Compressed Analyses with the Recursive Jigsaw Reconstruction

SUSY 2016
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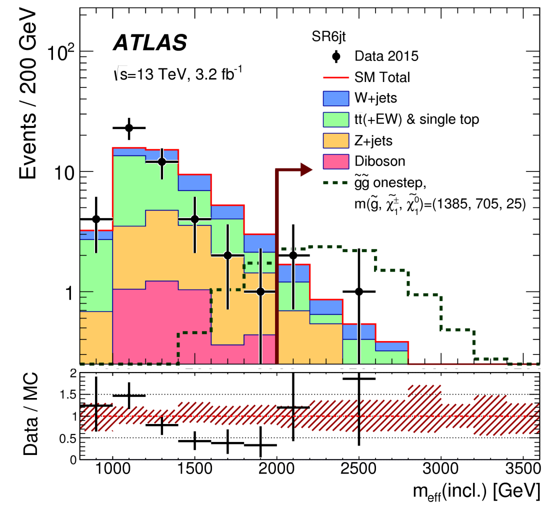
CoEPP
ARC Centre of Excellence for Particle Physics at the Terascale

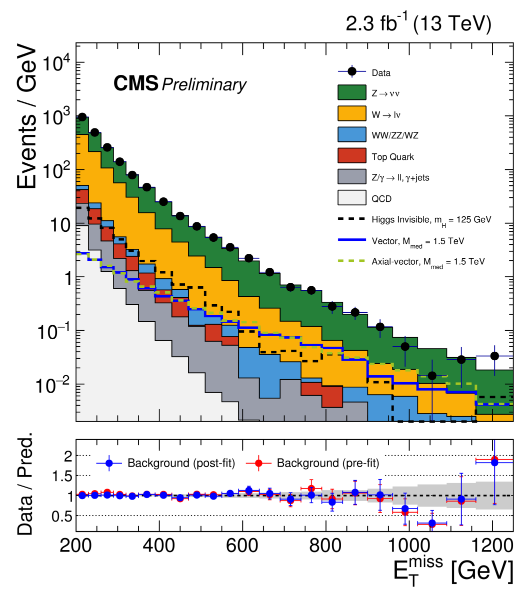
Paul Jackson
University of Adelaide

with Chris Rogan and Marco Santoni

- In general, we search for SUSY by asking for large “scale”
  - Heavier parents and large(-ish) mass splittings provide momentum for decay products, including weakly interacting particles which become MET



- For compressed signals, large MET has a different provenance
  - Weakly interacting particles do not receive large momentum from decay but, rather, from recoiling against ISR
  - Harder MET distribution results from WIMP system having more mass => LSPs receive more momentum from ISR kick (relative to backgrounds with neutrinos, particularly if there’s only one!)



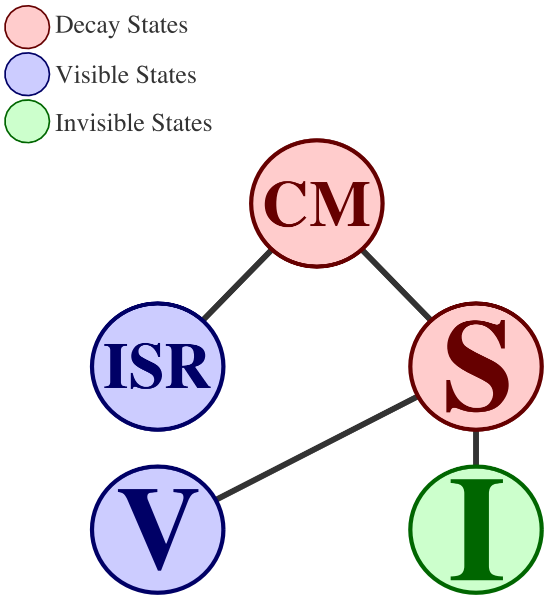
- In order to observe kinematic differences between signal and background we need an **ISR system to give our sparticles a transverse kick**: **the response of the sparticle decay products is sensitive to the mass of the LSP**

- In the limit of nearly degenerate parent sparticles $\tilde{p}$ and LSPs $\tilde{\chi}$:

$$\vec{E}_T^{\text{miss}} \sim -\vec{p}_T^{\,\text{ISR}} \times \frac{m_{\tilde{\chi}}}{m_{\tilde{p}}}$$

- Recent literature has suggested exploiting this feature, to search for, in these cases, compressed stop production:
  - arXiV:1506.00653
    - Use $\vec{E}_T^{\text{miss}}/\vec{p}_{Tj1}$ as an observable ← Requires restrictions of the angle between lead jet and MET, and a relatively hard jet in order for it have correspond to p_T^{ISR}
  - arXiV:1506.07885v1
    - Use $\vec{E}_T^{\text{miss}}/\sqrt{H_T}$ as an observable ← H_T is not necessarily a good proxy for p_T^{ISR}, diminishing resolution of the feature

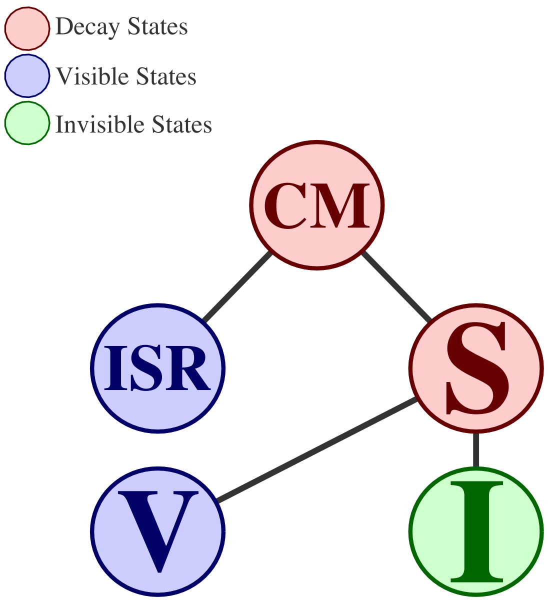
- Rather than relying on a clean mono-ISR signal we would like to be able to separate "*ISR objects*" from "*sparticle objects*"
- Accomplished with a simple decay view of the event
- CM: centre-of-mass system – including all visible objects and MET
- ISR: radiation not coming from sparticle decays
- S: sparticle system
  - V: visible decay products
  - I: weakly interacting particles



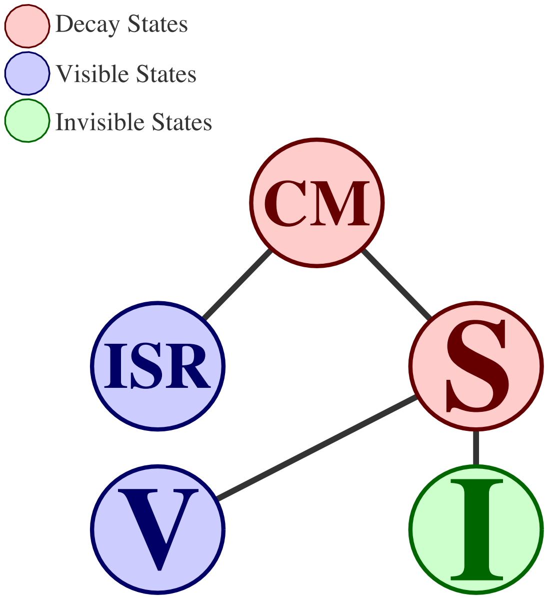
See talks by L. Lee (parallel) and C. Rogan (plenary) for details on RJR

Consider compressed signals with only jets and MET

Jets in the events are split into two groups: those associated with the visible system (***V***) and those recoiling against it (***ISR***)



- We then reconstruct each event by:
  - Ignoring the *z*-momenta of all jets in a 'transverse' view of the event
  - Treat the MET and the transverse momentum of *I*, with zero mass
  - Partition all of the jets into the *ISR* and *V* groups by minimizing the mass of the *ISR* and *S* systems
  - Analyze the event kinematics in the transverse plane



Jets in the events are split into two groups: those associated with the visible system (***V***) and those recoiling against it (***ISR***)

- This is accomplished by:
  - Boost to the transverse CM frame of the jets+MET system
  - In the CM frame: $m_{CM} \equiv E_{CM} = \sqrt{m_S^2 + p^2} + \sqrt{m_{\rm ISR}^2 + p^2}$
  - With m_{CM} fixed we choose to assign the jets to maximize P, effectively minimizing m_S and m_{ISR}
  - Equivalent to finding the thrust axis in the CM frame

This provides a set of variables:

$\vec{p}_{T\,I}^{\,CM} \cdot \hat{p}_{T\,ISR}^{\,CM} \;/\; p_{T\,ISR}^{\,CM}$ => a choice for $m_{\tilde{\chi}}/m_{\tilde{p}}$ sensitive variable

$p_{T\,ISR}^{\,CM}$ => magnitude of vector-sum transverse momentum of all 'ISR' associated jets evaluated in CM frame

$M_{T\ S}$ => Transverse mass of S (V+I) system. Mass of all jets associated with visible system

N_{jet}^{V} => Number of jets assigned to the Visible system (i.e. not associated with ISR)

$\Delta\phi_{CM,\ V}$ => delta phi between CM frame momentum in lab frame and vector sum of all jets in CM frame. Looks for correlation between MET and energy not in jet collection.

To study the tractability of applying this approach to an analysis at the LHC we studied samples generated as part of the Snowmass study

They comprise samples of all major Standard Model backgrounds, simulated at 14TeV (see arXiv:1308.1636 and 1309.1057 for details) with additional jets. All samples are generated/simulated using Madgraph+Pythia+Delphes

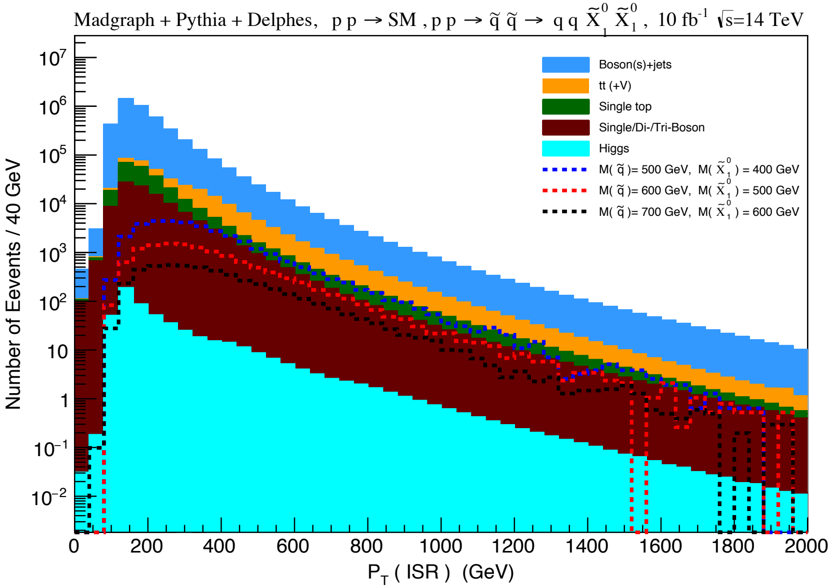
Signal samples produced at 14TeV with same versions of MG5, Pythia and Delphes

<u>Squark and Gluino pair production with compressed mass splittings:</u>

- Mass difference (parent sparticle – neutralino) = 25, 50, 100, 200, GeV
  - M(sq) = 400 –> 900 GeV
  - M(gluino) = 500 –> 1200 GeV

All samples are scaled to a projections of 10 and 100 fb^{-1}

Compressed Kinematics for inclusive squark/gluino



$$p_{TISR}^{CM}$$

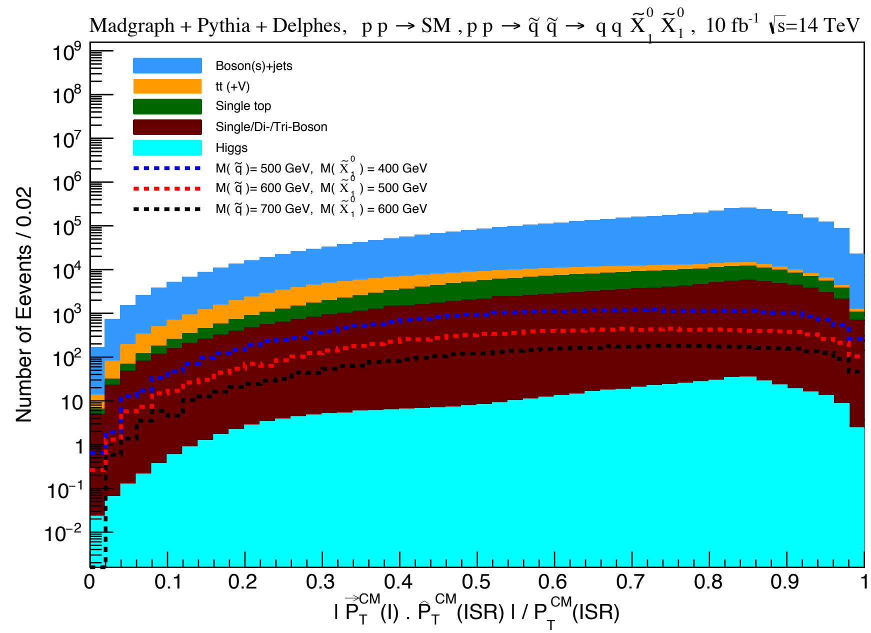
=> magnitude of vector-sum transverse momentum of all 'ISR' associated jets evaluated in CM frame

Little discrimination in the absence of other cuts

$$\vec{p}_{TI}^{\,CM} \cdot \hat{p}_{TISR}^{CM} \;/\; p_{TISR}^{CM}$$

=> a choice for $m_{\tilde{\chi}}/m_{\tilde{p}}$ sensitive variable

Works well in the ISR-regime



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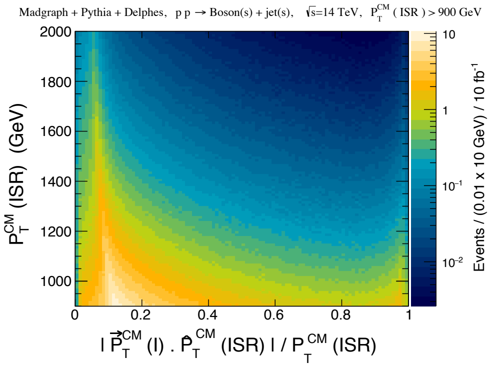
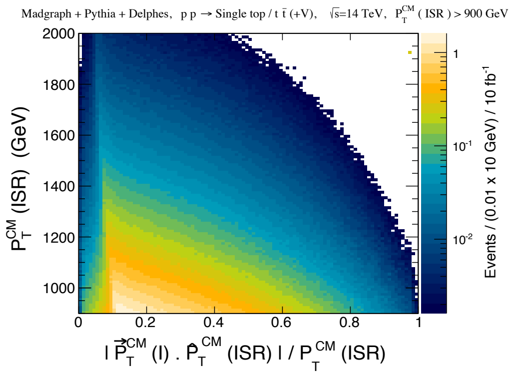
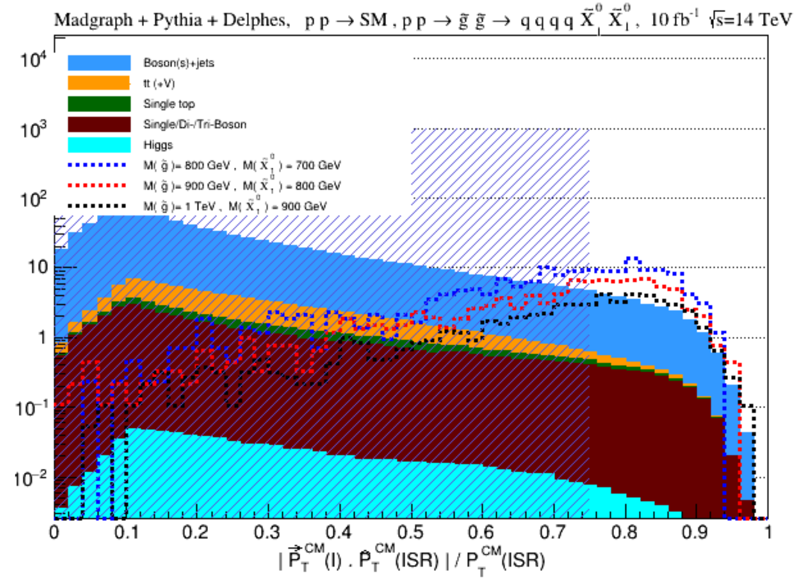
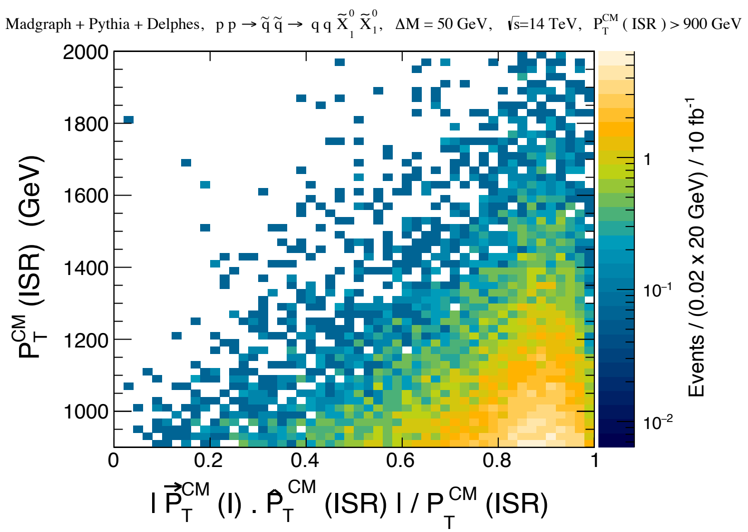
=> a choice for $m_{\tilde{\chi}}/m_{\tilde{p}}$ sensitive variable



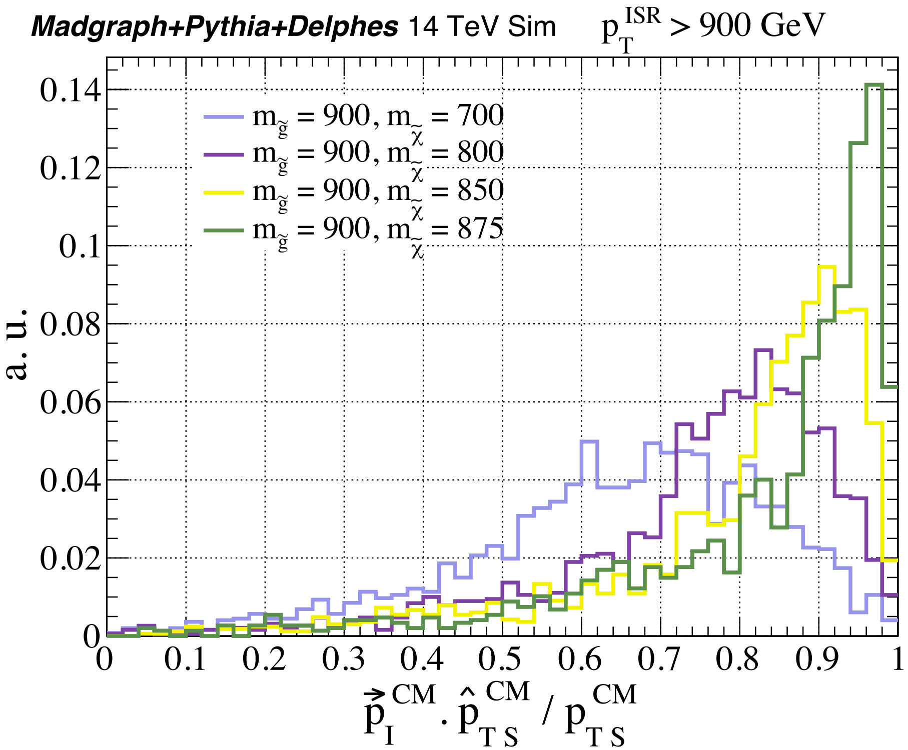


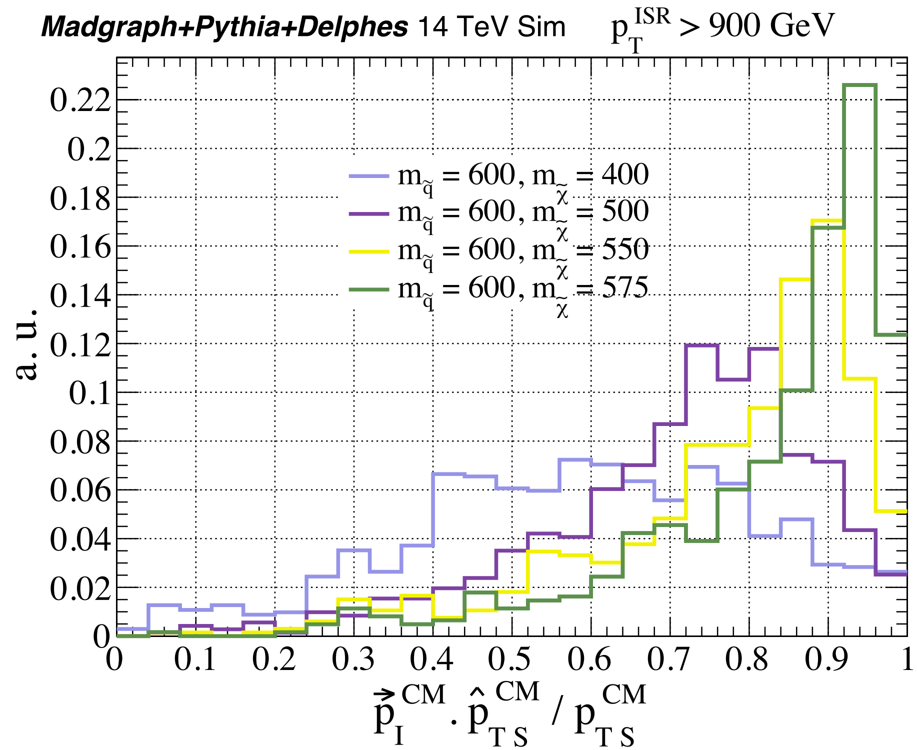




Works well in the high ISR-regime

Increasingly hard for backgrounds to have large ratio for higher p_T^{ISR}

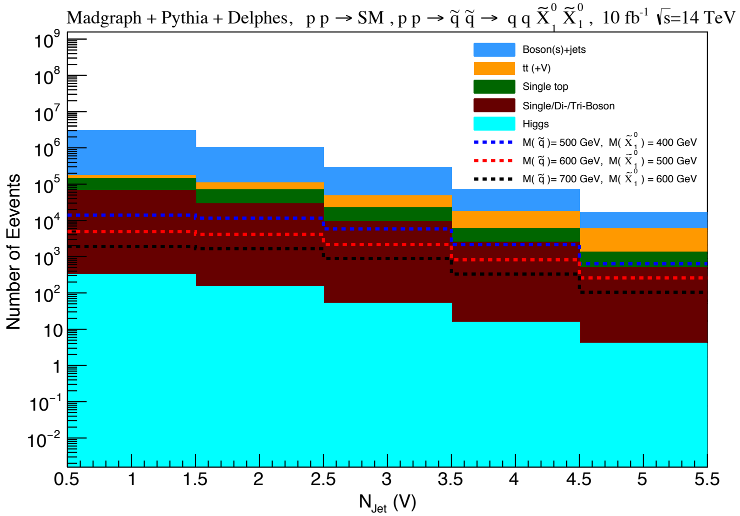


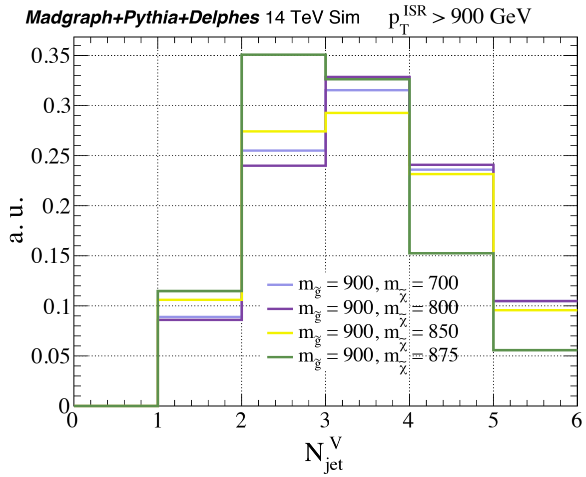


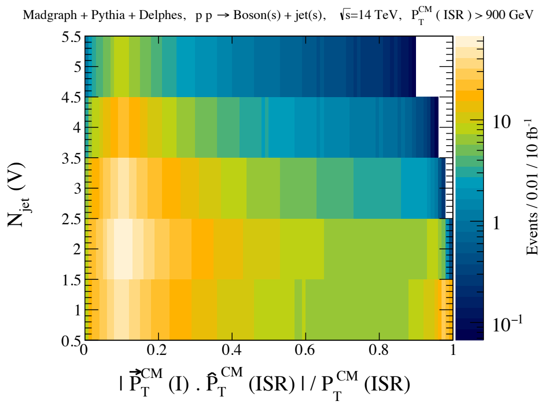
$\vec{p}_{TI}^{\,CM} \cdot \hat{p}_{TISR}^{\,CM} / p_{TISR}^{\,CM}$ distribution scales nicely with $m_{\tilde{\chi}}/m_{\tilde{p}}$ for signal events after requiring some p_T^{ISR}

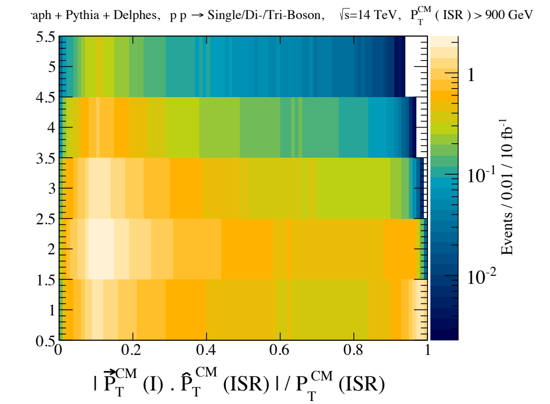
$$N_{jet}^{V}$$

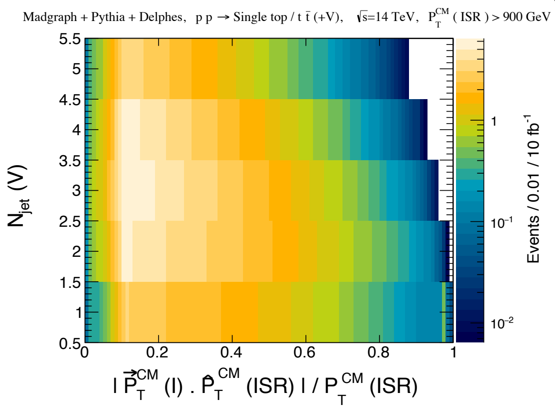
Excellent discrimination, particularly against V+jets and di-boson backgrounds

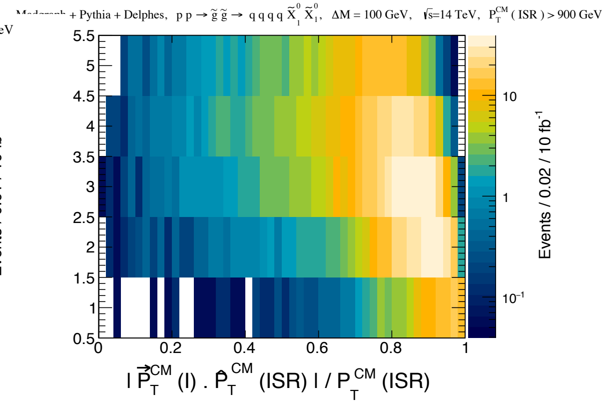






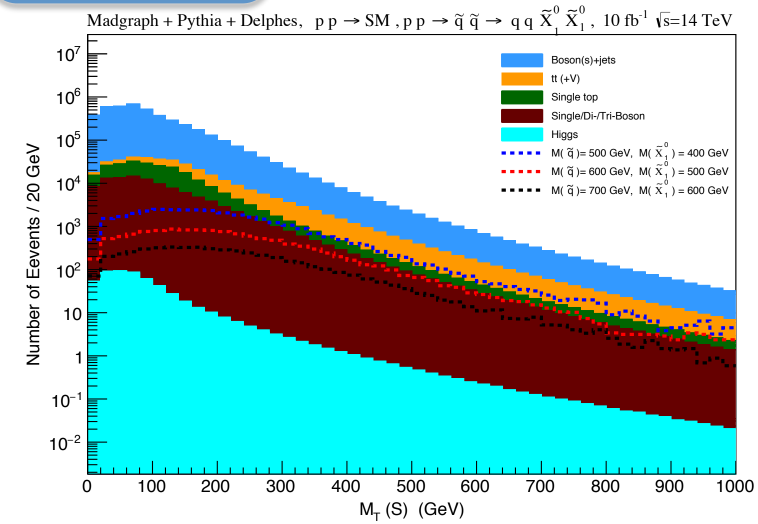






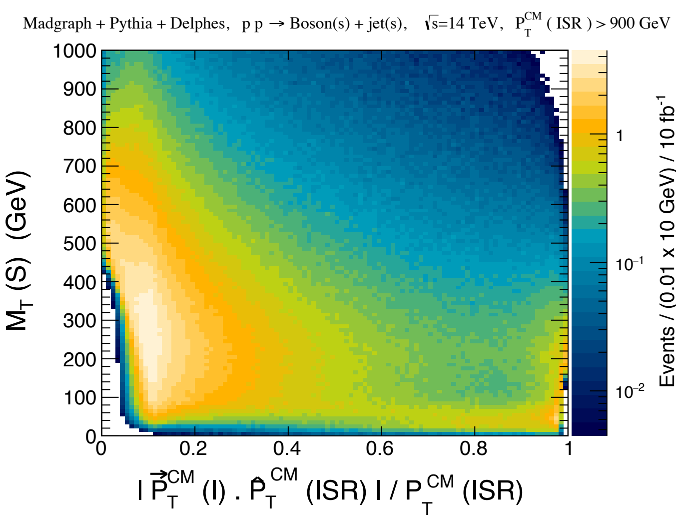
In concert with the ratio cut we get excellent performance cutting harder on the jet multiplicity

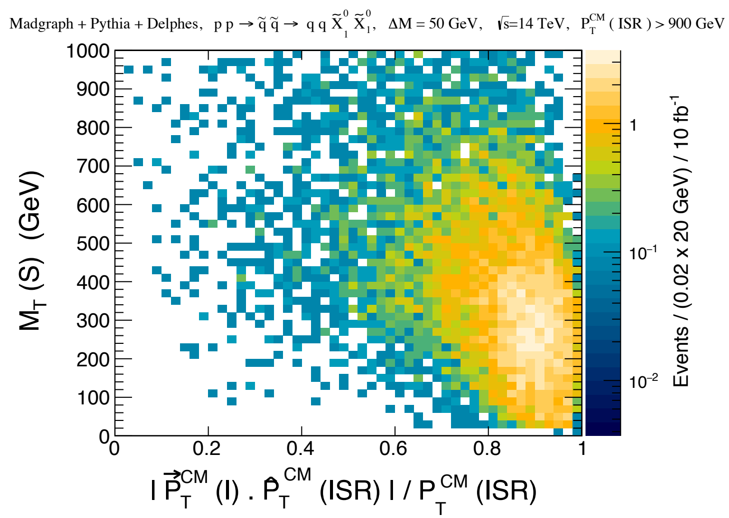
$M_{T\ S}$

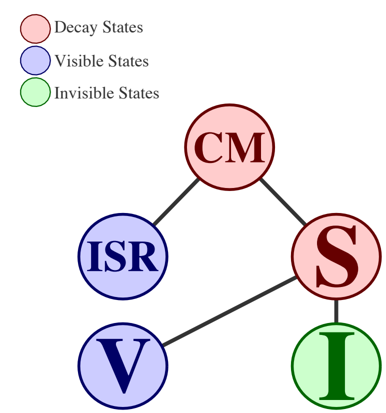


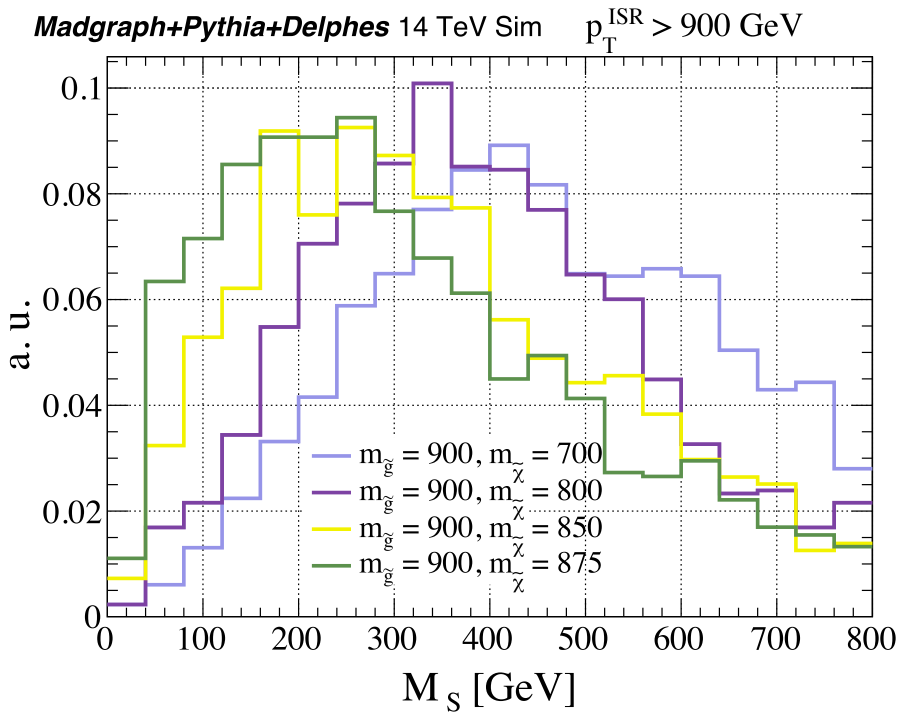
- Transverse mass of S (V+I) system. Mass of all jets associated with visible system V, and the invisible system
- Anti-correlation shows variables are highly complementary
- Improves further as min Jet pT is raised

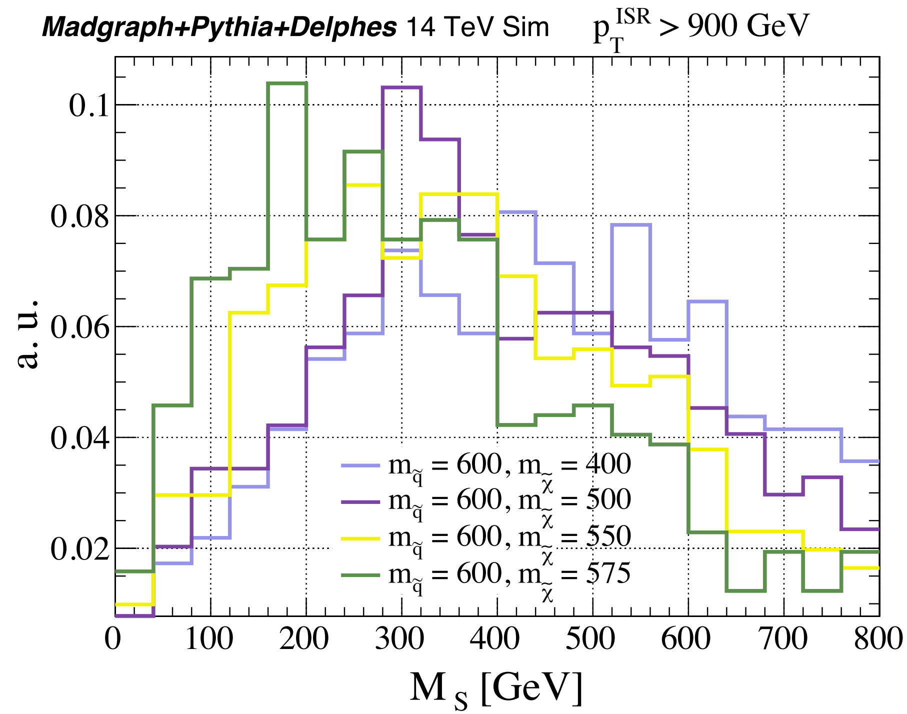
Good discrimination against all backgrounds, especially V+jets







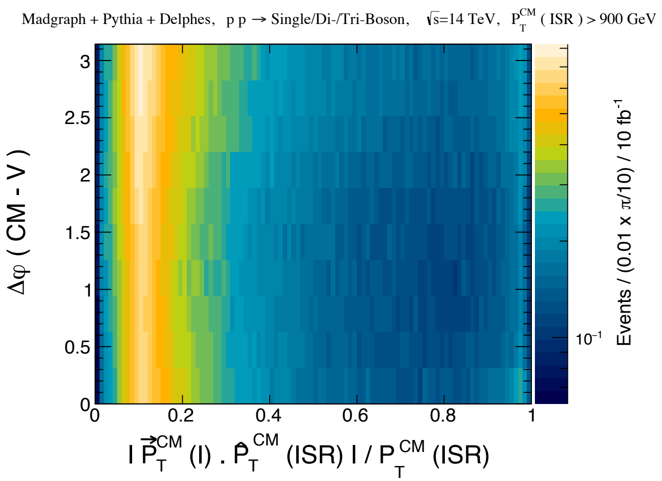


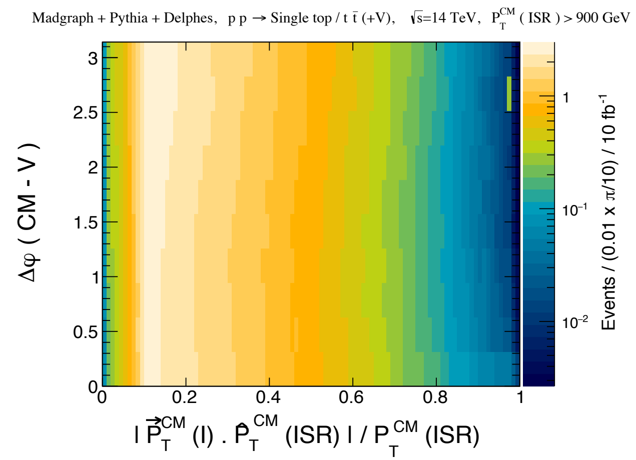


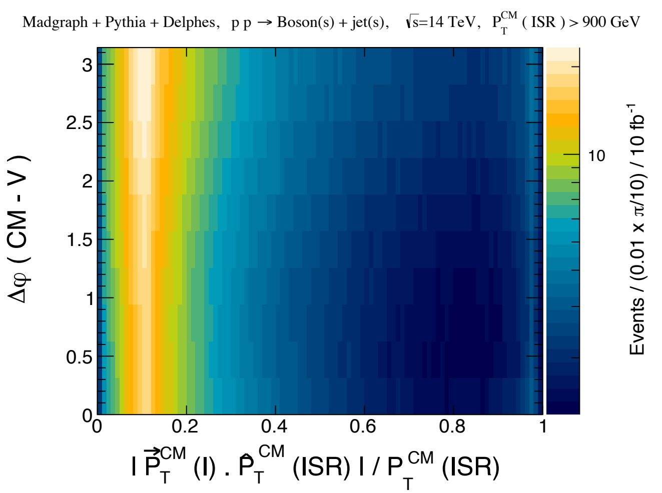
M_S scales with the parent sparticle/LSP mass splitting

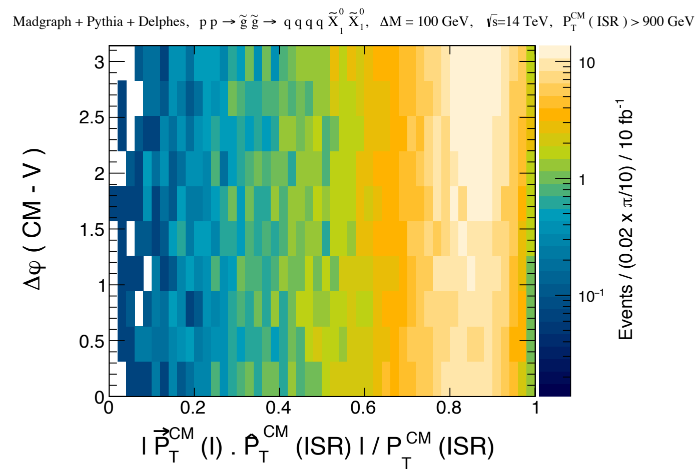
$$\Delta\phi_{CM,\ V}$$

delta phi between CM frame momentum in lab frame and vector sum of all jets in CM frame. Looks for correlation between MET and energy not in jet collection.

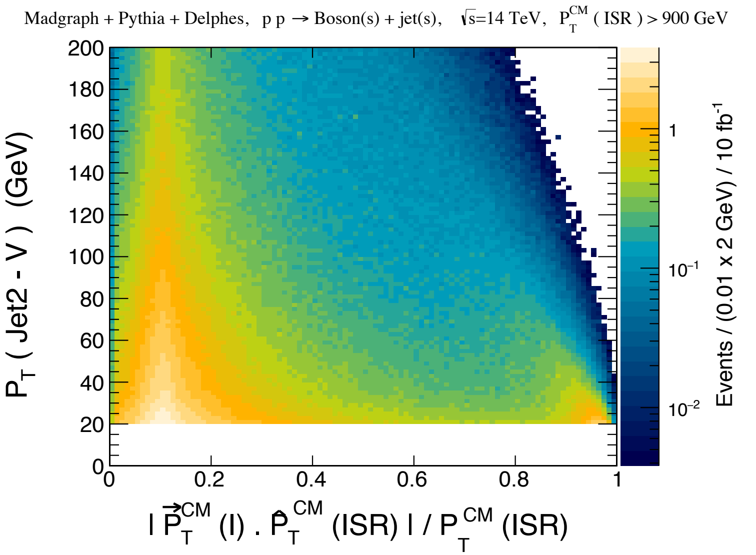




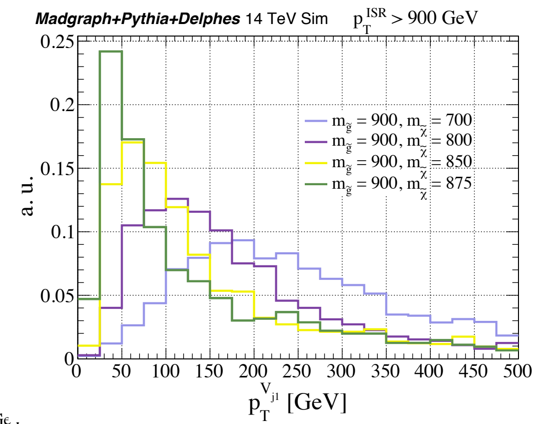


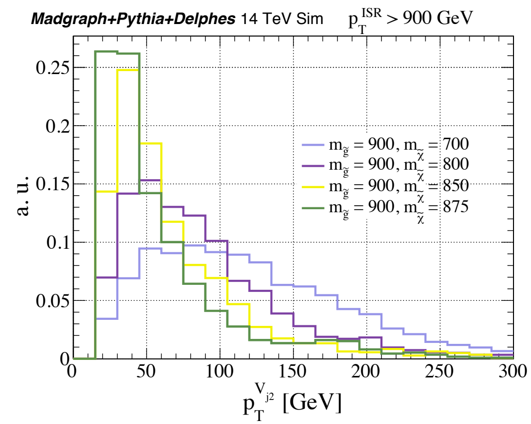


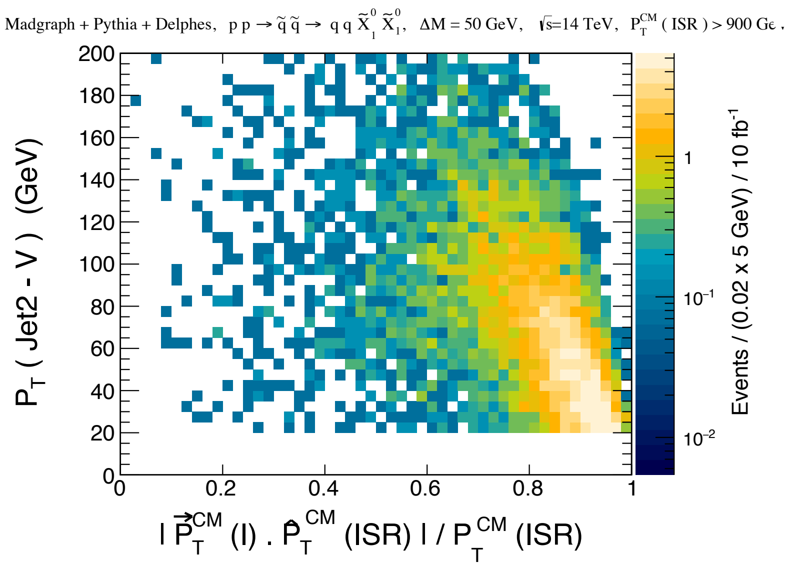
Modest but unique discrimination against important backgrounds

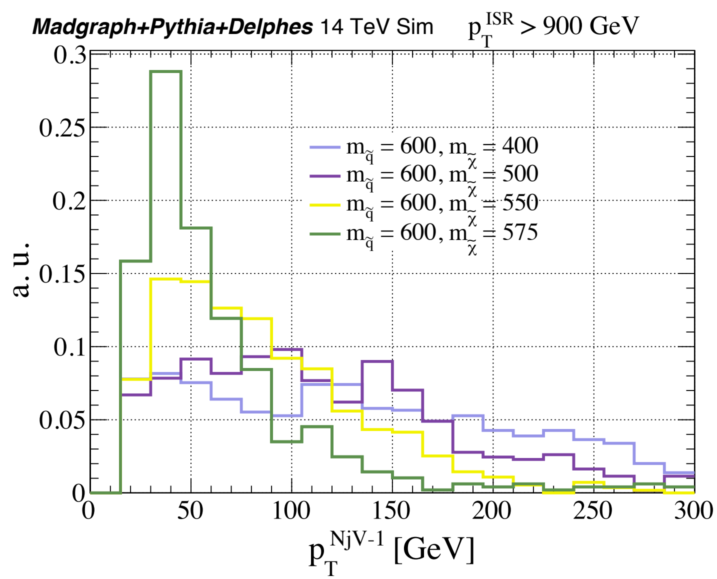


Leading and sub-leading Jet p_T provides further discrimination. Even stronger handle as N_{jet}^V and scales as Δm increases





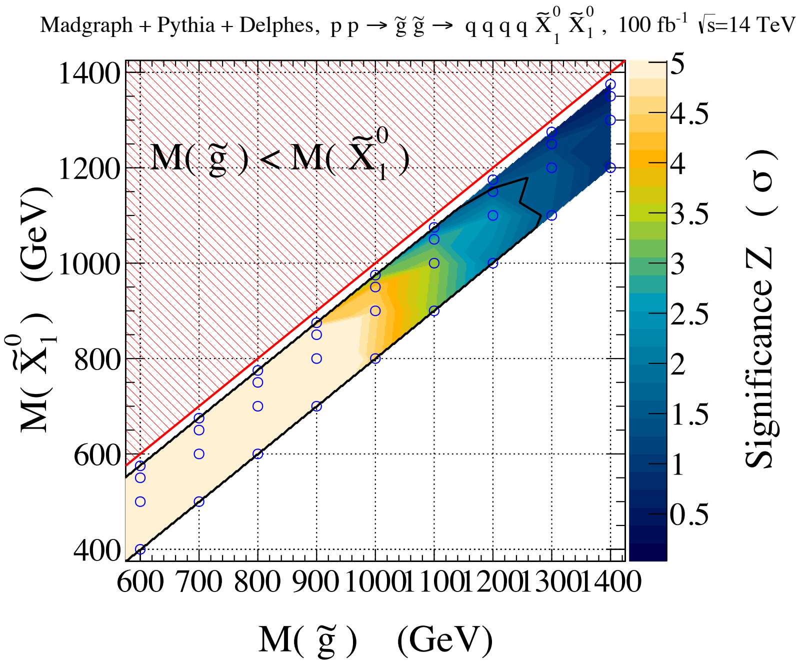


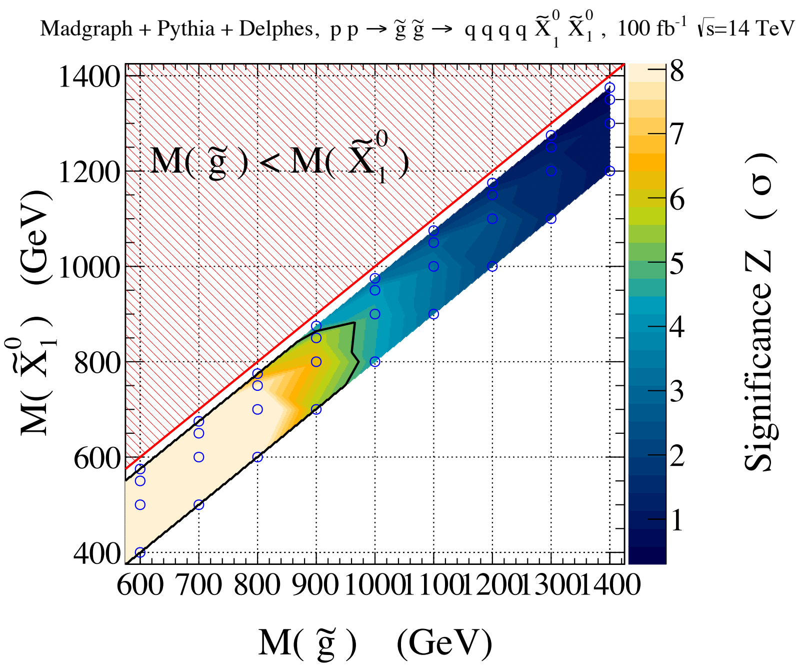


	Δm = 25 GeV	Δm = 50 GeV	Δm = 100 GeV	Δm = 200 GeV
Preselection Criteria	lepton veto (e and μ), $\vec{\not{E}}_T > 100$ GeV, jet $p_T > 20$ GeV			
p_T^{CM} (ISR) [GeV]	> 900			
$\vec{p}_I^{\,\mathrm{CM}} \cdot \hat{p}_{\mathrm{TS}}^{\,\mathrm{CM}} / p_{\mathrm{TS}}^{\,\mathrm{CM}}$	> 0.87	> 0.8	> 0.7	> 0.65
M_T^S (GeV)	–	> 100	> 200	> 350
N_j^V	≥ 2			
p_T^V (GeV)	≥ 30	≥ 50	≥ 50	≥ 80
$\Delta\phi$ (CM - V)	> 1.4	> 1.0		

For a selection of pair-produced gluinos - a simple set of selection criteria can yield powerful results

Compressed Kinematics for inclusive squark/gluino





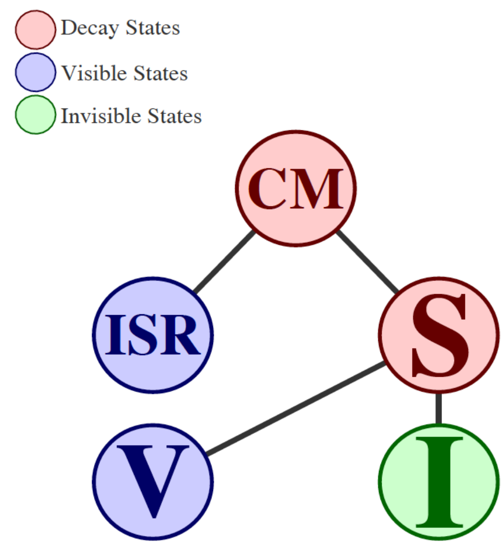
For 100fb^{-1} - studying compressed spectra where 25GeV < $\Delta m(g-\chi_1^0)$ < 200GeV

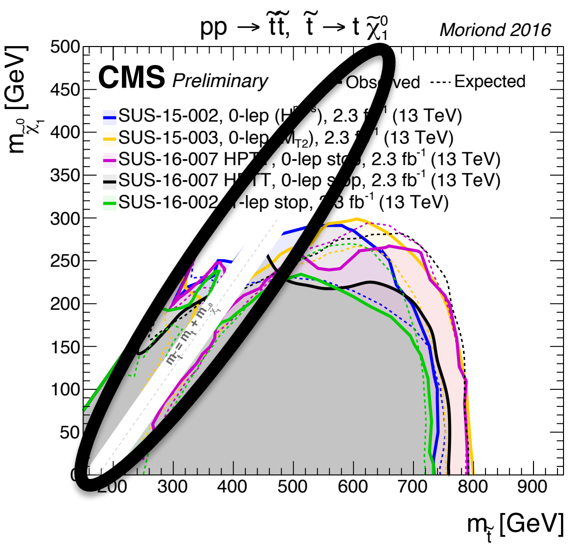
Exclude (2σ) gluinos between **1.2TeV and 1.3TeV**
Discover (5σ) gluinos with compressed spectra around **1TeV**
With optimization this can be improved this further….

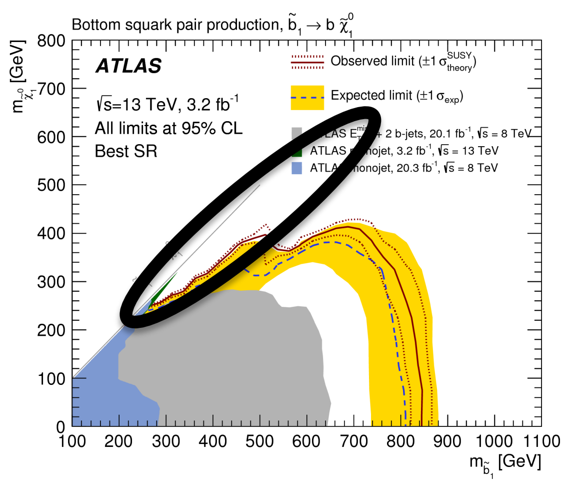
With additional objects, and richness in the event, improvements can be quite vast

- Compressed here refers to Δm ≈ 25-200GeV
- As you get additional handles with extra objects the sensitivity improves still further
- In all cases there is a simple method, only a few, quite intuitive, selection criteria to impose, and the improvements can be quite dramatic

- Additional handles from object counting of leptons, b-jets etc make transition to ***any*** compressed analysis trivial







A dedicated approach to any/all intermediate or compressed analyses

- Recursive Jigsaw Reconstruction (RJR) approach
  - is to not only develop 'good' mass estimator variables, but to decompose each event into a ***basis of kinematic variables*** (see talks by Larry Lee and Chris Rogan)
  - Through the recursive procedure, each variable is (as much as possible***) independent of the others***
- Compressed Analyses
  - Demonstrated new approach based on RJR
  - Excellent performance for all mass-splittings and final states studied
  - Squark and Gluino pair-production presented herein but extendable to any other compressed scenario

BACKUP SLIDES

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…..and…….

- In order to observe kinematic differences between signal and background we need an ISR system to give our sparticles a transverse kick; the response of the sparticle decay products is sensitive to the mass of the LSP.
- In the limit of nearly degenerate parent sparticles ($\tilde{p}$) and LSP's ($\tilde{\chi}$):

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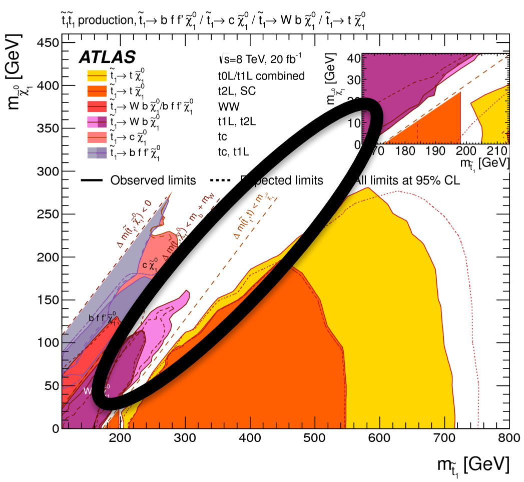

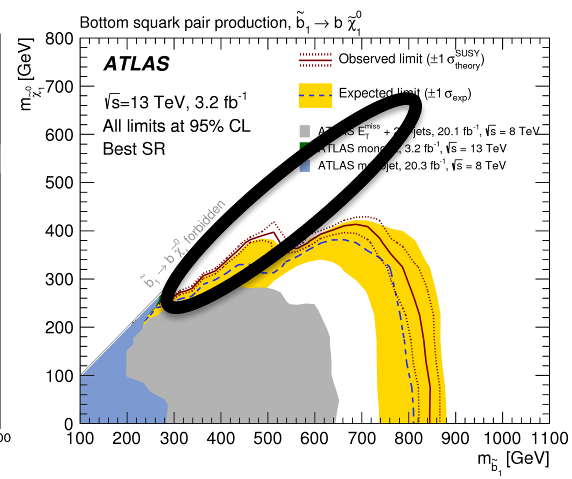

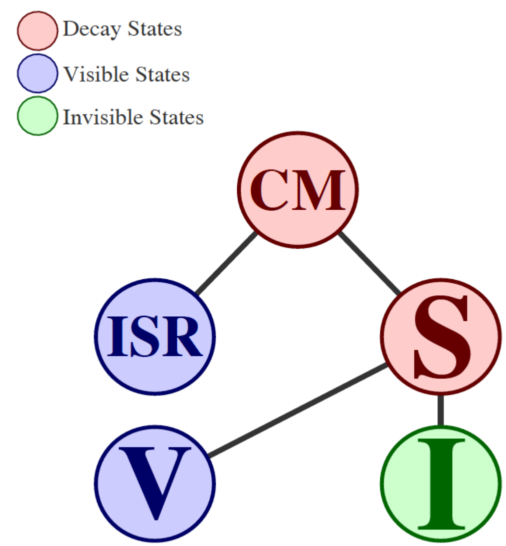

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