Applications and Development of RJR

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Welcome to Adelaide

What this talk will cover

1. Recursive Jigsaw Reconstruction
2. Specific approach
3. Abstracted approach
4. RestFrames package
5. Where it has been used
6. Some applications and ideas moving forward
Difficulties in HEP Analysis

An event with leptons, jets and/or $E_T^{miss}$

Kinematic: Unmeasured particles
Combinatoric: Identical particles

Which part of the signal did these particles originate?

The signal has two sources of $E_T^{miss}$ how to split?
What is RJR?

- Developed by P. Jackson and C. Rogan
- RJR is a method which allows us to resolve \textit{kinematic} and \textit{combinatorial} ambiguities
- To do this we need two things:
  - A signal topology
  - Rules to constrain the unknown dofs
- The rules are called \textit{Jigsaw} rules
- They are \textit{Physics Driven}
- 1 unknown = 1 assumption (Jigsaw)
- Recursive because we can then bootstrap through the decay tree
What the decay tree means

Standard Approach

We define a decay tree

- **Visible** frames (Va, Vb)
- **Invisible** frames (Ia, Ib)
- **Intermediate** frames (Pa, Pb)
- **LAB** frame (LAB)

An event defined in the **PP** frame

Vector Sum of **Visibles** + **Invisibles**

Scalar Sum of **Visibles** + **Invisibles**
What if I don’t want the detail?

**Specific RJR Decay Tree**

**ISR RJR Decay Tree**
The **ISR Decay Tree** is specified below

- We have 5 major frames, **ISR**, **CM**, **I**, **V**, **LAB**
- We apply the mass minimisation Jigsaw rule
- Once we have assignment we have every restframe

**ISR RJ Tree**

**Assign based on the Minimum Mass Combination**
The ISR Decay Tree is specified below

- We have 5 major frames, ISR, CM, I, V, LAB
- We apply the mass minimisation Jigsaw rule
- Once we have assignment we have every object in every restframe

ISR, INV in CM frame and frame drift in LAB frame

\[ p_{T_{ISR}}^{CM} \]
\[ \left| \vec{p}_{T_{I}}^{CM} \cdot \vec{p}_{T_{ISR}}^{CM} \right| \]
\[ \Delta \phi_{CM,I}^{ISR,I} \]
\[ p_{T_{I}}^{CM} \]

Ratio of Invisibles along ISR axis, in units of ISR

\[ \left| \vec{p}_{T_{I}}^{CM} \cdot \vec{p}_{T_{ISR}}^{CM} \right| \]
\[ \left| \vec{p}_{T_{ISR}}^{CM} \right| \]

\[ R_{ISR} = \frac{\left| \vec{p}_{T_{I}}^{CM} \cdot \vec{p}_{T_{ISR}}^{CM} \right|}{\left| \vec{p}_{T_{ISR}}^{CM} \right|} \]
The RJR package

RestFrames (C. Rogan www.restframes.com)

- Implements RJR in ROOT
- Many examples with its own event generator
- Customise your own decay trees
- Interchange Jigsaw rules
- Easily integrated into other frameworks

Declaration of a decay tree

LabRecoFrame
DecayRecoFrame
DecayRecoFrame
DecayRecoFrame
VisibleRecoFrame
VisibleRecoFrame
Lab("LAB","LAB");
H("H","H[{0}]");
Wa("Wa","W_{a}[a]");
Wb("Wb","W_{b}[b]");
La("La","#it[l]_{a}[a]");
Na("Na","#nu_{a}[a]");
Lb("Lb","#it[l]_{b}[b]");
Nb("Nb","#nu_{b}[b]");

LAB.SetChildFrame(H);
H.AddChildFrame(Wa);
H.AddChildFrame(Wb);
Wa.AddChildFrame(La);
Wa.AddChildFrame(Na);
Wb.AddChildFrame(Lb);
Wb.AddChildFrame(Nb);

LAB.InitializeTree();
Publications using RJR

- **Recursive Jigsaw Reconstruction**: HEP event analysis in the presence of kinematic and combinatoric ambiguities
- **Sparticles in Motion**: getting to the line in compressed scenarios with the Recursive Jigsaw Reconstruction
- Probing compressed mass spectra in electroweak supersymmetry with **Recursive Jigsaw Reconstruction**
- **ATLAS Inclusive Squark Gluino search**:
- **ATLAS Compressed Stop 0, 1 and 2L**
- **ATLAS Chargino-Neutralino production 2L / 3L**

Where has RJR been used?
Higgstralung WH

**Higgs Mass**

RestFrames Event Generation

$W^0 \rightarrow W(1\nu) W(1\nu) W(1\nu)$

![Higgs Mass Distribution](image)

- $m_{H^0} = 100$
- $m_{H^0} = 125$
- $m_{H^0} = 150$
- $m_{H^0} = 175$
- $m_{H^0} = 200$

**Transversity**

RestFrames Event Generation

$WH^0 \rightarrow W(1\nu) W(1\nu) W(1\nu)$

![Transversity Distribution](image)

- $m_{W^0} = 100$
- $m_{W^0} = 125$
- $m_{W^0} = 150$
- $m_{W^0} = 175$
- $m_{W^0} = 200$

**W&H momentum fraction**

RestFrames Event Generation

$WH^0 \rightarrow W(1\nu) W(1\nu) W(1\nu)$

![W&H Momentum Fraction](image)

**Ratio momentum in Invisibles**

RestFrames Event Generation

$WH^0 \rightarrow W(1\nu) W(1\nu) W(1\nu)$

![Ratio Invisibles](image)

- $m_{W^0} = 100$
- $m_{W^0} = 125$
- $m_{W^0} = 150$
- $m_{W^0} = 175$
- $m_{W^0} = 200$

**Opening Angles**

RestFrames Event Generation

$WH^0 \rightarrow W(1\nu) W(1\nu) W(1\nu)$

![Opening Angles](image)
2D Correlation Plots
How to tell if an event naturally likes being in your decay tree

**Specific Drift variable**

\[ R_{PT}^{LAB} = \frac{p_{T,PP}^{LAB}}{p_{T,PP}^{LAB} + H_{T,4,1}^{PP}} \]

**ISR Drift variable**

\[ R_{CM} = \frac{|p_{T,CM}^{LAB} \cdot p_{T,ISR}^{LAB}|}{|p_{T,ISR}^{LAB}|} \]

**Extract the Boosts**

\[ \beta_x \beta_y \beta_z \]
Future Work

➤ Topo aware B-tagging (Implemented)
➤ Recursive Jigsaw in triggers
➤ Kinematic basis for machine learning
➤ Background rejection
➤ ISR treatment for SM processes
➤ Continue variable development
Got an idea? Need help? Give us an email!

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Concluding Remarks

1. RJR creates a kinematic basis for study
2. RJR has found success in SUSY exclusion
3. We have developed variables which allow diagnostics of a decay tree
4. Topo aware b-tagging provides new handles
5. Looking to implementing RJ in more scenarios

Questions?
Different Recursive Jigsaw Decay Trees
Examples of Jigsaw Rules

**Kinematic ambiguity Jigsaw Rules**

- **Invisible Rapidity**
  - Set rapidity of dineutrino system to the visible system
- **Invisible Mass Rule**
  - Once we apply all Jigsaw Rules, we require the invisible particles to have non-negative mass.
- **Contra boost invariant**
  - Require $M_{VaVb} = M_{VbIb}$

**Combinatoric Jigsaw Rules**

- **Combinatoric Mass Minimisation**
- **Minimise Masses Squared**
- **Invisible Minimize Masses**
- **Invisible Minimize Difference in mass**