ISR Tagging

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Based on work with L. Randall and L.-T. Wang (1101.0810)
Outline

- Introduction & Motivation
- Tagging an ISR Jet
- Uses of an ISR Jet
- Conclusion
Takeaway

* Initial state radiation (ISR) is normally a nuisance.
* It can contaminate jets, and makes sorting out combinatorics hard.
* However,
  * When ISR produces a jet it can often be tagged (through methods we introduce).
  * By investigating an ISR jet we can learn valuable information about the event which produced it.
Introduction & Motivations
Busy Final States

- The LHC will, hopefully, allow us to produce and study particles from physics beyond the SM.

- Even at leading order the decay processes of these new particles can yield busy final states.

  Example: \( \tilde{g} \rightarrow t\bar{t}\chi_0 \rightarrow 6j + \chi_0 \)

- However, what we observe in the detector is actually much more complicated than the leading tree level diagrams suggest.
Initial & Final State Radiation (ISR/FSR)

- This is because leading order tree level considerations neglect initial state radiation.
- Colored final state particles will emit soft/collinear radiation (FSR).
  - These emissions are together resolved as jets - a spray of radiation in one direction.
- In the same way, partons in the proton will emit soft/collinear radiation (ISR) before they scatter into/via new physics states.
Lowest order diagram for the production and decay of a $Z'$

Production of $Z'$ showing ISR/FSR
Effects of ISR

• We see ISR emissions as additional states in the detector.

• Basically, they can do two things

  1. Some emissions will spatially overlap with `signal’ jets (motivation for jet topiary).

  2. Others will be assigned their own jets.
So, if we can identify ISR jets on an event-by-event basis then we can do a better job at reconstructing new physics events.

- This will be our goal.

- We’ll see that we can even learn something new about BSM events.
Tagging an ISR Jet
Setup

• To tag an ISR jet we need to identify the criteria which distinguish it from FSR.

• These criteria are a little dependent on the event topology, although as we will see, adopting them from one process to another isn’t too hard.

• Here we’ll focus on the symmetric production of new physics states which decay into jets:

\[ pp \rightarrow N_f J + 2\chi_1^0 + \text{ISR} \]

where \( N_f = 2(4) \) for di-squark and di-gluino production.
• In symmetric processes each jet should have a partner with roughly similar kinematics & color structure.

• Look for unpaired jets

• Furthermore, the hard interaction distinguishes a region of rapidity which is more likely to be populated by FSR jets - outside this region jets more likely to come form ISR.

Figure stolen from John Conway’s PGS talk: http://online.itp.ucsb.edu/online/lhco_c06/conway/
Summary of Tagging Procedure

- **Tag (all `or’ conditions)**
  - Taking the hardest N+1 jets. Look for those
    - 1. Distinguished in $p_T$
    - 2. Distinguished in rapidity
    - 3. Distinguished in $m/p_T$

- **Check (all `and’ conditions)**
  - Require the candidate ISR jet
    1. Not be central
    2. Remain somewhat isolated in rapidity
  - Require that the implicit FSR jets be
    1. Close in $p_T$
    2. Central
Uses of an ISR Jet
What’s ISR Tagging Good For?

The most obvious use of ISR tagging is in resolving combinatorics. However, there are a number of other interesting possibilities:

1. The ISR $p_T$ can tell us about the scale probed in the interaction

2. ISR $p_T$ can also tell us about the initial states (valence quark/sea quark/gluon)

3. Curiously, requiring an ISR tag is a good signal/background discriminant

4. We can make use of a cute trick and measure the recoil of FSR against ISR, and thus infer the mass of the BSM system produced.
Starting Configuration

Note: In our system there is missing energy - the above picture is only true on average - i.e. there is no exact balance.
variables or observables such as invariant mass which only rely upon basic kinematics.

The starting configuration with the ISR jet shown in red double lines.

The next two show all panels showing jets in the plane transverse to the beam direction. The leftmost illustration shows phenomenologically interesting quantities but they also require a careful treatment of mass.

Figure 3: For examples of the sort of analytic treatment which could prove essential in interpreting ISR, see Cross Section [A.U.]

Solidify any interpretations derived from radiative observables and, as it is an independent property like the conservation of energy, rather than in the detailed behavior.

There is no net projection along the ISR axis.

Finally, in the rightmost panel, the correct choice has been made and there is a clear ISR jet.

Figure 4: QCD radiation.

Pre-boost

Under boost

Over boost

Correct boost
Main Result

\( m_{\text{Glunio}} = 0.5 \ (1.0) \ \text{TeV for left (right) plots} \)

Where we expect \( \langle \sigma \rangle = 0 \)
To emphasize what happened

On the previous page, for a 1 TeV gluino with a 900 GeV LSP we were able to infer the presence of 2.5 TeV physics from four dinky ($p_T \sim 50$ GeV) FSR jets and ISR. Not bad!
Future Directions & Conclusion
Future Directions

- We were able to get pretty far with a simple minded ISR tagger based on only three observables.

- Surely a more accurate tagger can be made, and it would be interesting to think of what could be added.

- Especially interesting to think of how to adapt it to even busier environments.
Conclusions

- In looking for new physics at the LHC, we’ll have to contend with initial state radiation (ISR).

- Not only can we mitigate its effects when it contaminates `signal’ jets (through jet topiary), here we have shown that we can reliably tag jets as having come from ISR.

- This not only improves combinatorics - we saw we can actually derive new information from ISR jets to improve our understanding of BSM events.
Backup Note

How do we know we’re tagging ISR and not something else?

After all, technically ISR is not very well defined especially when you have color connections between the initial and final states.

Answer: Use the LL parton shower definition of ISR

When you simulate events with ISR find a tagging rate (X), when you simulate without ISR you get another tagging rate (Y). As long as X >> Y you can be confident you’re tagging mostly ISR.

Note: Even if we add in ME/PS matching the rates, distributions don’t change much compared to LO+PS -> This gives us added confidence in our results.