

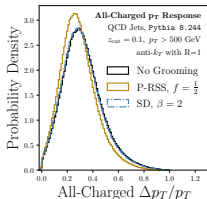
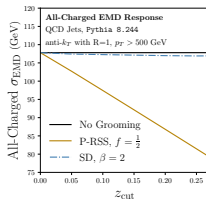
Performance of
PIRANHA

RSS All-Charged Response

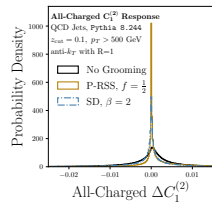
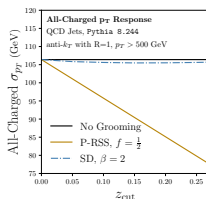
► Overview



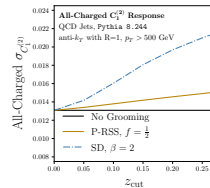
All-Charged EMD (GeV)



All-Charged $\Delta p_T / p_T$



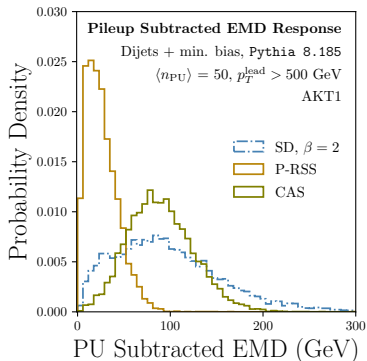
All-Charged $\Delta C_1^{(2)}$



Motivation

PIRANHAs from
Geometry

Performance of
PIRANHA

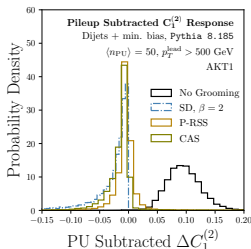
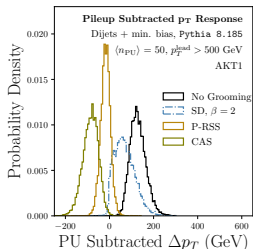
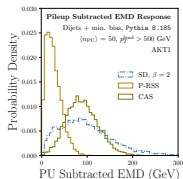


- ▶ **P-RSS**: Subtract pileup \rightarrow smaller changes
- ▶ **SD, CAS**: Subtract pileup \rightarrow larger changes

Motivation

PIRANHAs from
Geometry

Performance of
PIRANHA



▶ **P-RSS**: Subtract pileup \rightarrow smaller changes

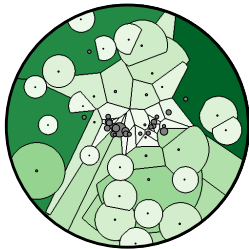
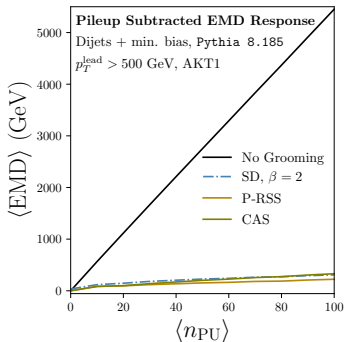
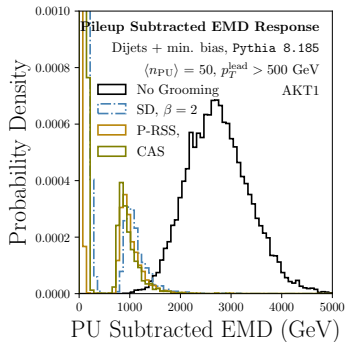
▶ **SD, CAS**: Subtract pileup \rightarrow larger changes

▶ **Preliminary**: requires additional tuning; would like $\langle \Delta p_T \rangle_{CAS} = 0$. However, still expect wider variance for CAS, as above. Haven't tested against more popular pileup mitigation algorithms.

Motivation

PIRANHAs from
Geometry

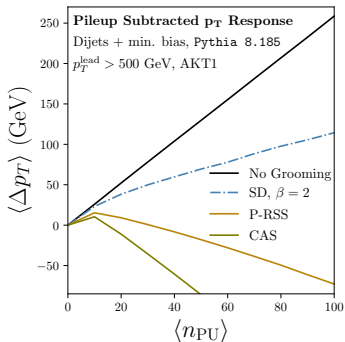
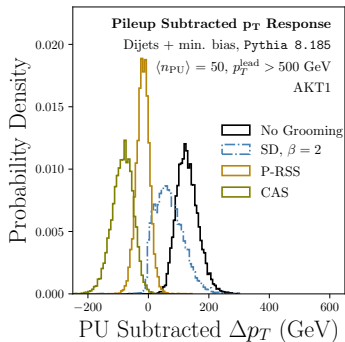
Performance of
PIRANHA



Motivation

PIRANHAs from
Geometry

Performance of
PIRANHA



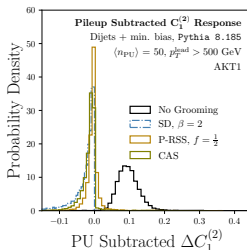
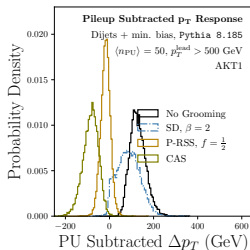
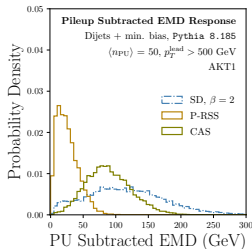
Motivation

PIRANHAs from
Geometry

Performance of
PIRANHA



- $z_{\text{cut}} = \rho_{\text{GMBE}} A_{\text{jet}}/p_T$ for **P-RSS**.
- $z_{\text{cut}} = .1$ for **Soft Drop**.



Motivation

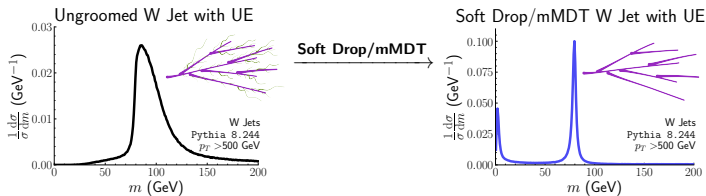
PIRANHAs from Geometry

Performance of PIRANHA

PIRANHA Performance: UE Mass Resolution



- ▶ Grooming often used for mass resolution and boosted object tagging
- ▶ Underlying event (UE) an important source of contamination in these contexts



Motivation

PIRANHAs from
Geometry

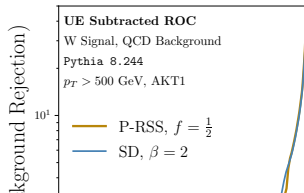
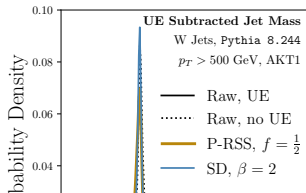
Performance of
PIRANHA

PIRANHA Performance: UE Mass Resolution



- ▶ Grooming often used for mass resolution and boosted object tagging
 - ▶ Underlying event (UE) an important source of contamination in these contexts
 - ▶ Simulate UE with multi-parton interaction in Pythia
- ## Can RSS Compete?

- ▶ Tune z_{cut} for **P-RSS** and **Soft Drop** to produce a sharply peaked mass distribution (left)
- ▶ Reject QCD background (right): restrict to mass windows ($m_W - \delta m, m_W + \delta m$)



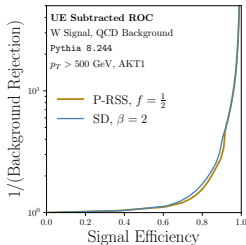
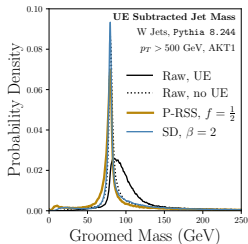
Motivation

PIRANHAs from
Geometry

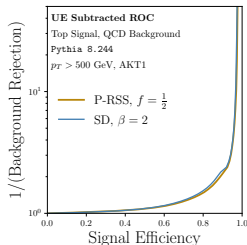
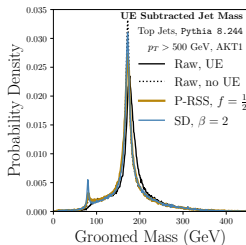
Performance of
PIRANHA



W Jets with UE:



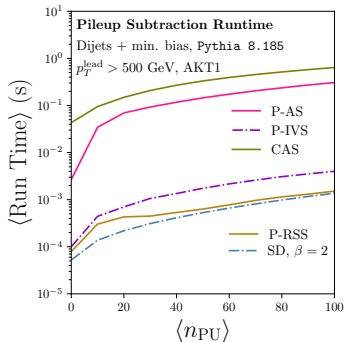
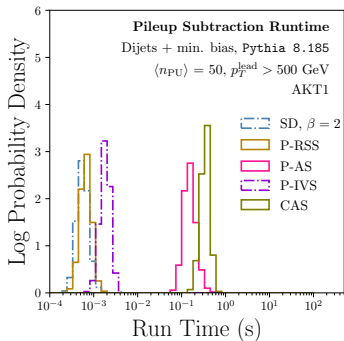
Top Jets with UE:



Motivation

PIRANHAs from
Geometry

Performance of
PIRANHA



Motivation

PIRANHAs from
Geometry

Performance of
PIRANHA



Non-Global Logarithms:

Jet substructure with analytical methods

[1307.0013]

Mrinal Dasgupta,¹ Alessandro Fregoso,² Simone Marzani³ and Alexander Powling²

³Since non-global logarithms arise away from the collinear region, in this calculation we shall not make a collinear approximation and hence use the distance measure $\Delta_\alpha^2 = 2(1 - \cos \alpha)$.

Motivation

PIRANHAs from
Geometry

Performance of
PIRANHA

Clustering Logarithms:

Soft Drop

[1402.2657]

Andrew J. Larkoski,^a Simone Marzani,^b Gregory Soyez,^c and Jesse Thaler^a

⁵Because the original jet is defined with the anti- k_t algorithm, we are not sensitive to clustering logarithms first described in Ref. [118].

Generations of Groomers



c. 2008

1st Generation (Mass Drop): **IRC safety**



c. 2015

2nd Generation (mMDT, Soft Drop): **Calculability**



c. 2022

PIRANHA (Apollonius, IVS, RSS): **Continuity**

Motivation

PIRANHAs from
Geometry

Performance of
PIRANHA



All Observables

Measurable at a collider

Defined on Energy Flows

Invariant to exact infrared & collinear emissions everywhere except a negligible set of events

Infrared & Collinear Safe

EMD continuous everywhere except a negligible set of events

EMD Hölder Continuous

Everywhere invariant to infinitesimal infrared & collinear emissions

Sudakov Safe

Discontinuous on some N-particle manifolds

Motivation

PIRANHAs from
Geometry

Performance of
PIRANHA

Komiske-Methodiev-Thaler: [2004.04159]



- ▶ Dropped energy

$$\Delta_E = E(\mathcal{E}) - E(\mathcal{E}_{\text{groomed}})$$

- ▶ Generalized jet energy correlation functions (GECFs)

$$C_1^{(\beta)} = \sum_{i,j \in \text{jet}} z_i z_j \theta^\beta,$$

$$(C_1^{(2)} \sim m^2/p_T^2)$$

Motivation

PIRANHAs from
Geometry

Performance of
PIRANHA

Recursive Subtraction with a Fraction (RSF)



SD/mMDT

- ▶ **Check**
 $z > z_{\text{cut}} \theta^\beta.$

RSF

- ▶ **Check** $z > fz_{\text{cut}}^{(n)}.$
 $(z_{\text{cut}}^{(0)} = z_{\text{cut}})$

In RSF, f is the fraction of energy removed from the softer branch.

▶▶ Main presentation

Motivation

PIRANHAs from
Geometry

Performance of
PIRANHA

Recursive Subtraction with a Fraction (RSF)



SD/mMDT

- ▶ **Check**
 $z > z_{\text{cut}}\theta^\beta.$
- ▶ **Failed:**
Groom softer branch and continue

RSF

- ▶ **Check** $z > fz_{\text{cut}}^{(n)}$.
($z_{\text{cut}}^{(0)} = z_{\text{cut}}$)
- ▶ **Failed:** Groom energy from both branches (softer branch completely), set $z_{\text{cut}}^{(n+1)} = z_{\text{cut}}^{(n)} - z/f$, and continue

In RSF, f is the fraction of energy removed from the softer branch.

▶▶ Main presentation

Motivation

PIRANHAs from Geometry

Performance of PIRANHA

Recursive Subtraction with a Fraction (RSF)



SD/mMDT

- ▶ **Check**
 $z > z_{\text{cut}}\theta^\beta.$
- ▶ **Failed:**
Groom softer branch and continue
- ▶ **Passed:**
Keep remaining jet

RSF

- ▶ **Check** $z > fz_{\text{cut}}^{(n)}$.
($z_{\text{cut}}^{(0)} = z_{\text{cut}}$)
- ▶ **Failed:** Groom energy from both branches (softer branch completely), set $z_{\text{cut}}^{(n+1)} = z_{\text{cut}}^{(n)} - z/f$, and continue
- ▶ **Passed:** Groom energy from both branches, $z \rightarrow z - fz_{\text{cut}}^{(n)}$, and keep remaining jet.

In RSF, f is the fraction of energy removed from the softer branch.

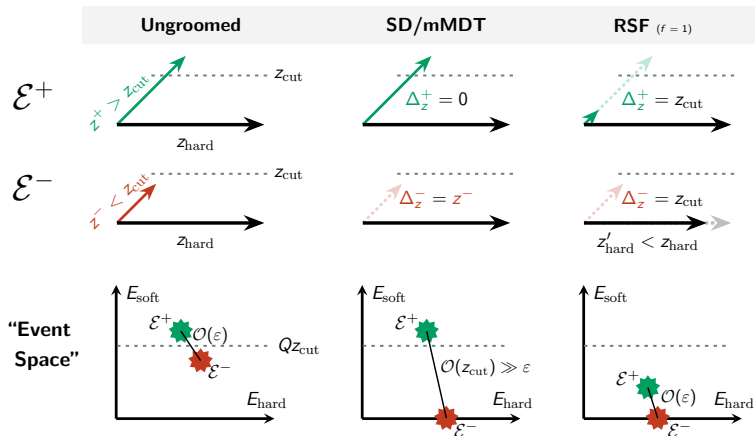
▶▶ Main presentation

Motivation

PIRANHAs from Geometry

Performance of PIRANHA

Almost PIRANHA: RSF Examples



Motivation

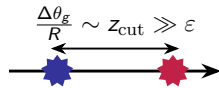
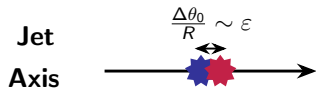
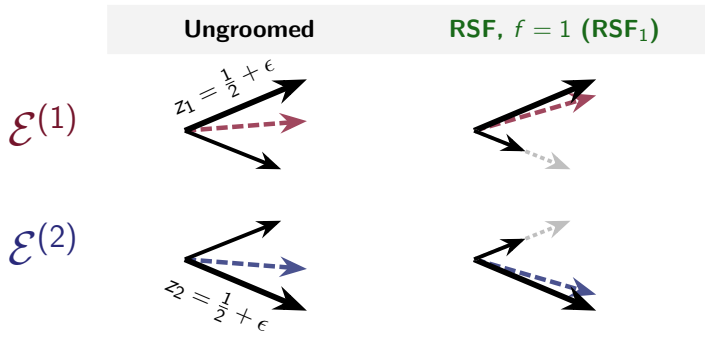
PIRANHAs from
Geometry

Performance of
PIRANHA

Almost PIRANHA: RSF Examples



Recursive Subtraction with a Fraction $f \neq 1/2$ is discontinuous:



Motivation

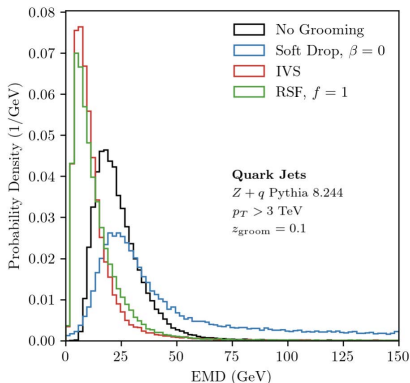
PIRANHAs from Geometry

Performance of PIRANHA

RSF Performance: Hadronization



Hadronization tweaks energy; susceptible to discontinuity!



- ▶ **mMDT/Soft Drop**: Small tweaks \rightarrow large changes.
- ▶ **PIRANHA (IVS)**, **RSF₁**: Tweaks \rightarrow small changes!
- ▶ EMD bounds changes of a broad class of observables.

Komiske-Metodiev-Thaler:[1902.02346] Eqn (2) and Figure 2.

Motivation

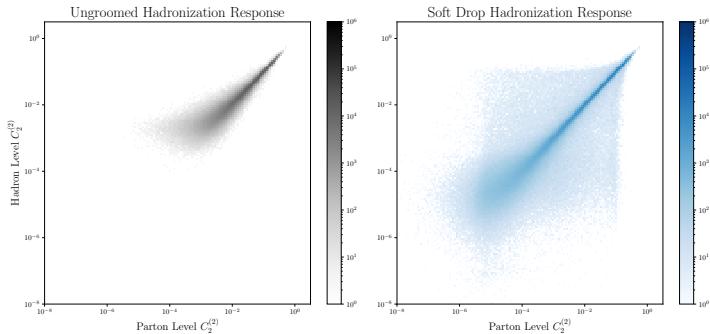
PIRANHAs from
Geometry

Performance of
PIRANHA

RSF Performance: Hadronization



Response of Grooming to Hadronization



Motivation

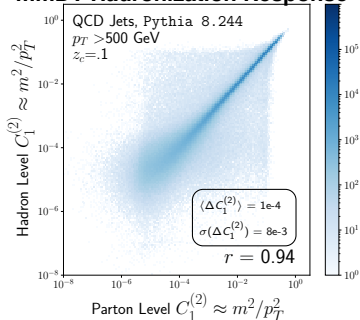
PIRANHAs from
Geometry

Performance of
PIRANHA

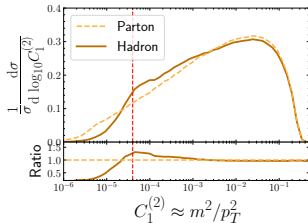
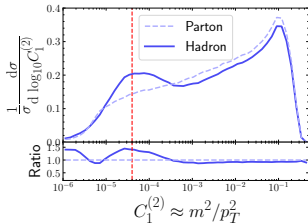
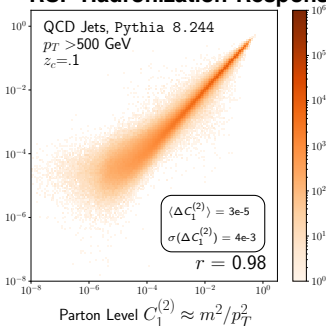
RSF Performance: Hadronization



mmMDT Hadronization Response



RSF Hadronization Response



Motivation

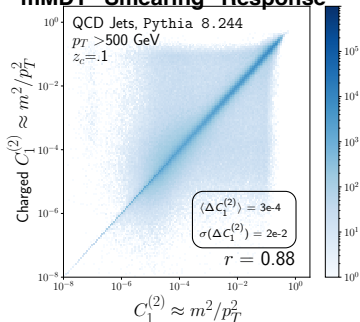
PIRANHAs from
 Geometry

Performance of
 PIRANHA

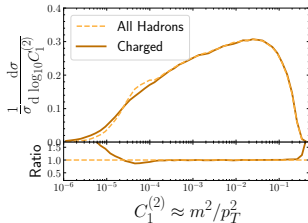
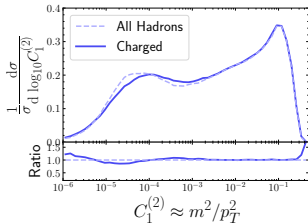
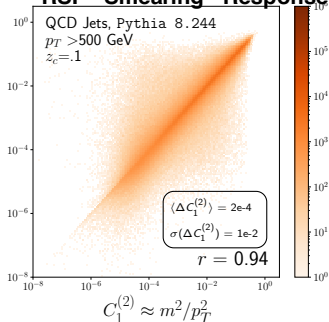
RSF Performance: Detector Proxy



mMDT "Smearing" Response



RSF "Smearing" Response



Motivation

PIRANHAs from
 Geometry

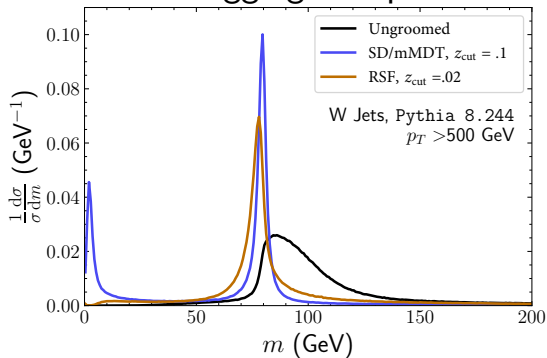
Performance of
 PIRANHA

RSF Performance: Underlying Event



W Jets: RSS leads to shifted mass determinations and slightly worse mass resolution:

W Tagging Comparison



- ▶ Tune z_{cut} to remove radiation from the UE.
- ▶ Mass shifted by $\sim 2\%$.

Motivation

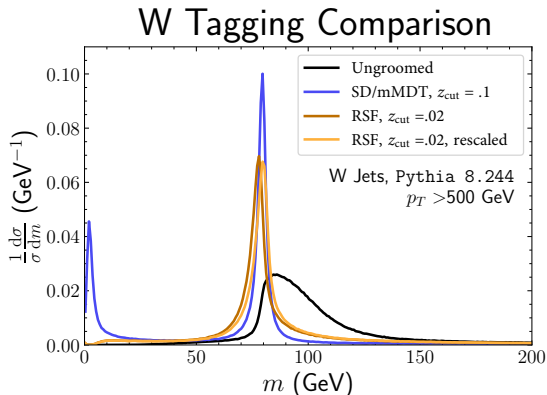
PIRANHAs from
Geometry

Performance of
PIRANHA

RSF Performance: Mass Resolution



W Tagging: RSS leads to shifted mass determinations and worse mass resolution:



- ▶ Tune z_{cut} to remove radiation from the UE.
- ▶ Mass shifted by $\sim 2\%$.

Motivation

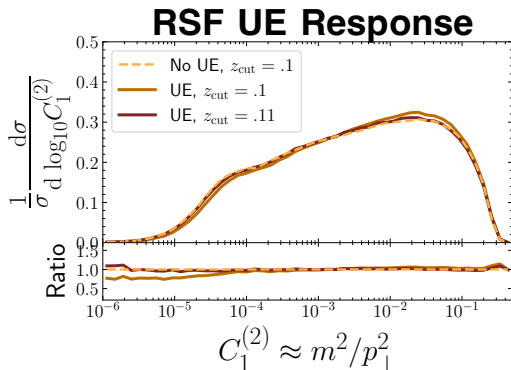
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RSF Performance: Underlying Event



- ▶ For RSF (similar to RSS): increase z_{cut} to remove additional radiation/corrections from the UE:



- ▶ UE, $z_{\text{cut}} = .1$: Max is 106% the max of no UE
- ▶ UE, $z_{\text{cut}} = .11$: Max is 101% the max of no UE

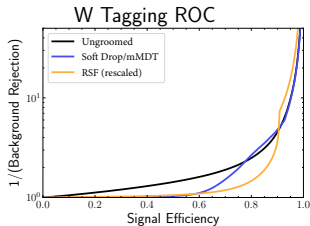
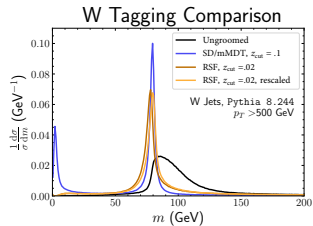
Motivation

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Recursive Subtraction with a Fraction (RSF) gives worse W mass resolution than **mMDT/Soft Drop**, potentially greater acceptance:



Motivation

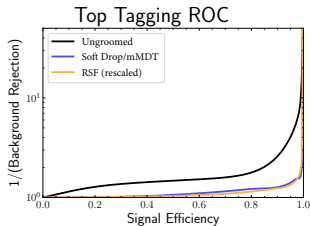
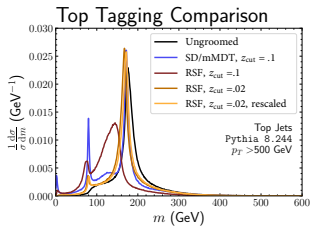
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RSF: Top Mass Resolution



Recursive Subtraction with a Fraction (RSF) gives worse Top mass resolution than **mMDT/Soft Drop**, potentially greater acceptance:



Motivation

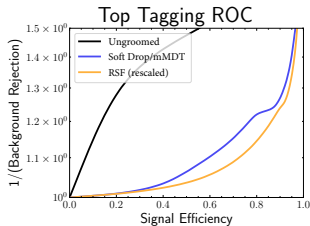
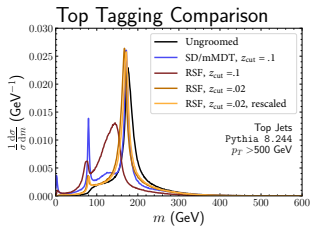
PIRANHAs from Geometry

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RSF: Top Mass Resolution



Recursive Subtraction with a Fraction (RSF) gives worse mass resolution than **mMDT/Soft Drop**, potentially greater acceptance:



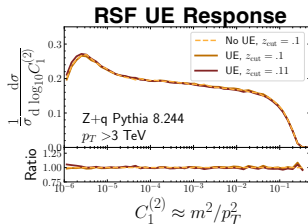
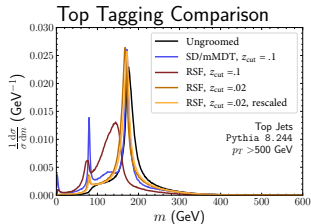
Motivation

PIRANHAs from
Geometry

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If z -cut is adjusted for measuring the W -mass (or to account for underlying event in a particular case), is it possible to use this same z -cut elsewhere with RSF?



- ▶ Groomed energy scales with energy of hard process/leading vertex.
- ▶ Expect similar behavior in, say, UE reduction from similar z_{cut} values at the same energy scales, but not as the energy scale is changed.

Motivation

PIRANHAs from Geometry

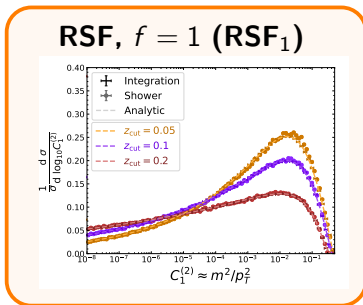
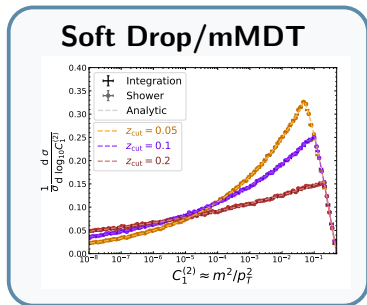
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Towards Resummed Calculation



Re-summation for the first surviving emission, RSF, $f = 1$.

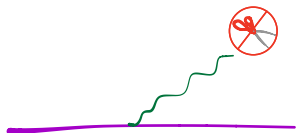
Fixed coupling, **one emission** calculations:



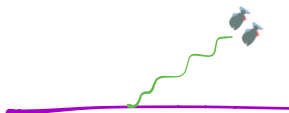
Motivation

PIRANHAs from Geometry

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Sharp cutoff \rightarrow kink



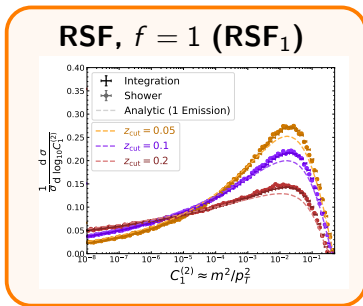
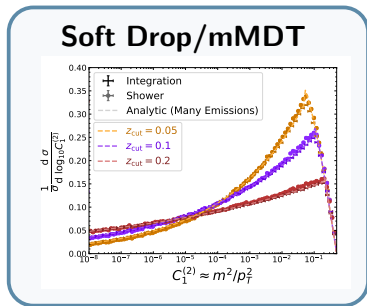
No sharp cutoff \rightarrow smooth

Towards Resummed Calculation



Re-summation for the first surviving emission, RSF, $f = 1$.

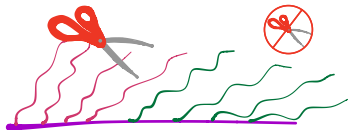
Fixed coupling, **multiple emission** calculations:



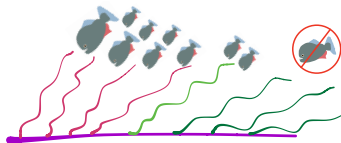
Motivation

PIRANHAs from Geometry

Performance of PIRANHA



Sharp cutoff \rightarrow kink

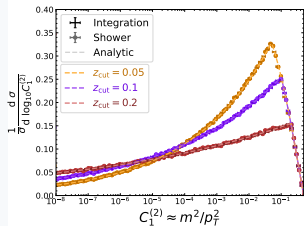


No sharp cutoff \rightarrow smooth

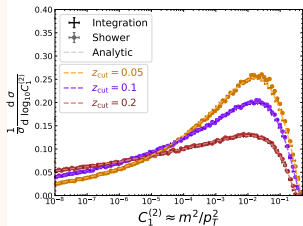


Single emission:

Soft Drop/mMDT



RSF, $f = 1$ (RSF₁)



- ▶ **Soft Drop** has single logarithmic structure below z_{cut} and double logarithmic structure above (piece-wise).
- ▶ **RSF** ($f = 1$) has a single logarithmic structure (not piece-wise). Does not exponentiate, but expansions and approximations reveal single logarithmic structure.

Motivation

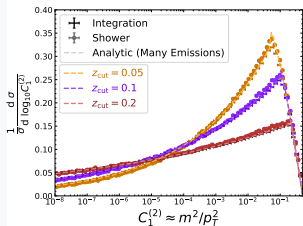
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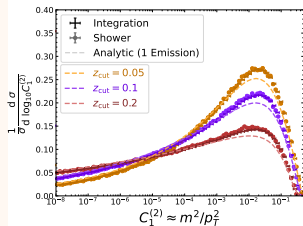


Multiple emissions:

Soft Drop/mMDT



RSF, $f = 1$ (RSF₁)



- ▶ **Soft Drop** is amenable to simpler methods/calculations in the case of multiple emissions.
- ▶ **RSF** ($f = 1$) has an intricate structure of correlations between emissions, and is addressed here only numerically (i.e. no “CAESAR formula”!).

Motivation

PIRANHAs from
Geometry

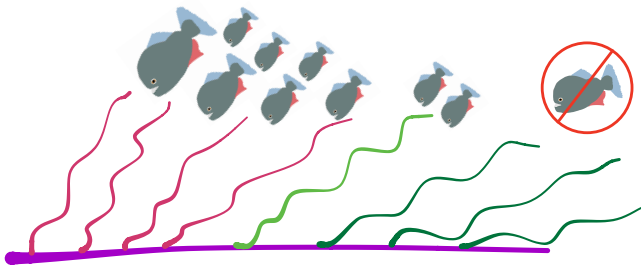
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Emissions of RSF Groomed Jets



RSF where at every branch, only the softer branch is groomed ($f = 1$). There will be three types of emissions:

- ▶ **Pre-critical emissions:** completely groomed away, using up some of the grooming parameter
- ▶ One **critical emission:** the first emission to survive the grooming process
- ▶ **Subsequent emissions:** emissions after the critical emission, completely ungroomed



Motivation

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$$\iint_{\text{blue circle}} d \log \theta \, z \, d \log z \, \frac{\alpha_s}{\pi} [\bar{\rho}(z)]_+^{(1/2)} \triangleq \text{graph (2)},$$

(2)

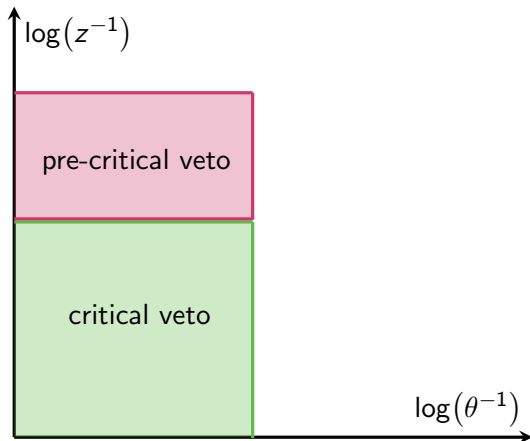
$$\text{blue square} = 0, \quad \text{blue square with white circle} = - \text{graph (3)}.$$

(3)

Motivation

PIRANHAs from
Geometry

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Motivation

PIRANHAs from
Geometry

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$$\Sigma_{\text{crit}}(\theta) \approx \exp \left[- \int_{\theta' < \theta}^{z < z_{\text{cut}}} \right]$$
$$= \exp \left[- \frac{\alpha_s}{\pi} \int_{\theta}^1 \frac{d\theta'}{\theta'} \int_{z_{\text{cut}}}^{1/2} \bar{p}(z) \right]$$

Motivation

PIRANHAs from
Geometry

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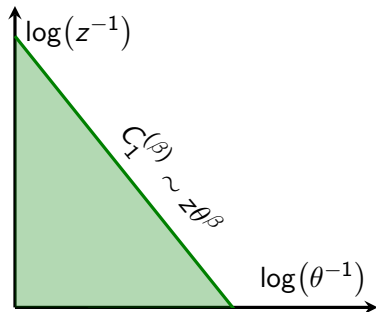
$$\Sigma_{\text{pre}}(z_{\text{pre}}|\theta_{\text{crit}})\Sigma_{\text{crit}}(\theta_{\text{crit}}) = \exp \left[- \int \right]$$
A 2D coordinate system with a vertical y-axis and a horizontal x-axis. A rectangular region is shaded, divided into two parts: a green rectangle at the bottom and a pink rectangle on top. The entire shaded region is enclosed within large square brackets, with a minus sign to the left of the opening bracket, indicating an exponential decay factor.

Motivation

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Lund Diagrammar: Subsequent Emissions



$$\Sigma_{\text{sub}}(C_1^{(\beta)}) \approx \exp \left[- \left(\text{diagram} \right) \right]$$

Motivation

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