Down to the Line:
Compressed Kinematics in SUSY Searches

Julia Gonski
Harvard University

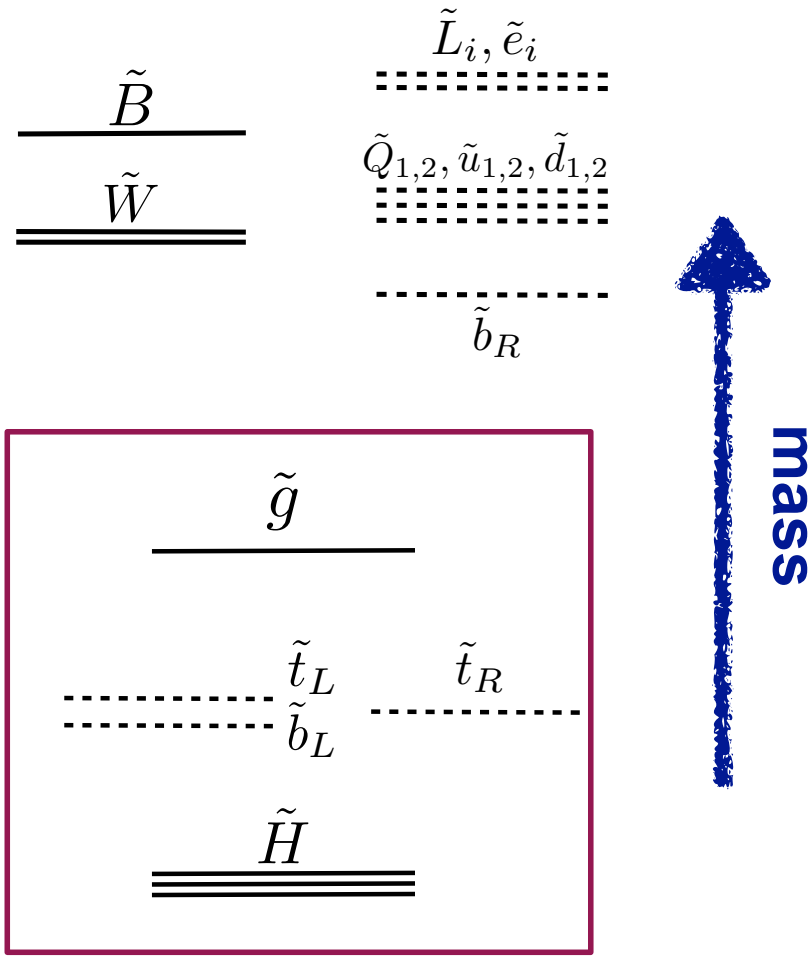
2 November 2017
US LHC User's Association
Annual Meeting

ATLAS EXPERIMENT

A Tribute to SUSY

- Provides mechanism for electroweak symmetry breaking, unification of forces, and dark matter candidate

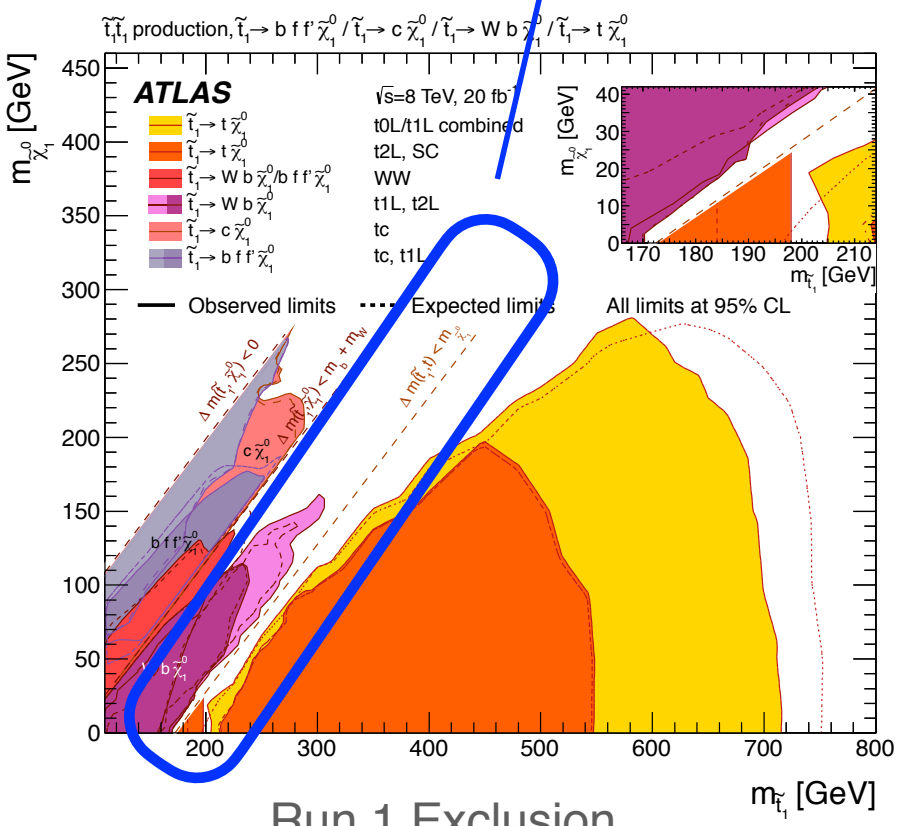
- **Naturalness:** should have light stops, gluinos, & Higgsinos (~GeV mass splittings)



Physics On The Edge

$$m_{\tilde{t}} - m_{\tilde{\chi}_1^0} \cong m_t$$

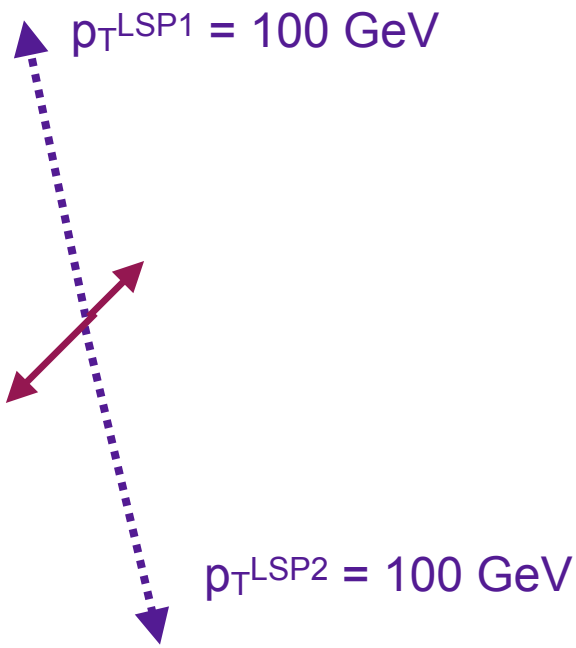
- Small mass splittings between parent & daughter particles are experimentally challenging
  - Daughter particles produced practically at rest: **soft final state objects, little E_T^{miss}** from LSP
  - Limits historically worse on these "diagonals"
- Requires clever use of kinematics and **ISR-assisted topologies**



Run 1 Exclusion

Making E_T^{miss} with ISR

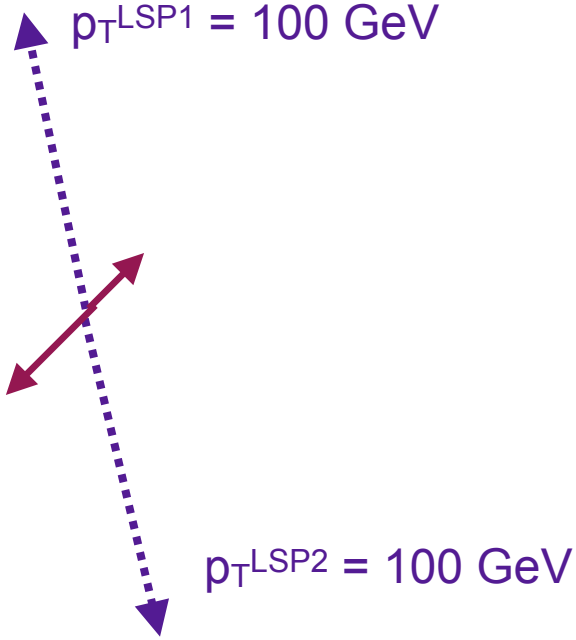
- With no other final state objects, LSPs are back to back, no E_T^{miss} in event



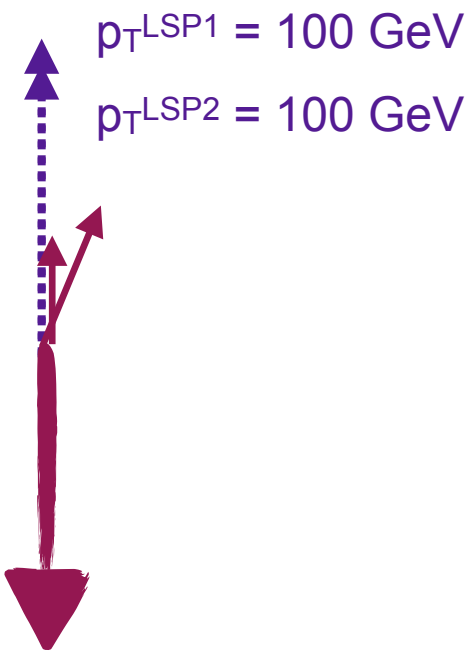
Total E_T^{miss} = 0 GeV

Making E_T^{miss} with ISR

- With no other final state objects, LSPs are back to back, no E_T^{miss} in event
- Require ISR jet: collimate LSPs, generate measurable E_T^{miss} for trigger

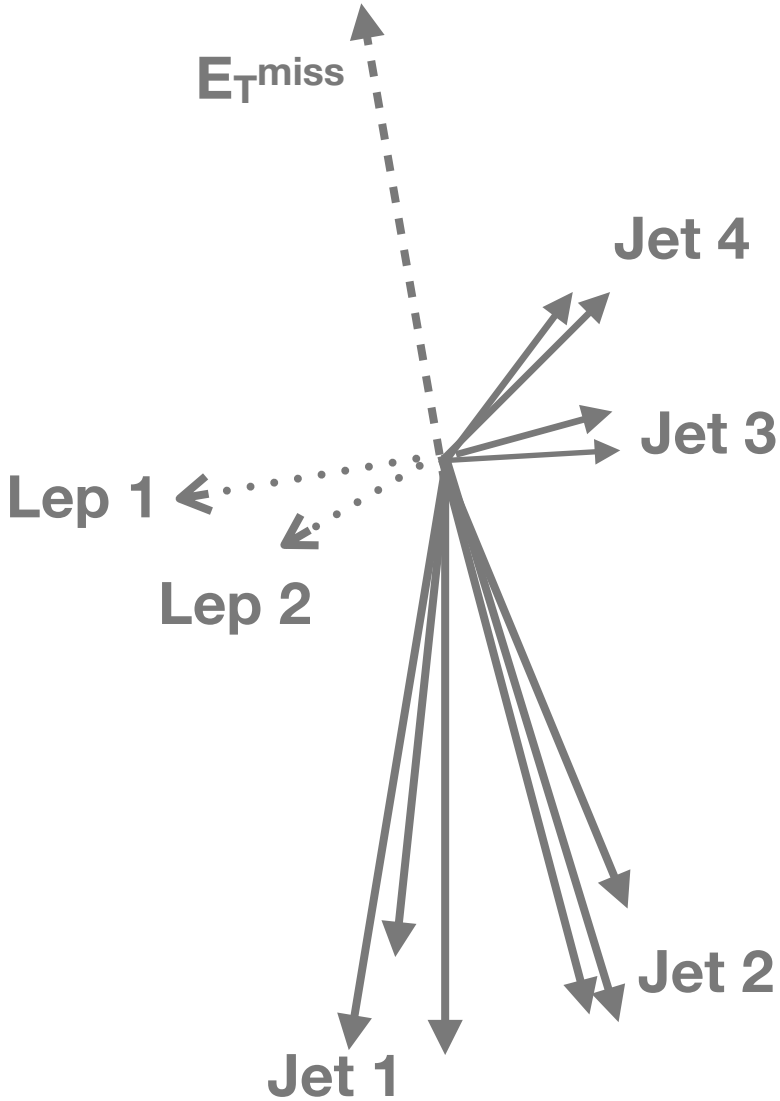


Total E_T^{miss} = 0 GeV

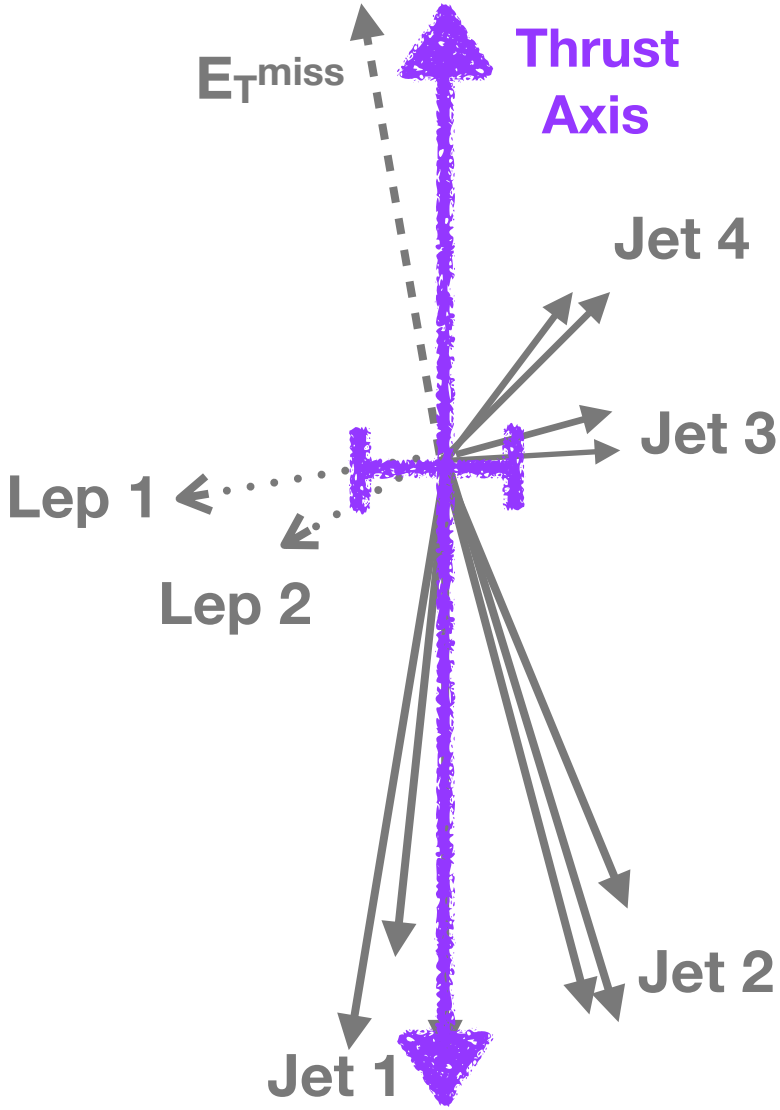


Total E_T^{miss} = 200 GeV

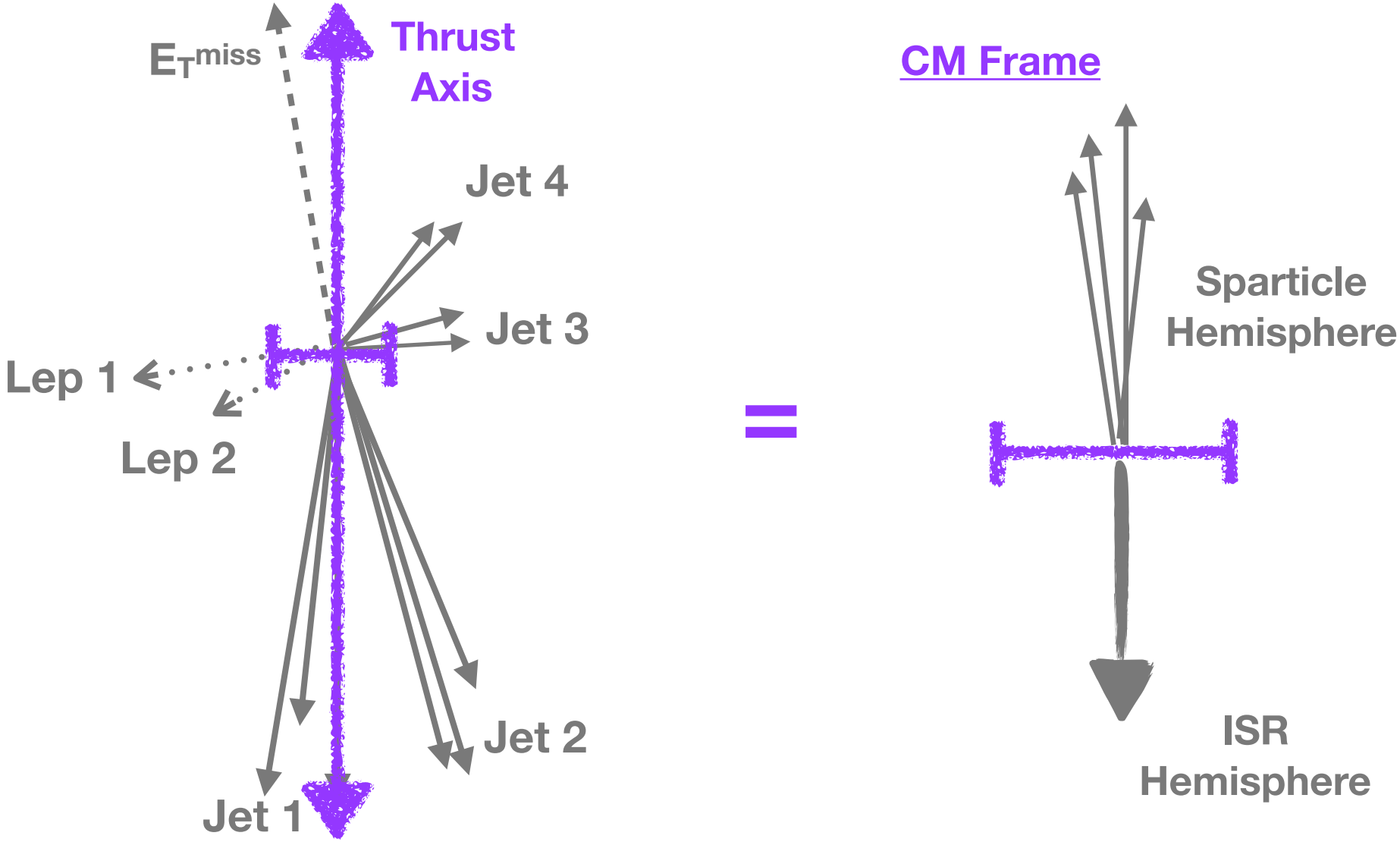
Recursive Jigsaw Reconstruction



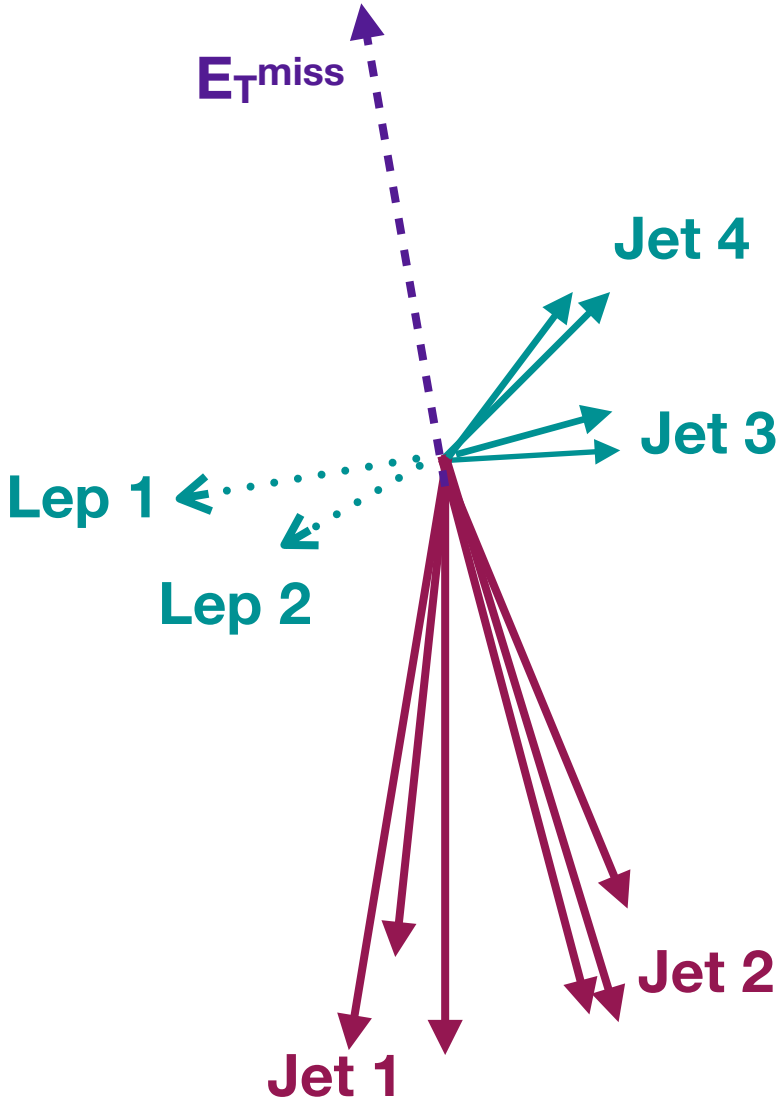
Recursive Jigsaw Reconstruction



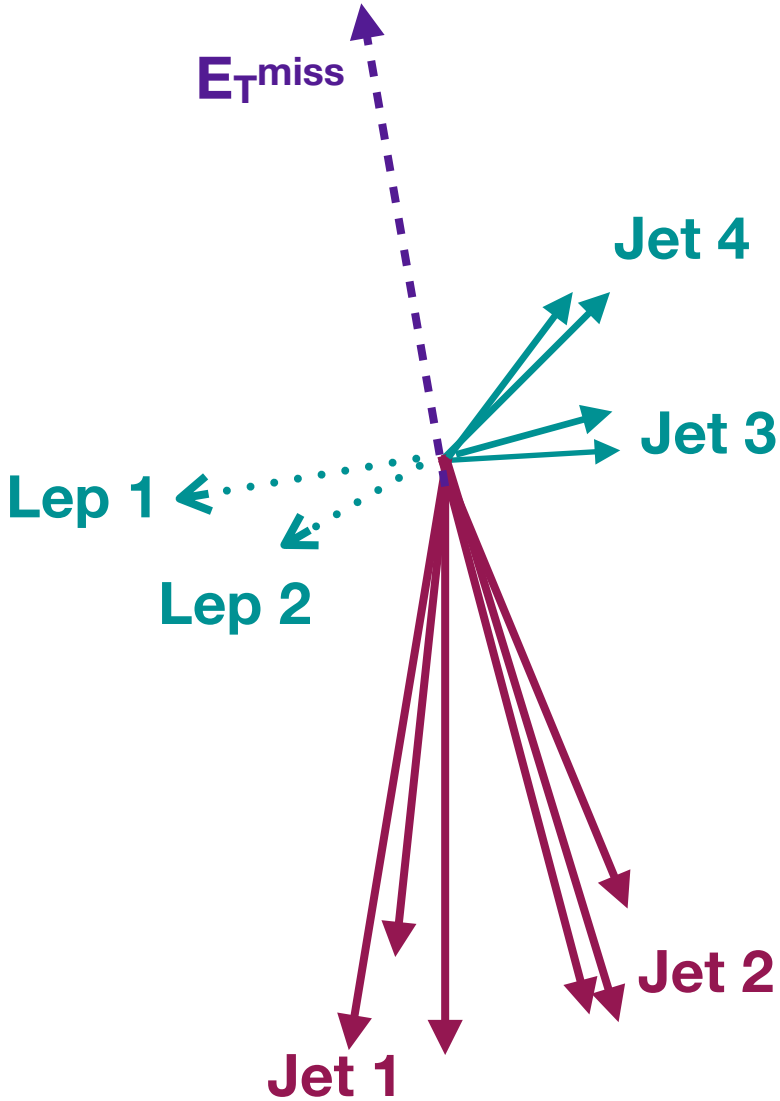
Recursive Jigsaw Reconstruction

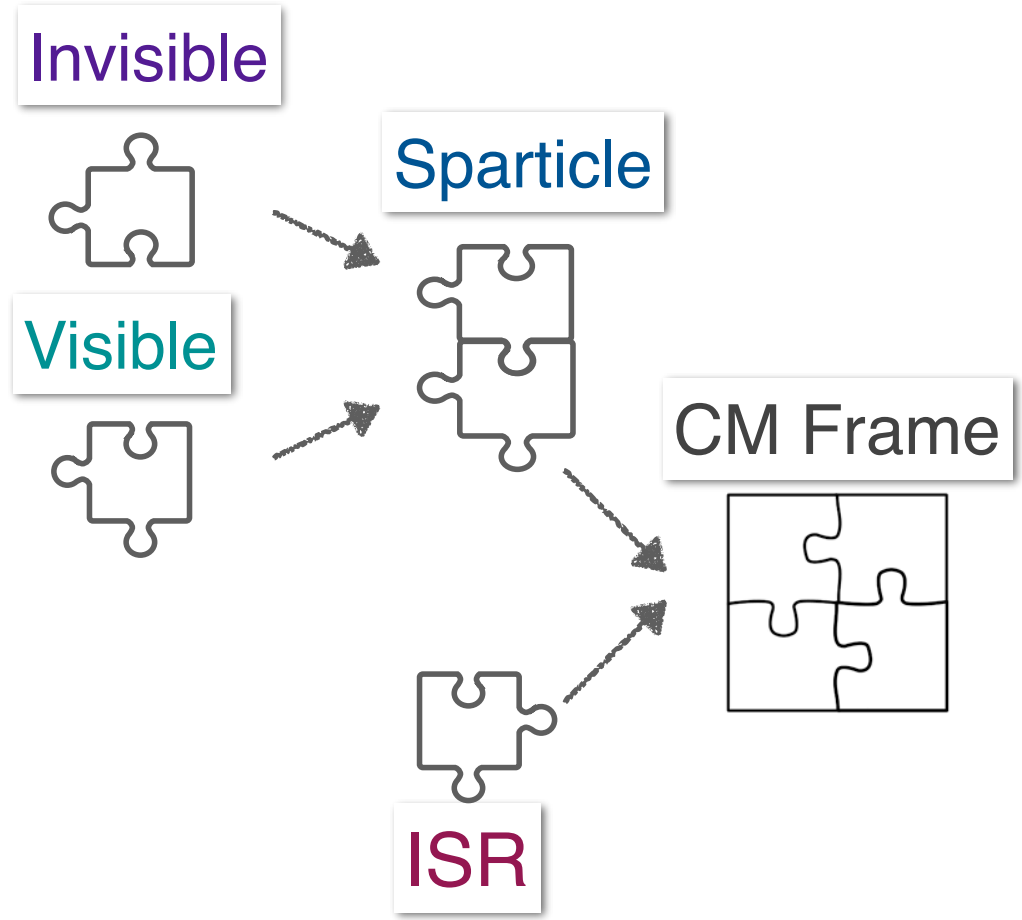


Recursive Jigsaw Reconstruction



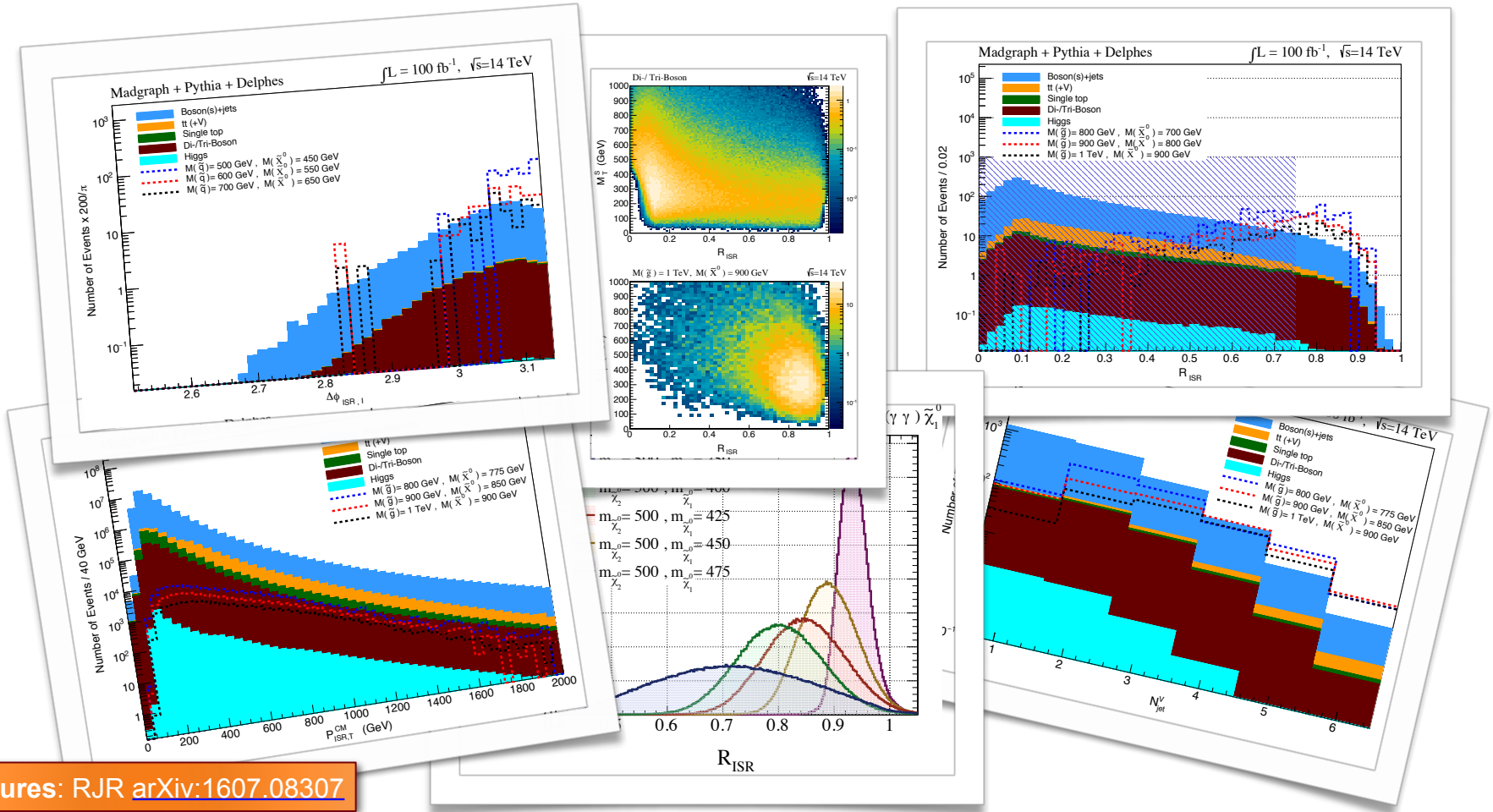
Recursive Jigsaw Reconstruction





A Variable Zoo

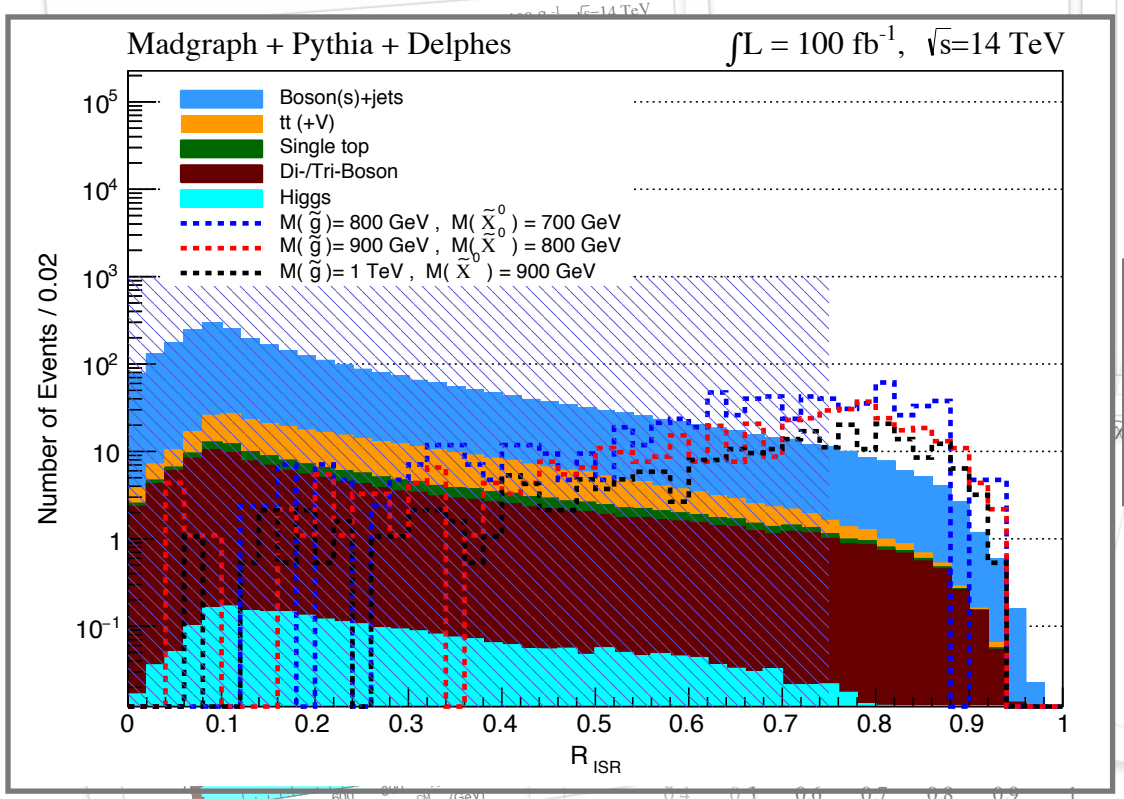
↣ Recursive Jigsaw Reconstruction (RJR) is an effective **model independent** technique for enhancing sensitivity with compressed signals and soft decay products



Figures: RJR arXiv:1607.08307

A Variable Zoo

↣ Recursive Jigsaw Reconstruction (RJR) is an effective **model independent** technique for enhancing sensitivity with compressed signals and soft decay products



$$R_{\mathrm{ISR}} \equiv \frac{|\vec{p}^{\,\mathrm{CM}}_{\mathrm{I},T} \cdot \hat{p}^{\,\mathrm{CM}}_{\mathrm{ISR},T}|}{|\vec{p}^{\,\mathrm{CM}}_{\mathrm{ISR},T}|}$$

$$\sim \frac{m_{\mathrm{daughter}}}{m_{\mathrm{parent}}}$$

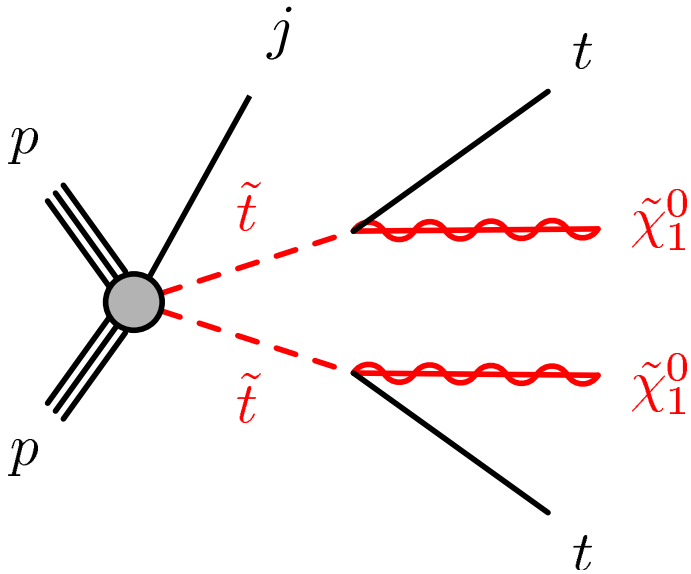
(for very small mass splittings)

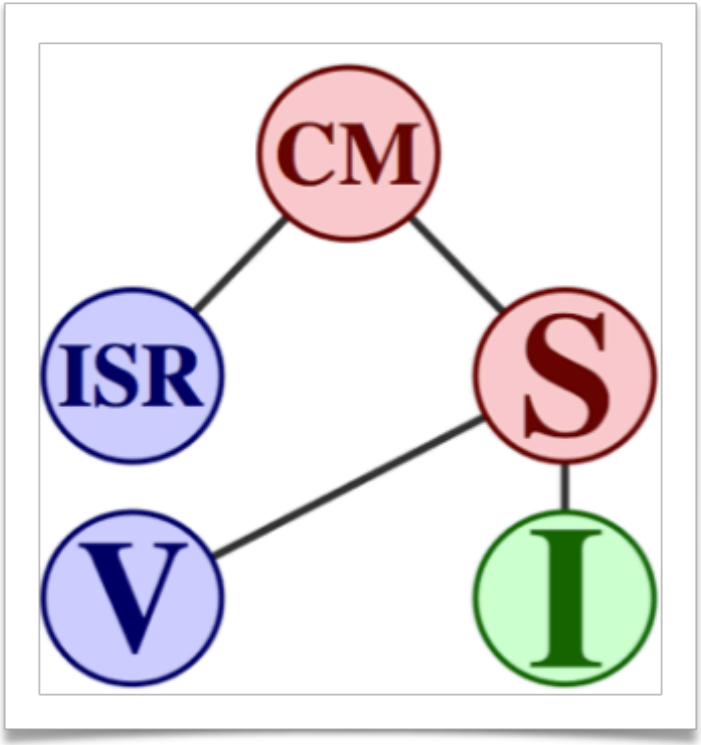
Figures: RJR arXiv:1607.08307

Stop Diagonal Search

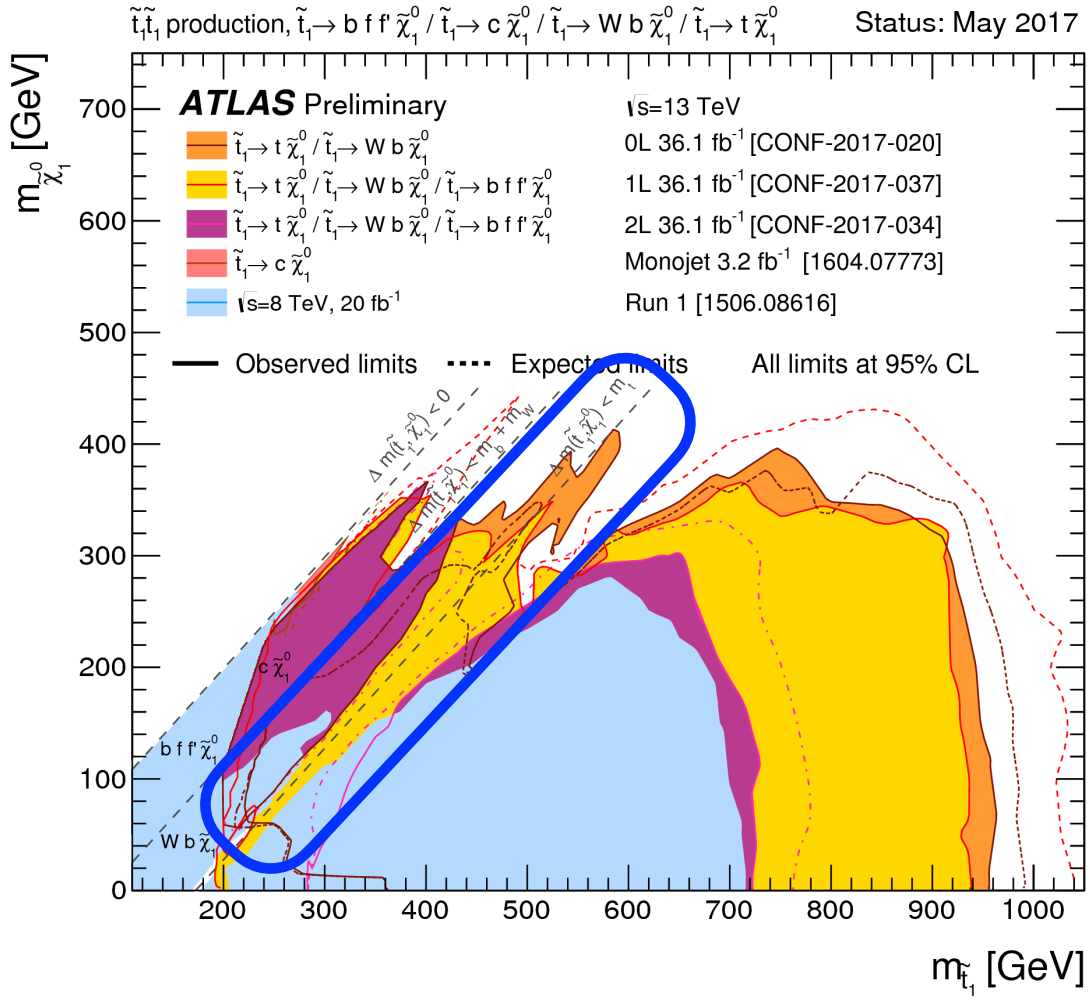
- $\Delta m \cong 0 \quad \rightarrow \quad RISR \cong m_{LSP} / m_{stop}$

- Technique used on diagonal in 0L, 1L final states





Stop Exclusions + RJR



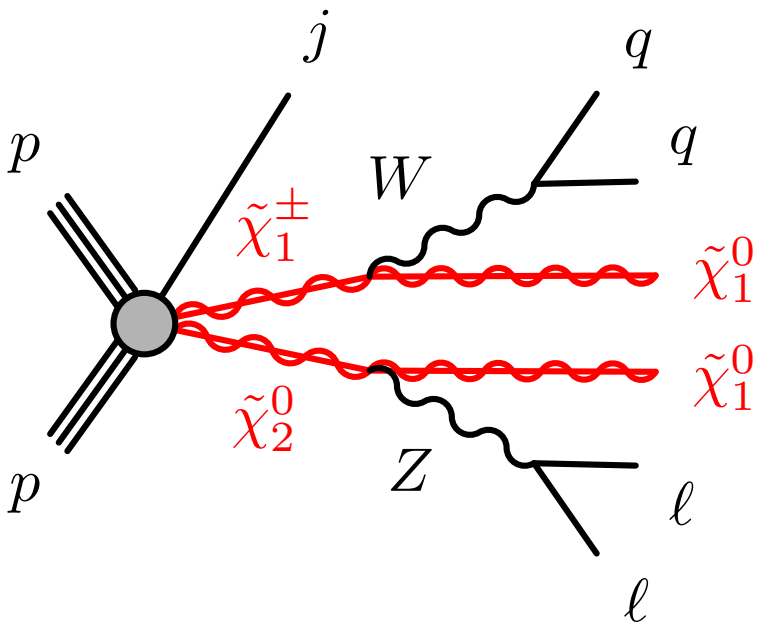
See: stop 0L (arXiv:1709.04183), stop 1L(arXiv.1606.03903)

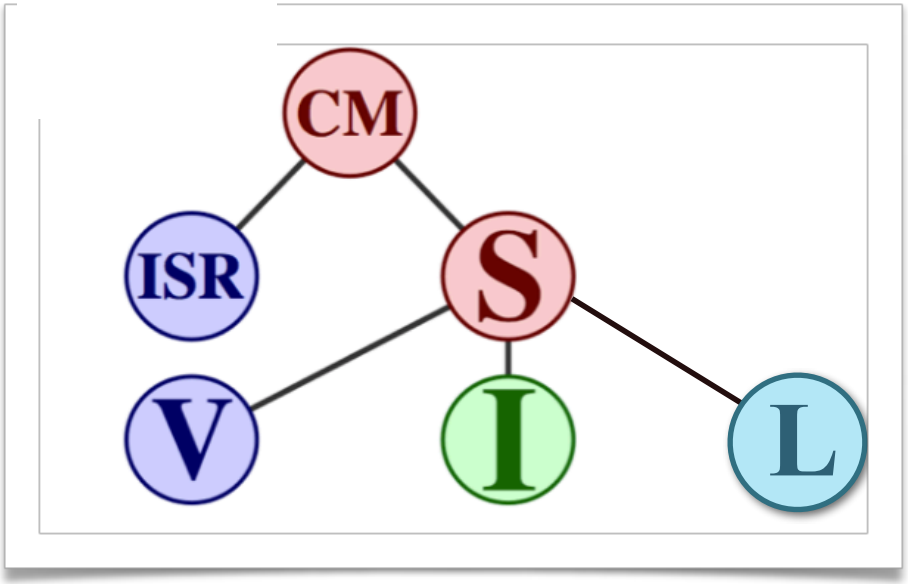
Higgsino Diagonal Search

- $\Delta m \cong 0 \quad \rightarrow \quad RISR \sim m_{LSP} / m_{chargino}$

- Combine with new soft lepton strategies and triggers to reach $\Delta m < 5$ GeV

⇢ *coming soon!*

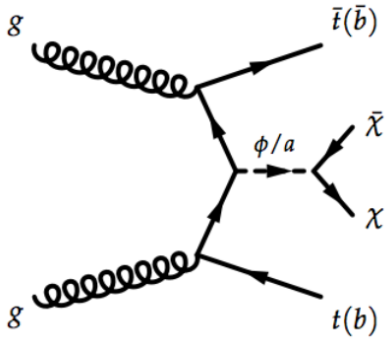




Conclusions

- Compressed SUSY models will continue to be a cornerstone of the LHC search program
- Recursive Jigsaw Reconstruction (RJR) can provide extra sensitivity to compressed signals via kinematics
- Expanding use across all kinds of SUSY searches

  - Many new physics searches are (fundamentally) similar! Can imagine building an RJR tree for any decay chain…

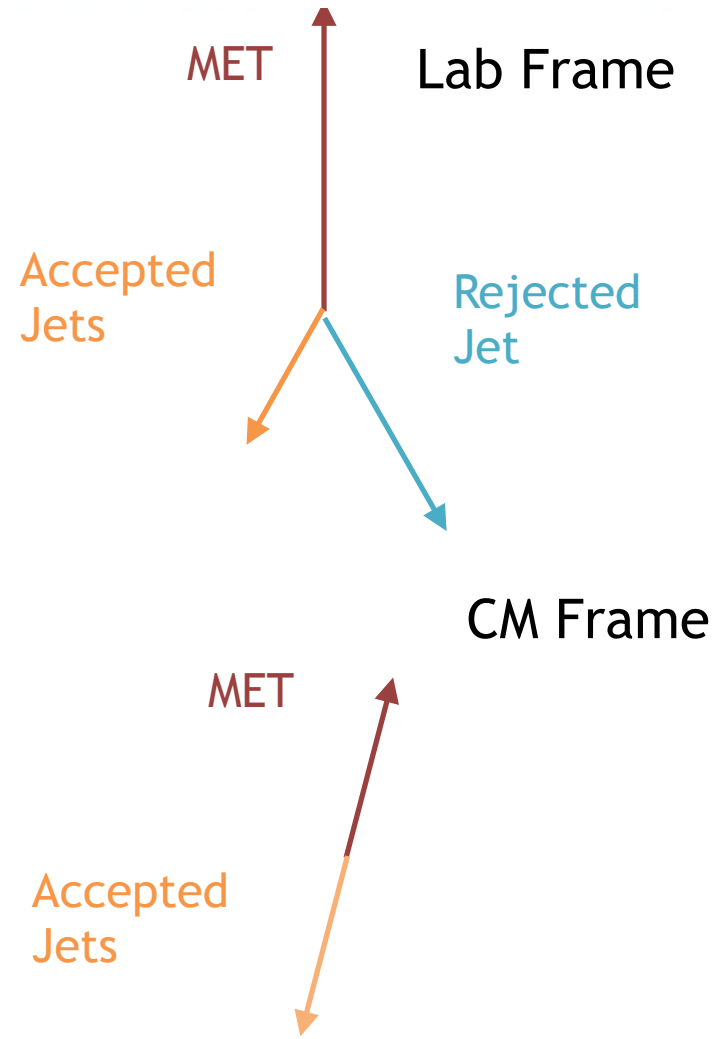


DM + ttbar

Backup

RJR Algorithm

- Use "event CM" frame to identify ISR jets and calculate $R_{ISR.}$
  - makes sure that the MET and jets used in the analysis balances each other out.
- "CM" frame is the frame that all objects accepted into the event has Pt = 0
- So set MET P_z = 0 and mass = 0.
- Set all Jet P_z=0 and E^2 = m^2 + P_T^2.
- Sum all 4 vectors of all accepted signal objects and boost to the where P_T = 0 for this combined 4 vector.
  - Do nothing in the Z direction
- 0st order correction for MET coming from jets or other objects that you don't accept into your analysis and ensures R_{ISR} has an upper bound of 1.
- A simplified and exaggerated case for 2 jets is shown in the right



RJR Algorithm

- ISR is identified in the CM frame by minimizing the sparticle system and ISR system masses

- Can think of this in 2 equivalent ways

1. Large jet clustering along two jet axis that are back to back using mass as a distance metric

2. Minimizing M_s and M_{ISR} is identical to maximizing the amount of back to back P_T of the two systems.
   - Because $E_{tot} = \mathrm{sqrt}(M_S^2 + P_{T\,S}^2) + \mathrm{sqrt}(M_{ISR}^2 + P_{T\,ISR}^2)$
   - E_{tot} is constant for the event and $P_T = P_{T\,S} = -P_{T\,ISR}$
   - Maximizing P_T along a back to back axis is the same thing as calculating the thrust axis
   - The event is then divided into hemisphere wheres the hemisphere containing the MET is the sparticle system and other hemisphere the ISR system.