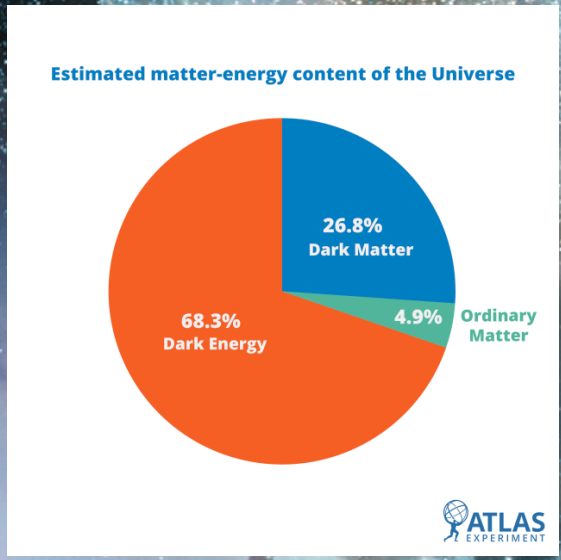
Invisible objects at the LHC

Paul Jackson

Nov 27th, 2020

Direct searches for Dark Matter at the LHC

- The LHC will remain the highest energy particle collider on the planet for the next ~20 years
- With this machine we can explore the energy frontier with high intensity and precision
- This facility provides a unique laboratory to explore the dark universe



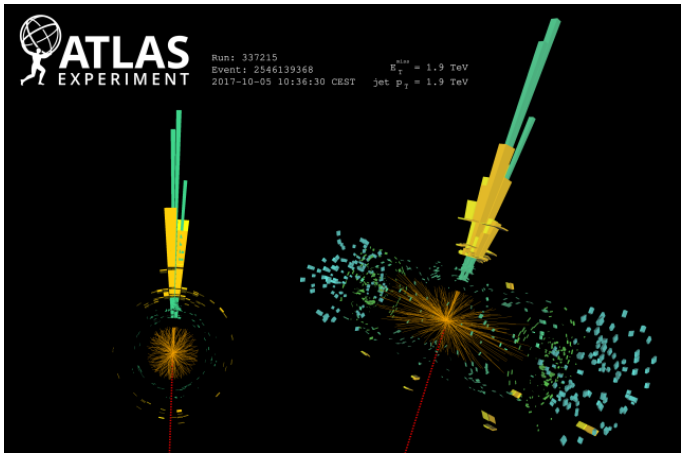
A well understood experiment, improved object reconstruction and a fresh dataset make the coming years very exciting

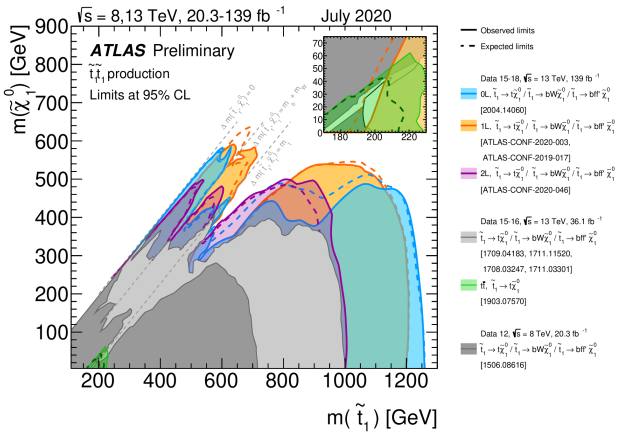
I'll flash a few highlights of work we're involved in

Direct Dark Matter searches at the LHC

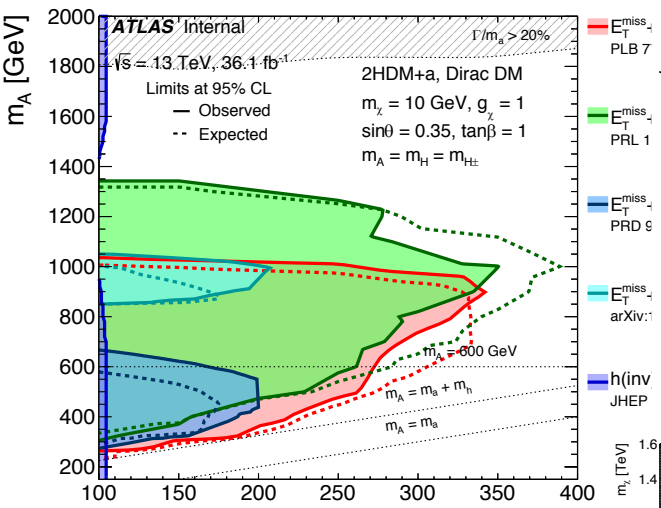
- Several ways to search for dark matter in pp collisions
- Mono-X (jet, Z, W, photon+E_T^{miss})
- t-channel production
- Di-jet, di-lepton bump hunts
- **ISR+anything**
- **nSM+E_T^{miss} (where n>1) (aka SUSY)**

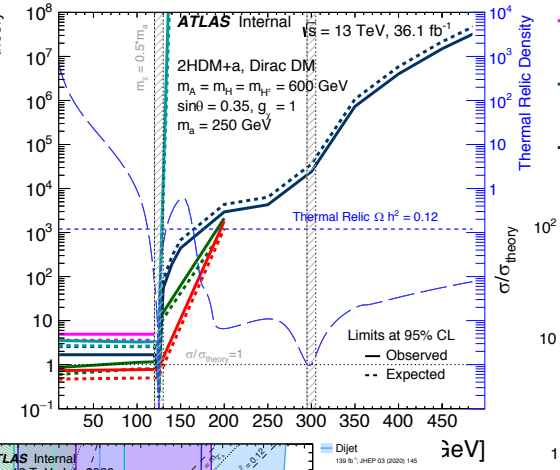
- We have already learned a lot about where Dark Matter isn't!

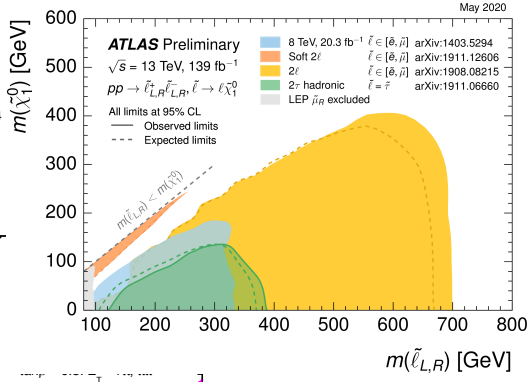


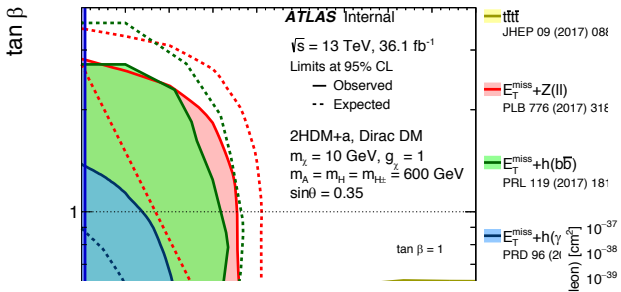


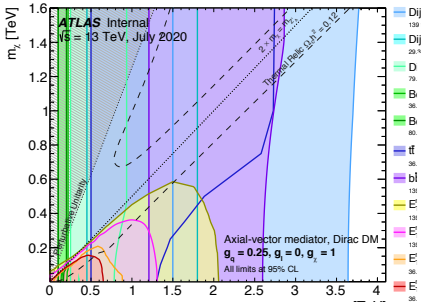
Direct Dark Matter searches at the LHC

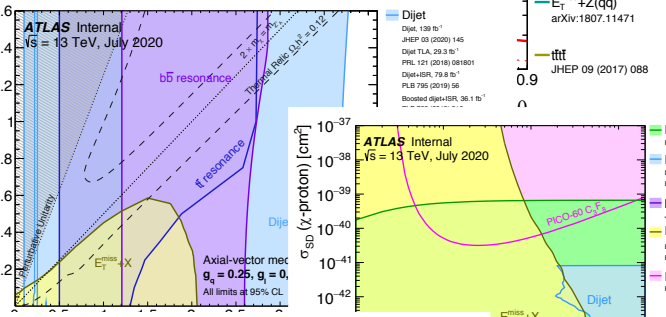


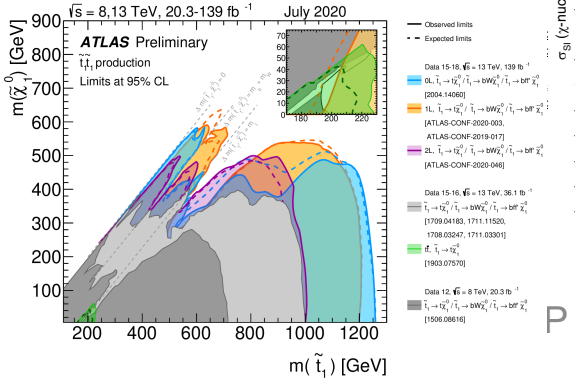


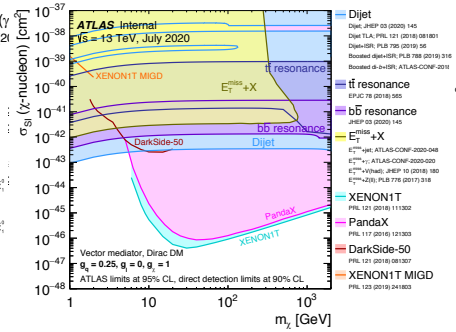


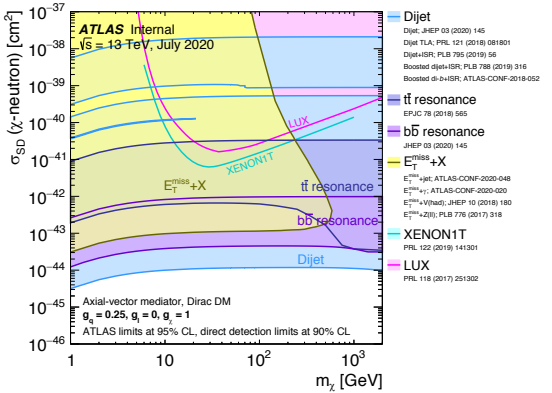












Recent work

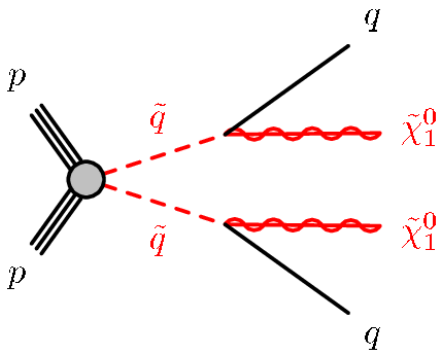
- Flagship DM searches at the LHC are under the remit of the combined DM group, the search groups each participate in this

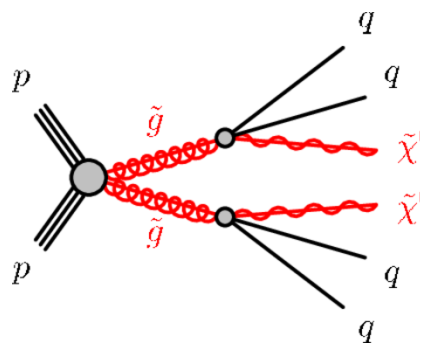
Recently submitted updated search for jets and missing energy using full Run2 data https://arxiv.org/abs/2010.14293

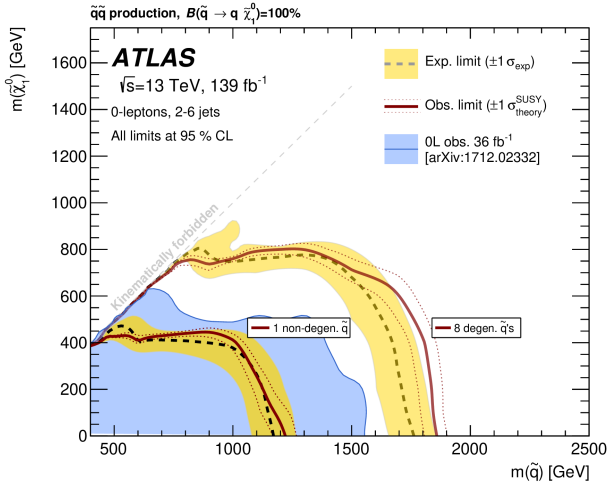
No excesses observed

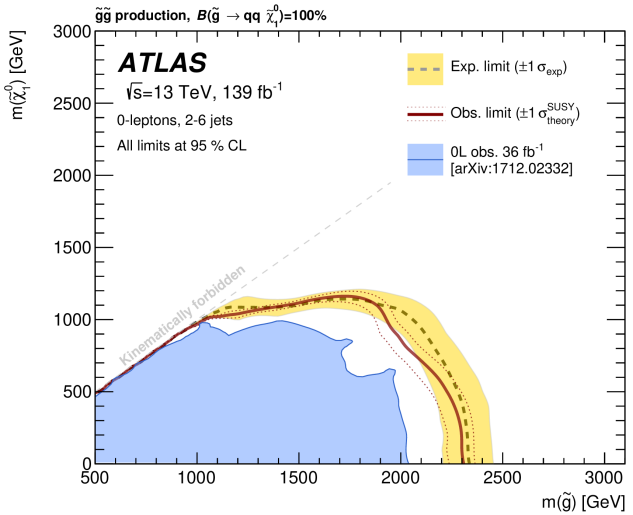
Place stringent limits on squark and gluino production.

More canonically, limits on invisible objects produced in association with jets.







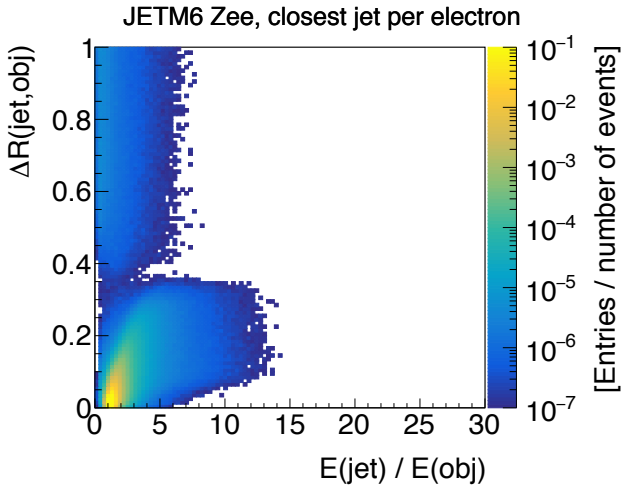


Jet/MET - Performance work

- During Run 3 we're preparing to collect ~150fb-1 of data
- Improving the way in which we reconstruct objects and trigger will be vital to our ability to explore these data effectively
- The use of particle flow (PFlow) techniques for jet reconstruction has proven to be an effective means of improving jet performance as evaluated using a range of metrics.
- Improved machine learning techniques to classify and calibrate jets using more information than currently leveraged

Jet/MET - Performance work, highlights

- Particle Flow jet reconstruction verified to improve performance for a range of metrics wrt EMtopo, and will be adopted in run 3
  - important to understand the extent to which PFlow jets overlap with other objects (this will have an impact on MET calculations, object selection for analyses, etc...)

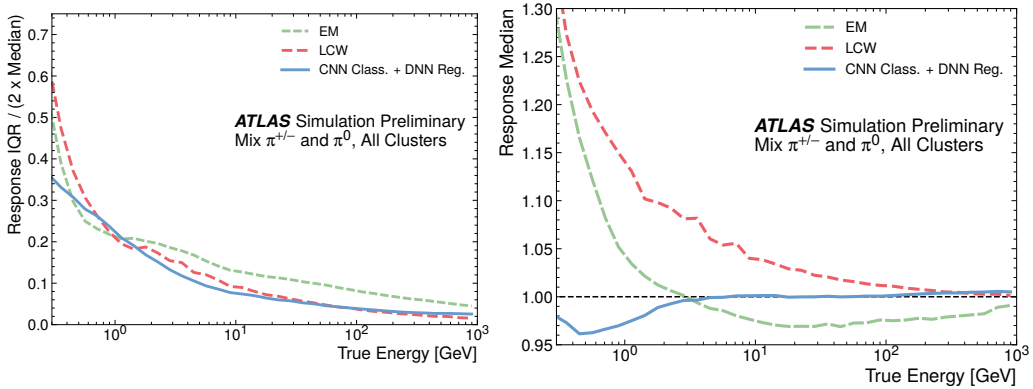


Edmund Ting

Machine learning approach for classifying and calibrating the energy of pions

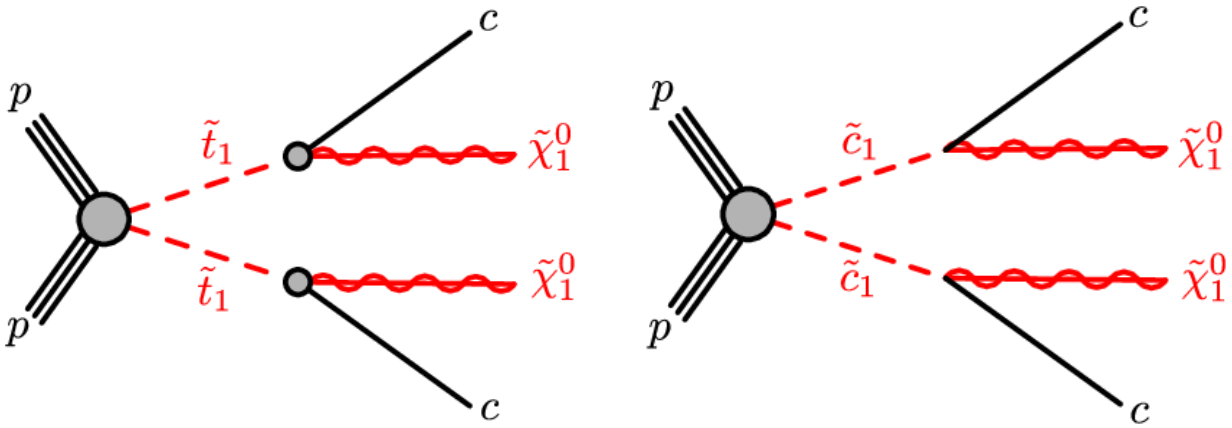
Leveraging information contained in shape of showers as they develop across the various calorimeter layers

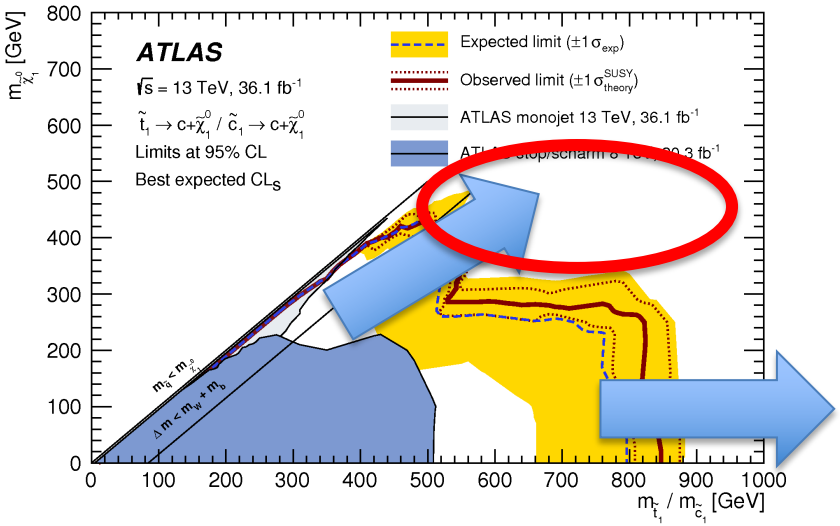
An example of where we can gain massive benefits by rethinking how we use some of the fundamental objects we reconstruct from detector readouts.



Albert Kong

cc+MET and tc+MET





We're working with colleagues at Argonne National Laboratory to improve the analysis with flavour-tagged jets.

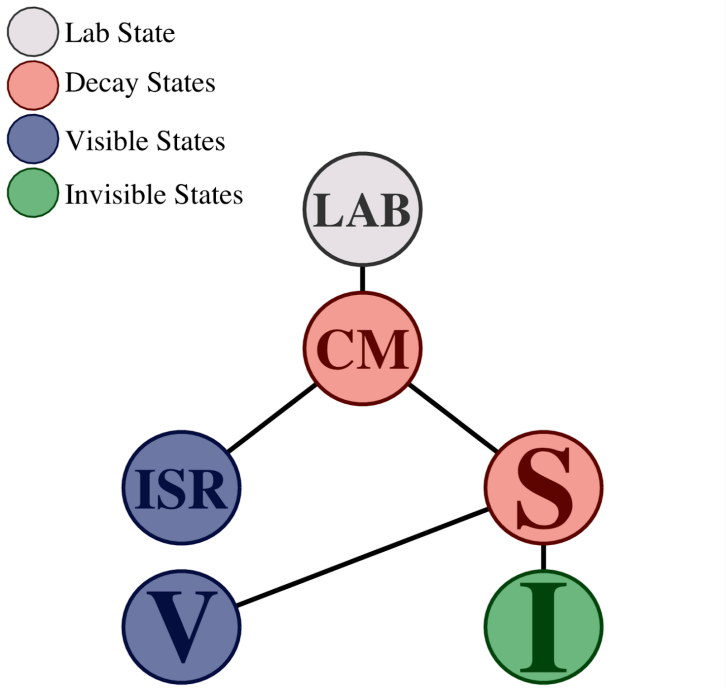
As shown in this exclusion plot the results are complementary to the mono-jet exclusion.

Improvements will rely on applying new methods and improving charm-tagging.

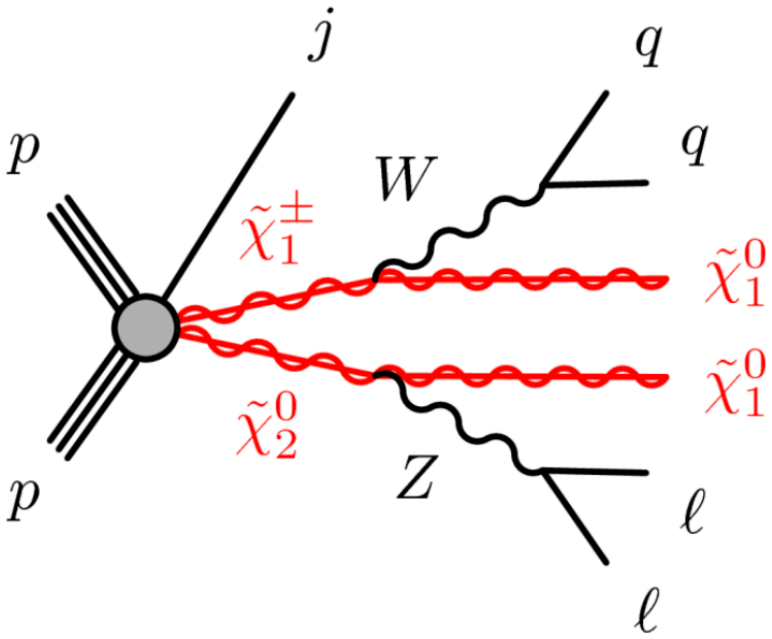
Recursive Jigsaw Reconstruction

This method then provides a basis of variables that can be used for ***any Dark Matter search*** with either an ISR jet or photon.

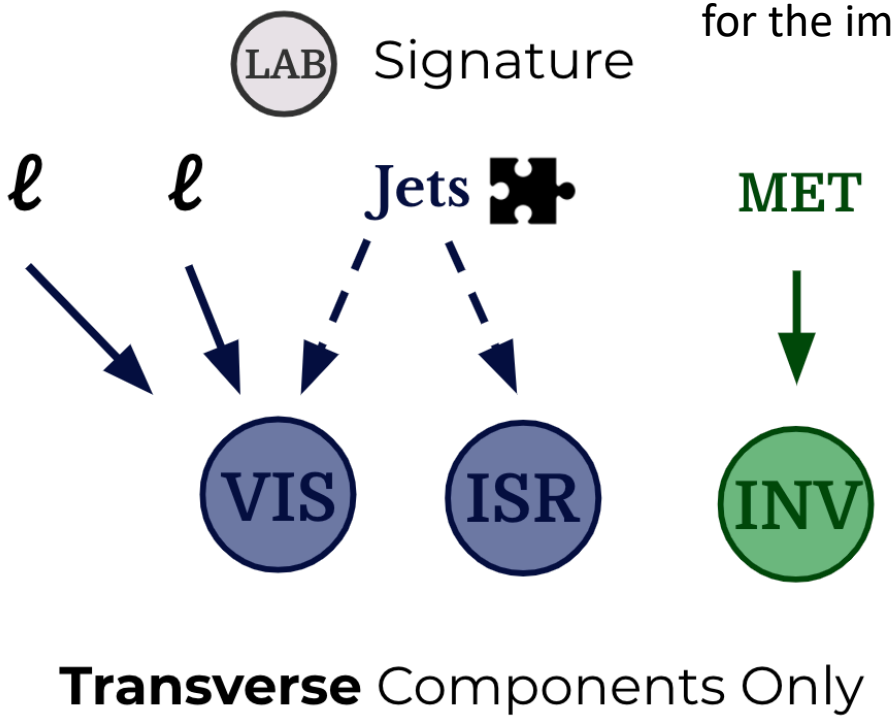
While this could touch on the simple mono-X program, the method also works for *all* compressed Supersymmetry



RJR for ISR-boosted signals



Thanks to Jason Oliver for the images



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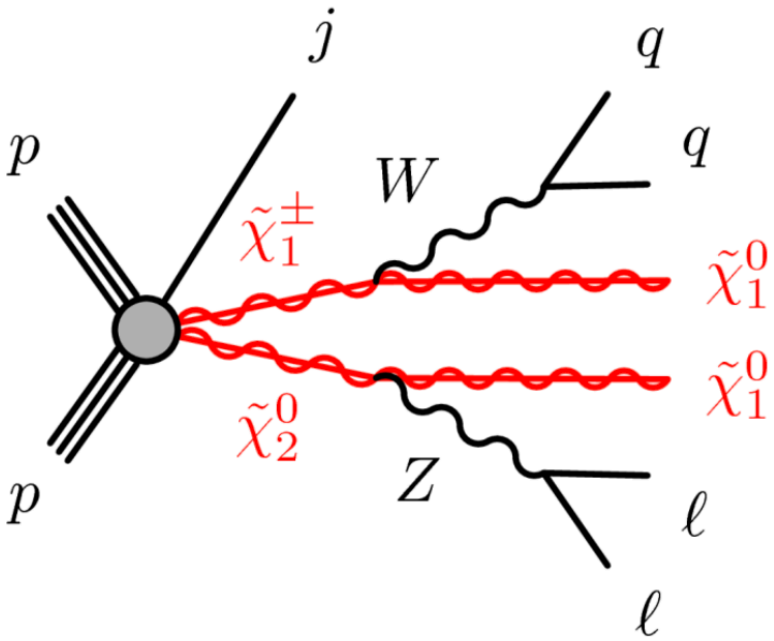
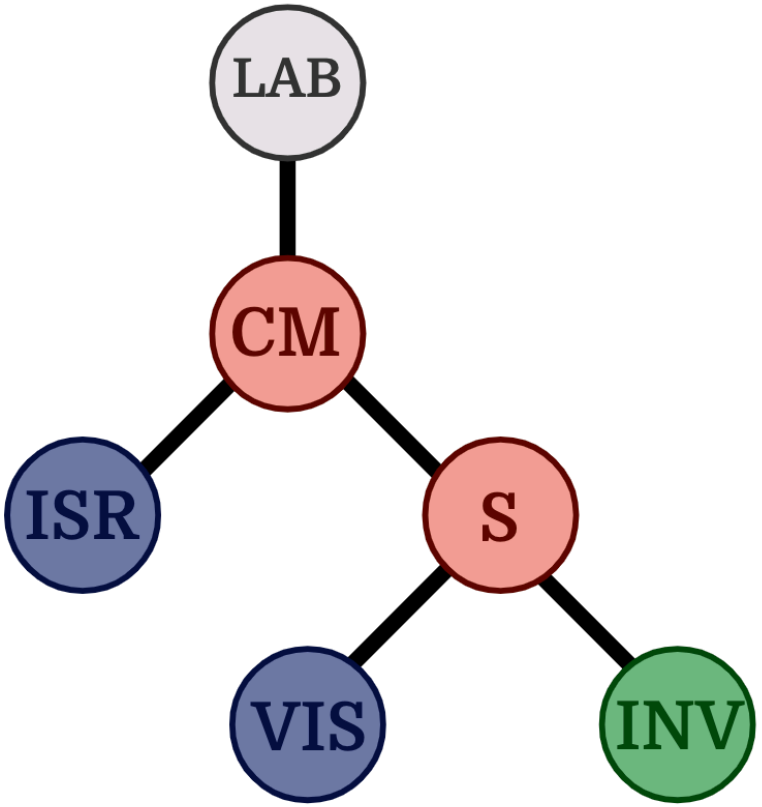
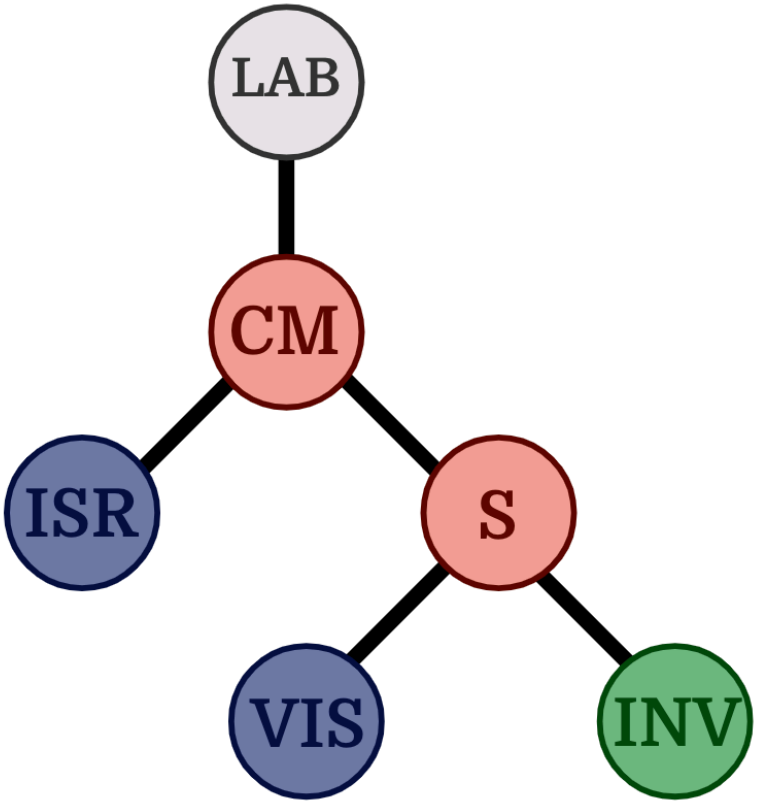




RJR for ISR-boosted signals

How do we determine **ISR** ?

We apply a **Jigsaw Rule**

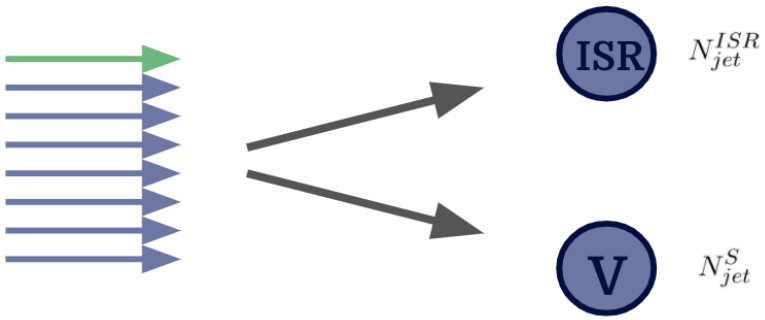


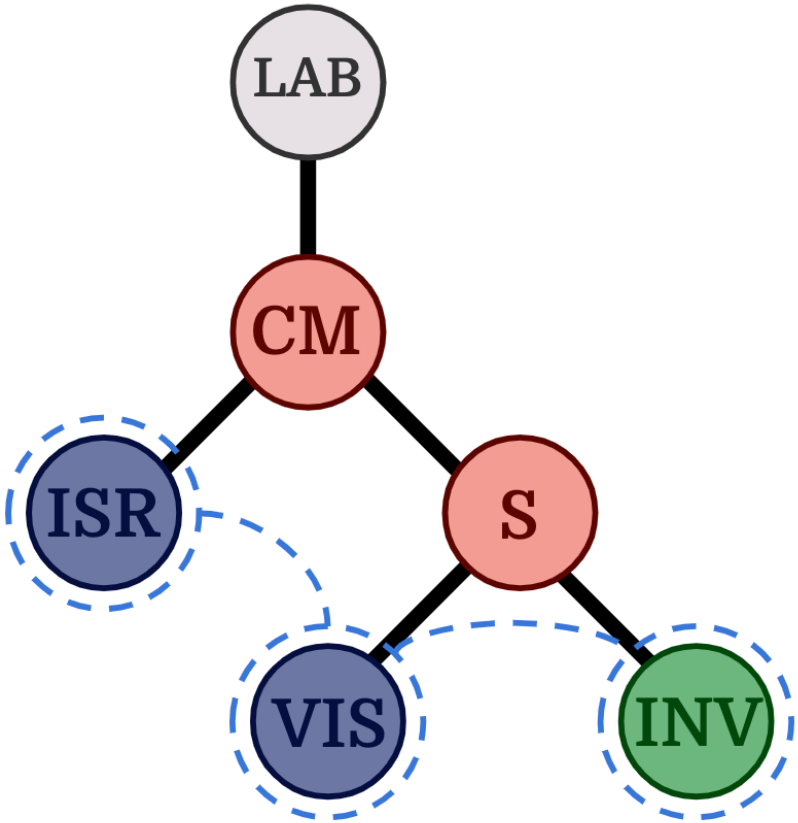
RJR for ISR-boosted signals

How do we determine **ISR** ?

We apply a **Jigsaw Rule**

We add take all combinations of jets into **ISR** and **VIS** and assign based on the minimum mass combination





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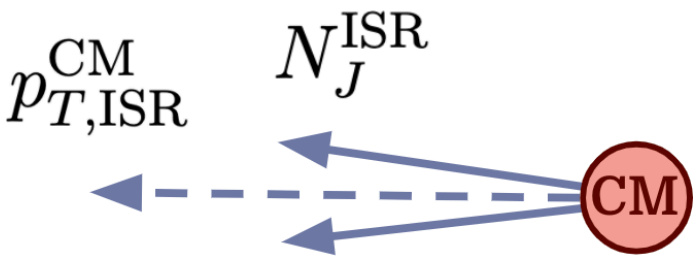

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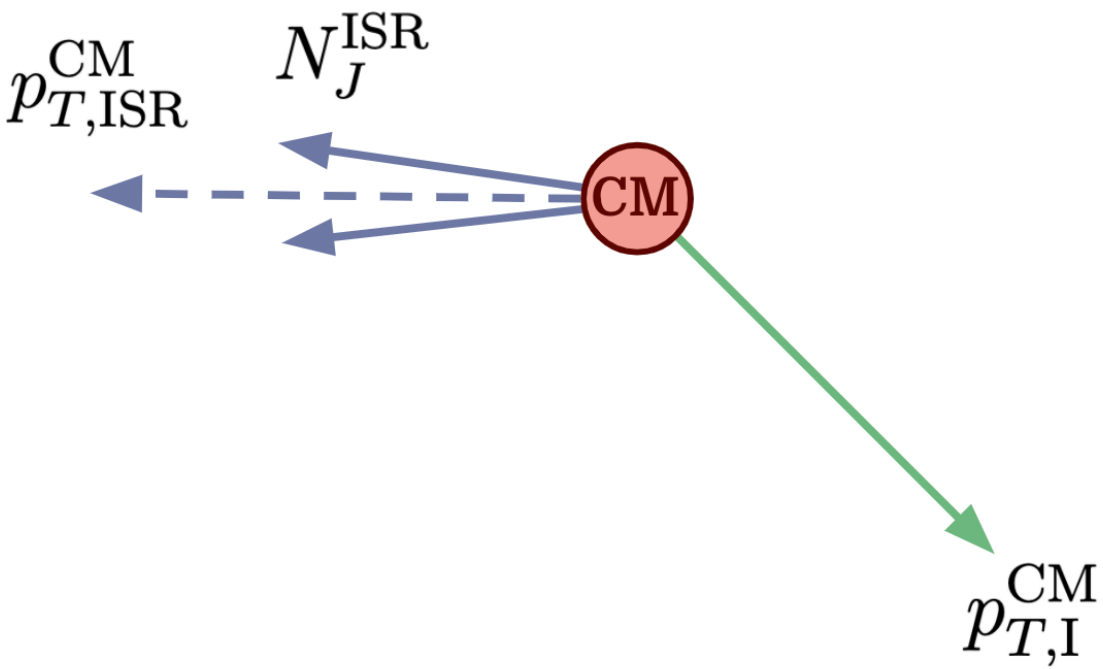

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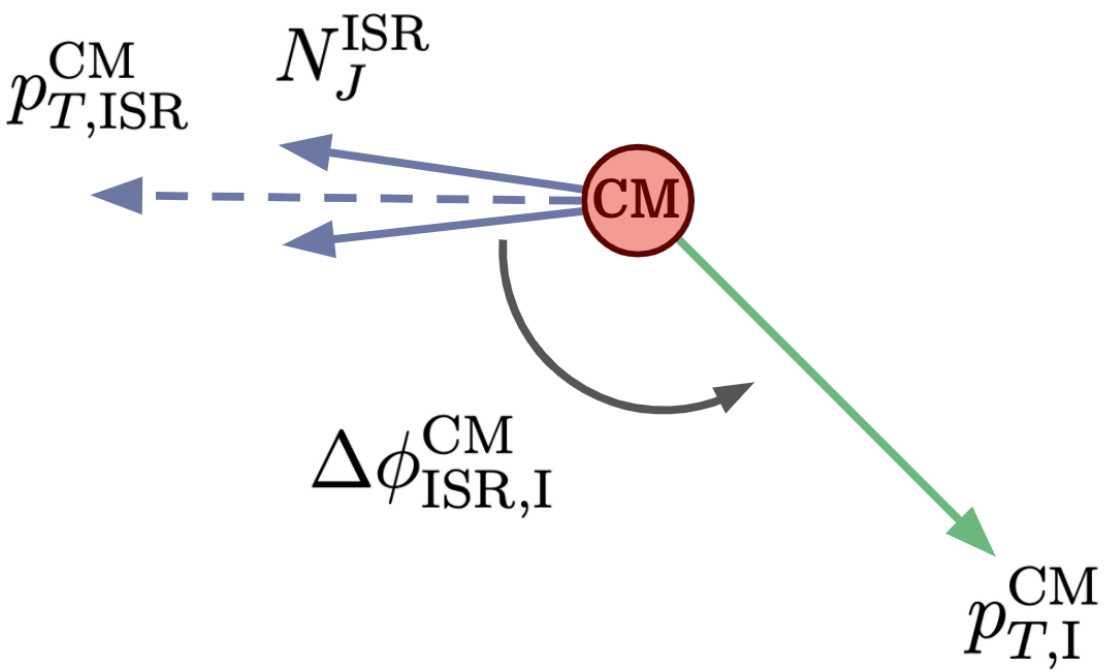

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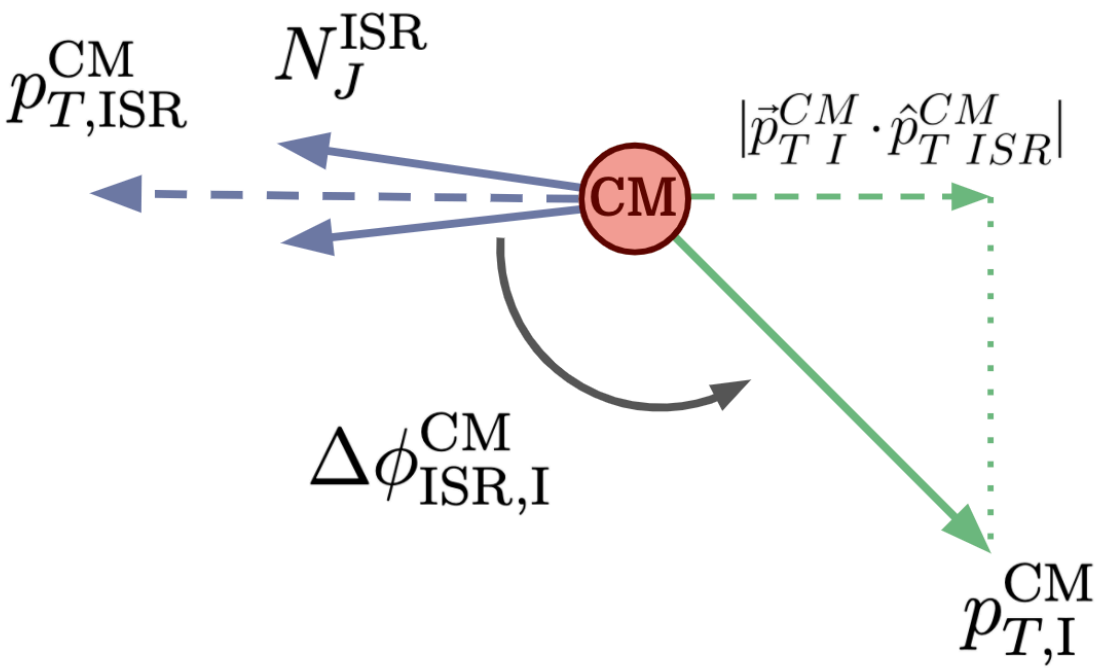

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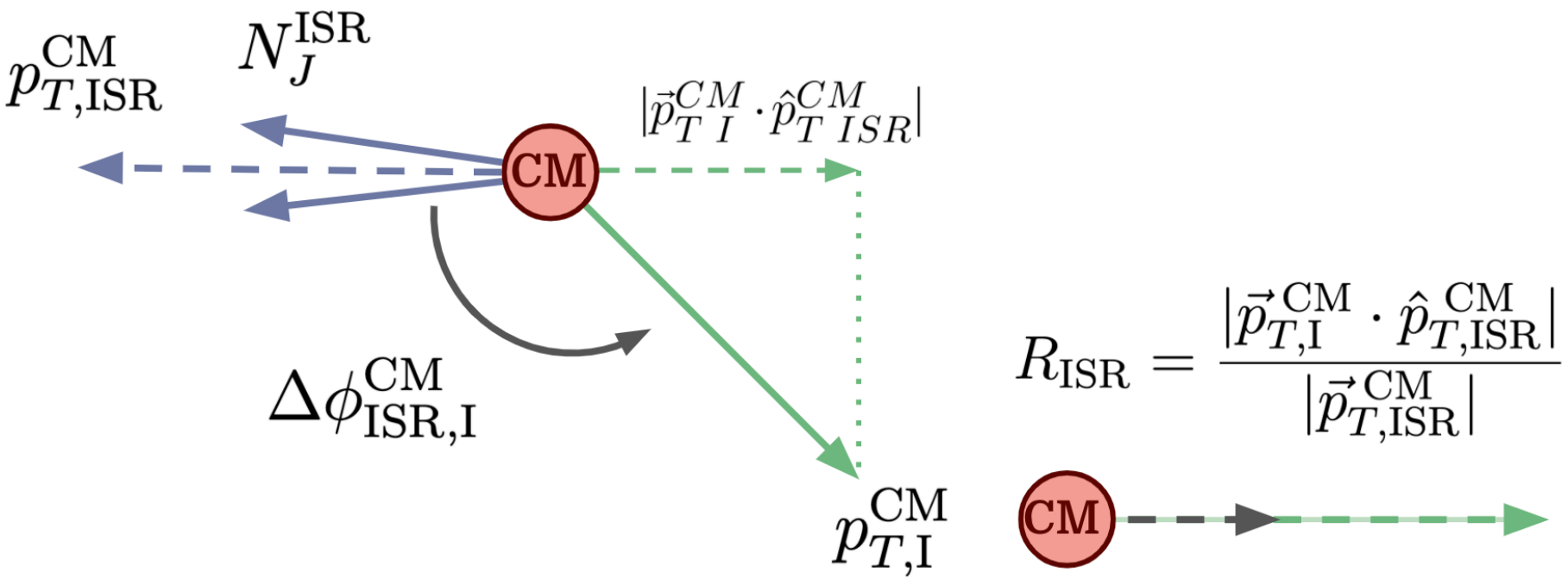

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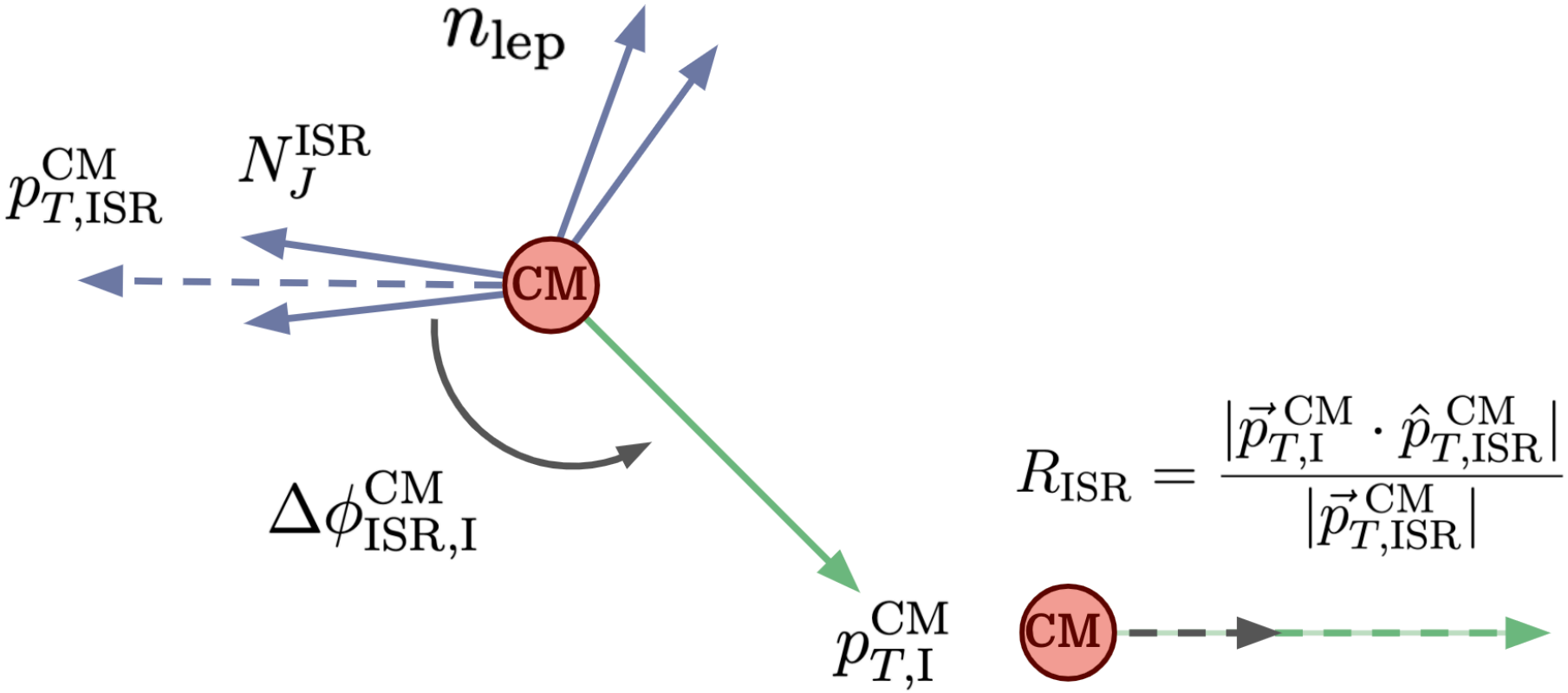

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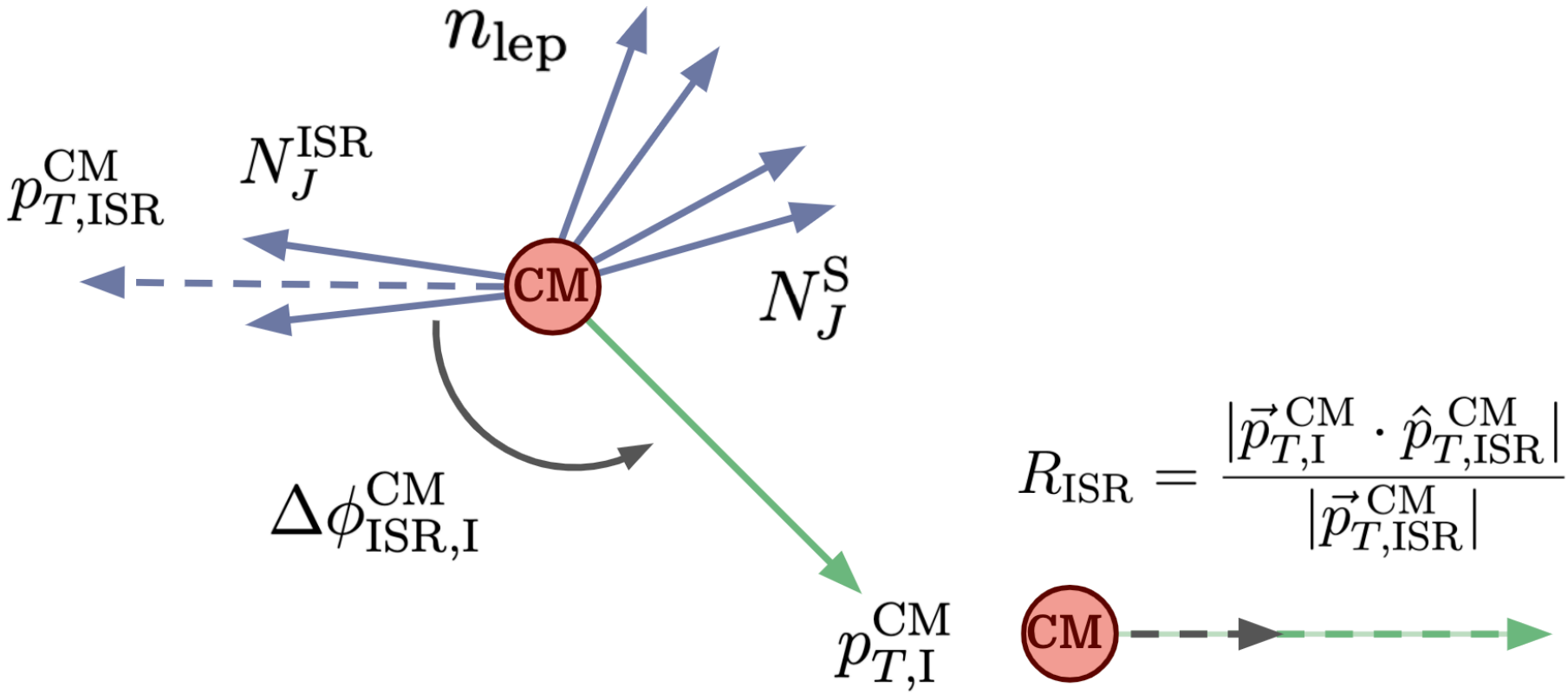

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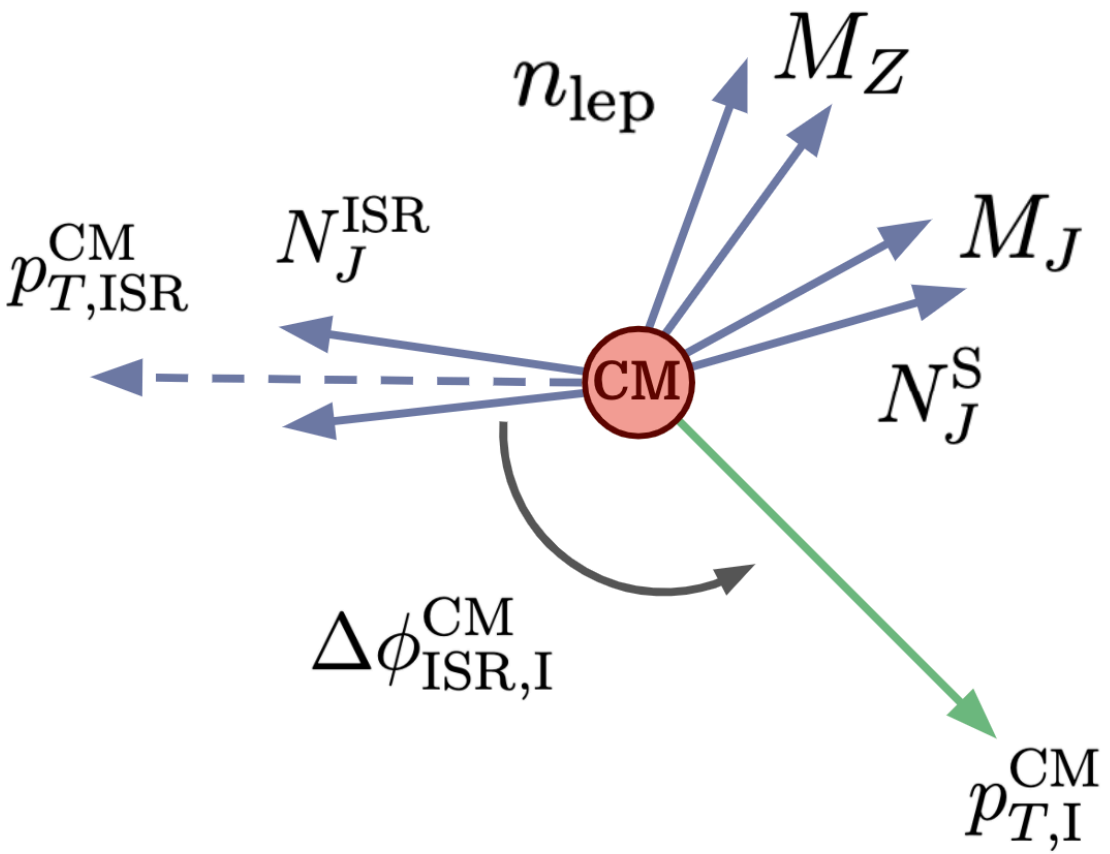
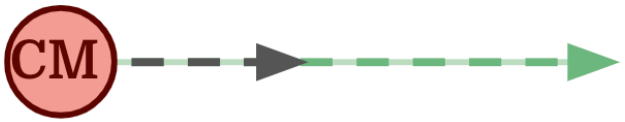


$$R_{\text{ISR}} = \frac{|\vec{p}_{T,\text{I}}^{\,\text{CM}} \cdot \hat{p}_{T,\text{ISR}}^{\,\text{CM}}|}{|\vec{p}_{T,\text{ISR}}^{\,\text{CM}}|}$$



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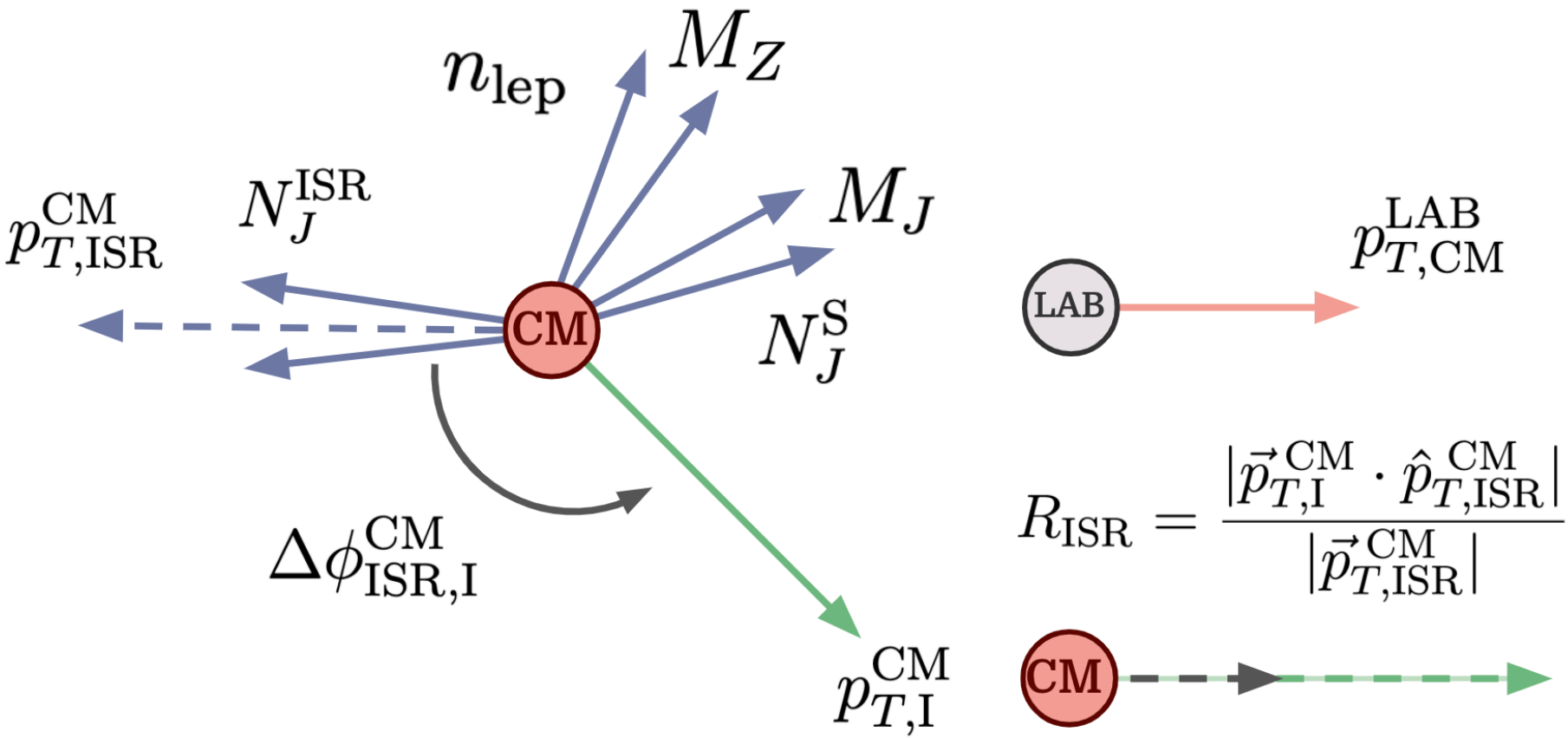

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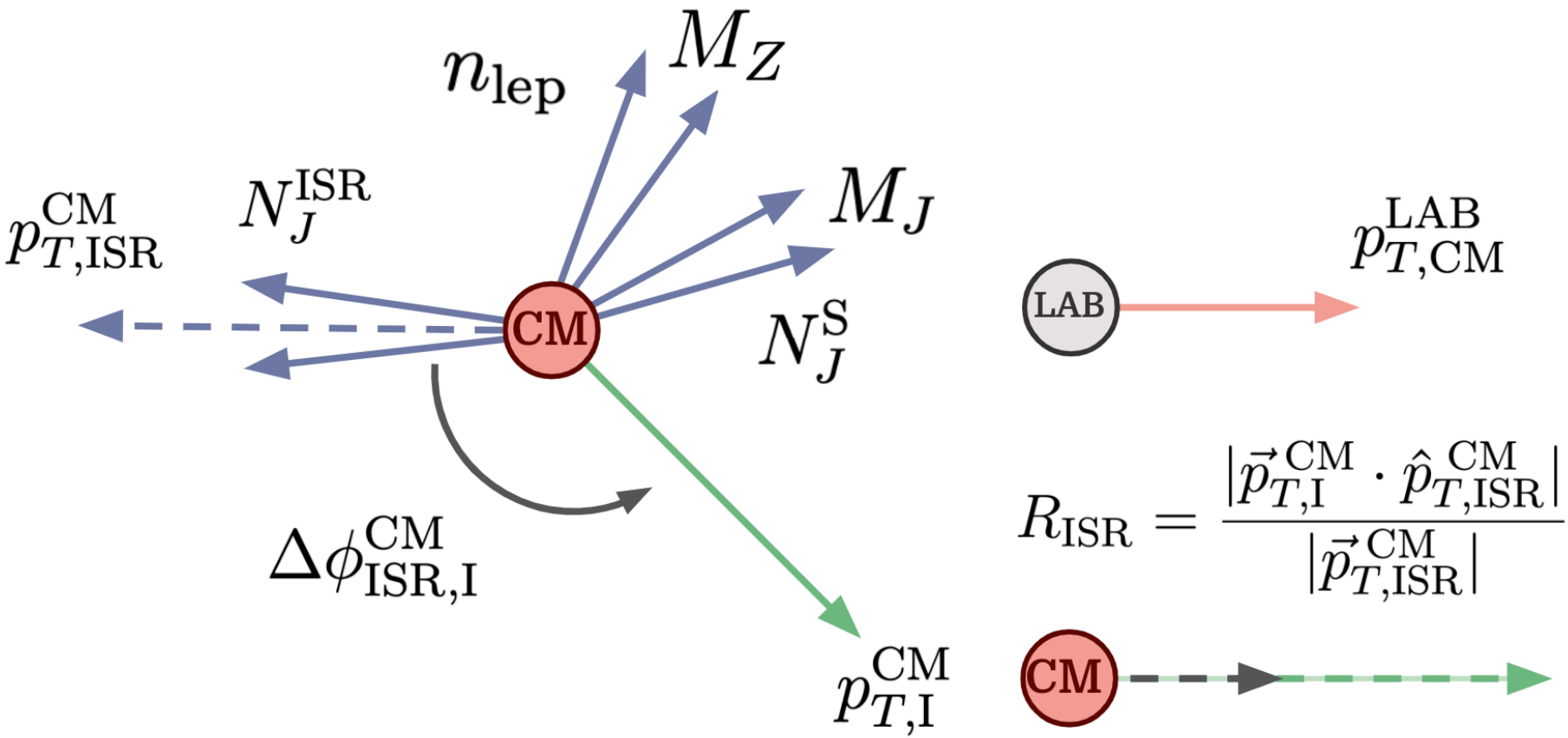

This suite of variables can be applied to a vast array of Dark Matter sensitive searches

Group effort

Paul Jackson (cc+MET analysis optimization, jet/MET, RJR and tt+X)
Martin White (Network analysis, jet/MET)

Abhishek Sharma (2l/3l RJR contact, cc+MET, tHq, ttX)
Jason Oliver (2l+2j +MET paper editor, ttbar studies)
Harish Potti (incoming postdoc)

Tristan Ruggeri (cc+MET analysis contact, RJR code development)
Albert Kong (Jet/MET ML)
Edmund Ting (Jet/MET pflow, charm-tagging for cc+MET)
Emily Filmer (Upgrade work, DM for HL-LHC)
Charles Grant (completing hons, incoming PhD working on tt+X)
Anna Mullin (Completing MPhil on network observables and ATLAS searches)
Stuart Nicholls (visiting student developing network analysis code)
Max Amerl (incoming MPhil – jet/MET trigger for DM)
Matthew Fewell (incoming PhD – jet/MET and DM searches)
…..plus other potential new students!

Summary

- The LHC will remain the highest energy particle collider on the planet for the next ~20 years
- We are:
  - developing new analysis techniques
  - developing new trigger ideas
  - improving jets and missing transverse momentum performance
  - leading analyses to search for invisibles with b- and c-tagged jets