Experience from Run 1 SUSY Searches at CMS

KITP Experimental Challenges for the LHC Run 2

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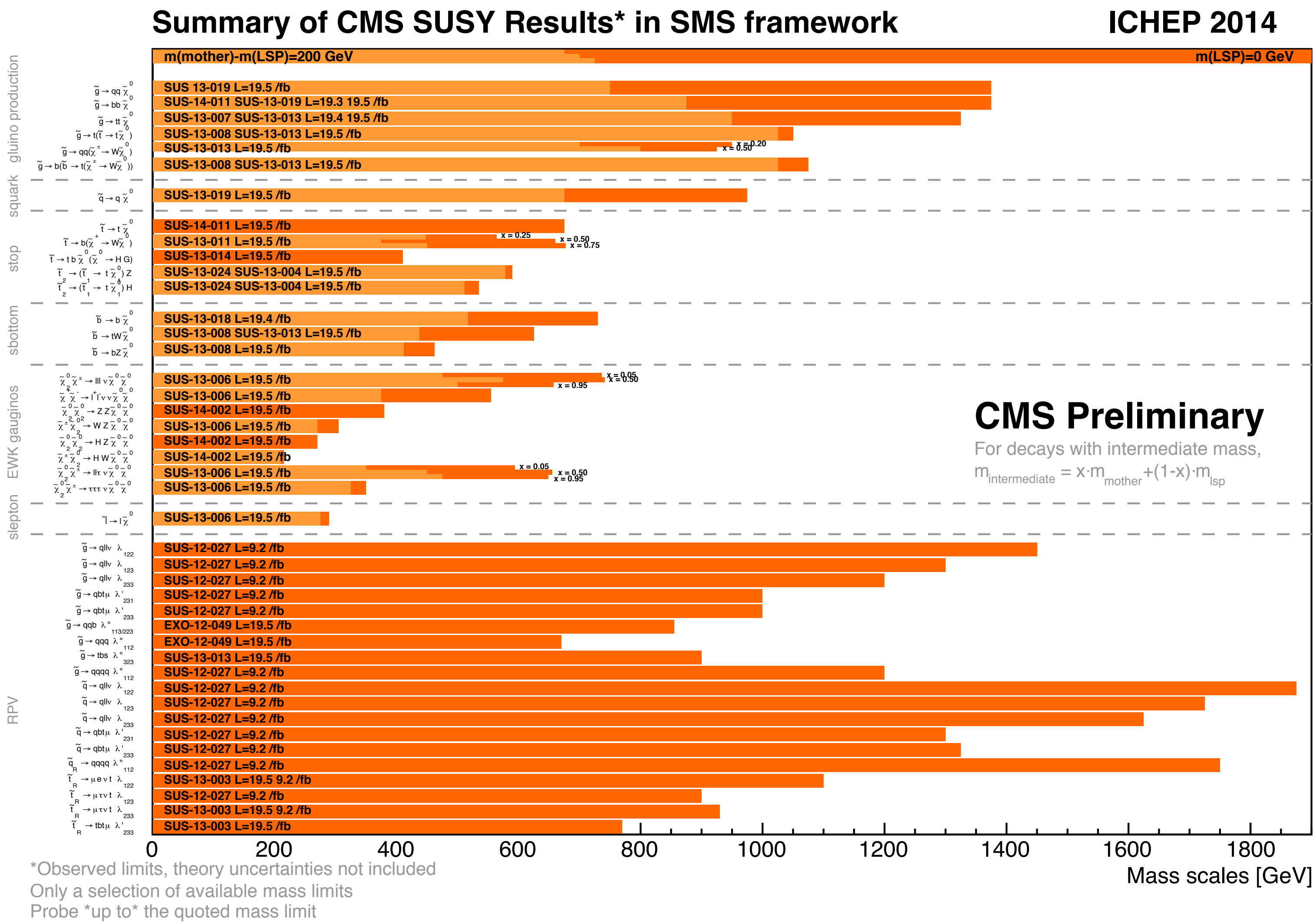
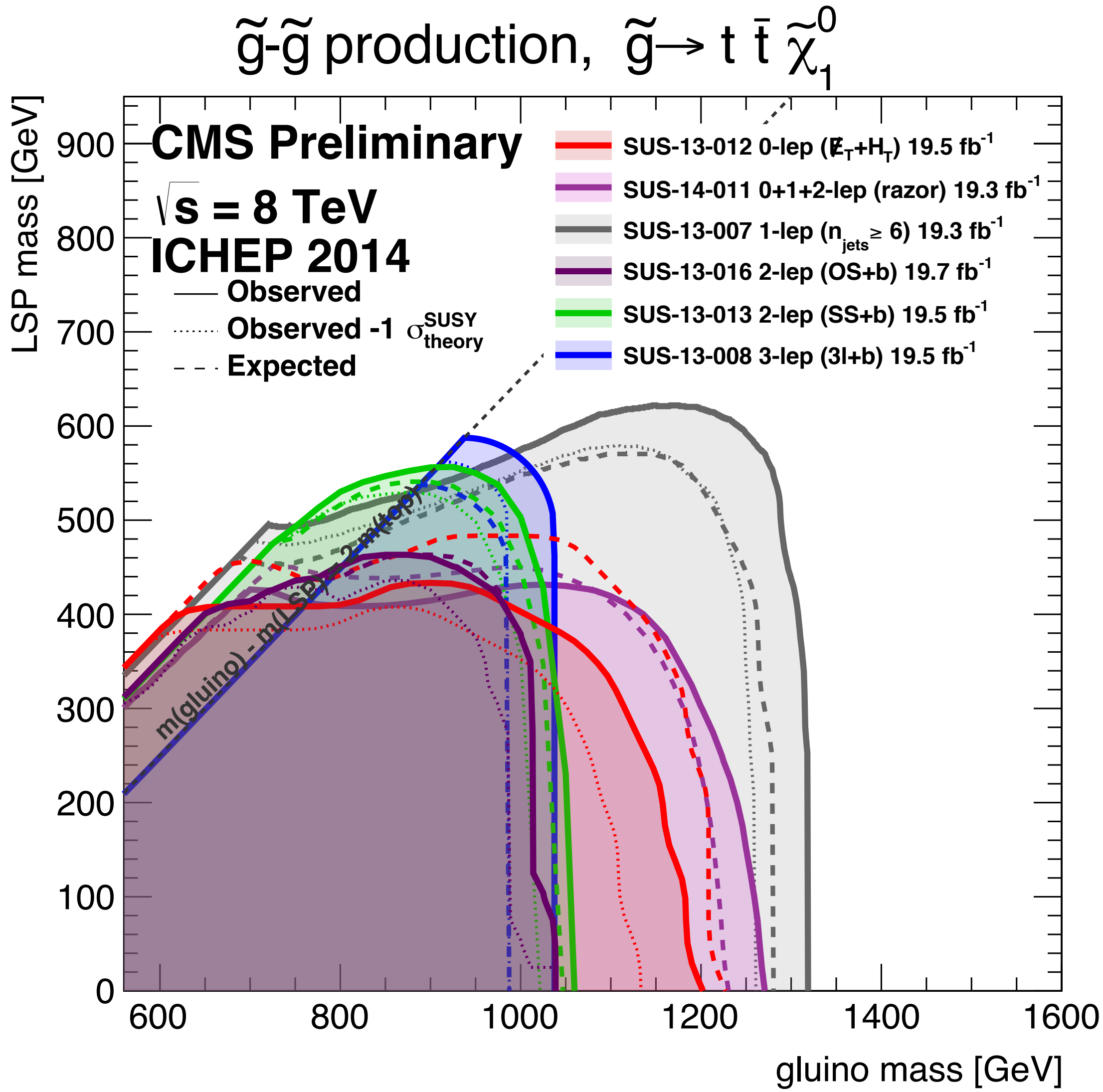
Lots of Results ➔ No SUSY



- 57 Run 1 CMS SUSY papers ➔ No discovery

Lots of Results → No SUSY



- 57 Run 1 CMS SUSY papers → No discovery

This talk

- Try to sketch broadly the evolving approach to two topics
  - How to cover so many potential signals
  - How to measure backgrounds

- Do not focus on interpretation of where the sum of null results leaves us

How to search for SUSY

- Want to cover a vast search space
  - To first order, any combination of SM particles + MET = RPC SUSY
- Still great interest in SUSY → many clever, motivated people searching for it
  - Ideally, would have them working in a complementary way
- Since we don't really know what we're looking for, we also won't really know what we've found

SUSY search organization

- Searches generally organized by final state particles

Search for supersymmetry with photons in pp collisions at $\sqrt{s} = 8$ TeV

Search for new physics in events with same-sign dileptons and jets in pp collisions at $\sqrt{s} = 8$ TeV

Search for supersymmetry in pp collisions at $\sqrt{s} = 8$ TeV in events with a single lepton, large jet multiplicity, and multiple b jets

CMS Collaboration*

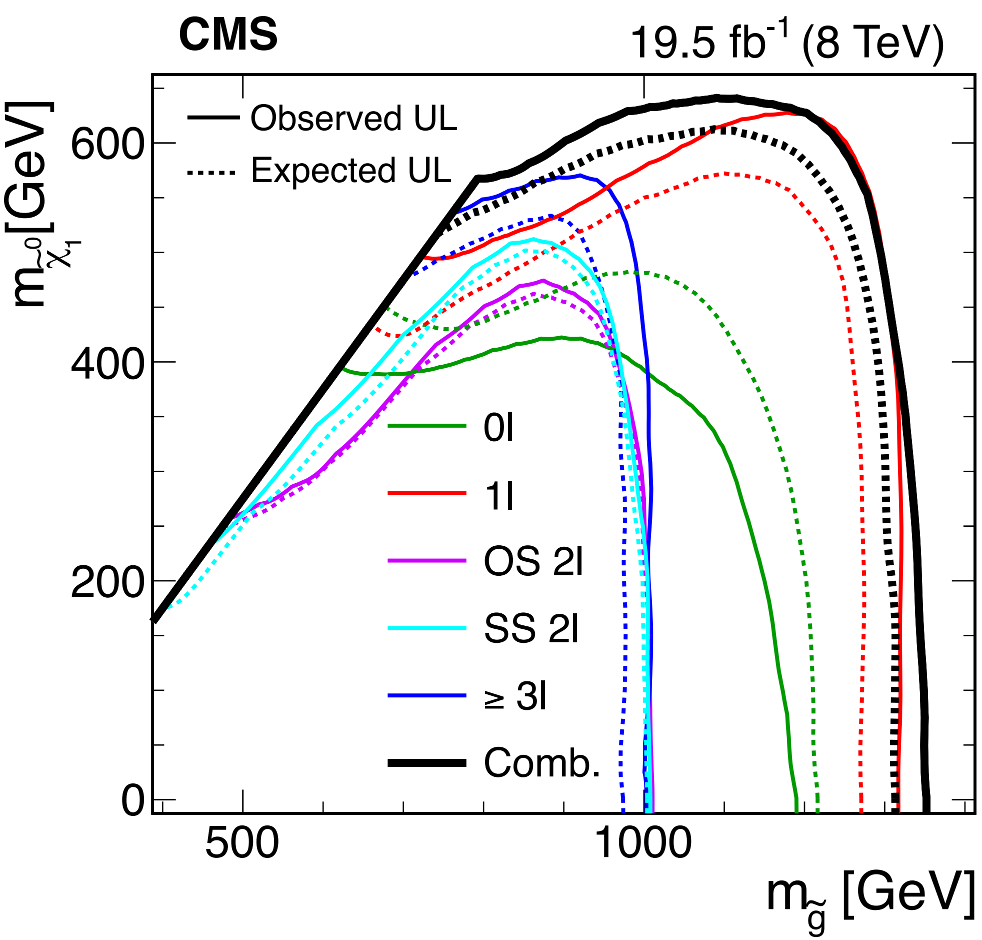
- Some sociology to this
  (Keeps us out of each other's hair)
- But also some physics…

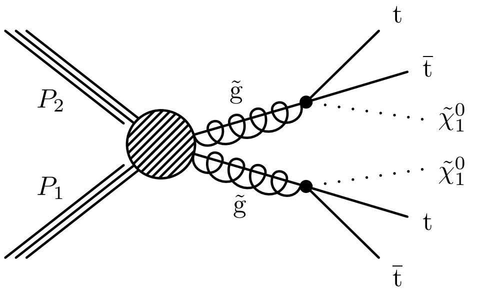
Complementarity

- Many non-overlapping final states allows for broad coverage of signature space
- Allows people to focus on specific challenges
  - 300 people understanding the shape of an inclusive MET tail would be bad
  - 300 people studying specific corners of the MET tails is more fruitful
    - Ex. backgrounds in a hadronic search are very different from a multi-lepton search

Combinations

- Formal separation of final states also allows for combinations of different searches for the same model





SUS-14-010

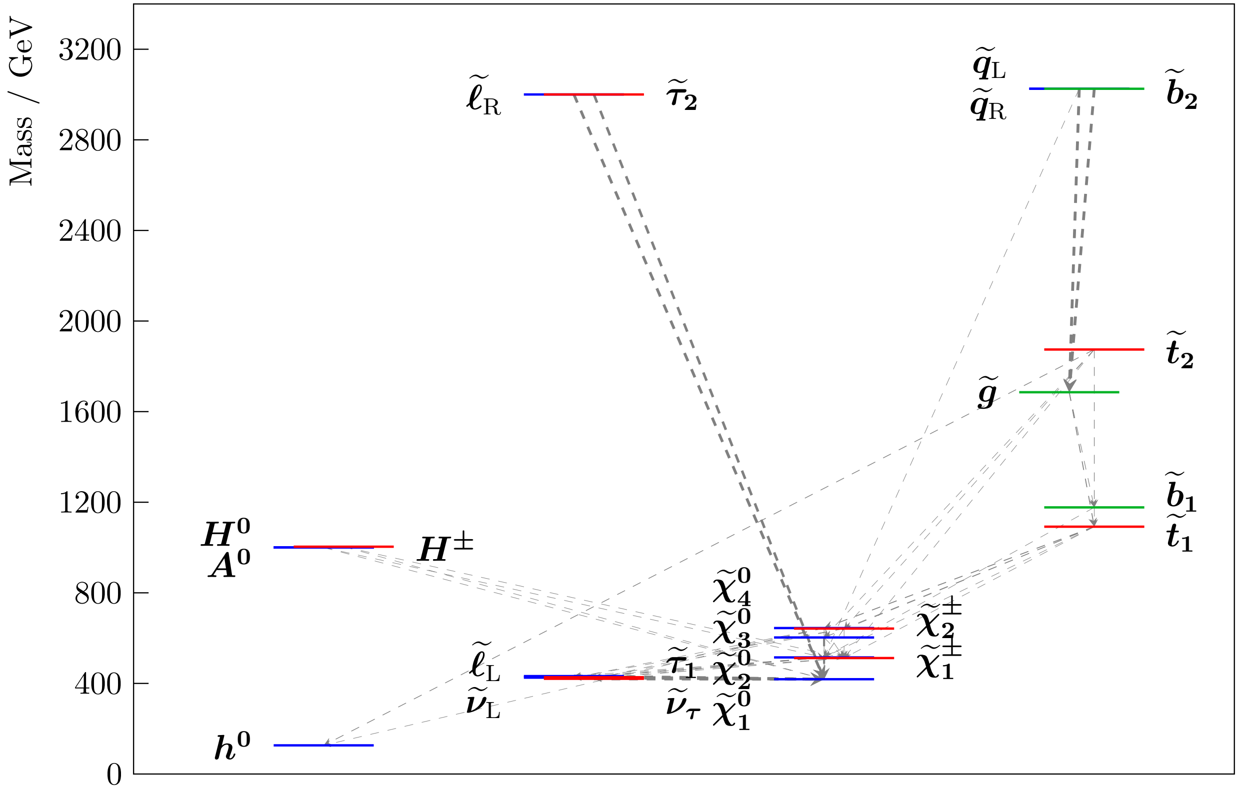
Pondering a Discovery

- SUSY discovery will be complicated
  - Not like H→ZZ or Z→μμ (or X_{750}->γγ!)
- We'll need the whole array of results (positive **and** negative) to tease out a discovery

Example from SUS-14-012 HL-LHC Upgrade studies

"Natural Model 1"

Gluino	~1600 GeV
Stop	~1100 GeV
Higgsino	~400 GeV



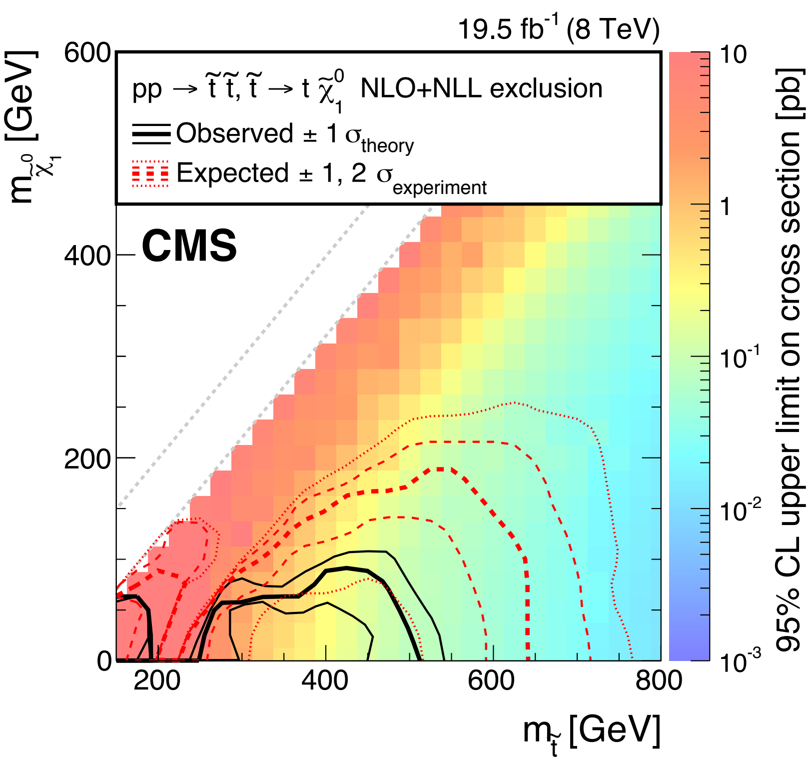
Pondering a Discovery

Analysis	Luminosity (fb^{-1})	Model: NM1	NM2	NM3	STC	STOC
all-hadronic (H_T-H_T^{miss}) search	300				$< 3\sigma$	$3-5\sigma$
	3000				$3-5\sigma$	$> 5\sigma$
all-hadronic (M_{T2}) search	300	$3-5\sigma$	$> 5\sigma$	$> 5\sigma$		
	3000	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$		
all-hadronic $\tilde{b}_1$ search	300	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$	$3-5\sigma$	$< 3\sigma$
	3000	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$	$> 5\sigma$	$< 3\sigma$
1-lepton $\tilde{t}_1$ search	300	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$3-5\sigma$	$< 3\sigma$
	3000	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$
monojet $\tilde{t}_1$ search	300					$3-5\sigma$
	3000					$3-5\sigma$
$m_{\ell^+\ell^-}$ kinematic edge	300	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$		
	3000	$> 5\sigma$	$< 3\sigma$	$< 3\sigma$		
multilepton + b-tag search	300	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$3-5\sigma$	
	3000	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	
multilepton search	300	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$	
	3000	$3-5\sigma$	$3-5\sigma$	$< 3\sigma$	$3-5\sigma$	
ewkino WH search	300		$< 3\sigma$			
	3000		$3-5\sigma$			

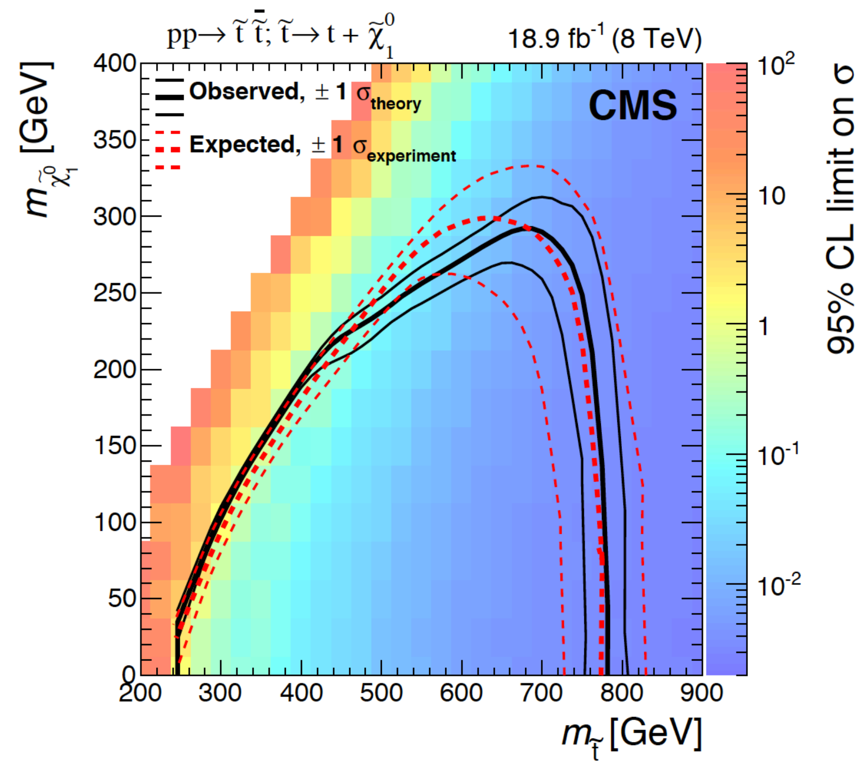
$< 3\sigma$ | $3-5\sigma$ | $> 5\sigma$

Inclusive vs Exclusive

- Searches designed within each final state to be broadly sensitive
  - Lots of MET vs little MET, Many jets vs few jets, etc.
- Some topics motivated well enough to target specifically
  - Ex. Direct stop pair production

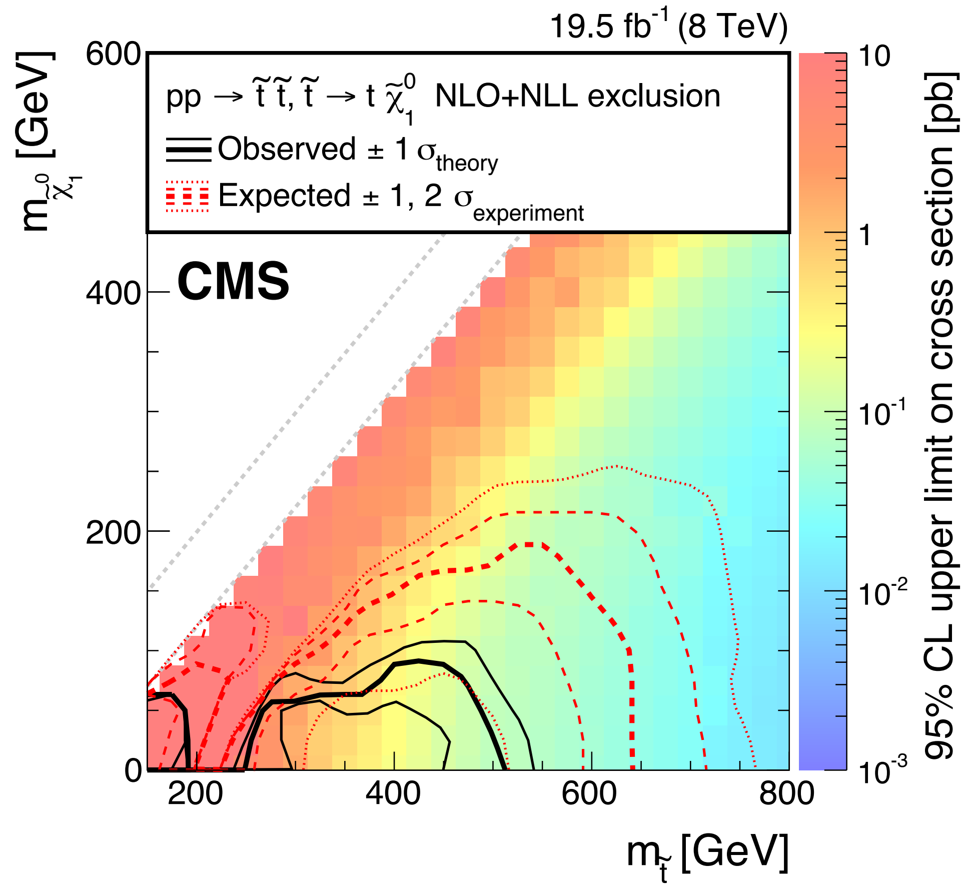


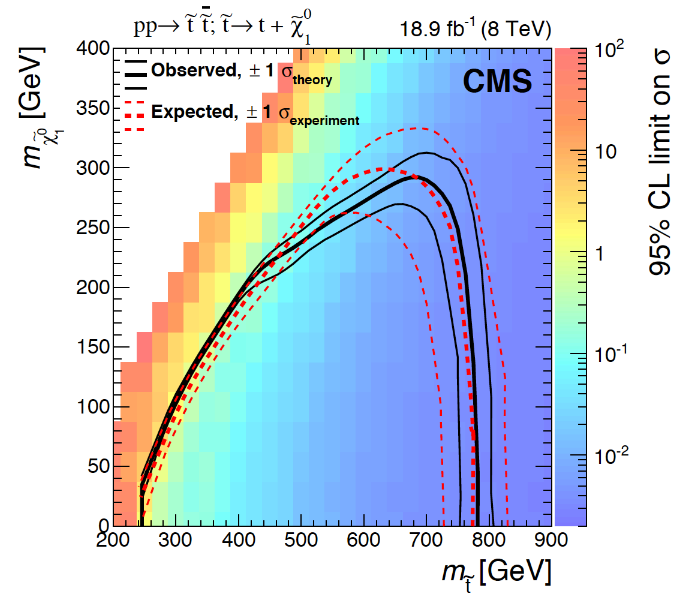
Inclusive hadronic (SUS-13-019)



Targeted search (SUS-13-023)

Inclusive vs Exclusive





- Mass reach improved ~100 GeV in m(stop) and m(LSP)
- Gain really only worth it for very well motivated scenarios
- Effect can cuts both ways (1L "stop" search does well in all future studies scenarios…)

Evolution of Inclusive searches

- Evolution to multi-dimensional binned searches

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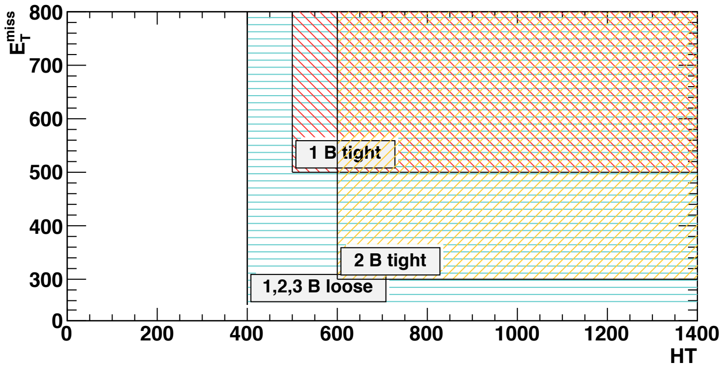

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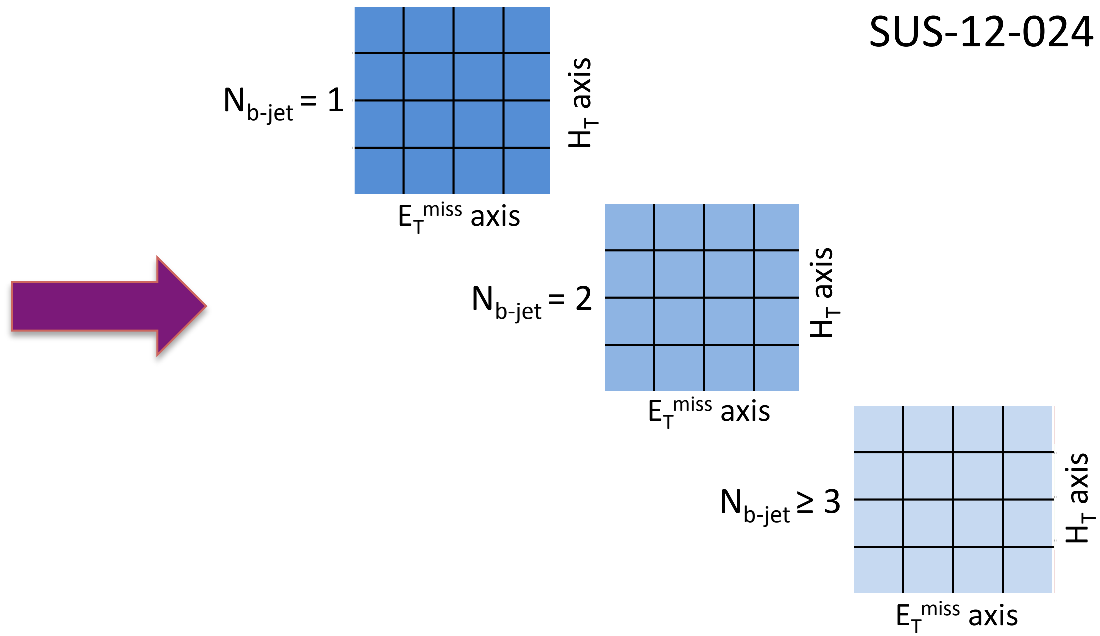


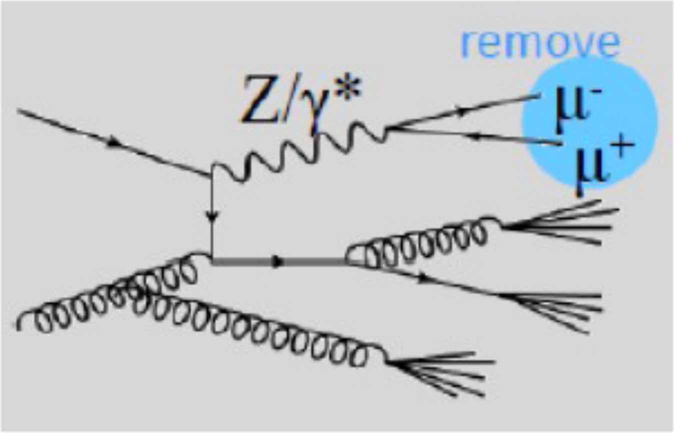
- Sensitivity to many areas of phase space simultaneously
  - Including many that you didn't explicitly target

Part 2: Backgrounds

- A search is really a background prediction compared to an observation
- Very strong culture in Run 1 of maintaining robust, highly data-driven background strategies
- The LHC and LHC energies were a giant unknown, and we were appropriately cautious

Data-driven backgrounds

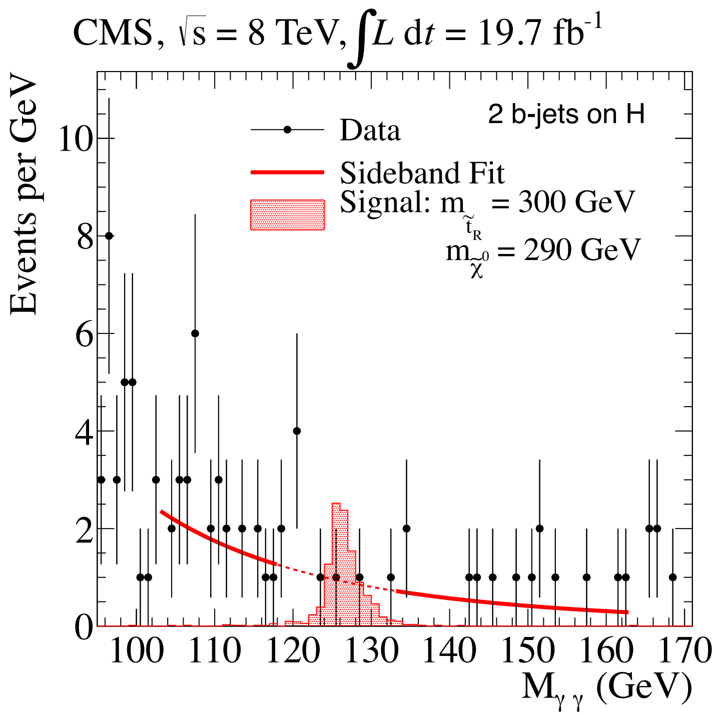
- Example: $Z \rightarrow \nu\nu$ + jets
  - Utilize data Z + jets events with exact selection as signal regions, except $Z \rightarrow \mu^+\mu^-$
  - Perfect understanding of jet activity, lepton vetos, etc.
  - Only need to know μ efficiency, but can measure that in $Z \rightarrow \mu^+\mu^-$ events, too



- But limitation is clear: $BR(Z \rightarrow \nu\nu)/BR(Z \rightarrow \mu^+\mu^-) \approx 6$
- Evolution: where can assumptions be well justified by known physics to improve precision?
  - Z-γ correspondence
  - independence of search variables

Data-driven backgrounds

- Other features well suited to nearly-fully data-driven predictions
- Example: Search in H→γγ plus jets and MET
  - Use sideband γγ shape
  - Can select exact search region outside of m(γγ)
- ABCD approaches with 2 uncorrelated variables
  - Must still understand the correlations very precisely



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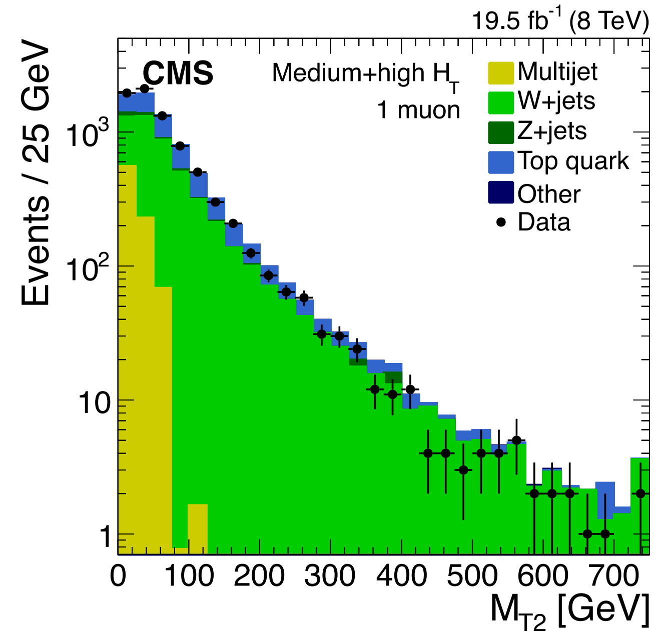
Transfer factors

- Utilize data control region with high purity for a given background
- Extrapolate to signal region background with MC
- Example: 1μ control region to predict hadronic "lost lepton" background
- Sig/SB ratio from MC mitigates many possible uncertainties

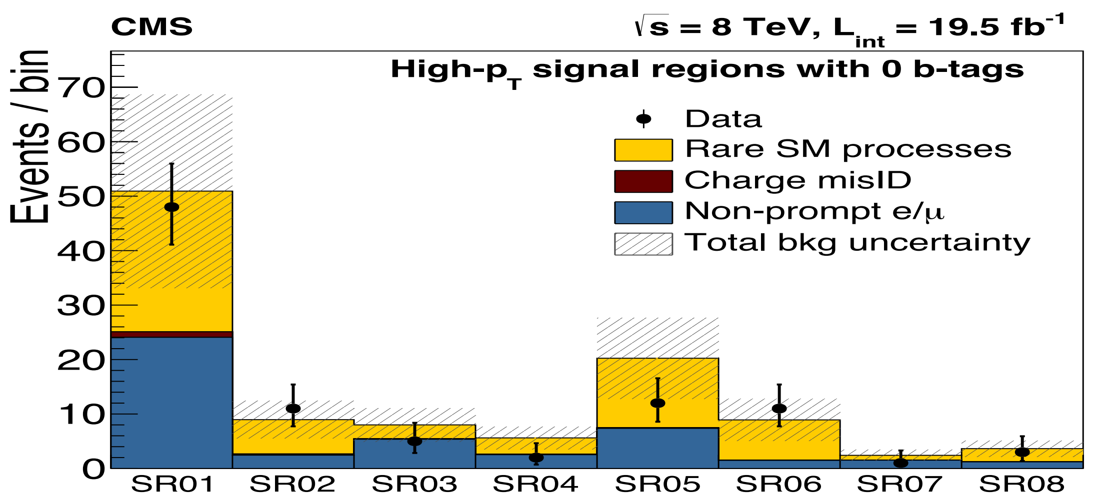


SUS-13-019

- Still rely on MC for "transfer factor"
  - Need theory uncertainties (in addition to experimental): scale variation, etc.
- Now have lots of Run 1 experience, where MC largely performs very well
- Plus MC tools evolving rapidly, too

Backgrounds from MC

- Rely on pure MC predictions for some “rare” backgrounds
  - “rare” = hard to utilize control regions
  - Often small contributions, so small effect on sensitivity
- Clear difficulty in assigning uncertainties
  - Often educated guesses (ex. 50%)
  - Finer binning in searches makes challenge even more difficult
  - Better MC tools and more data help



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Toward discovery

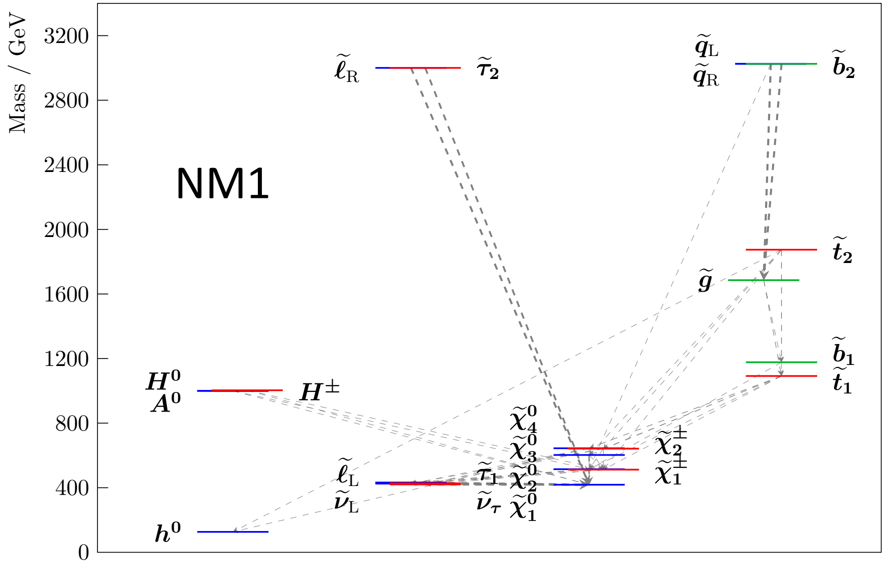
- So far, all we do is set limits
- But focus has to remain on discovery
- For background prediction, the issues can be different
  - Search in tails with low background → limit setting is question of how much signal can fit in the observed data counts
  - Discovery is opposite question: How well background prediction can fill the observed data counts
- Must be careful not to over-optimize for limits.
  - Need precise and believable background predictions (second is harder to quantify than the first....)

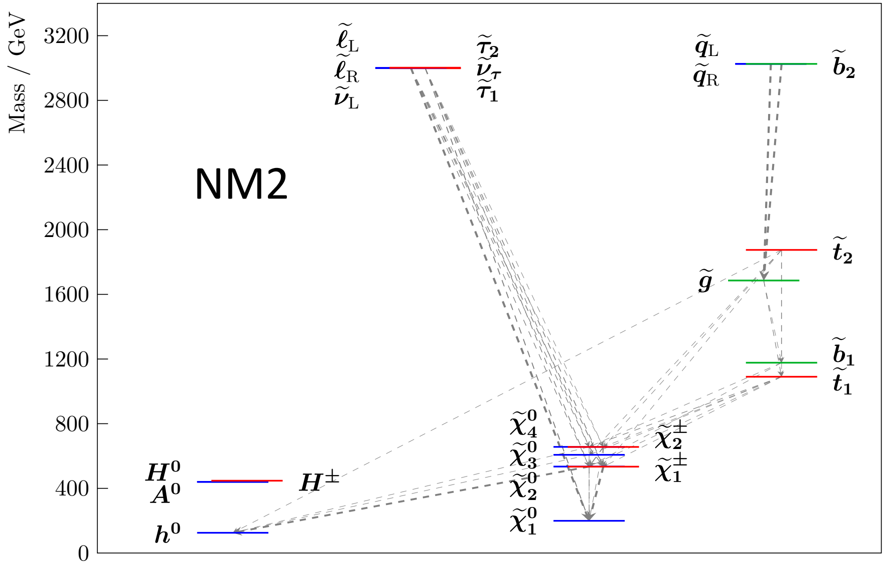
Conclusions

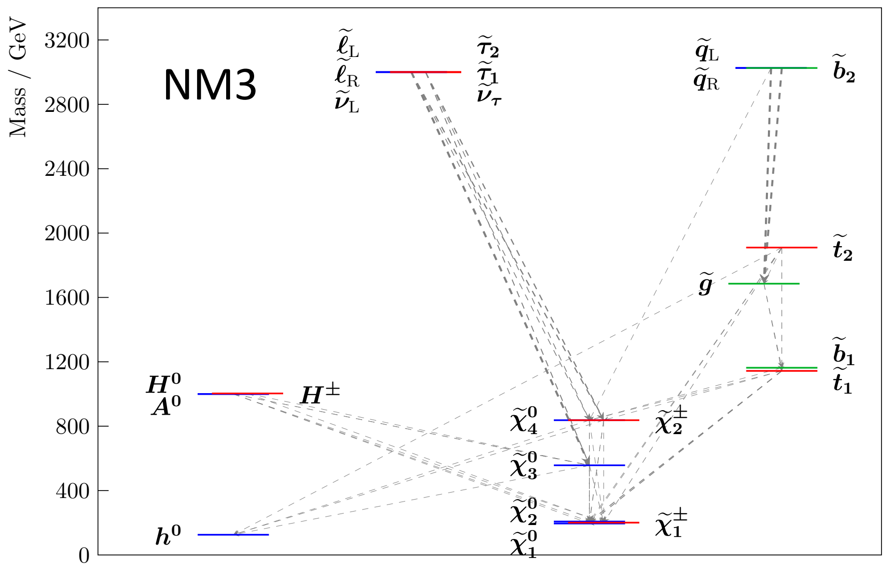
- Need well designed searches, and we had many at 8 TeV
- Need to understand interplay between them to really prepare for a SUSY discovery
- Diverse range of approaches to background prediction—should continue to improve with better tools and understanding of our data

Extra slides

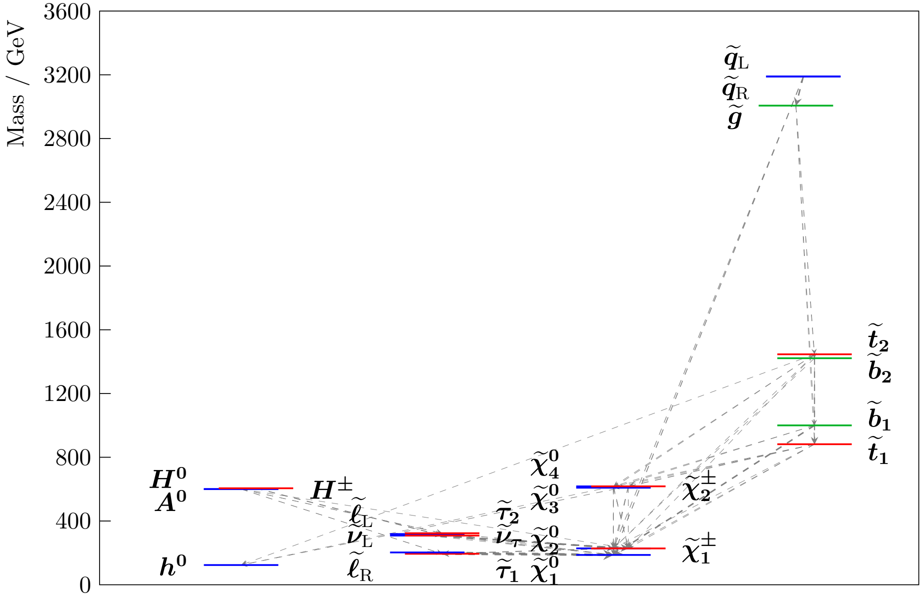
SUS-14-002 Models



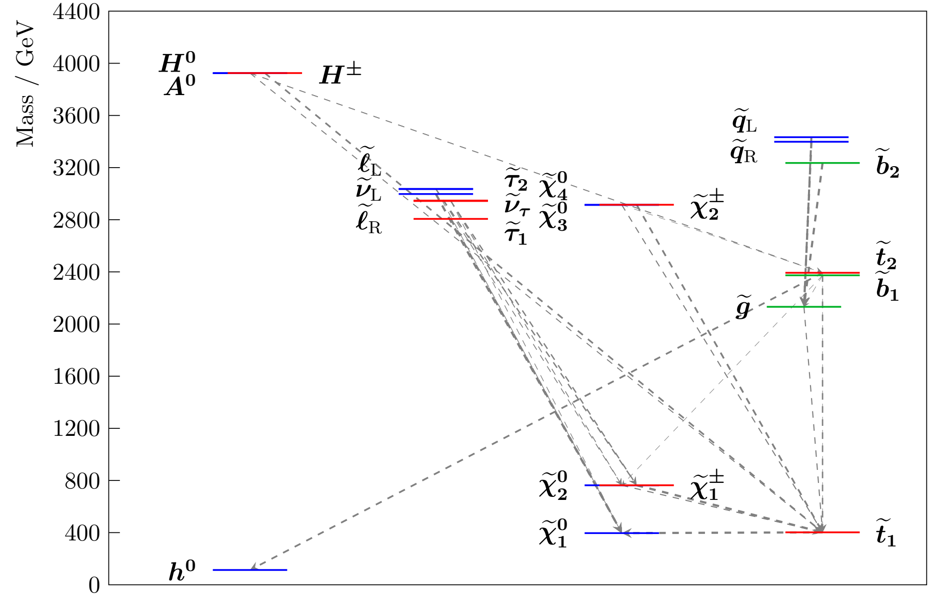




SUS-14-002 Models



Stau-coannihilation



Stop-coannihilation