Searching for new Electroweak Particles with New Razor Variables

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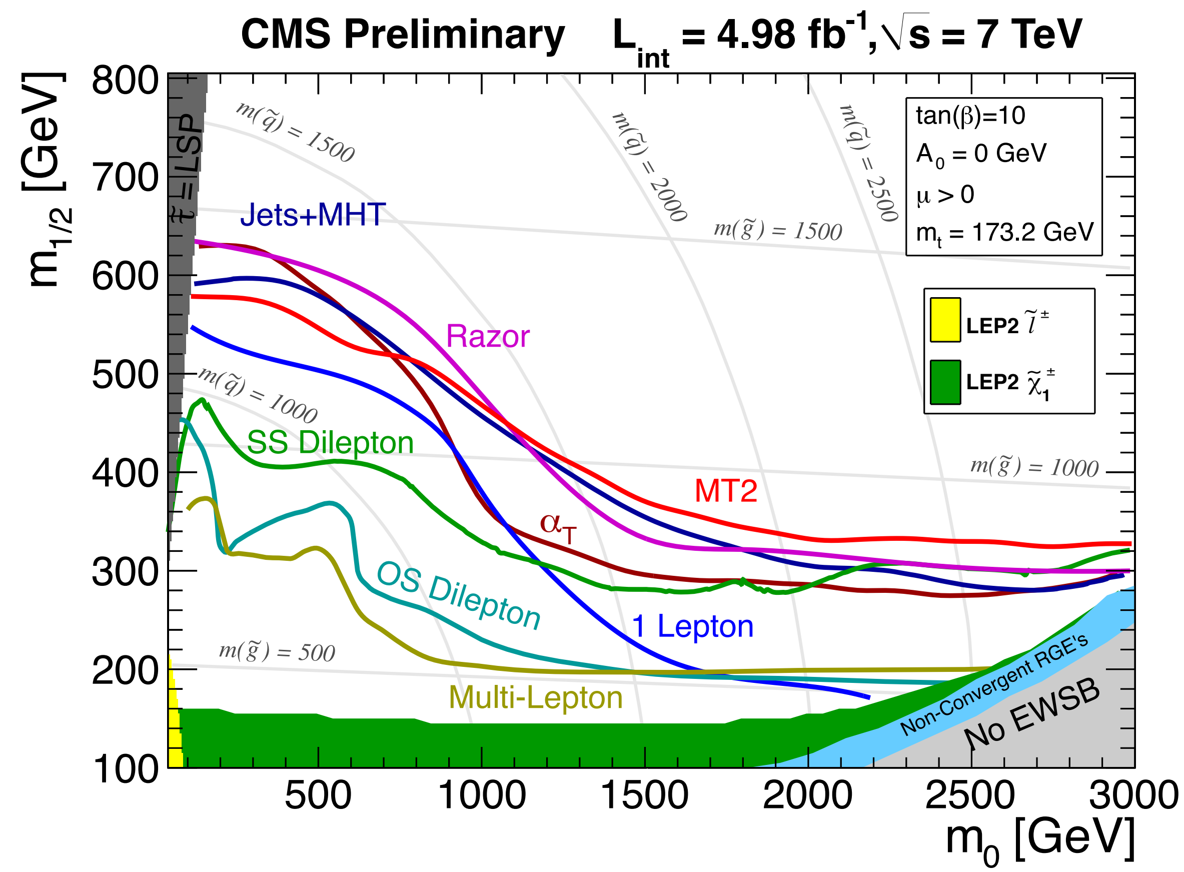
Work with J. Lykken, C. Rogan, M. Spiropulu

What Didn't We Find?



- No squarks/gluinos decaying into jets+$\not{E}_T$ masses $\lesssim 1$ TeV
- No evidence of non-SM Higgs physics.
- Things we were looking for were motivated by "simple" supersymmetry or were "easy" to find.
- Interesting things can still be lurked at or below a TeV:
  - 3rd generation partners
  - Degenerate mass spectrum
  - Direct electroweak production (sleptons, charginos, *etc.*)

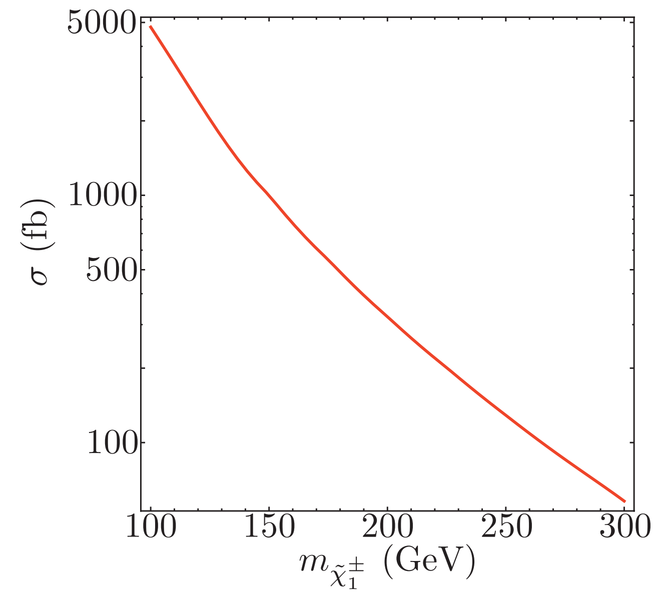
My talk today

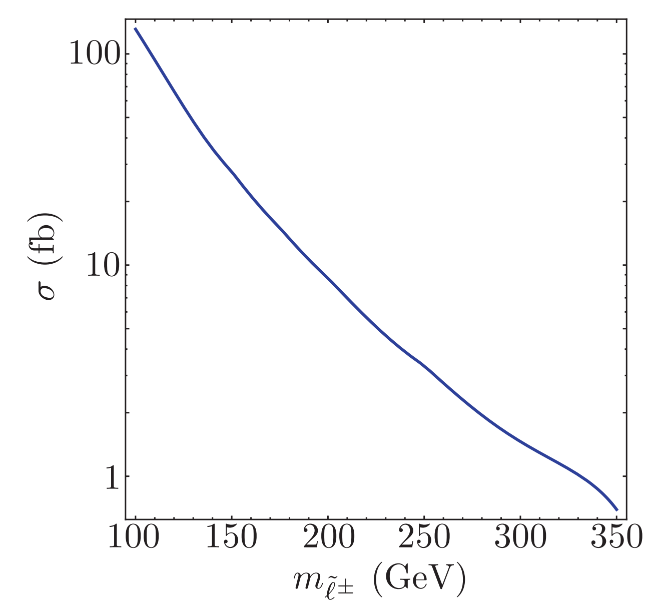
Electroweak Difficulties

- Interested in

$$pp \to \tilde{\chi}_1^- \tilde{\chi}_1^+ \to W^{(*)} W^{(*)} \tilde{\chi}_1^0 \tilde{\chi}_1^0 \to \ell^- \ell^+ + \not{E}_T$$
$$pp \to \tilde{\ell}^- \tilde{\ell}^+ \to \ell^- \ell^+ + \not{E}_T$$

- Slepton & charginos have small rates and large backgrounds



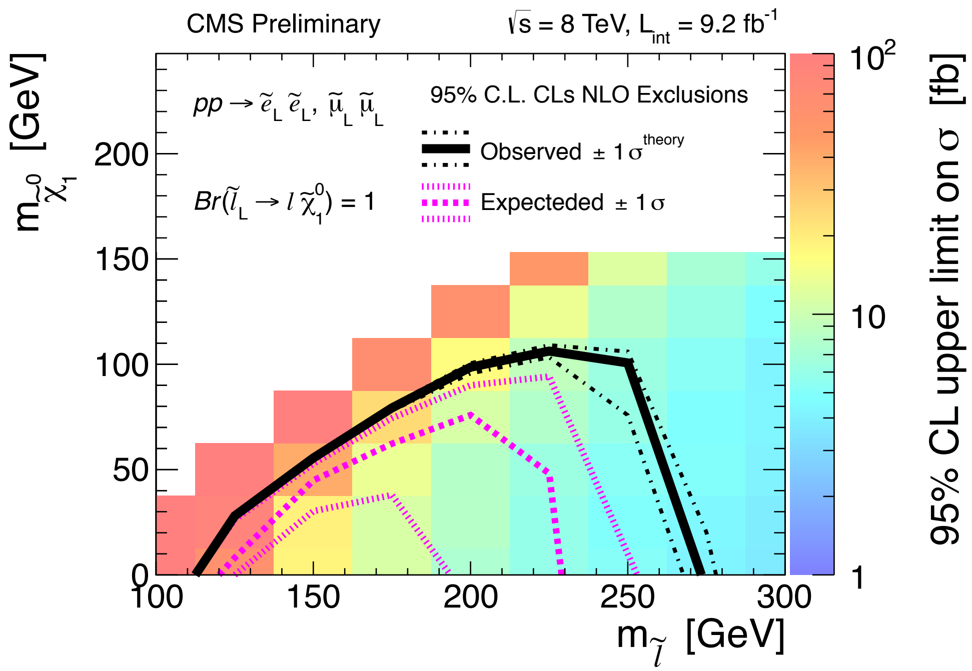


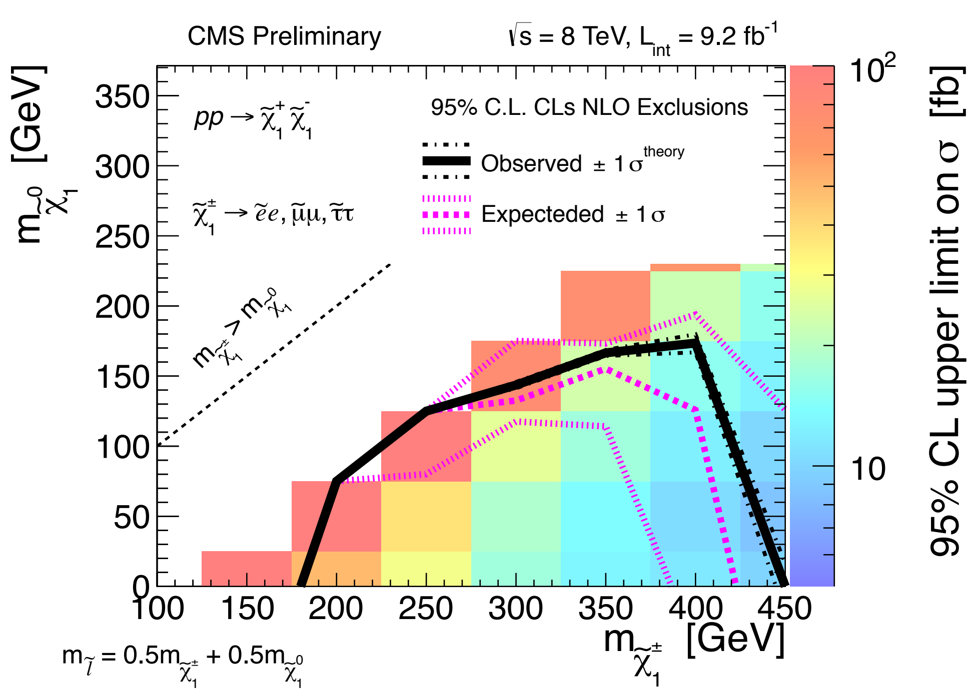
Channel	σ (fb)	$\epsilon(ee)$	$\epsilon(ee) \times \sigma$ (fb)	$\epsilon(e\mu)$	$\epsilon(e\mu) \times \sigma$ (fb)
$t\bar{t}$	2.27×10^5	9.64×10^{-5}	20.2	2.43×10^{-4}	55.2
Drell-Yan	2.56×10^6	4.27×10^{-5}	109	7.00×10^{-6}	17.9
W^+W^-	5.88×10^4	1.75×10^{-3}	103	4.35×10^{-3}	256

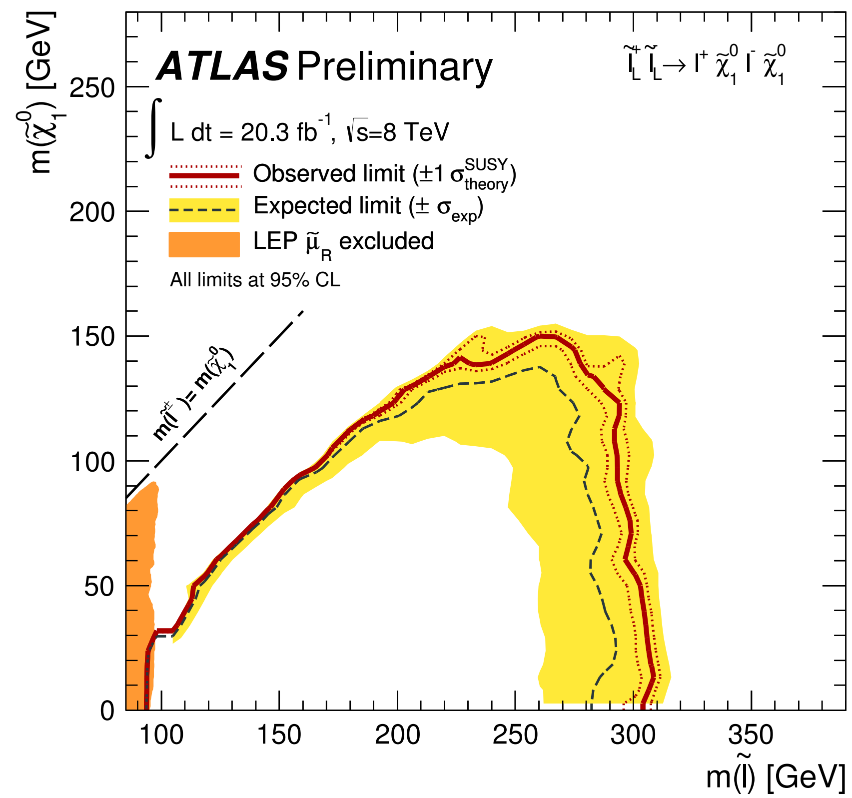
(after CMS-like selection cuts)

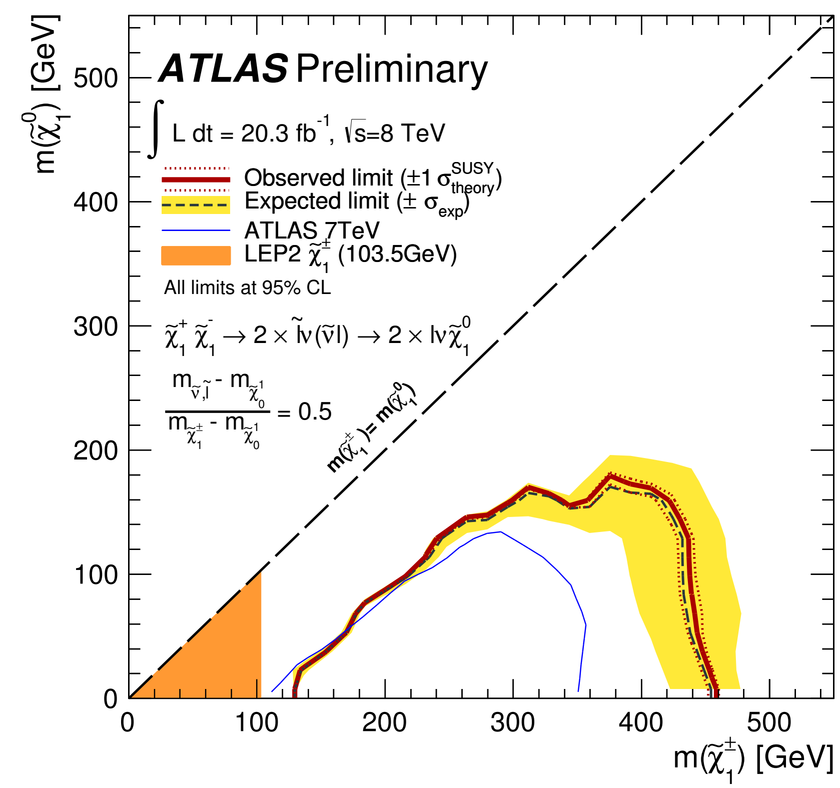
The Current State of the Art

- Current LHC bounds comparatively weak, relative to squarks/gluinos





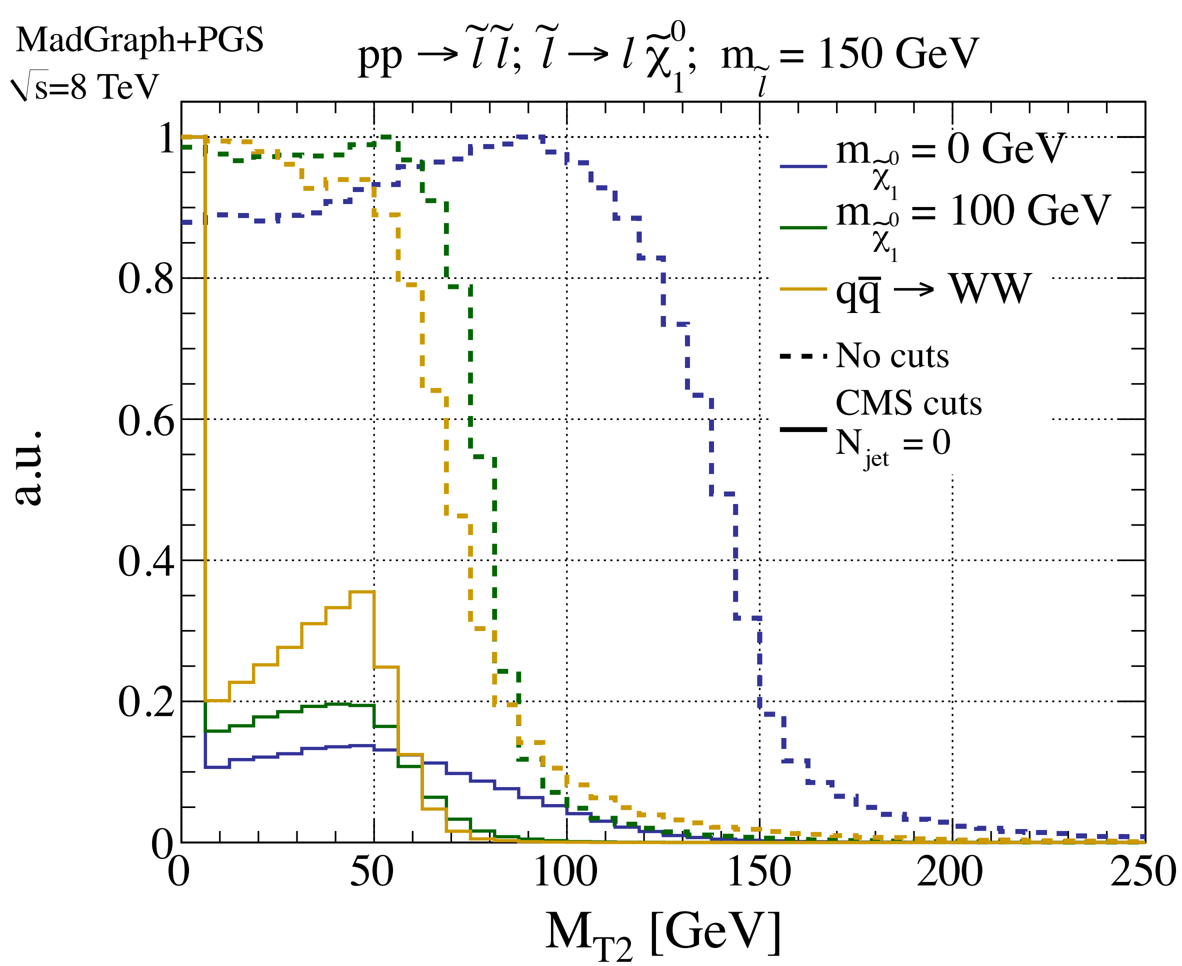


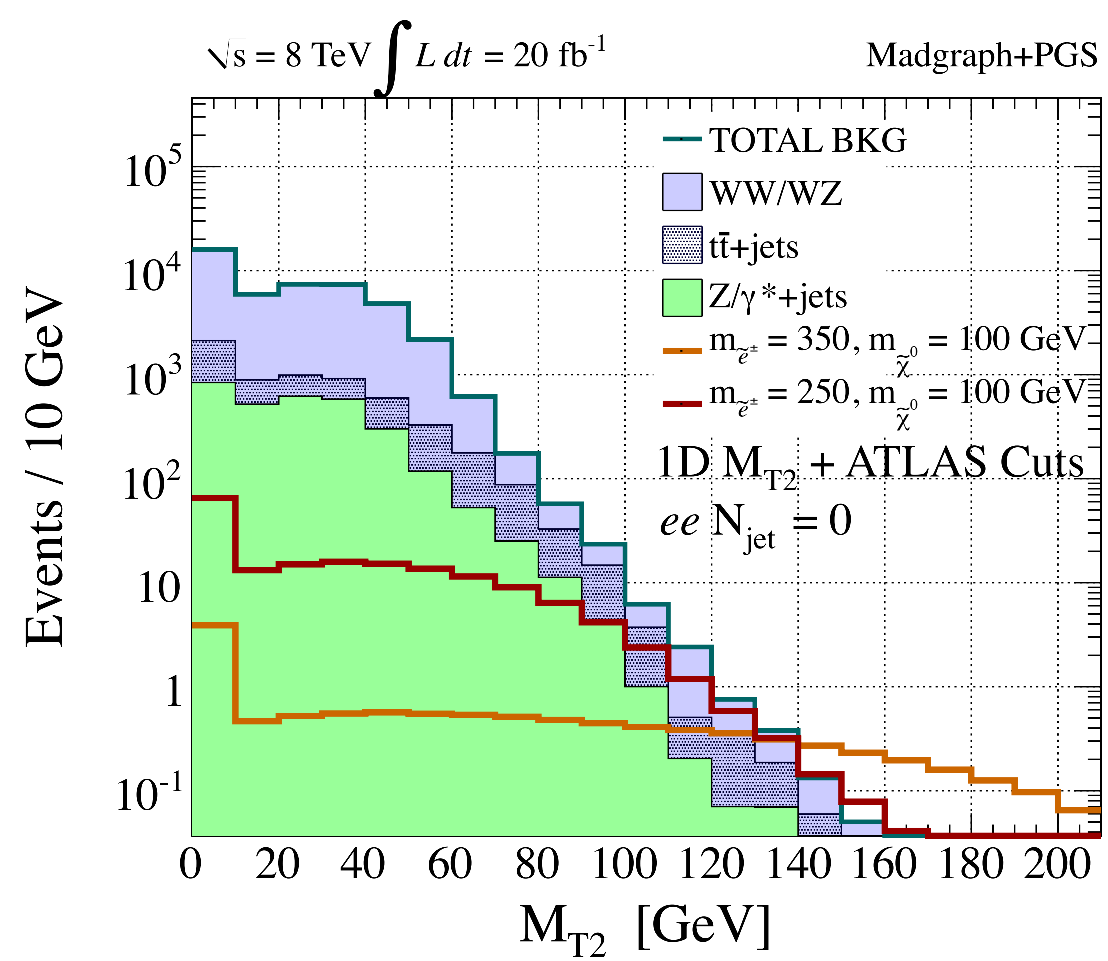


ATLAS Searches

$$m_{T2} = \min_{\mathbf{q}_T}\left[\max\left(m_T(\mathbf{p}_T^{\ell 1}, \mathbf{q}_T), m_T(\mathbf{p}_T^{\ell 2}, \mathbf{p}_T^{\text{miss}} - \mathbf{q}_T)\right)\right]$$

- Uses “stransverse” mass m_{T2}
  - Has endpoint at containing information about mass difference between parent and daughter particles.

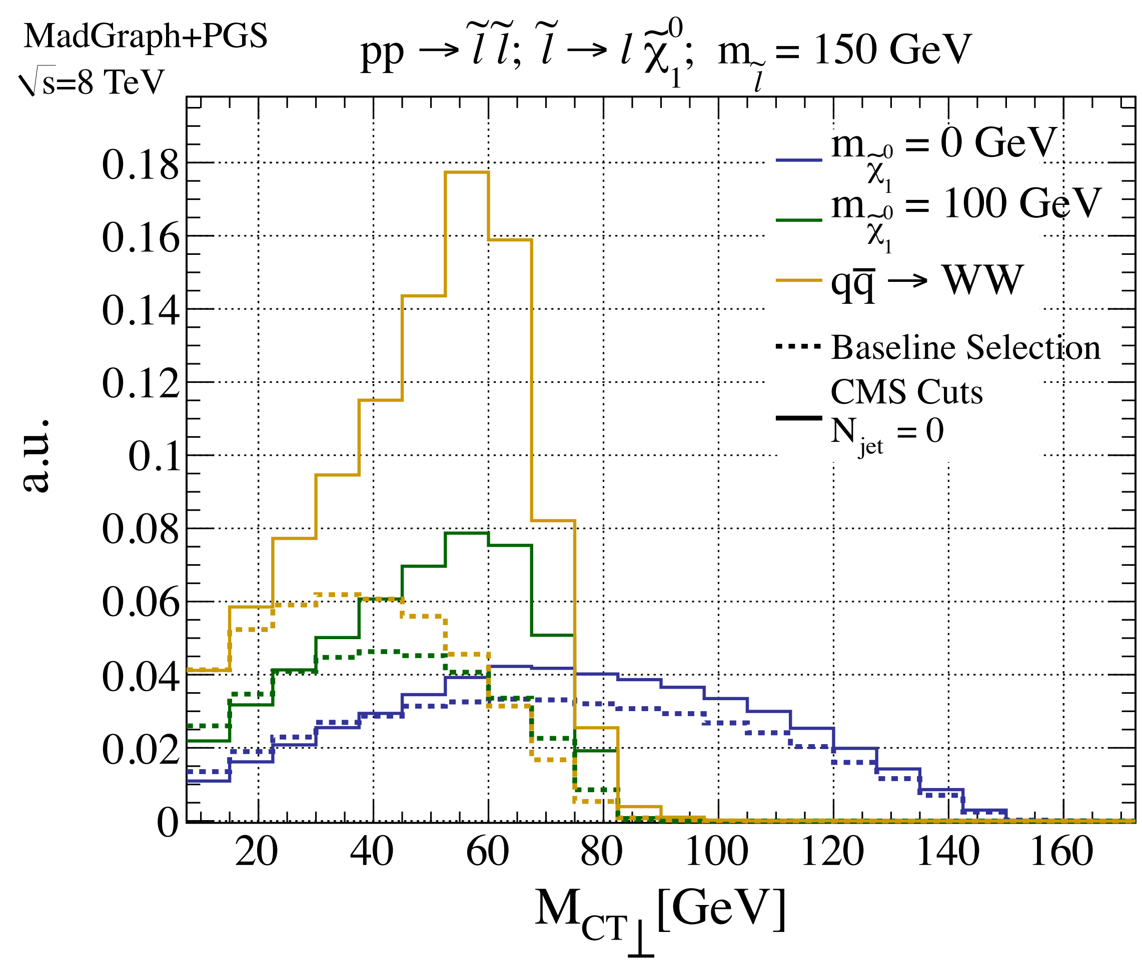




CMS Searches

- Uses $M_{\mathrm{CT}\perp}$ variable (Matchev and Park 0910.1584)
- Construct a M_{CT}-like variable that projects out the ISR jets that are assumed to be irrelevant to the physics: $M_{\mathrm{CT}\perp}$
- Use tail of $M_{\mathrm{CT}\perp}$, and note that

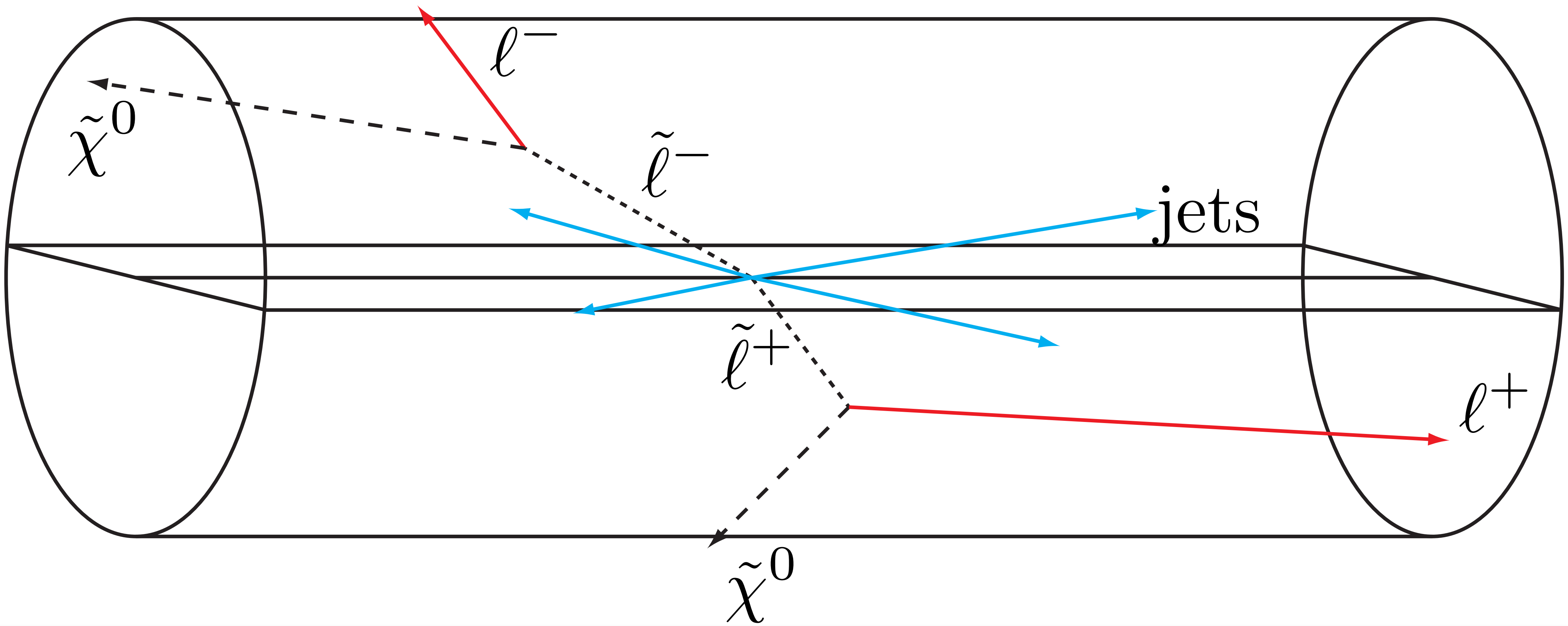
$$M_{\mathrm{CT}\perp} < (m_{\tilde{\ell}}^2 - m_{\tilde{\chi}}^2)/m_{\tilde{\ell}}$$



The Old-Fashioned Razor

- Introduced by Chris Rogan 1006.2727
  - Used by CMS in squark/gluino searches, by Fox *et al* in monojet dark matter searches

- Define two variables that approximate $M_\Delta \equiv (m_P^2 - m_\chi^2)/2m_P$ in pair production followed by decays into visible + $\not{E}_T$



The Old Fashioned Razor

- Boost into approximation of pair-production frame, where visible particles have $q_1^z = -q_2^z$
- If particles produced near threshold, then in this razor frame $|q_1| \approx |q_2| \approx M_\Delta$, so define boost invariant mass

$$M_R^2 = (q_1 + q_2)^2 - (q_1^z + q_2^z)^2$$

- Use transverse information to get 2nd estimator of M_Δ:

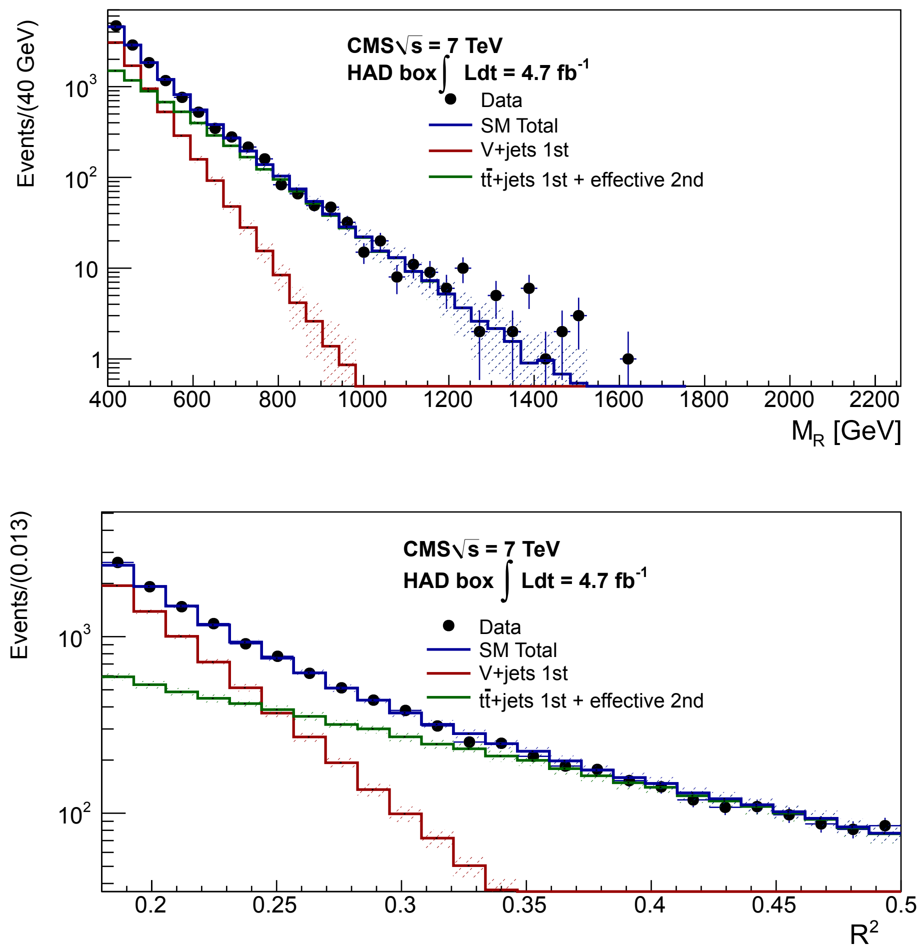
$$(M_T^R)^2 = \frac{1}{2}\left[\not{E}_T(q_{1T} + q_{2T}) - \vec{\not{E}}_T \cdot (\vec{q}_{1T} + \vec{q}_{2T})\right]$$

  - Prefer to use:

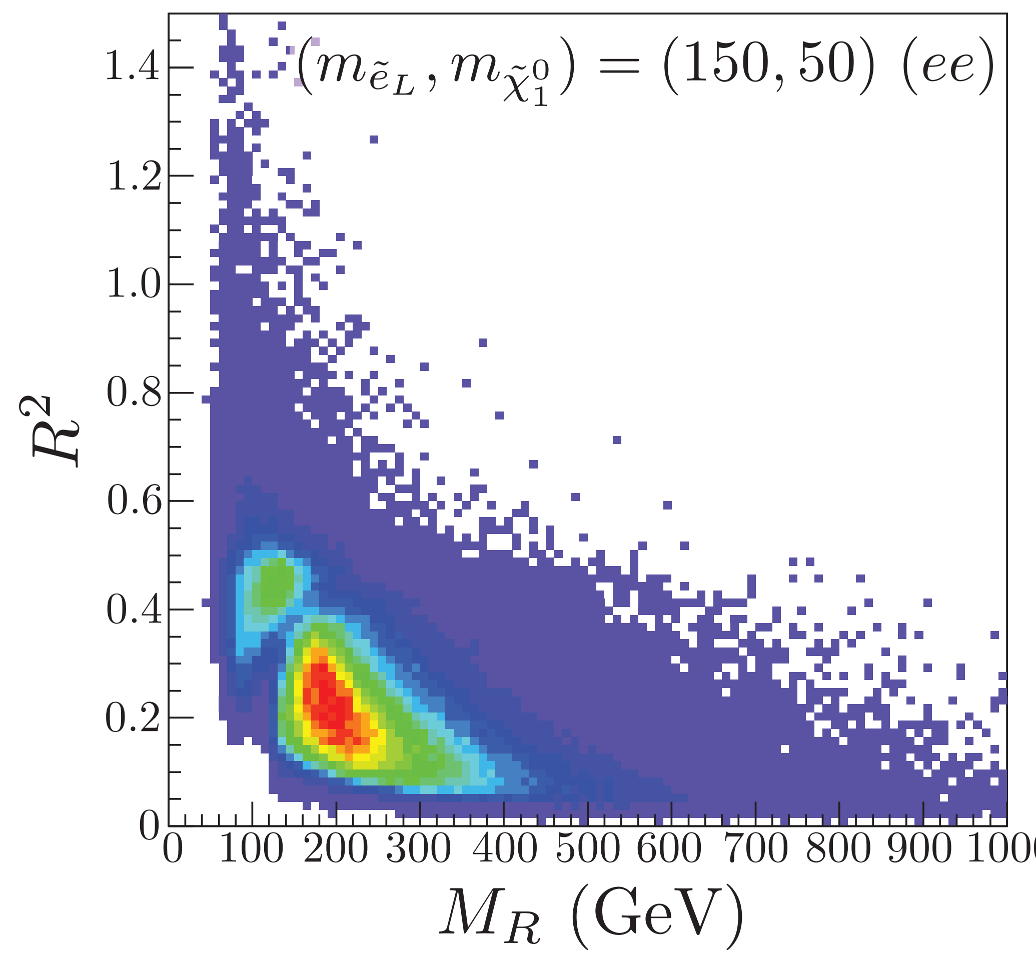
$$R^2 \equiv \frac{(M_T^R)^2}{M_R^2}$$

Old Fashioned Razor

- For gluino/squark jets+ $\not{E}_T$ background should be approximately scale free and drop exponentially.
- Signal should have structure near $M_R \sim M_\Delta$ and $R^2 \sim \frac{1}{4}$



CMS Razor backgrounds 1212.6961

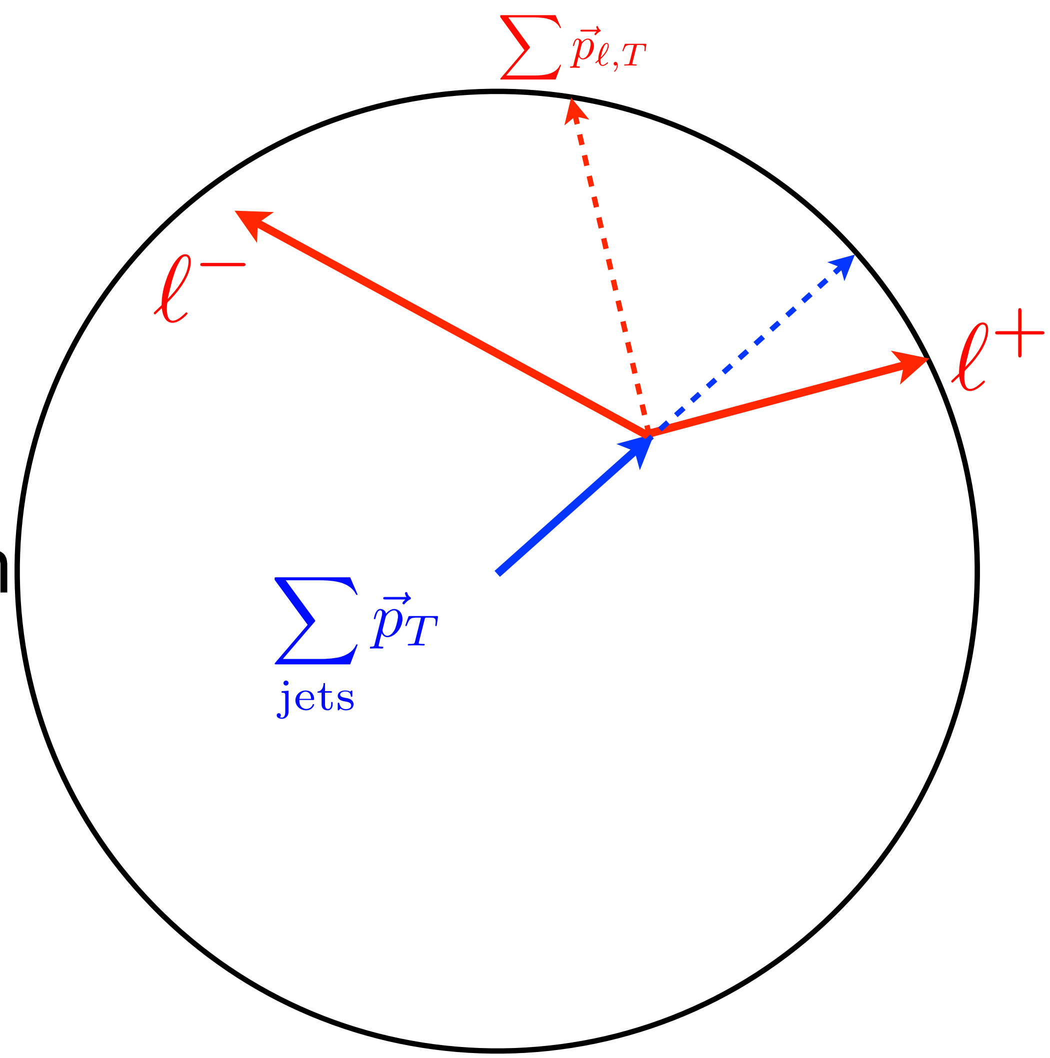


Super Razor

- Backgrounds in EW searches have real $\not{E}_T$ and mass splittings similar to signal.
  - So standard razor variables aren't the best choice
  - But: an additional handle in this type of event
    - Jets are assumed to not be part of the hard event

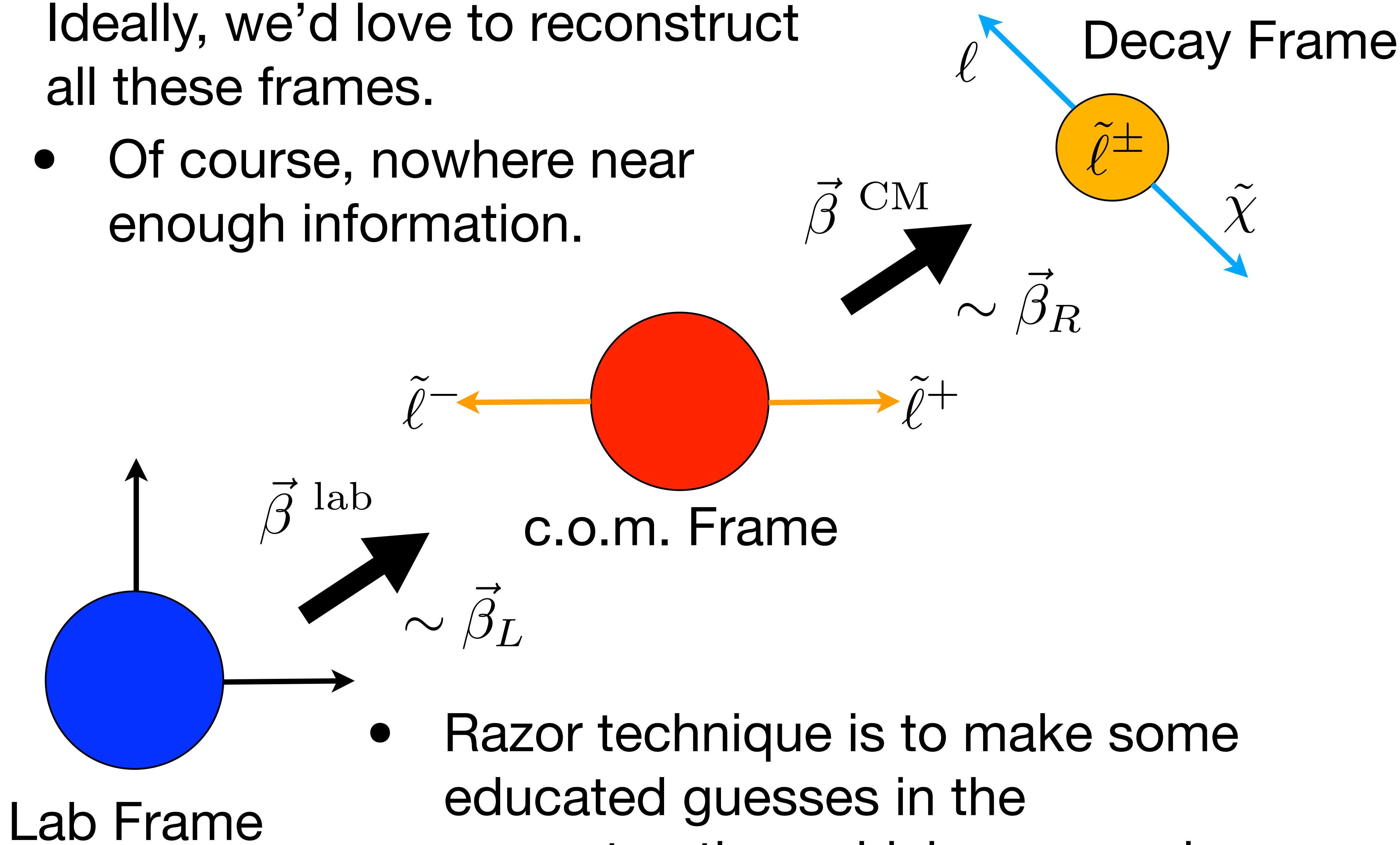
- Can make a transverse boost to remove ISR contamination of "interesting" physics

- CMS uses a similar motivation in construction of $M_{\mathrm{CT}\perp}$



Razor Frames

- Ideally, we'd love to reconstruct all these frames.
  - Of course, nowhere near enough information.



- Razor technique is to make some educated guesses in the reconstruction, which we can show give reasonable approximations.

Reconstructing the c.o.m. frame

- Need to make a series of assumptions to approximate the pair production frame
  - Designed to work if event is 2 heavy particles decaying to 2 visible and 2 invisible particles
- Not enough information to reconstruct the true $\vec{\beta}^{\,\mathrm{lab}}$

$$\vec{\beta}^{\,\mathrm{lab}} = \frac{\{\vec{\not\!\!E}_T + \vec{q}_{1T} + \vec{q}_{2T}, P_z^{\mathrm{CM}}\}}{\sqrt{|\vec{P}^{\mathrm{CM}}|^2 + \hat{s}}}$$

- Build a boost vector $\vec{\beta}_L$ that boosts to a frame R which approximates the true c.o.m. frame
  - Require that observables invariant under longitudinal boosts: fixes P_z^{CM}
  - Need to guess a mass scale $\sqrt{\hat{s}_R} \sim \sqrt{\hat{s}}$

$\hat{s}_R$

- By assuming the invariant mass of the visible system is the same as the invariant mass of the invisible, can solve for $\hat{s}_R$ (will be systematically lower than $\hat{s}_{\rm CM}$).
  - Sets the magnitude of the boost to the approximate c.o.m. frame, once we know $P_z^{\rm CM}$

- Requiring $\frac{\partial \sqrt{\hat{s}_R}}{\partial P_z^{\rm CM}} = 0$ sets our choice of $P_z^{\rm CM}$

- In terms of old Razor variable M_R:

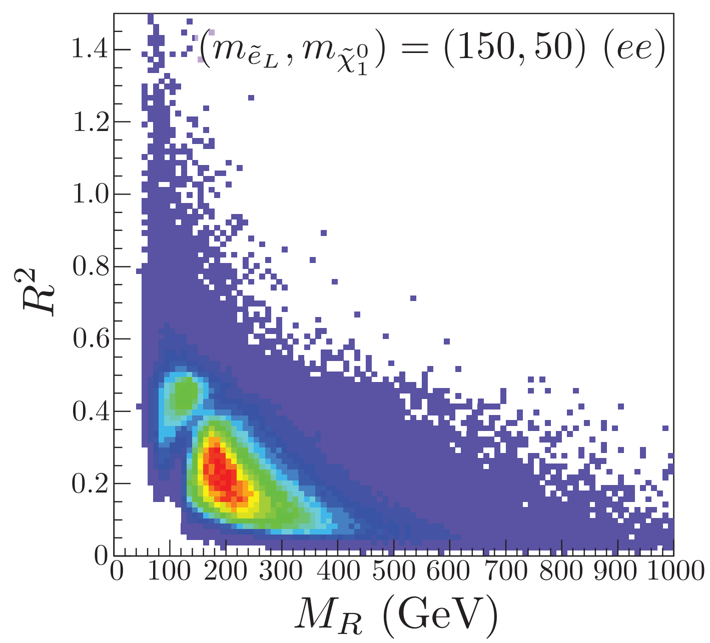
$$\hat{s}_R = 2M_R^2 - 2\vec{P}_T^{\rm CM} \cdot (\vec{q}_1^{\ell} + \vec{q}_2^{\ell}) + 2M_R\sqrt{M_R^2 + |\vec{P}_T^{\rm CM}|^2 - 2\vec{P}_T^{\rm CM} \cdot (\vec{q}_1^{\ell} + \vec{q}_2^{\ell})}$$

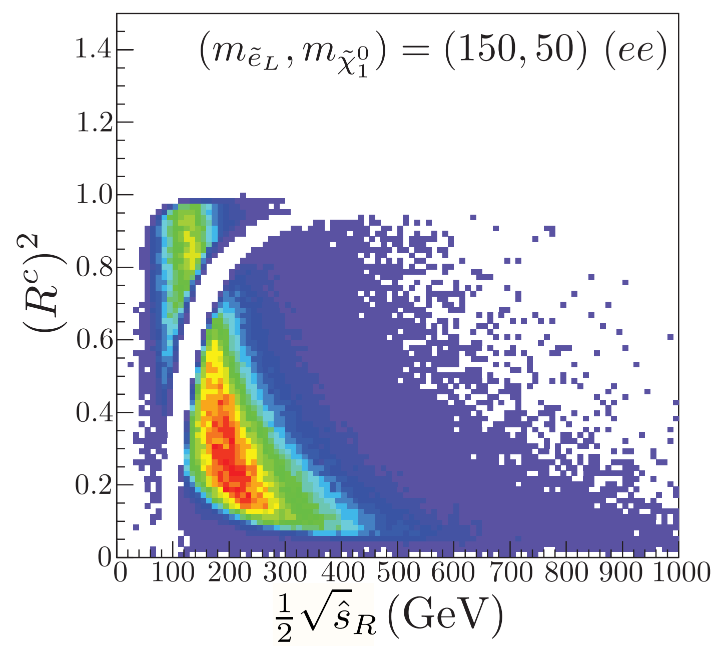
- New way to look at a variable from Zeppenfeld & Rainwater (hep-ph/9906218)

$\hat{s}_R$

- $\sqrt{\hat{s}_R}$ can be thought of as "transverse boost-corrected" version of the Razor variable M_R

- Lots of assumptions go into building $\sqrt{\hat{s}_R}$, how'd we do?





Reconstructing the Decay Frame

- Now need to get from the approximate c.o.m. frame to the two decay frames.
- Again, not enough information to do this perfectly, so we guess.

- Two decaying particles, so two boosts from R-frame
  - Need to be equal and opposite

$$\vec{\beta}_R = \frac{\vec{q}_1 - \vec{q}_2}{q_1 + q_2}$$

(q_1, q_2 lepton mom. in R-frame)

  - The boost with the right symmetry

M_{Δ}^{R}

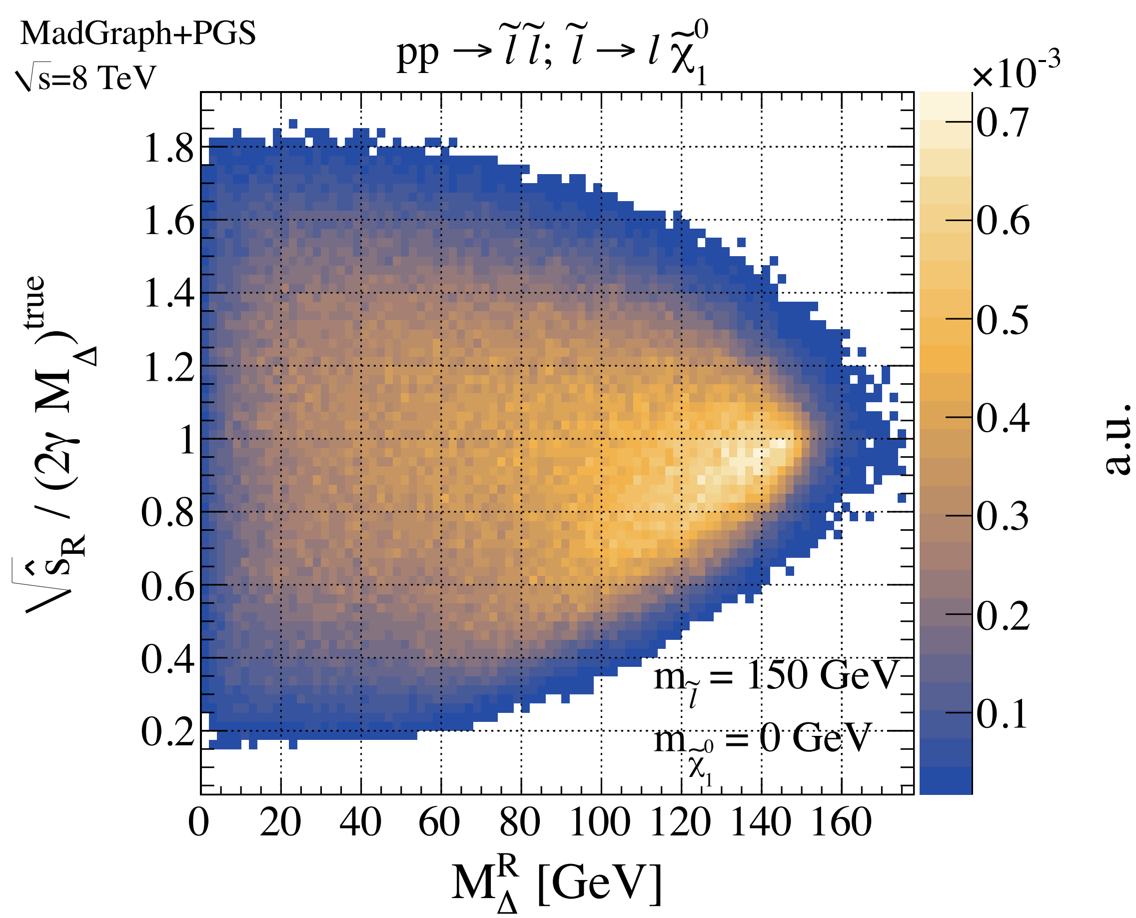
- The actual boost $\vec{\beta}^{\text{CM}}$ relates $\hat{s}_{\text{CM}}$ and M_P by

$$\sqrt{\hat{s}_{\text{CM}}} = 2\gamma_{\text{CM}} M_P$$

- Our approximate boost $\vec{\beta}_R$ relates $\hat{s}_R$ to an approximation of this mass. We're working only with the visible system though, we get approximation of M_{Δ}

$$\sqrt{\hat{s}_R} = 2\gamma_R M_{\Delta}^{R}$$

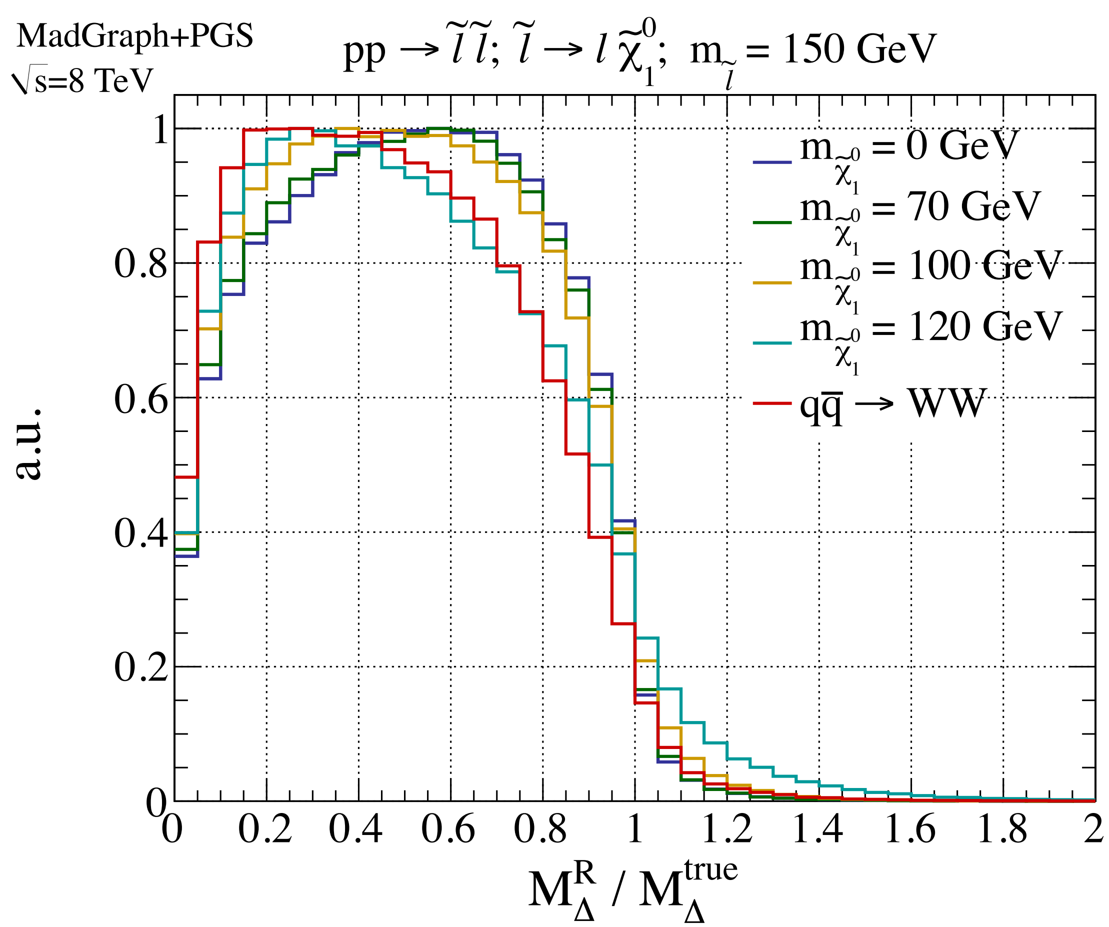
- M_{Δ}^{R} will have an edge at $M_{\Delta} \equiv (m_P^2 - m_{\chi}^2)/2m_P$ insofar as assumptions behind β_R, β_L are good

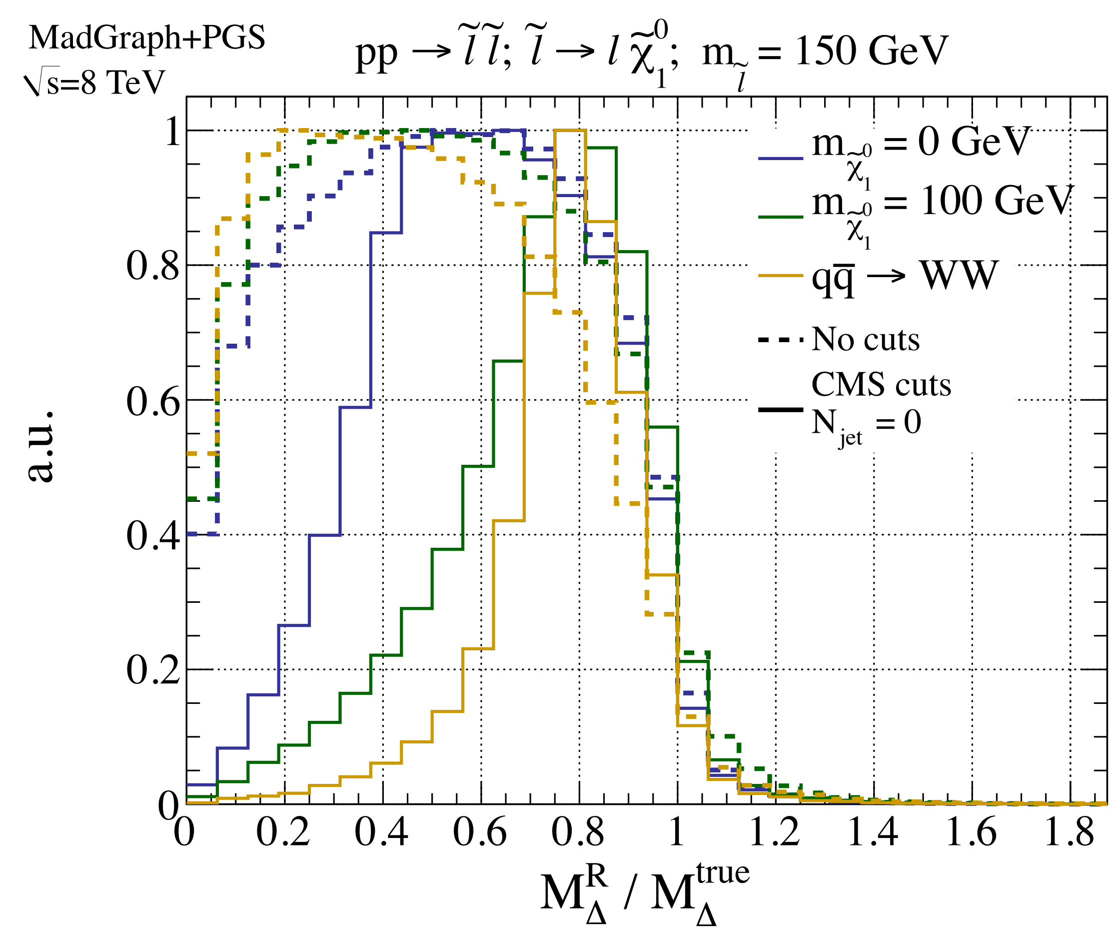


Tuesday, July 9, 13

M_Δ^R

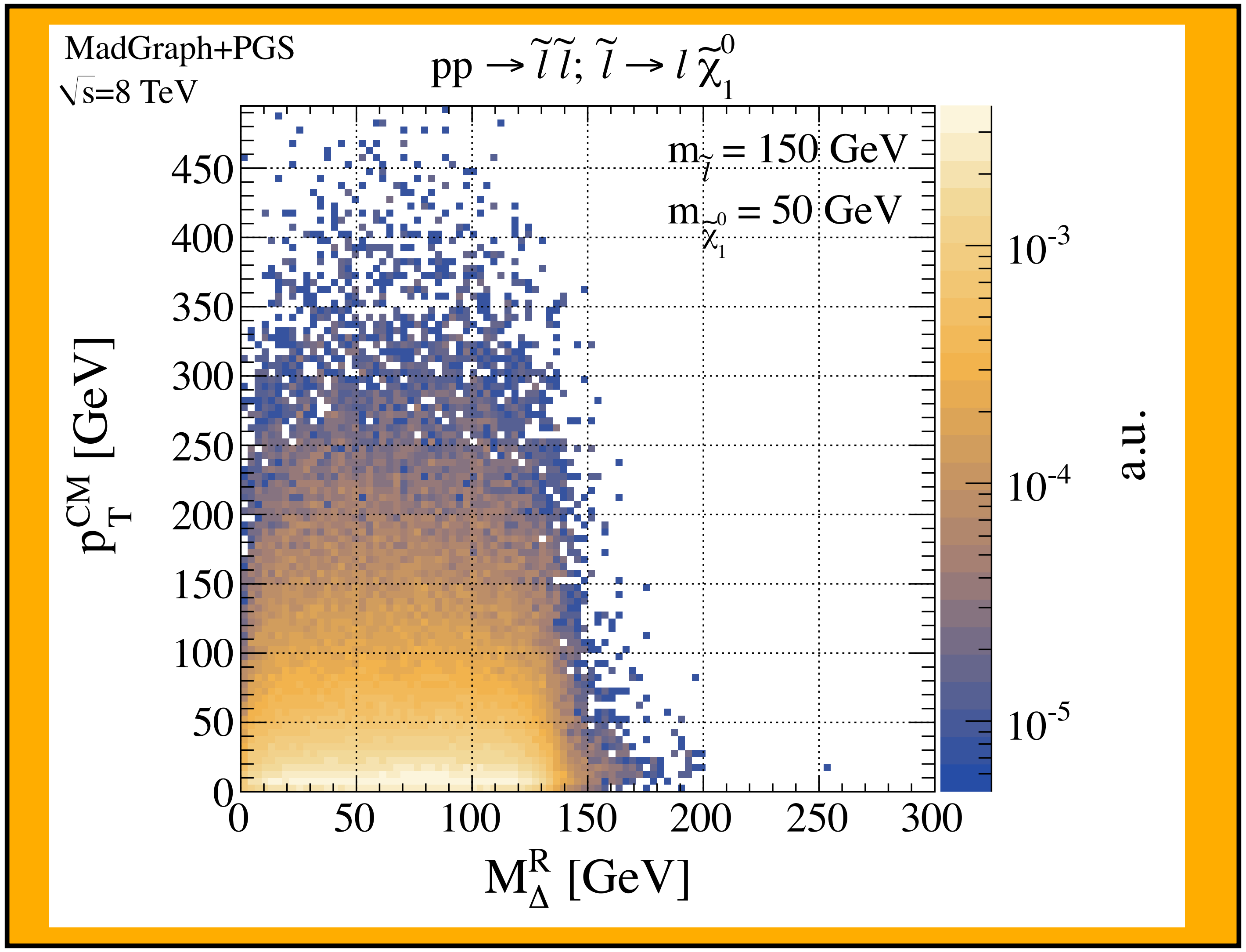
- Nice properties of our new variable:
  - Backgrounds have sharp kinematic edge; signal has longer tails (especially for high jet multiplicities)
  - Approximate reconstruction of production frame leads to further kinematic variables of interest (*work to be done*)





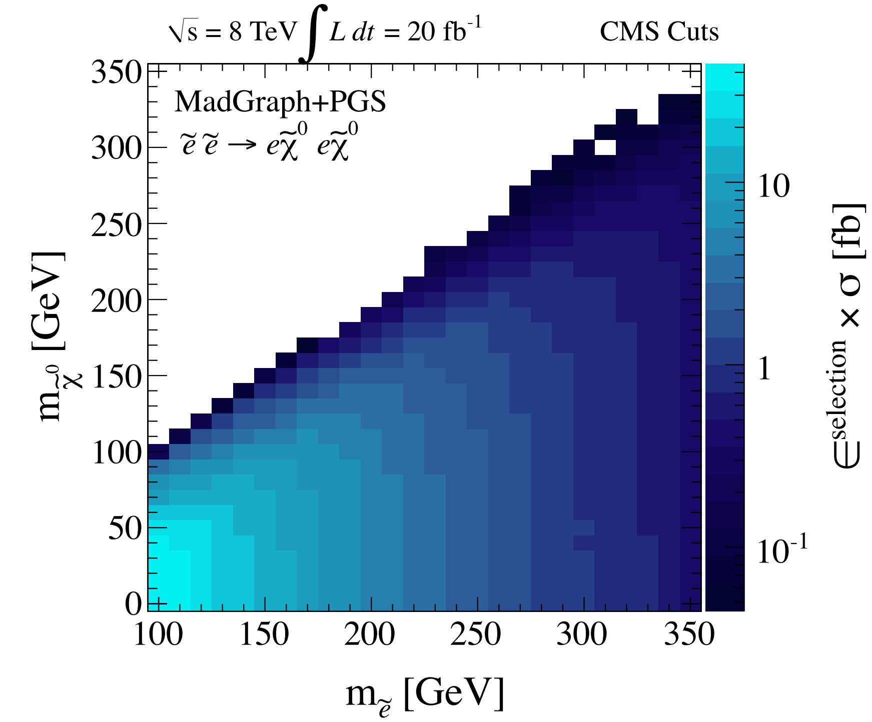
M_Δ^R

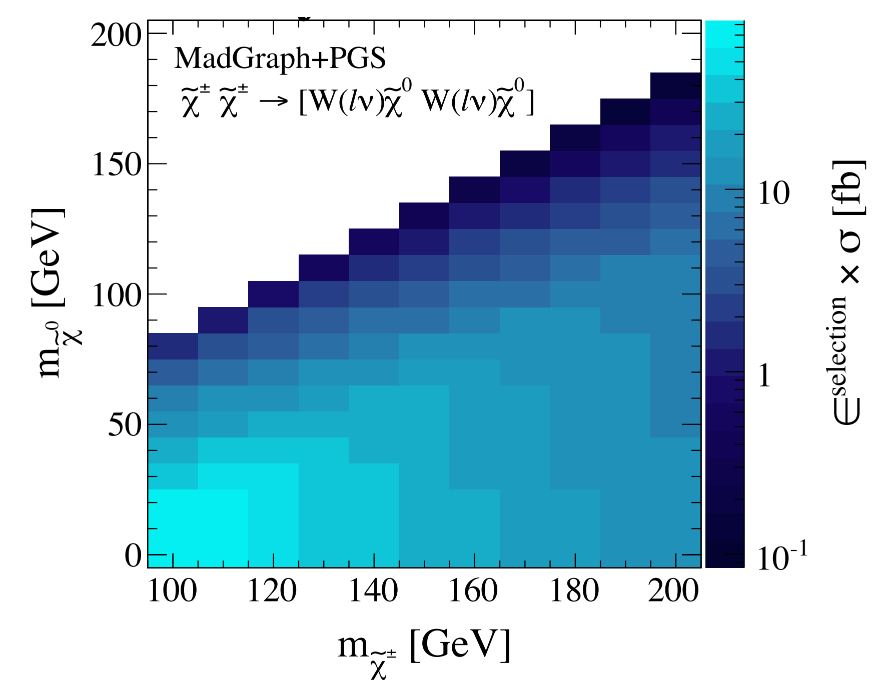
- M_Δ^R is relatively independent of the transverse momentum p_T^{CM} of c.o.m. relative to lab



Selection Criteria

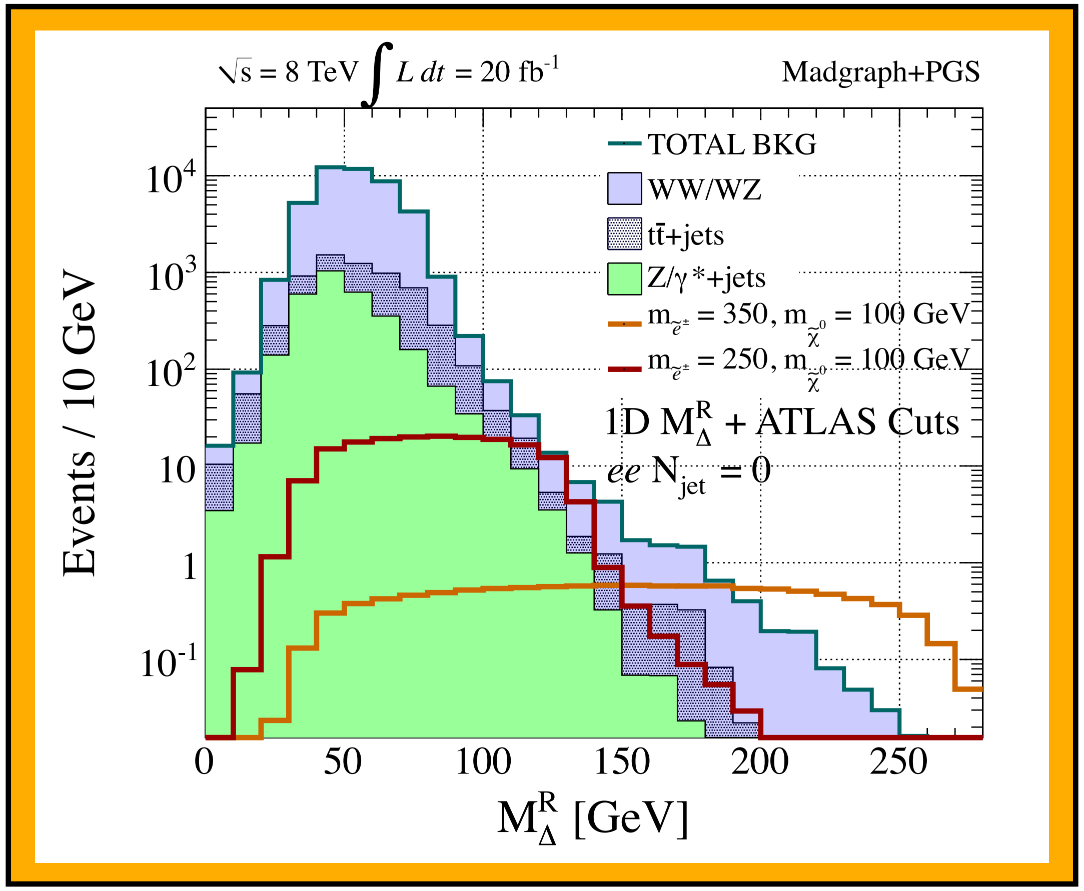
- Compare apples to apples:
  - Use ATLAS and CMS cuts in 2 separate analyses to compare our method (and theorist-level systematics) to the current market leaders
  - Cuts *a la* CMS-PAS-SUS-12-022 ATLAS-CONF-2013-049
- Most relevant:
  - MET cuts
  - Z-mass cuts
  - $p_{T,\text{jet}} > 30\ \text{GeV}$
    - Work with 0,1,2+ jet samples

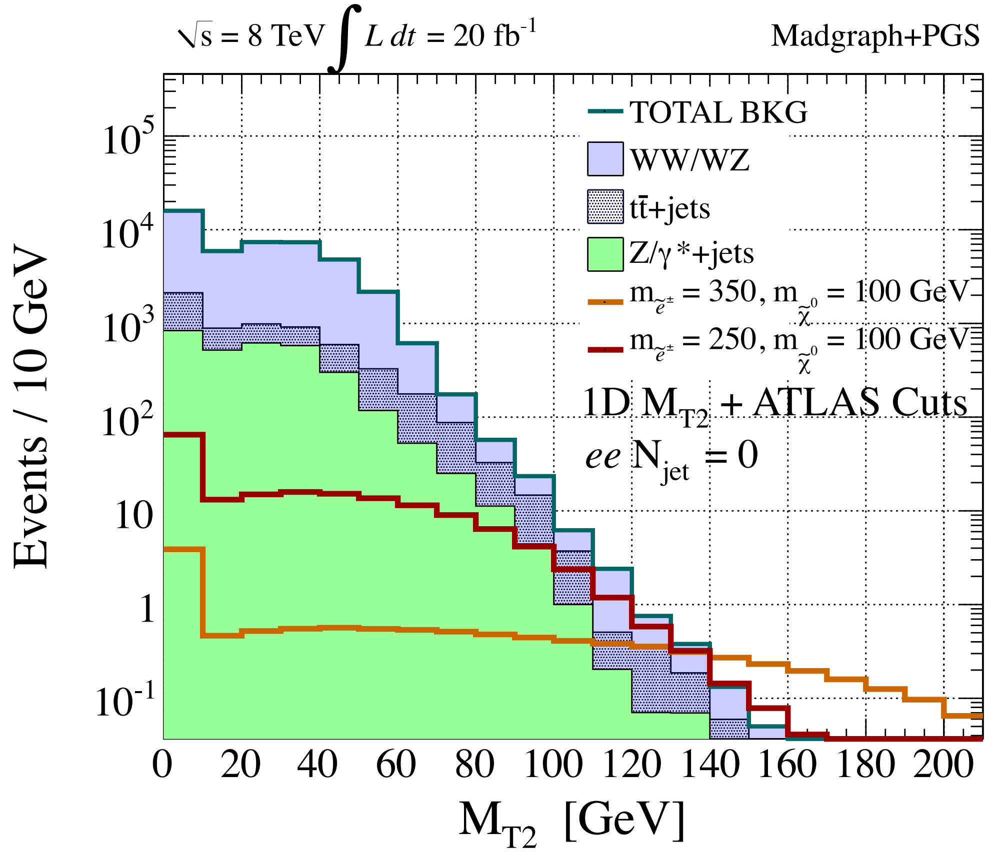




Comparing Variables

- Attempt to mock up experimental systematics:
  - 10% jet normalization (per jet)
  - 10% jet/MET energy scale shape systematic
  - 2% lepton ID
  - 10% cross section uncertainty

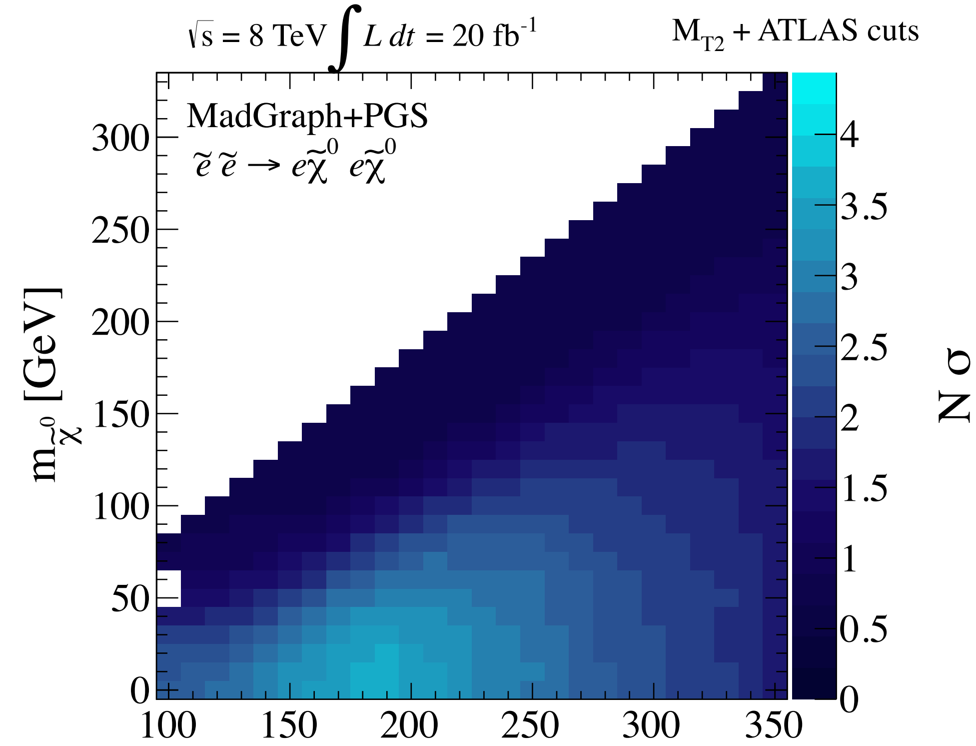


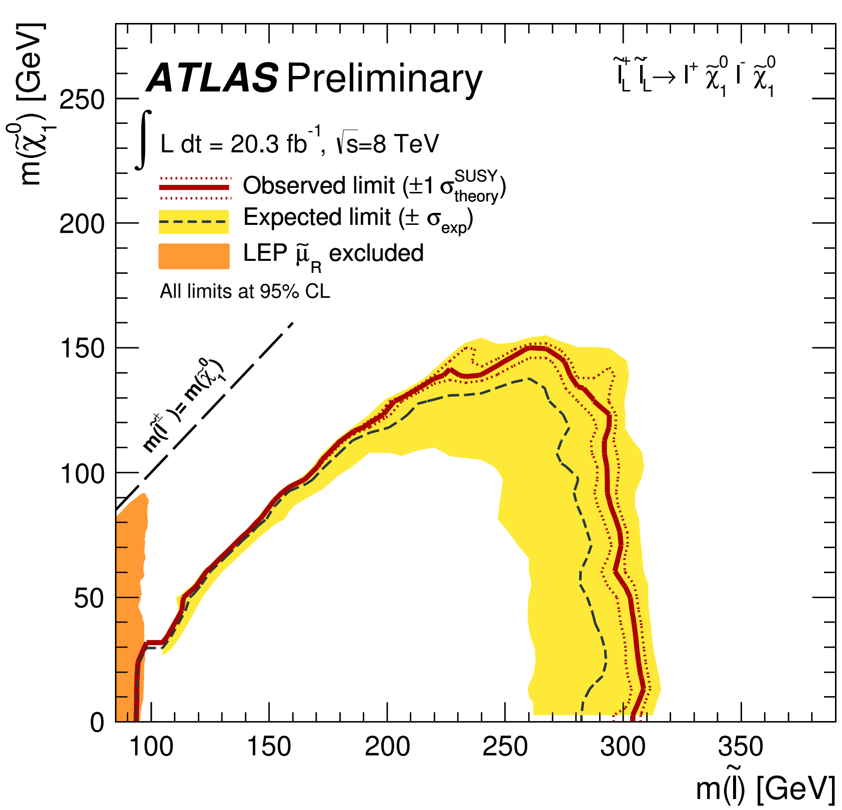


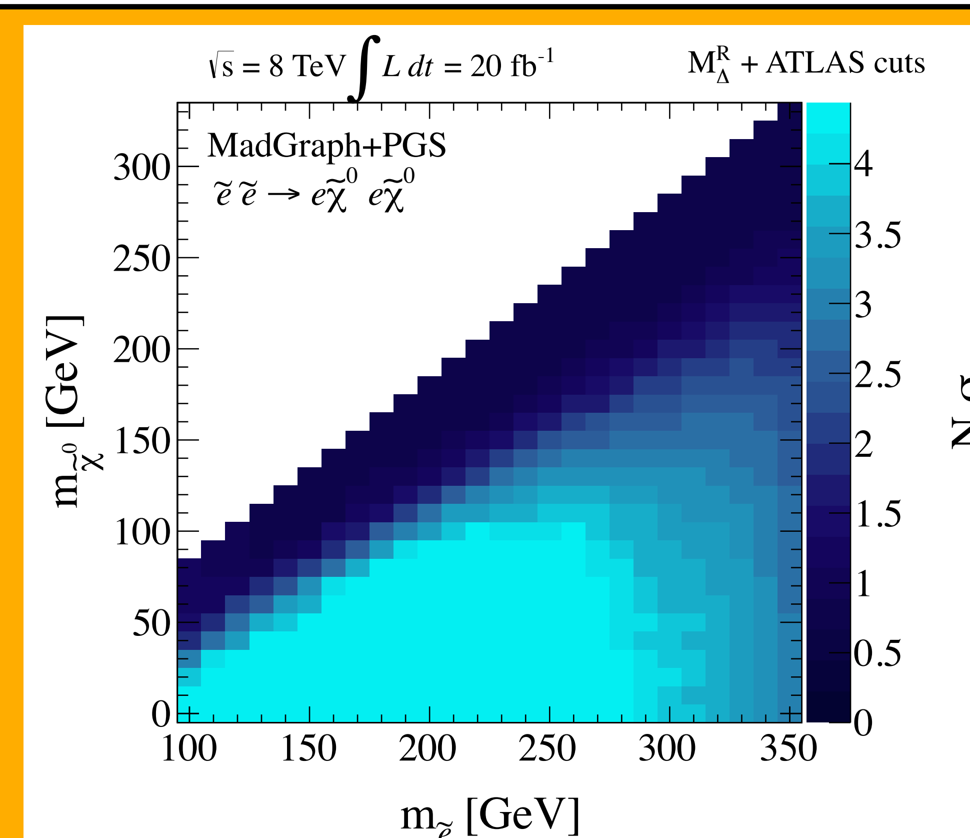
Tuesday, July 9, 13

Sensitivity to Sleptons

- Unfortunately, CMS $M_{\mathrm{CT}\perp}$ comparison plots not quite ready for this talk.
- We're assuming $\tilde{e}_L$ or $\tilde{\mu}_L$, CMS/ATLAS results assume both flavors degenerate
- Using CLs method for limits

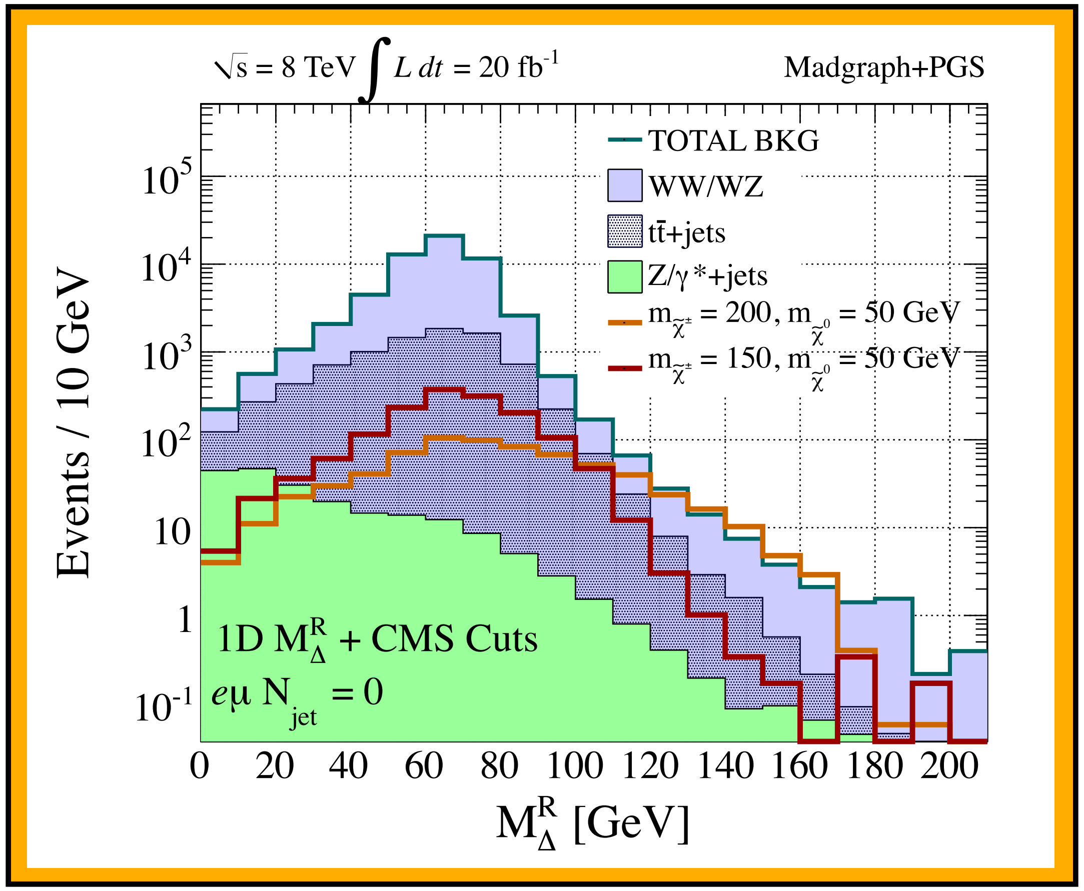


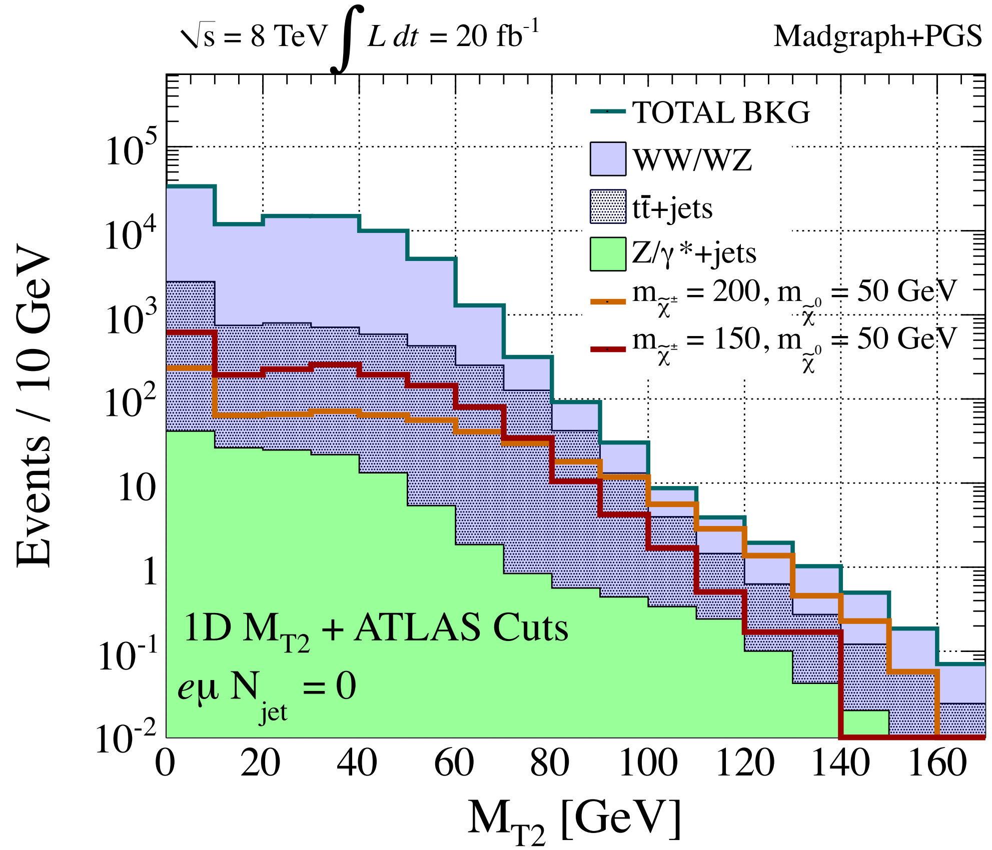




Chargino Applications

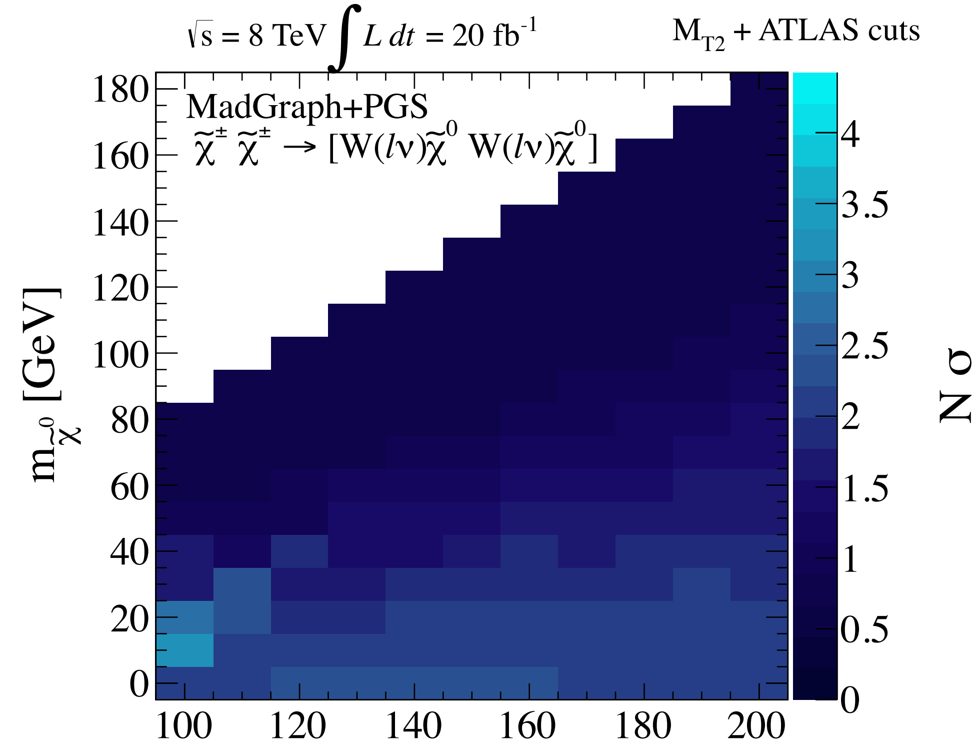
- Extra MET from SM neutrinos
- Don't expect to see the nice edge as in sleptons
- Regardless, still a useful variable.
  - (and further information from Razor frames to use)

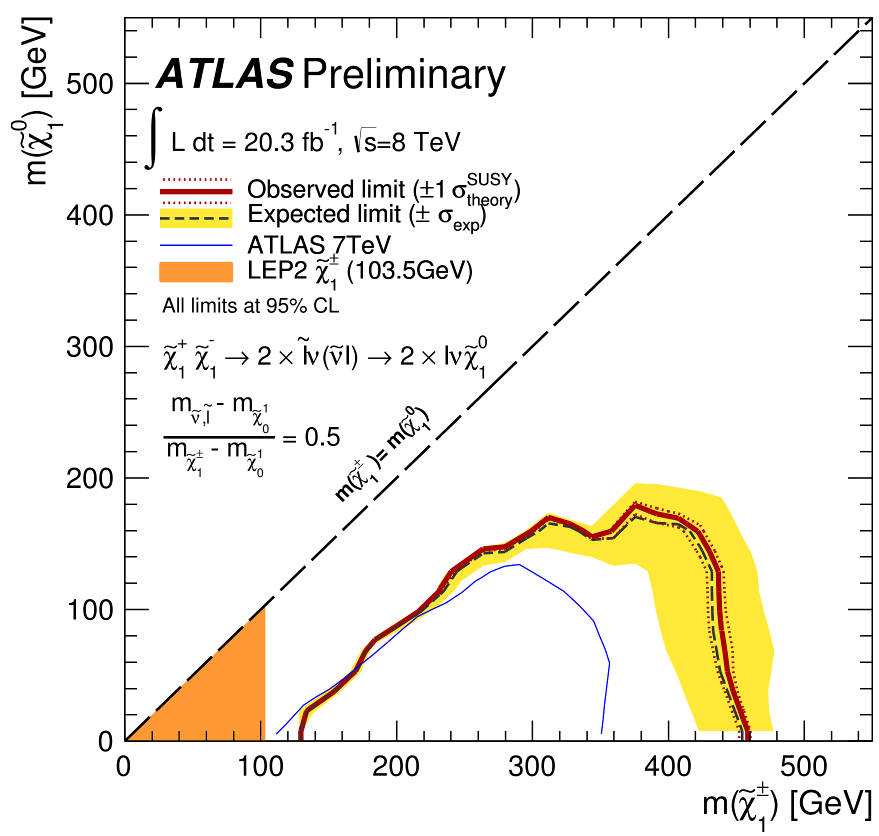


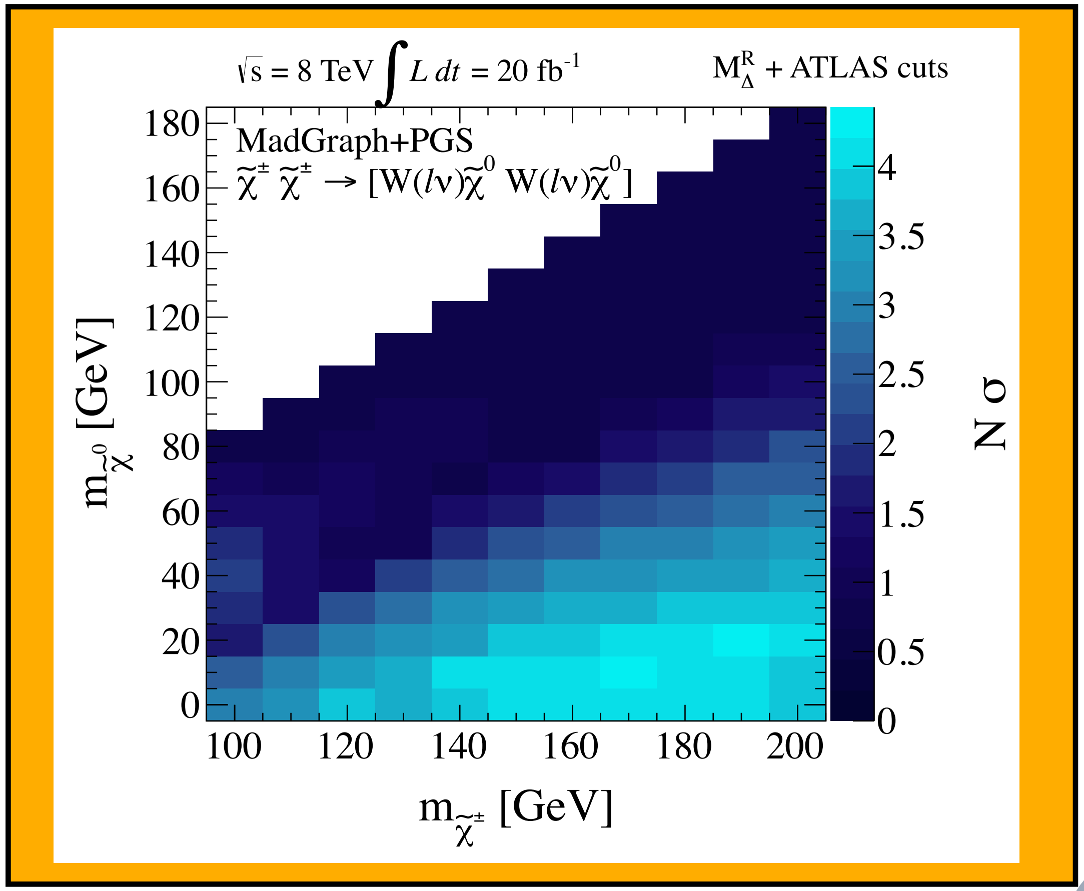


Sensitivity to Charginos

- Recall, we pay the W lepton BR twice for our chargino search.
- ATLAS and CMS publishes results for 100% BR into leptons.







Conclusions

- Razor variables have proven useful in a variety of searches involving jets + $\not{E}_T$
    - For events where we can identify jets that aren't "interesting" (*i.e.* ISR), we can do better.
    - EW production of new particles a prime candidate for these improved razor variables.
- Today I've talked about 2 of the most straightforward variables: $\hat{s}_R$ and M_{Δ}^{R}.
    - Approximations of the c.o.m. energy and mass differences in event
    - Clean distinctions between background + signal

- Approximations to c.o.m. and decay frames lead to other new and useful variables.

More to Come

Back-up Slides

M_{CT}

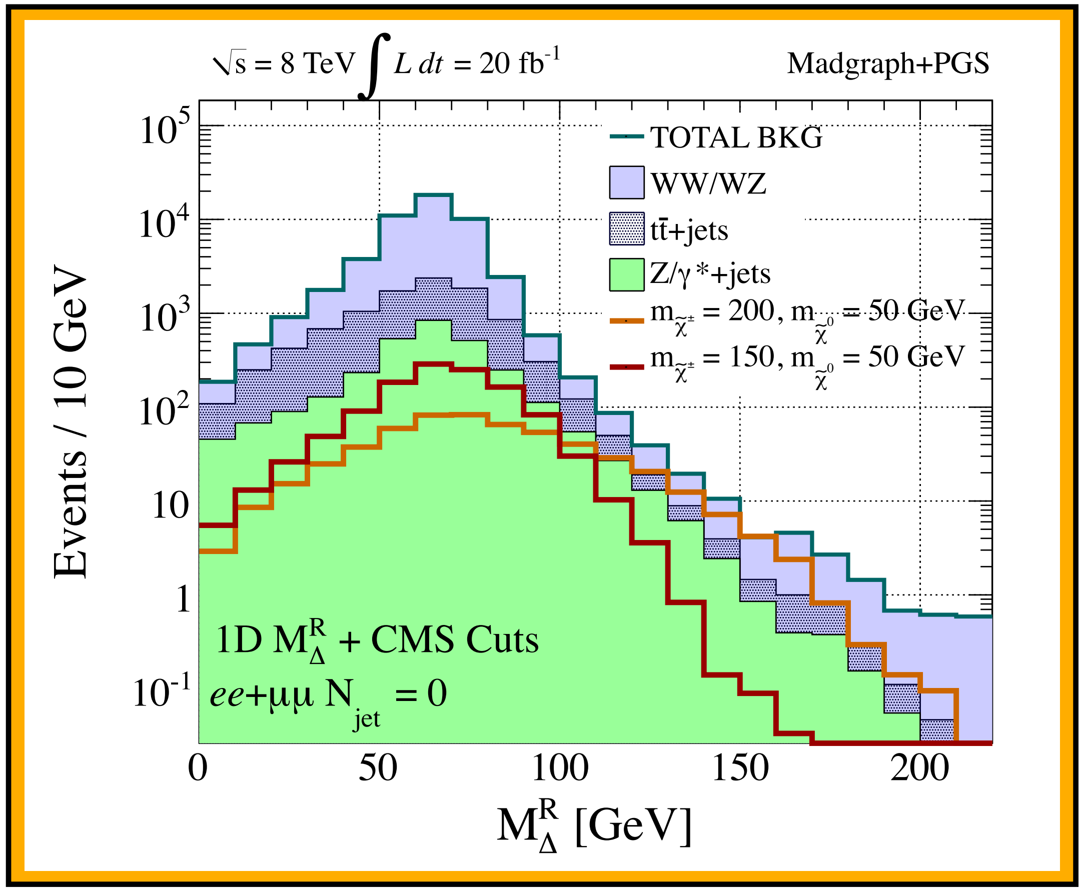
- Defined as

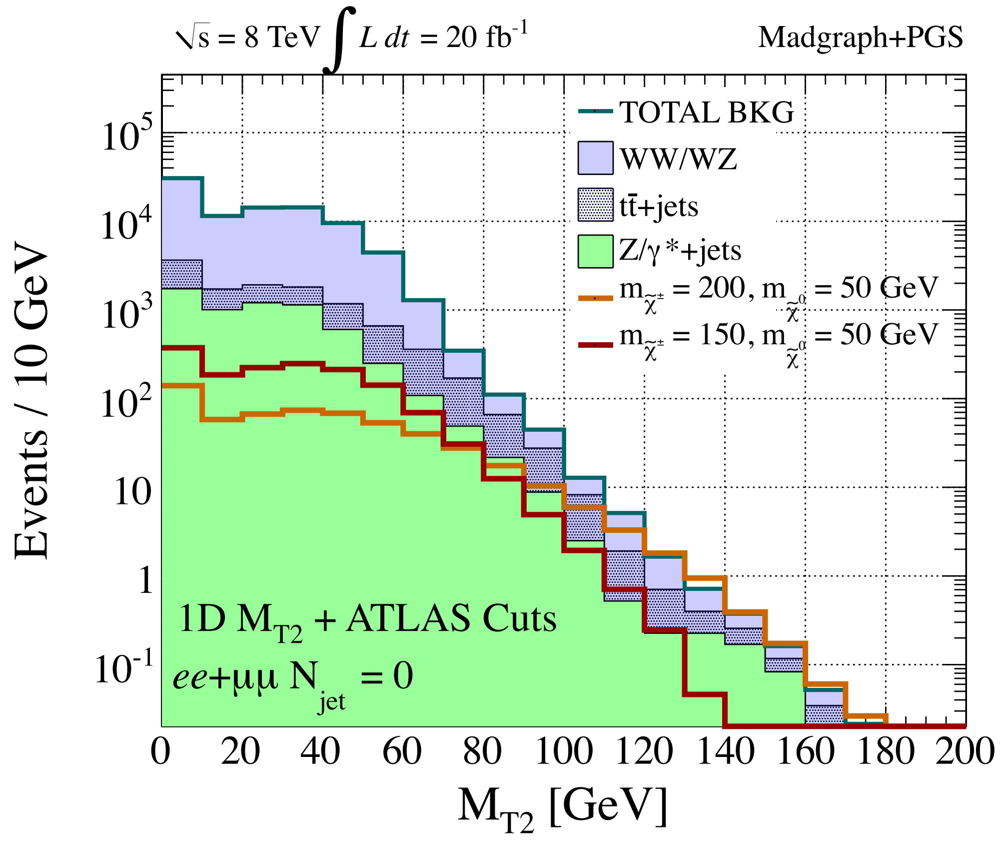
$$M_{\mathrm{CT}} = \sqrt{m_1^2 + m_2^2 + 2(e_{1T}e_{2T} + \vec{p}_{1T} \cdot \vec{p}_{2T})}$$

  - With $e_{iT} = \sqrt{m_i^2 + |\vec{p}_{iT}|^2}$

- If there were no objects in event other than leptons + MET, then M_{CT} has endpoint depending only on mass of parents and invisible particles.

SF Chargino Sample





CLs

- Use probability distribution functions to create toy experimental results, compare to background-only