Discovering MSSM Higgses with jet substructure

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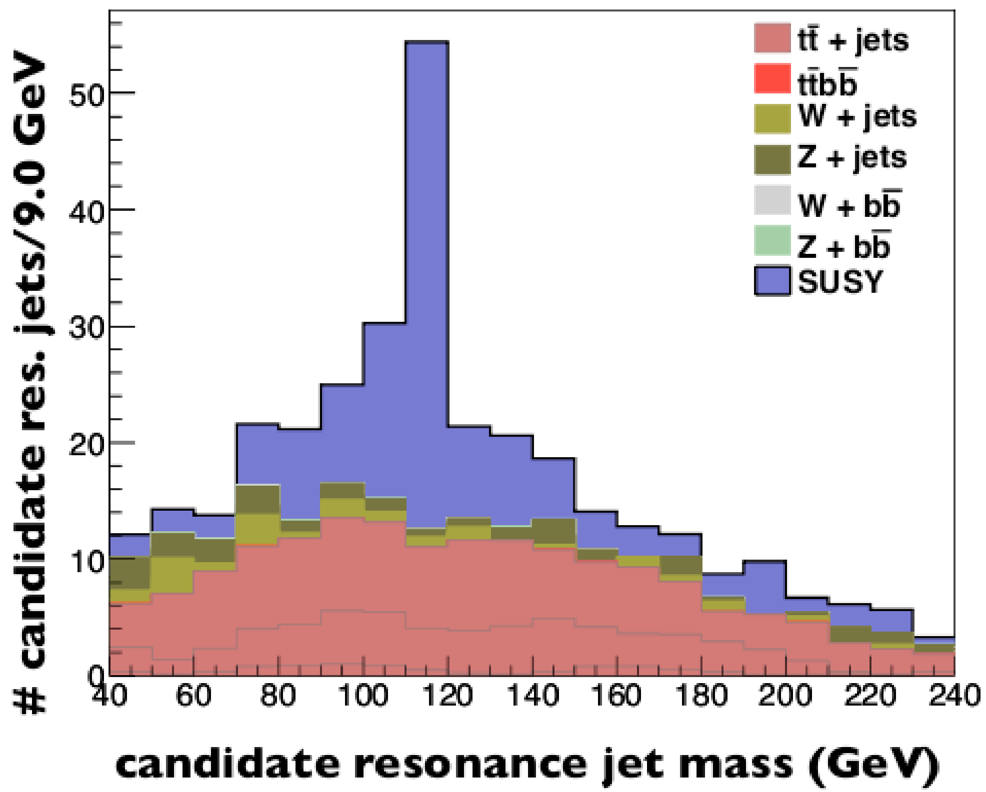
Fermilab

Punchline

MSSM Higgses h (& H,A) -> b bbar produced in the cascade decays of heavy sparticles are ideally suited to jet substructure/boosted techniques

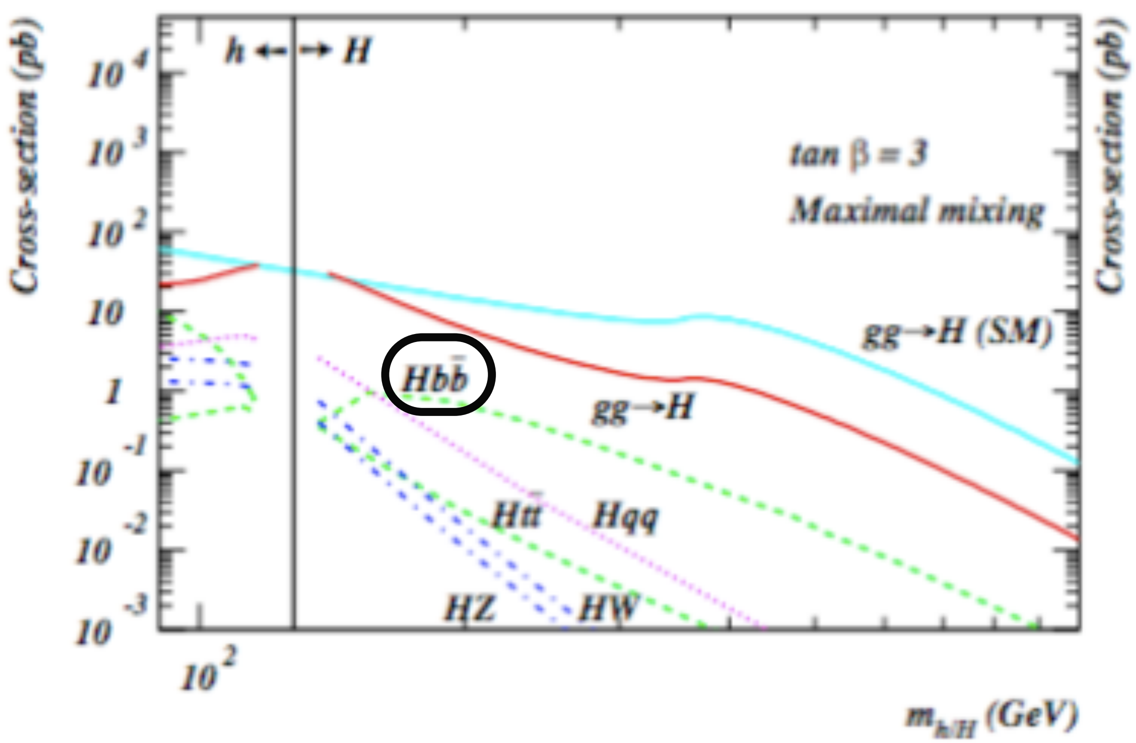
Could be **the first** h discovery mode, well before
h -> γγ, h -> ττ !!

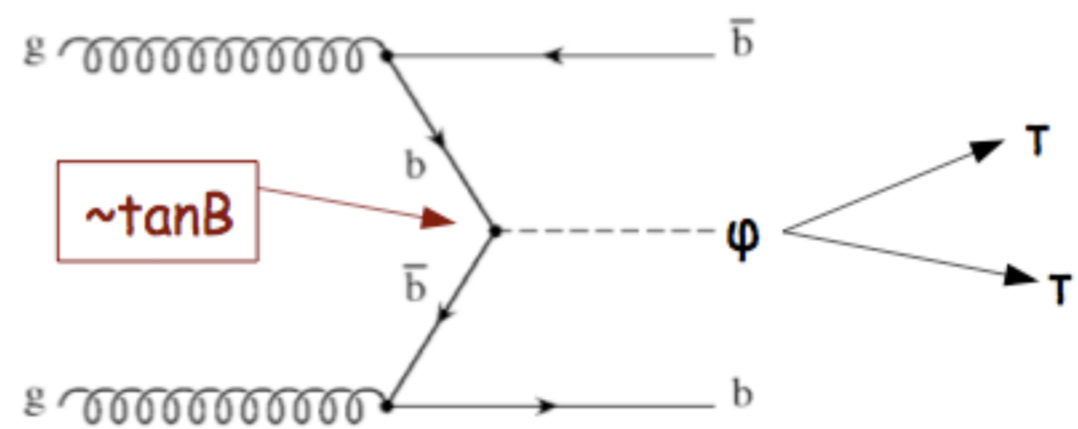
$L = 10\ \text{fb}^{-1}, \sqrt{s} = 14\ \text{TeV}$



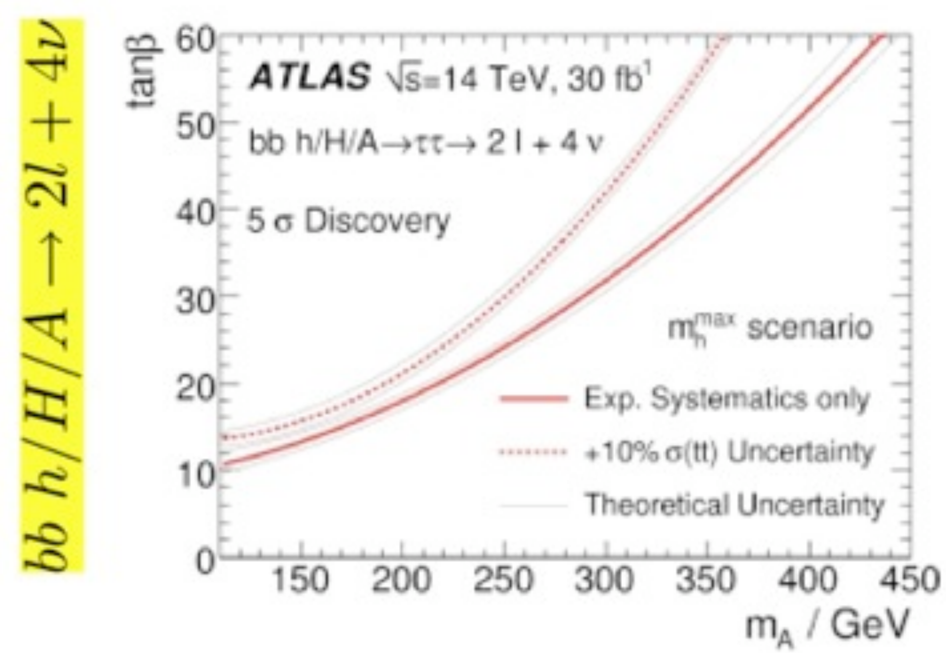
Higgs in the MSSM

- MSSM Higgs has to be light $m_h \lesssim 130$ GeV, decays dominantly to $b\bar{b}$
- conventional searches focus on Higgses produced in association with SM particles



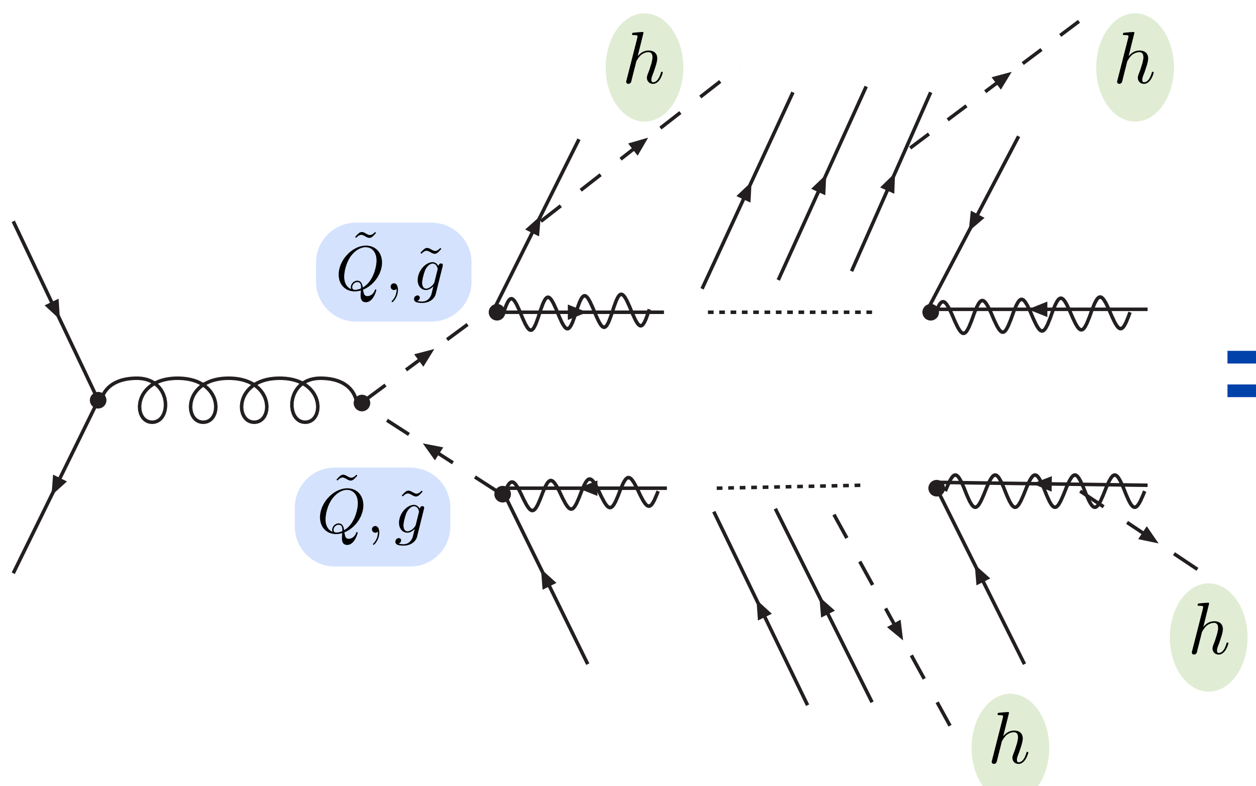


unless $\tan\beta \gg 1$ and light m_A, no real improvement over SM light-Higgs discovery



Higgs in a cascade

- Squarks/gluinos carry color, so they have a large production cross section despite being heavy
- Sparticles cascade decay, decay products can include Higgses
- Sparticles are heavy --> light decay products (h!) tend to be boosted
- All events have MET --> powerful discriminant vs. SM



= a new source of boosted Higgses

(Butterworth, Ellis, Raklev '07)

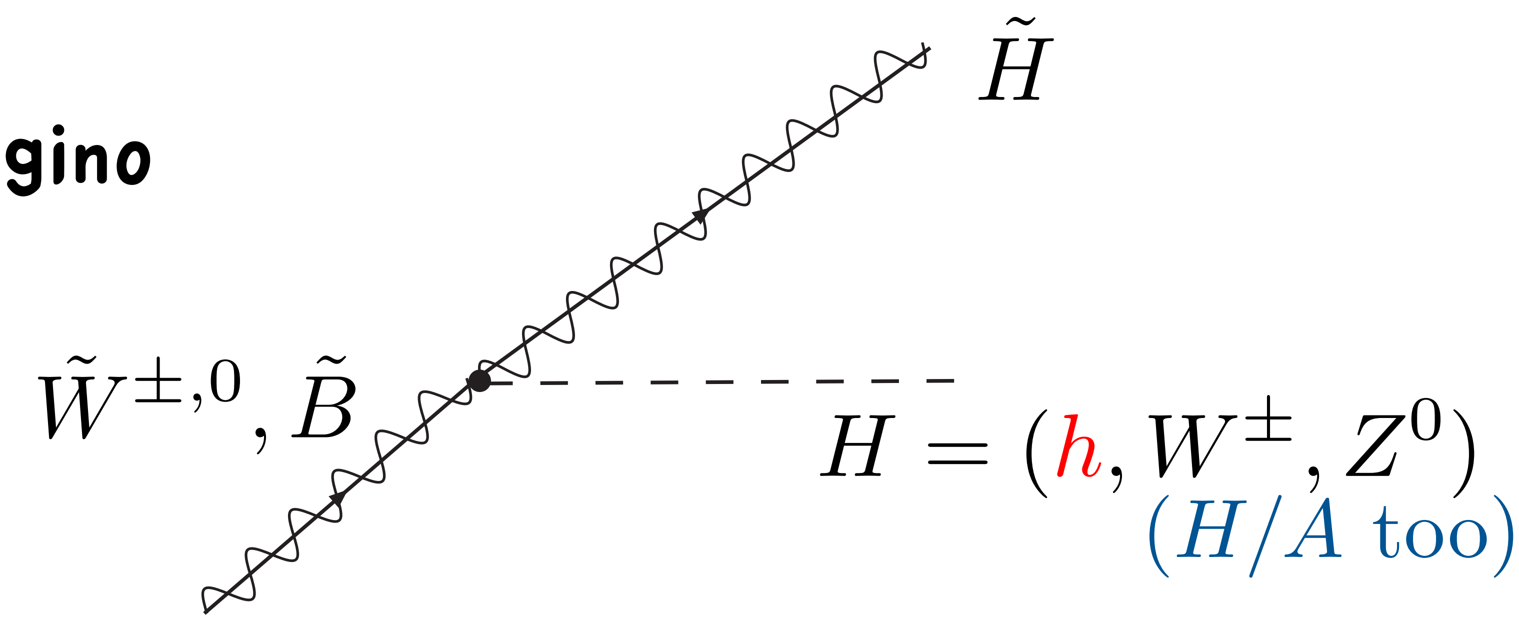
MSSM Higgses from cascade decays + jet substructure =

excellent opportunity for Higgs discovery

MSSM + boosted Higgses

1.)

Higgs-Higgsino-Gaugino interaction

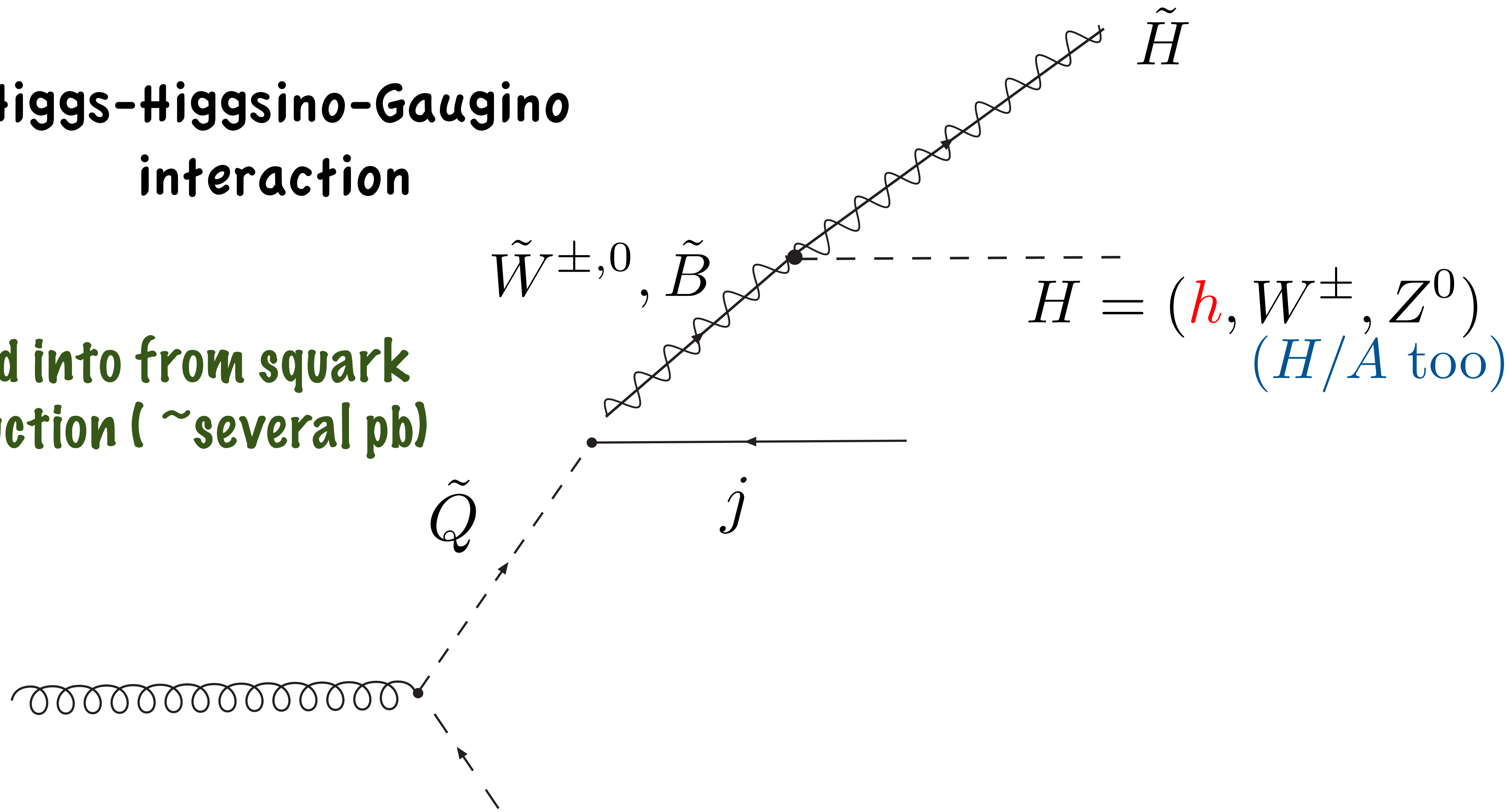


MSSM + boosted Higgses

1.)

Higgs-Higgsino-Gaugino interaction

... fed into from squark production (~several pb)



MSSM + boosted Higgses

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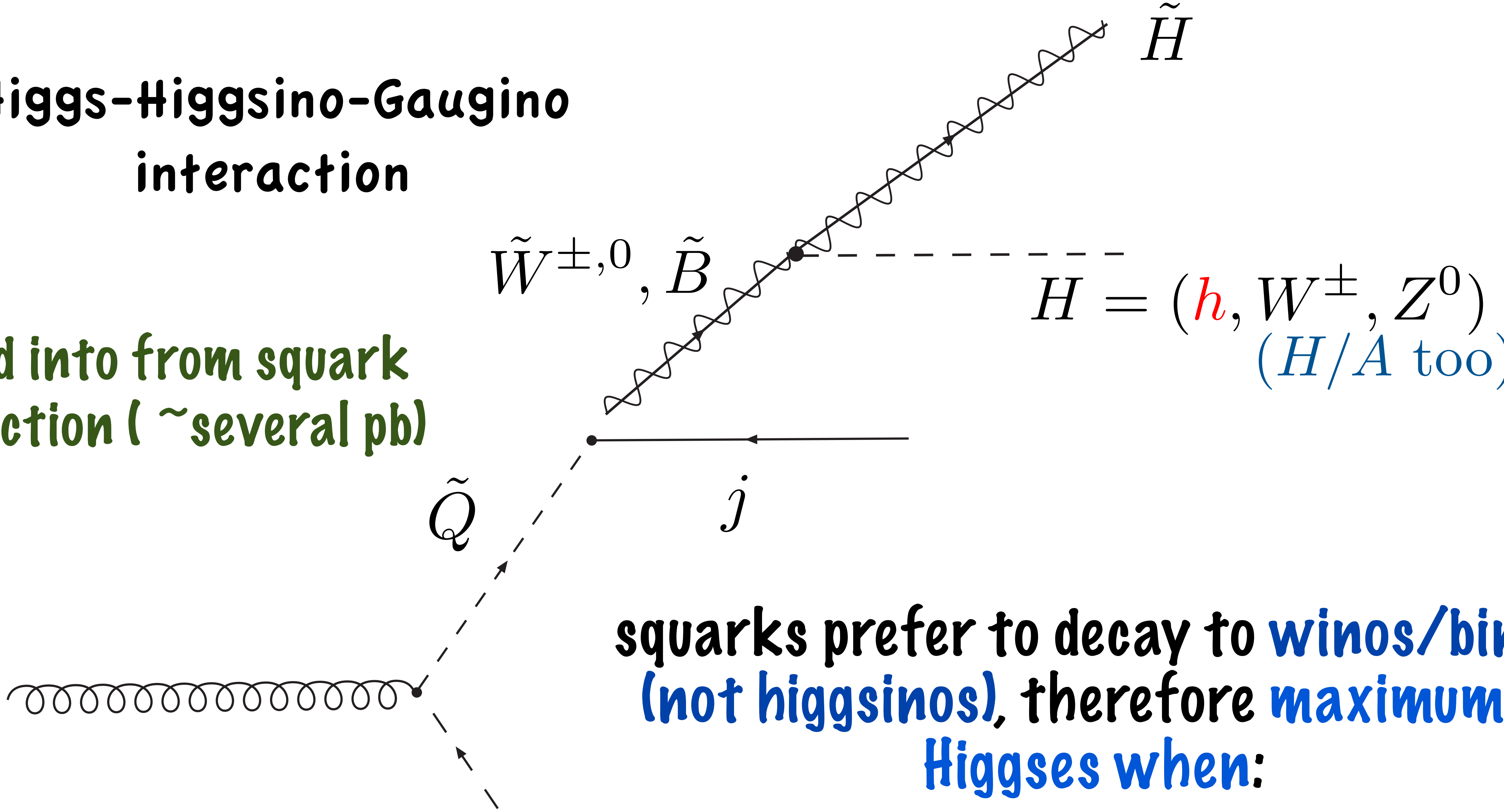


... fed into from squark production (~several pb)

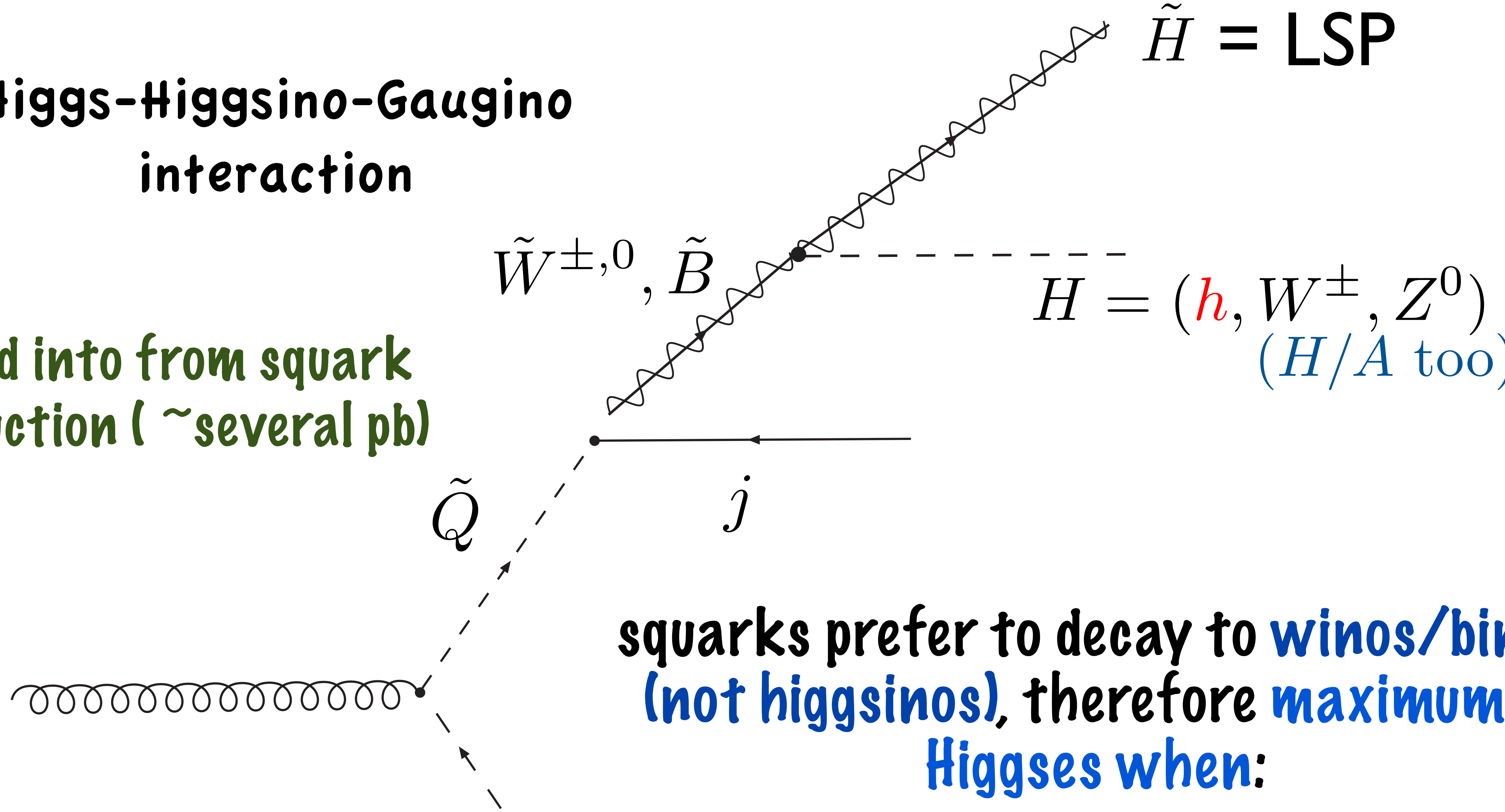
squarks prefer to decay to winos/binos (not higgsinos), therefore maximum # Higgses when:

$$M_{\tilde{Q}} > M_2, M_1 > \mu$$

MSSM + boosted Higgses

1.)

Higgs-Higgsino-Gaugino interaction



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$$M_{\tilde{Q}} > M_2, M_1 > \mu$$

MSSM + boosted Higgses

- we're not in mSUGRA (see talk by Raklev)

- Higgsino LSP is usually thought to be a bad DM candidate --
  annihilates too efficiently through gauge interactions
  = not enough DM

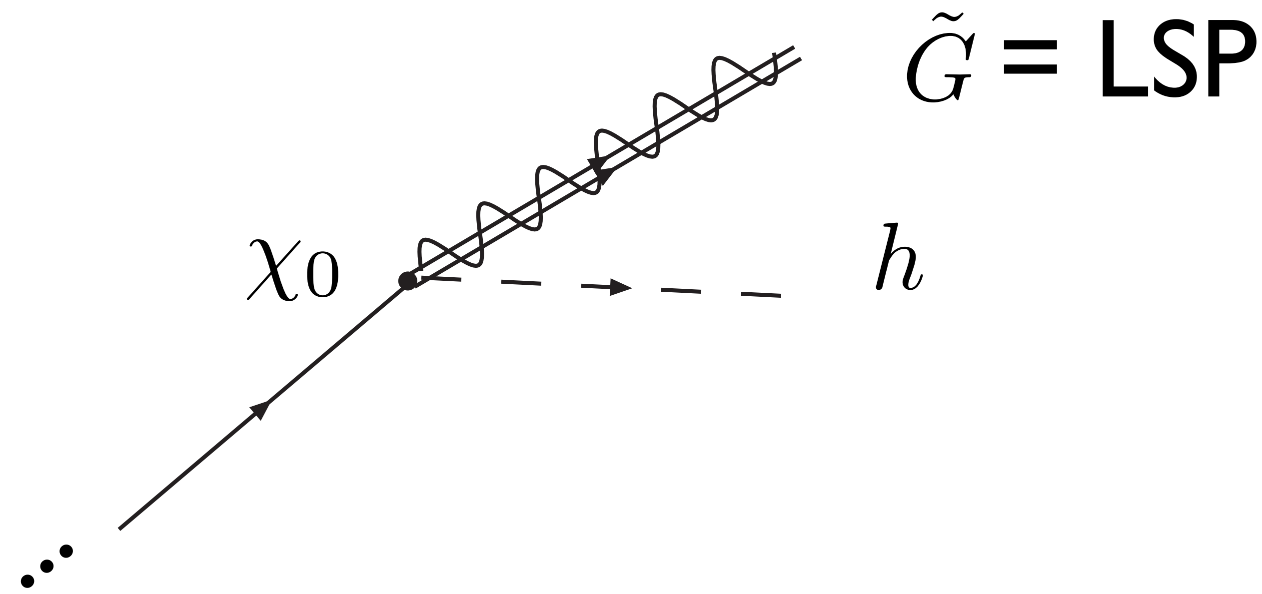
our focus is on Higgs discovery!

only require relic abundance $\lesssim \Omega_{DM}^{obs}$

- allows us to consider a much wider parameter region

MSSM + boosted Higgses

2.) when the scale of SUSY-breaking is light (gmsb), gravitino is the LSP



MSSM + boosted Higgses

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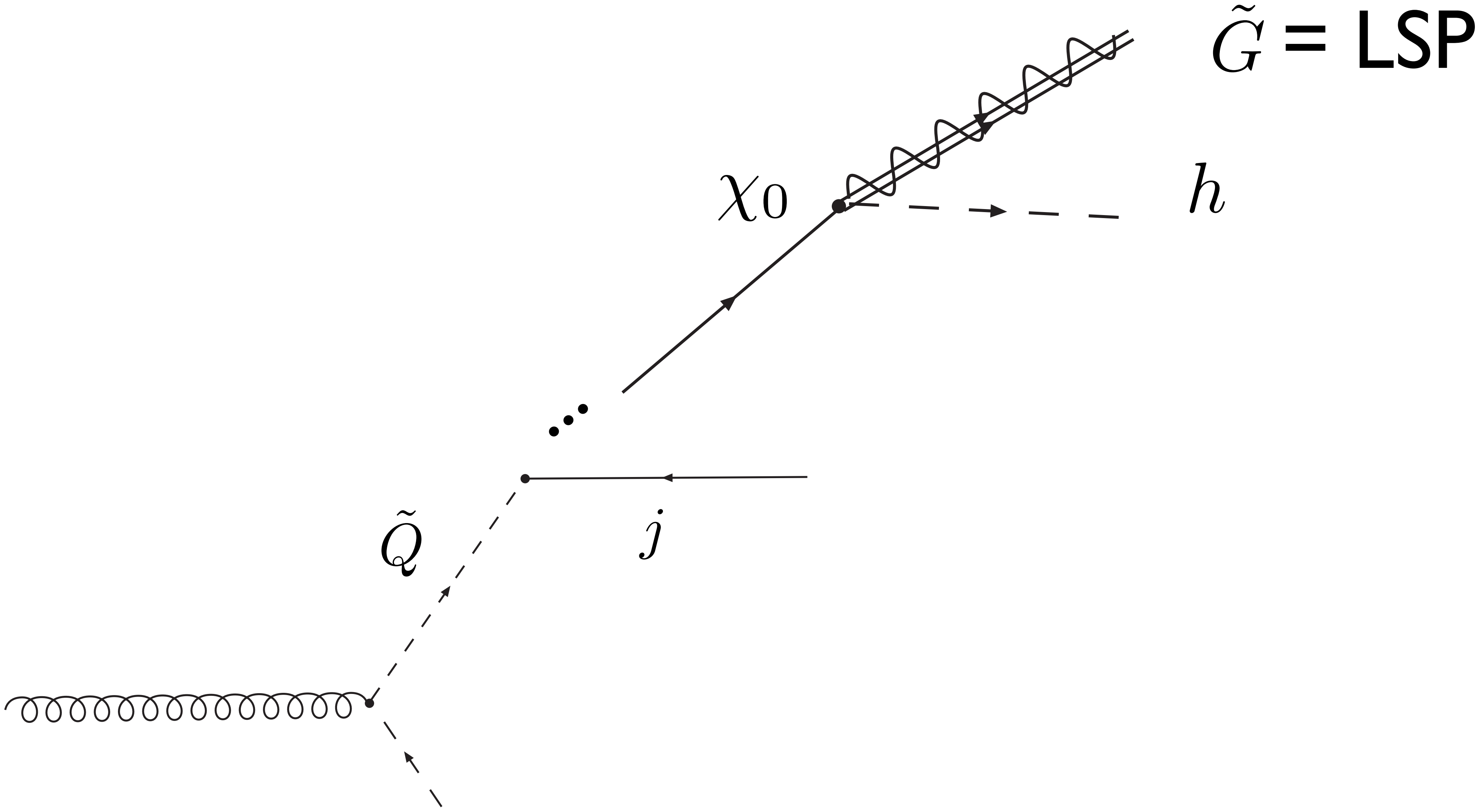

MSSM + boosted Higgses

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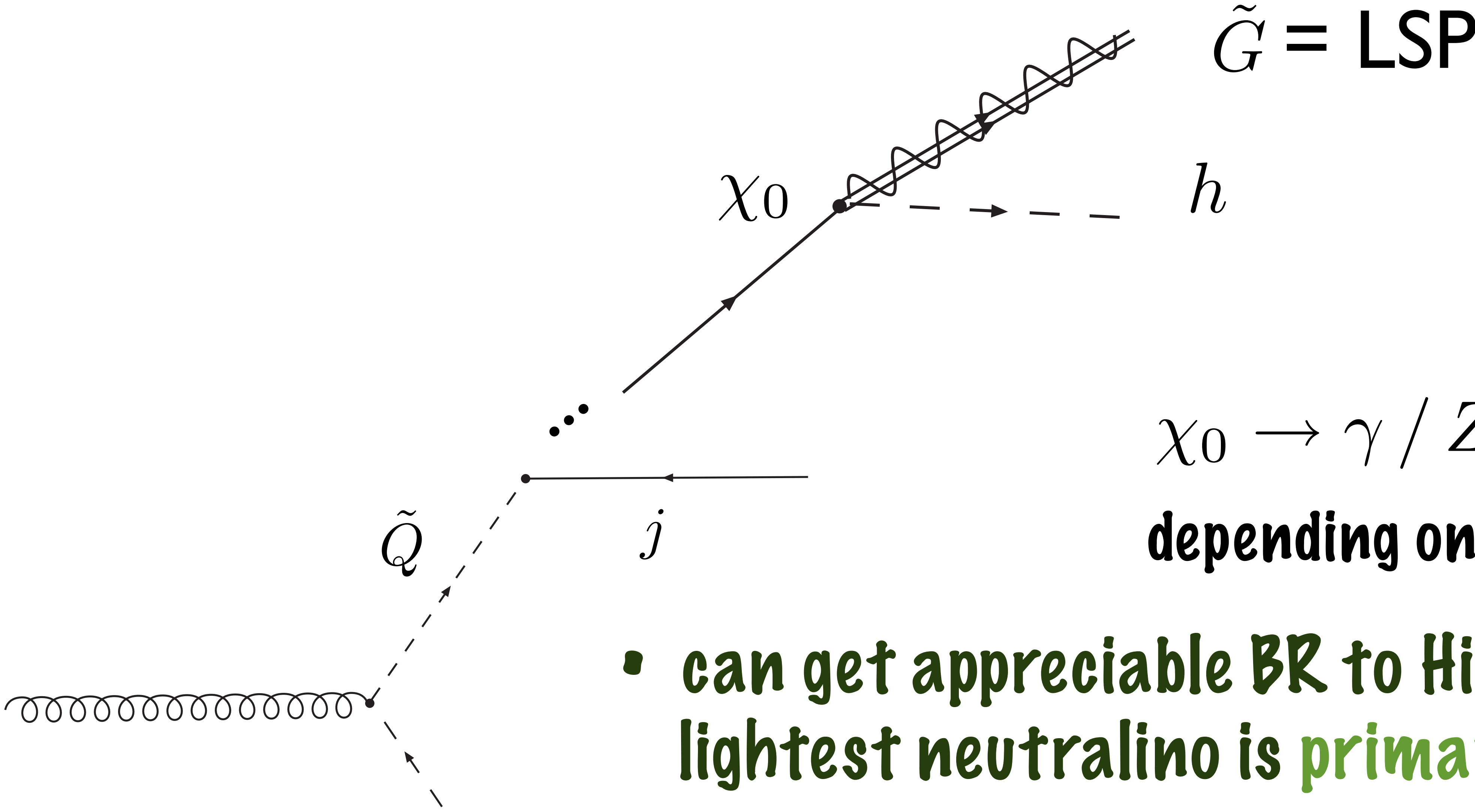


$\chi_0 \rightarrow \gamma \,/\, Z \,/ h$

depending on $M_1, M_2, \mu, \tan\beta$

- can get appreciable BR to Higgses when the lightest neutralino is primarily Higgsino

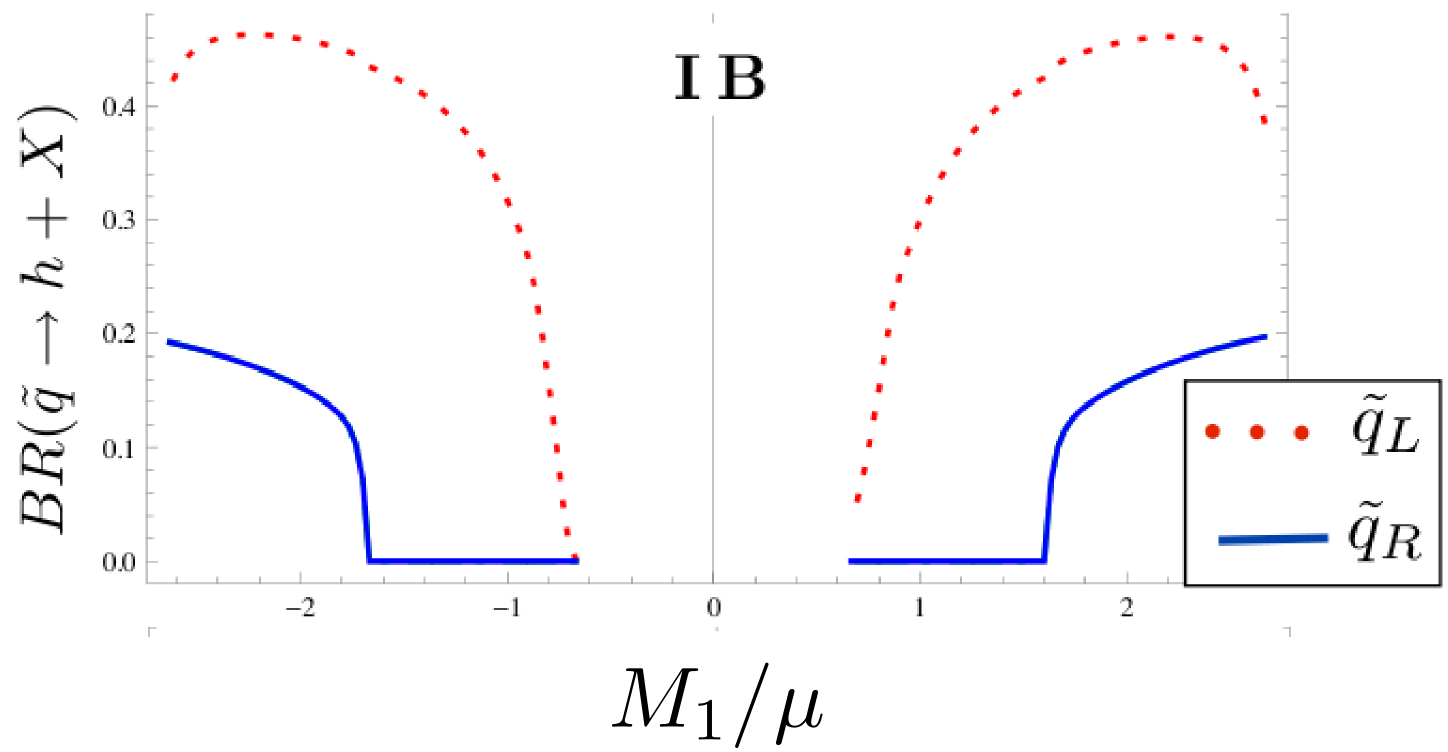
$|\mu| \ll M_1, M_2$ (Matchev, Thomas '99 Meade, Reece, Shih '09)

- Mixed decay mode $\chi_0 \chi_0 \rightarrow h + \gamma + \not{E}_T + X$ is especially clean

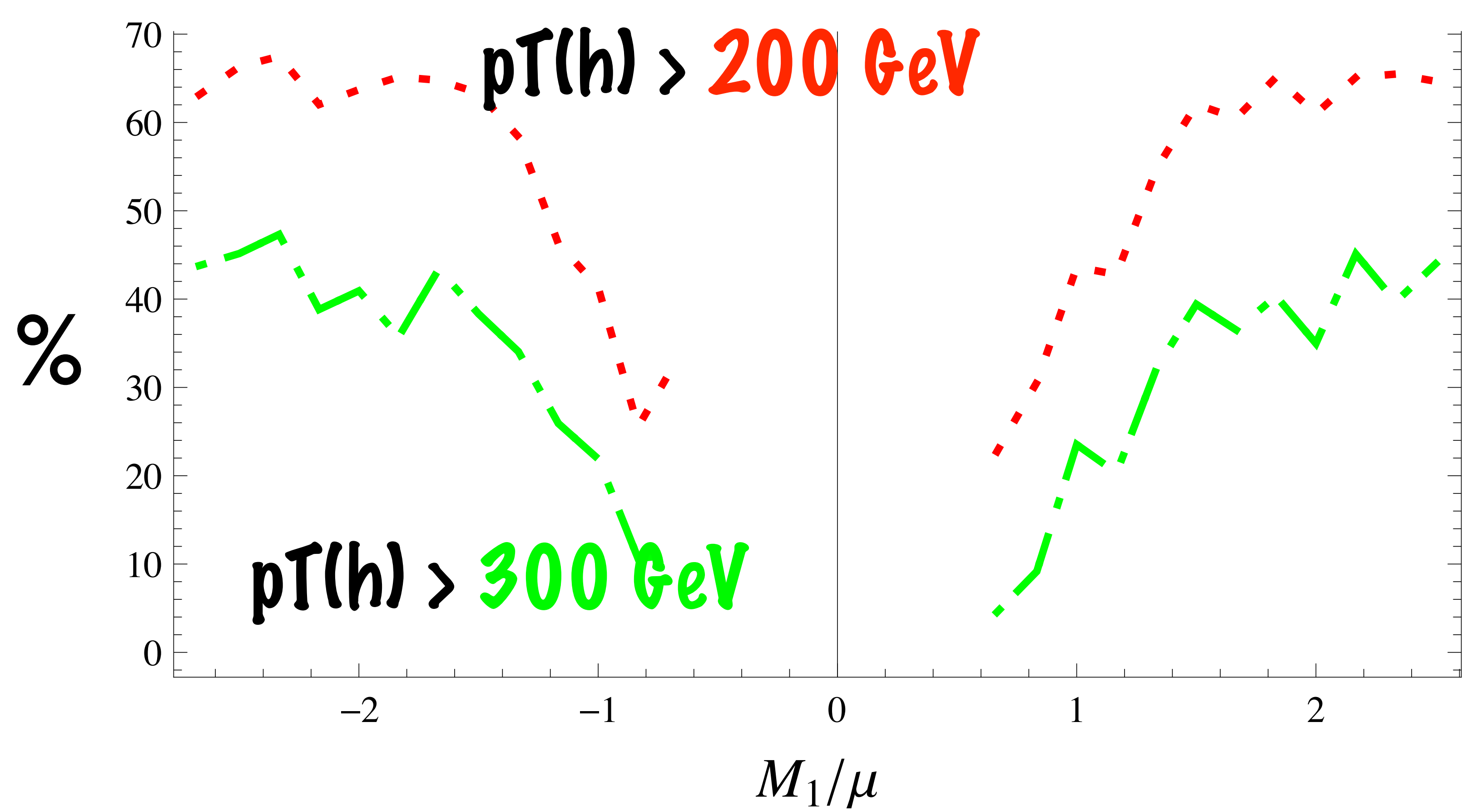
MSSM + boosted Higgses: χ_0 LSP

Ex.)

$$M_{\tilde{Q}} = 1\ \text{TeV}$$
$$\tan\beta = 10$$
$$\mu = 150\ \text{GeV}$$
$$M_{\tilde{L}} = 1\ \text{TeV}$$
$$M_2 = 2M_1, M_3 = 7M_1$$

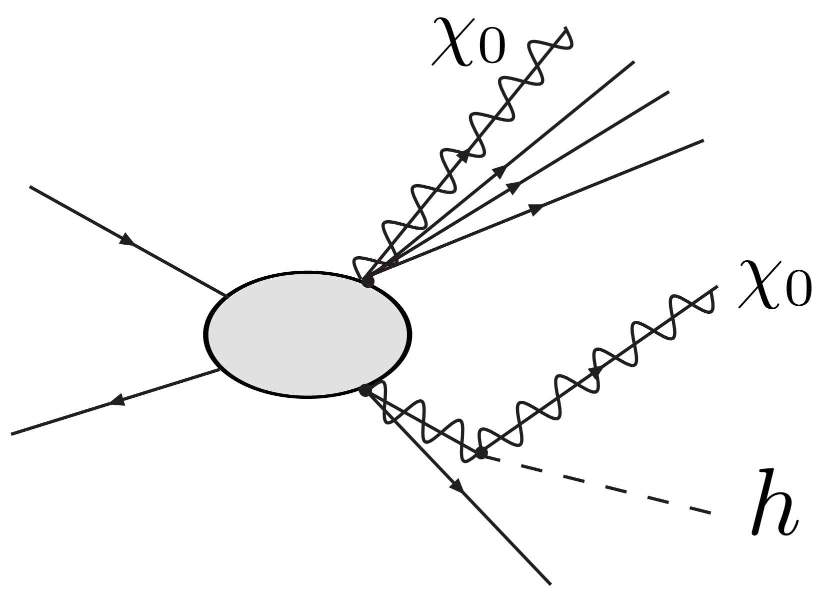


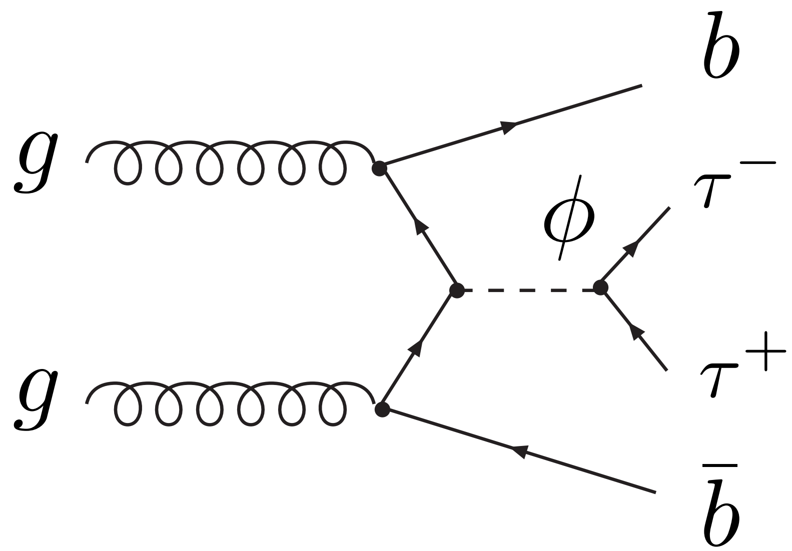
Boosted Fraction



Higgs source comparison

how we want to look for the MSSM Higgs	how people usually look for the MSSM Higgs





- ☑ Look for fat jets (R =1.2, C/A, p_T > 200 GeV)
- ☑ Impose cuts which suppress SM background:

  ex.) MET > 300 Gev, H_T > 1 TeV, 3+ jets

- ☑ Hunt for substructure in all b-tagged jets

  use approach similar to t tbar h -- Plehn, Salam, Spannowsky

Substructure for SUSY

SUSY events are busy. Lots of extra high-p_T partons flying around from decays of $\tilde{q}/\chi^{\pm,0}/t$

Specifically:

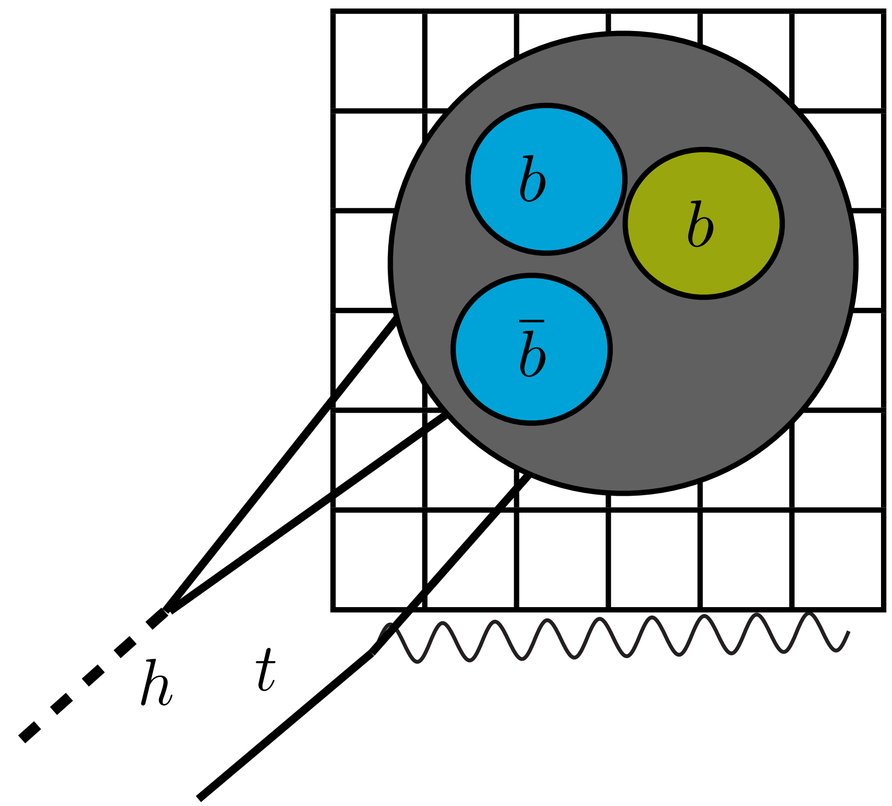
1. undo clustering: j -> $j_1 + j_2$

2a. if a mass drop (BDRS):

- keep j_2 = constituent
- j_1 -> j, goto 1.)

2b. otherwise, j_1 -> j, goto 1.

3. continue until $p_{T,j}$ < 30 GeV



take 2 b-tagged constituents with most similar p_T, filter

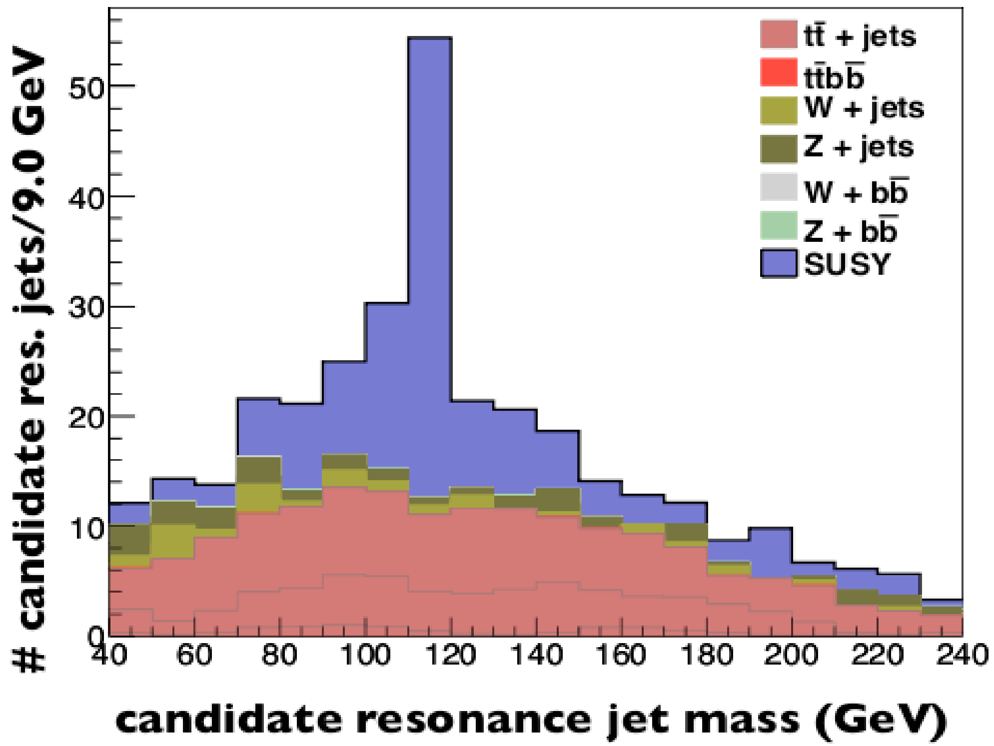
↓

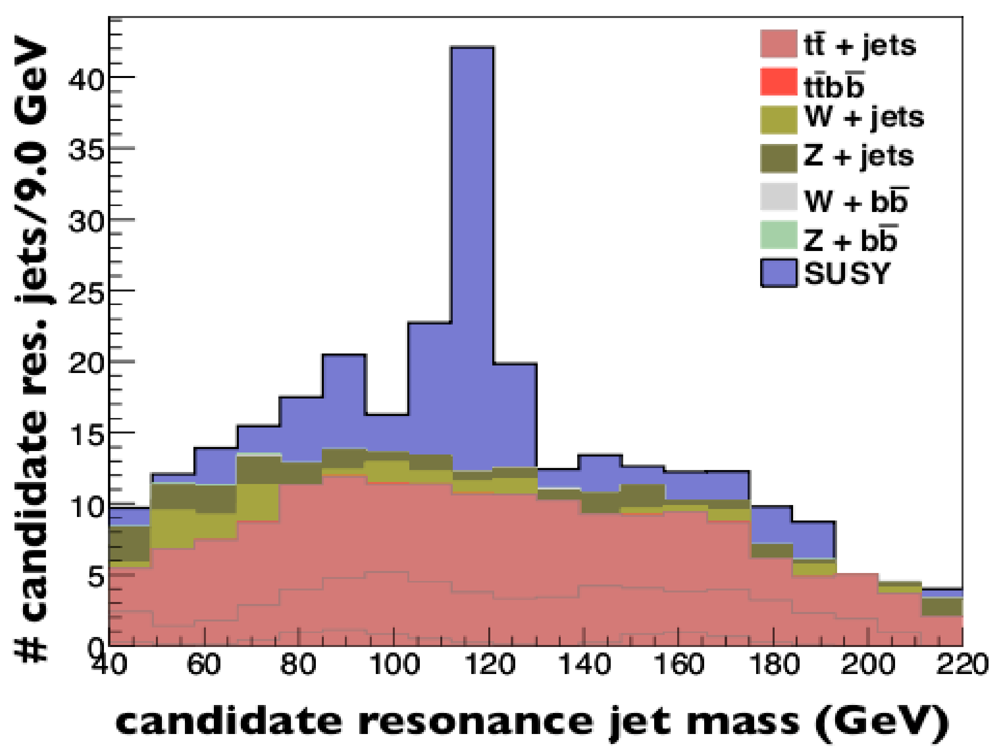
candidate higgs

now, results..

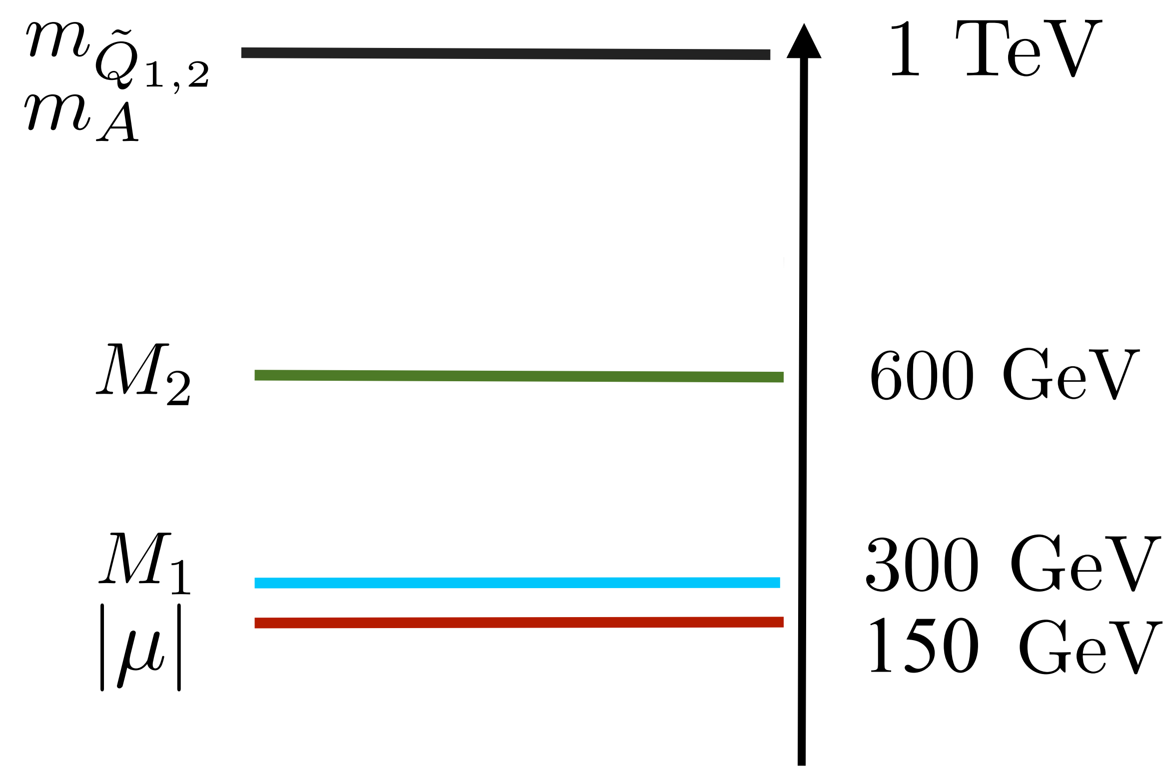
Neutralino LSP Results: #1

$L = 10\ \text{fb}^{-1}, \sqrt{s} = 14\ \text{TeV}$





$$BR(\tilde{u}_L, \tilde{d}_L \to h + X) \sim 23\%$$
$$BR(\tilde{u}_R, \tilde{d}_R \to h + X) \sim 16\%$$



$$BR(\tilde{u}_L, \tilde{d}_L \to h + X) \sim 16\%$$
$$BR(\tilde{u}_R, \tilde{d}_R \to h + X) \sim 9\%$$

Neutralino LSP Results: #1

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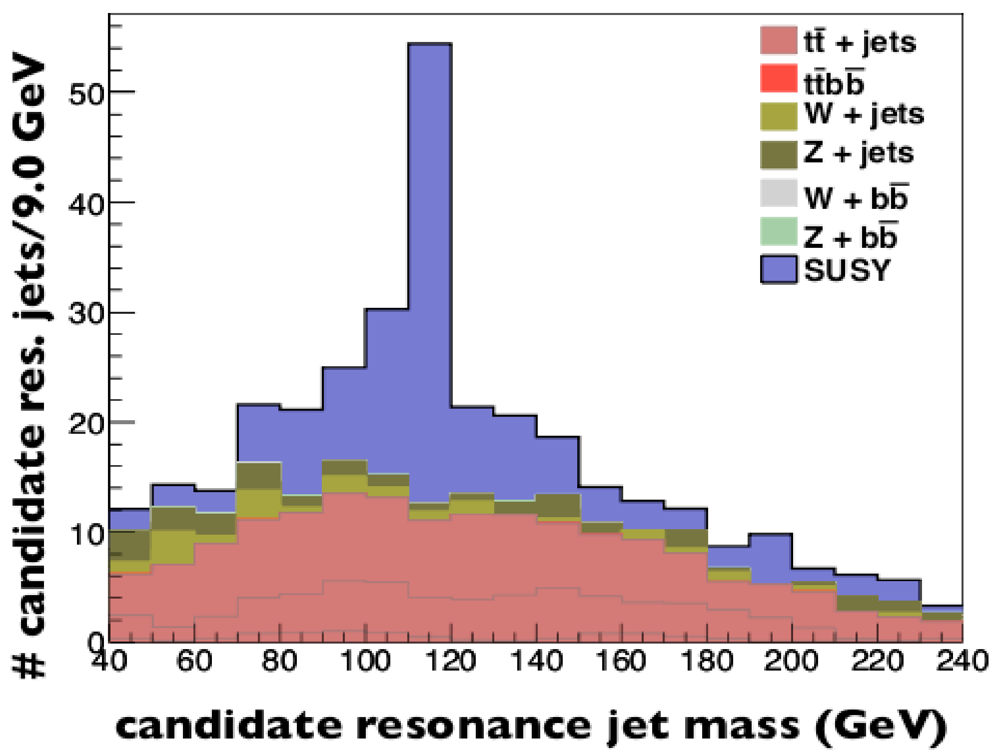

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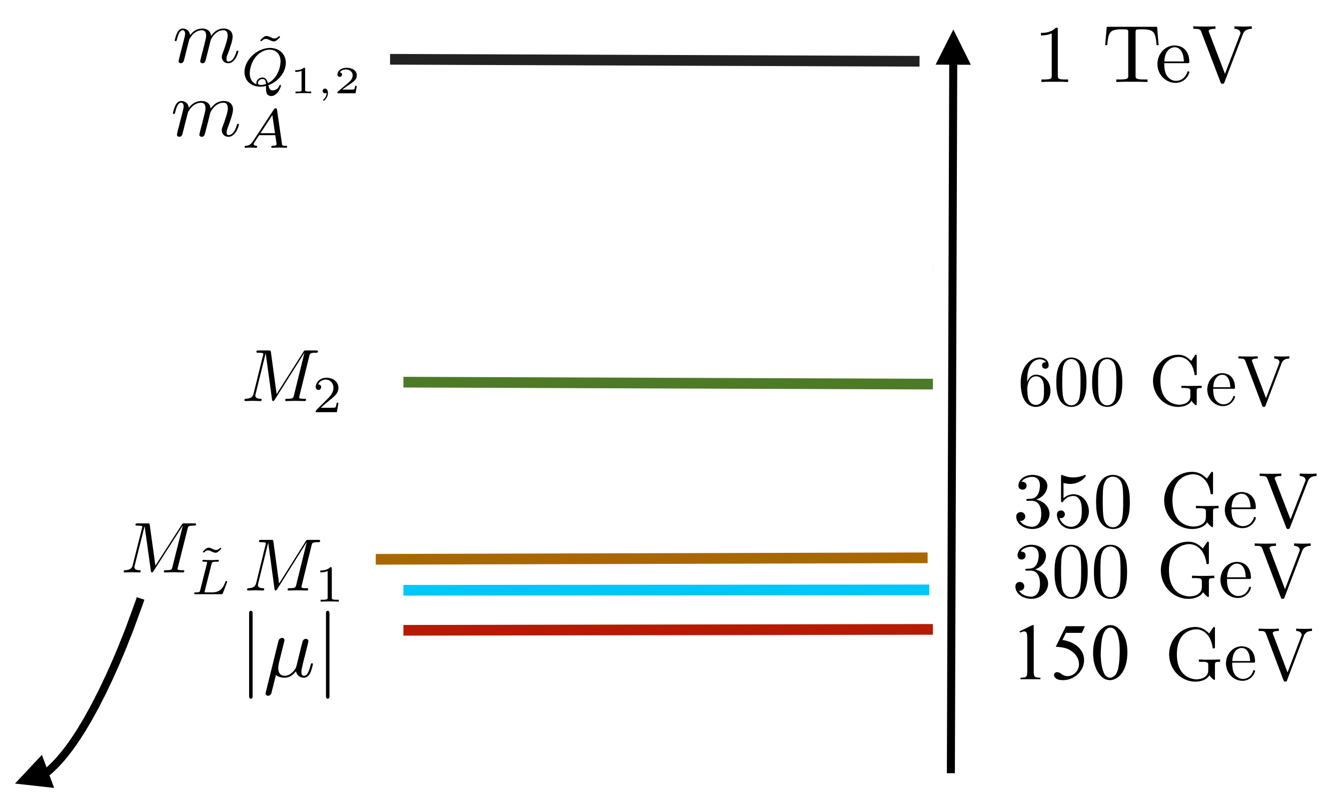
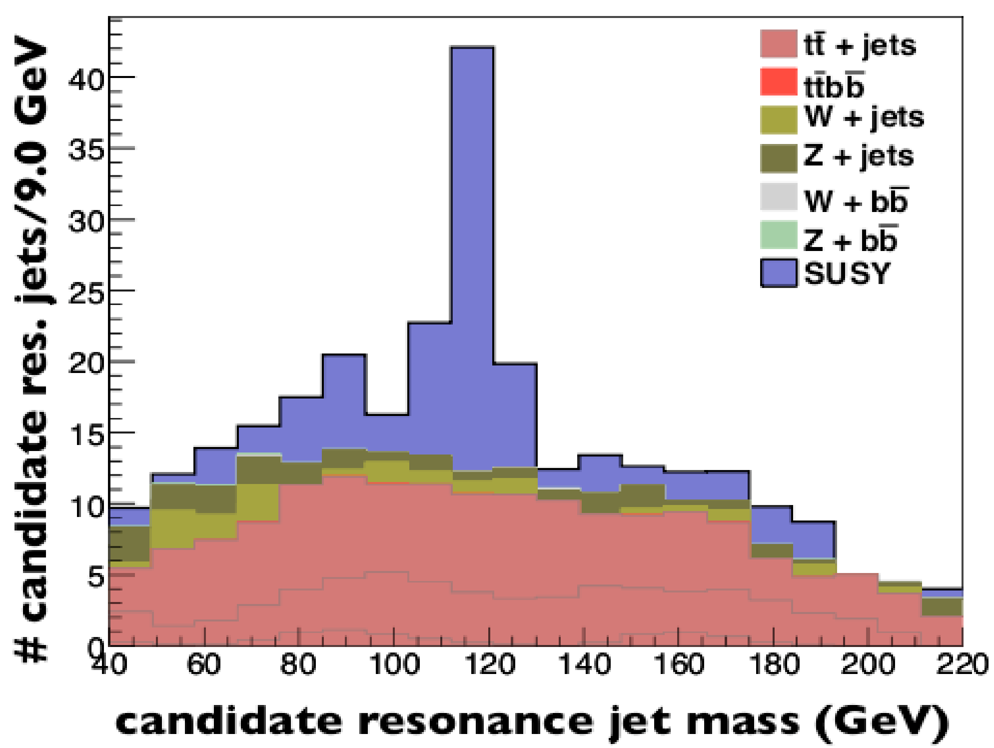
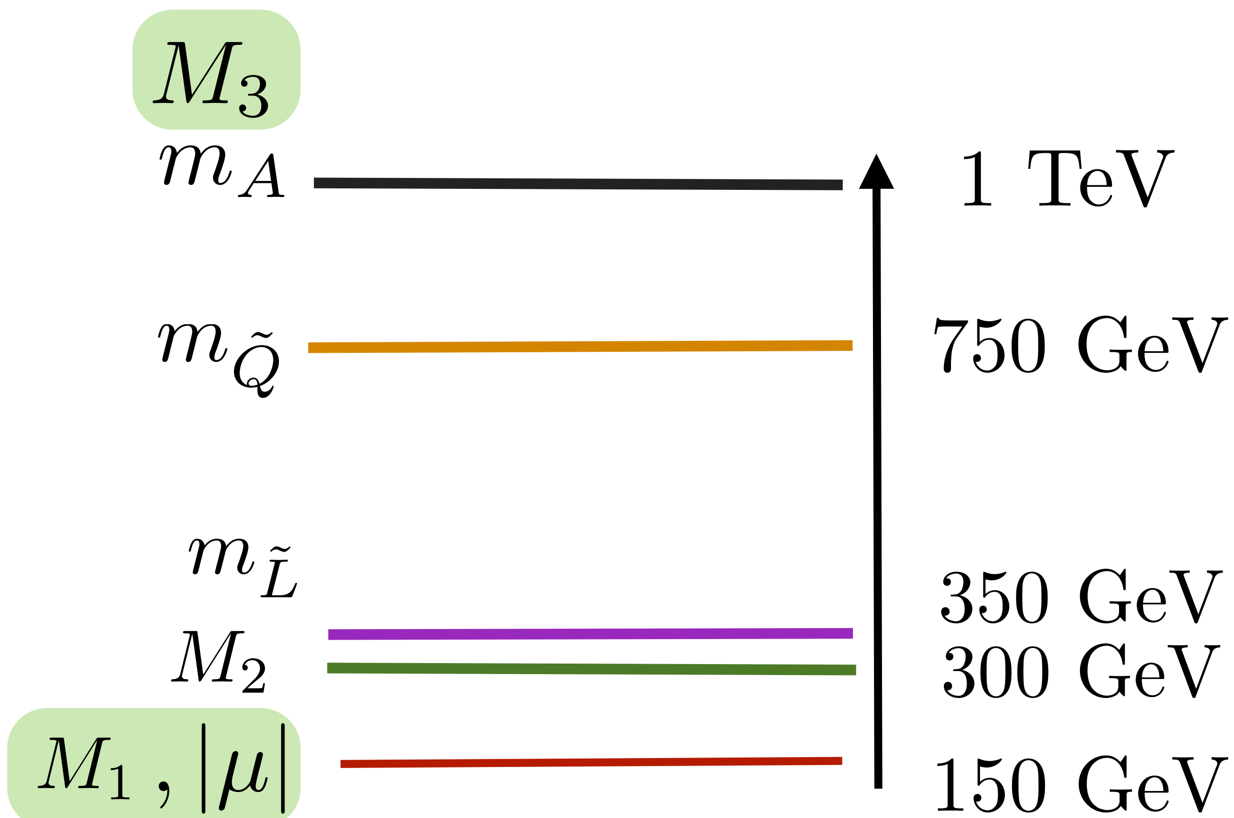


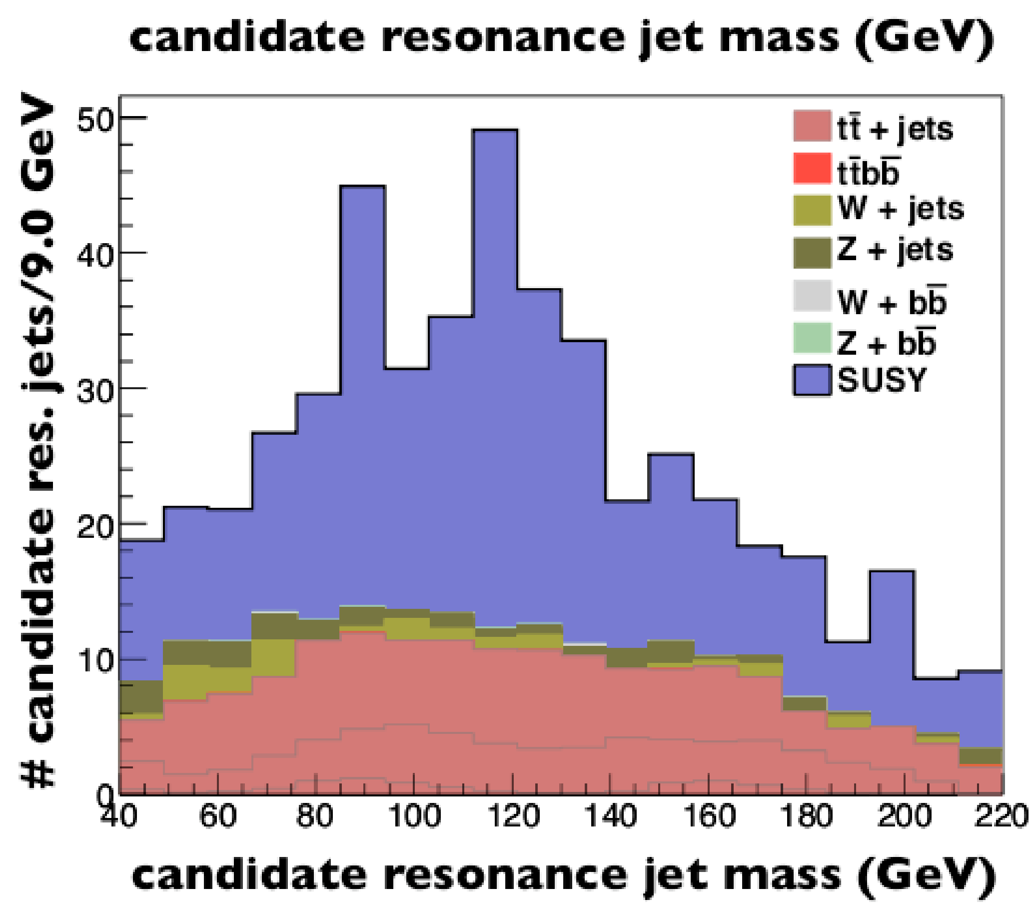


$$BR(\tilde{u}_L, \tilde{d}_L \to h + X) \sim 16\%$$
$$BR(\tilde{u}_R, \tilde{d}_R \to h + X) \sim 9\%$$

Neutralino LSP Results: #2

busier final states...



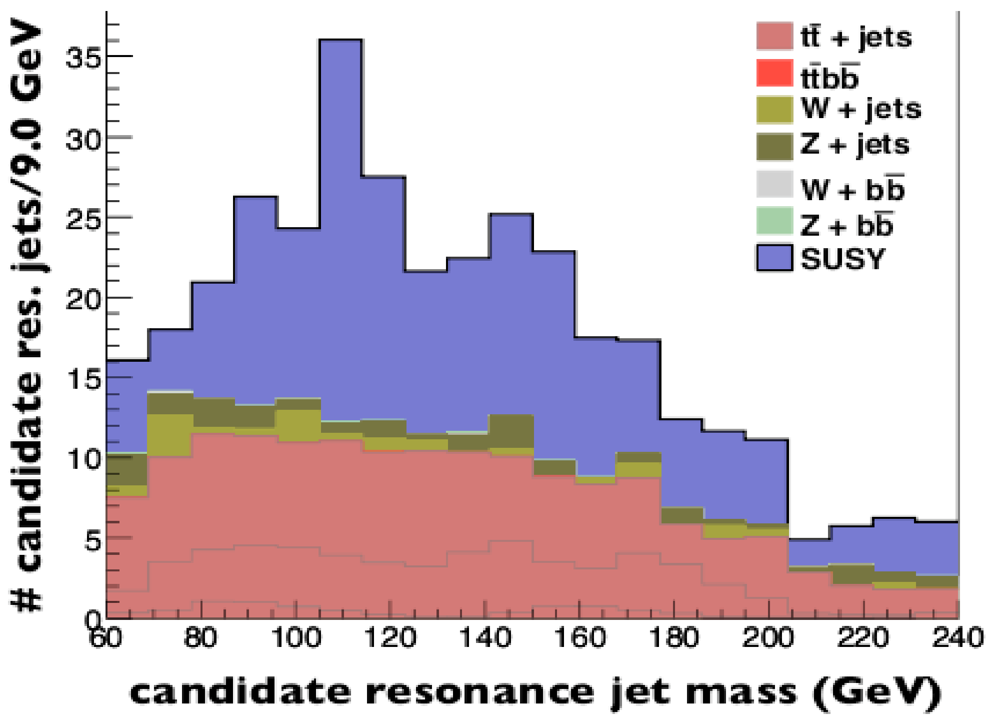


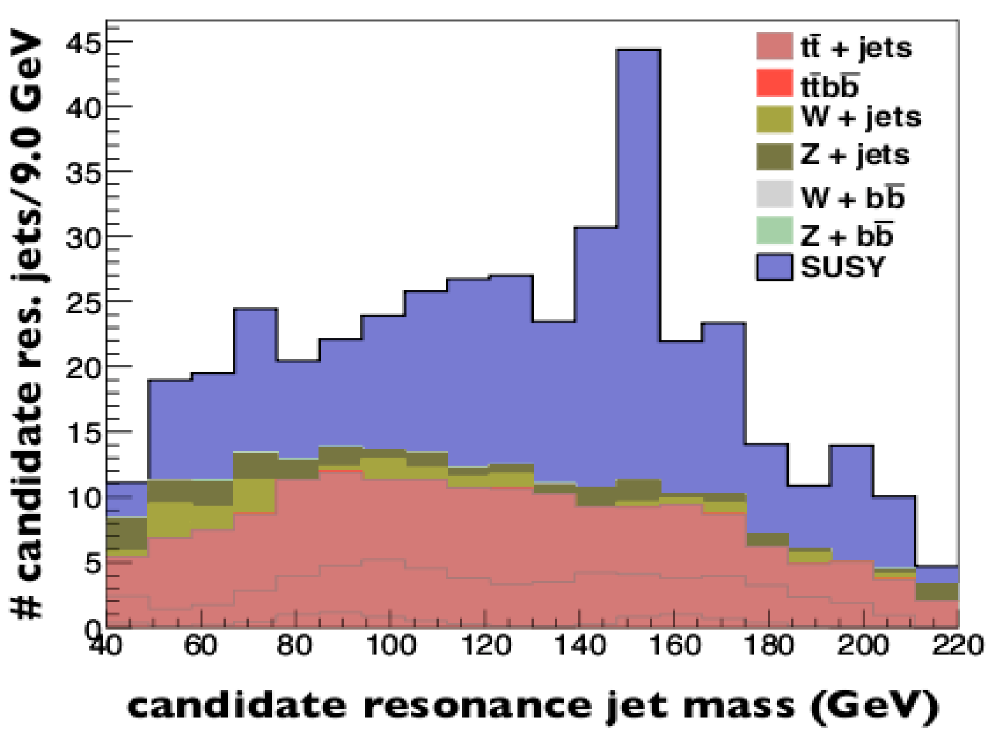
contamination from extra partons,
but Higgs peak still visible

improvements?

Neutralino LSP Results: #3

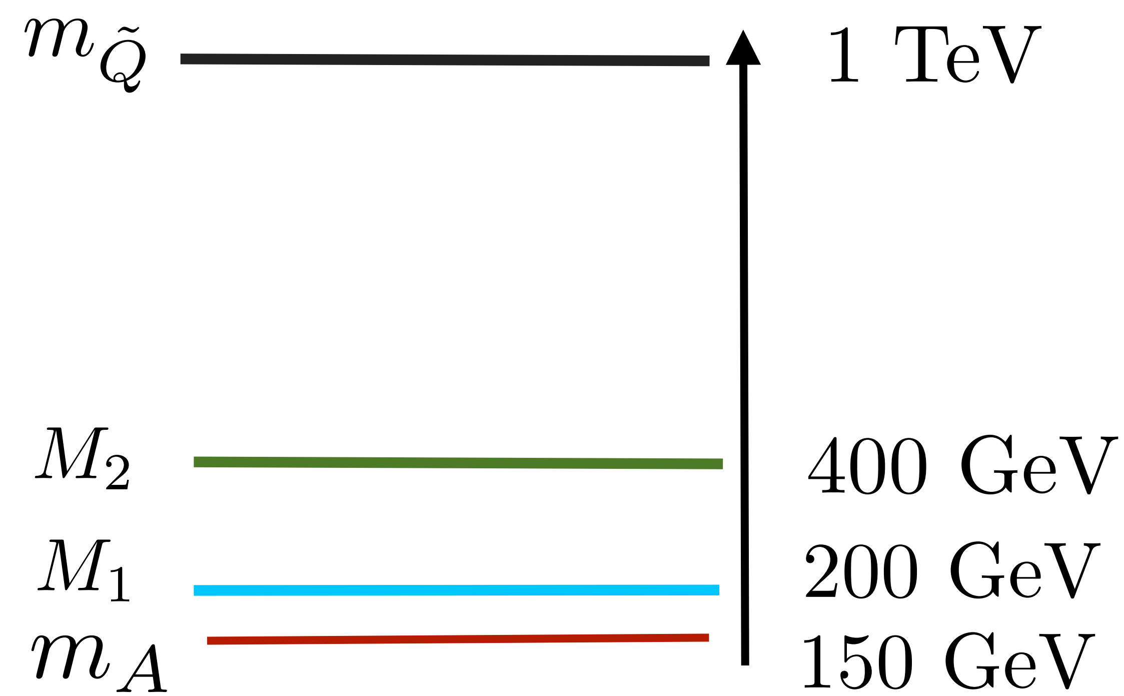
$\mu = 200\ \text{GeV},\ \tan\beta = 5$





$\mu = -150\ \text{GeV},\ \tan\beta = 6.5$

technique holds up at low m_A and $\tan\beta$, where traditional approaches have the most trouble



Can even discover heavier A,H states!

Conclusions

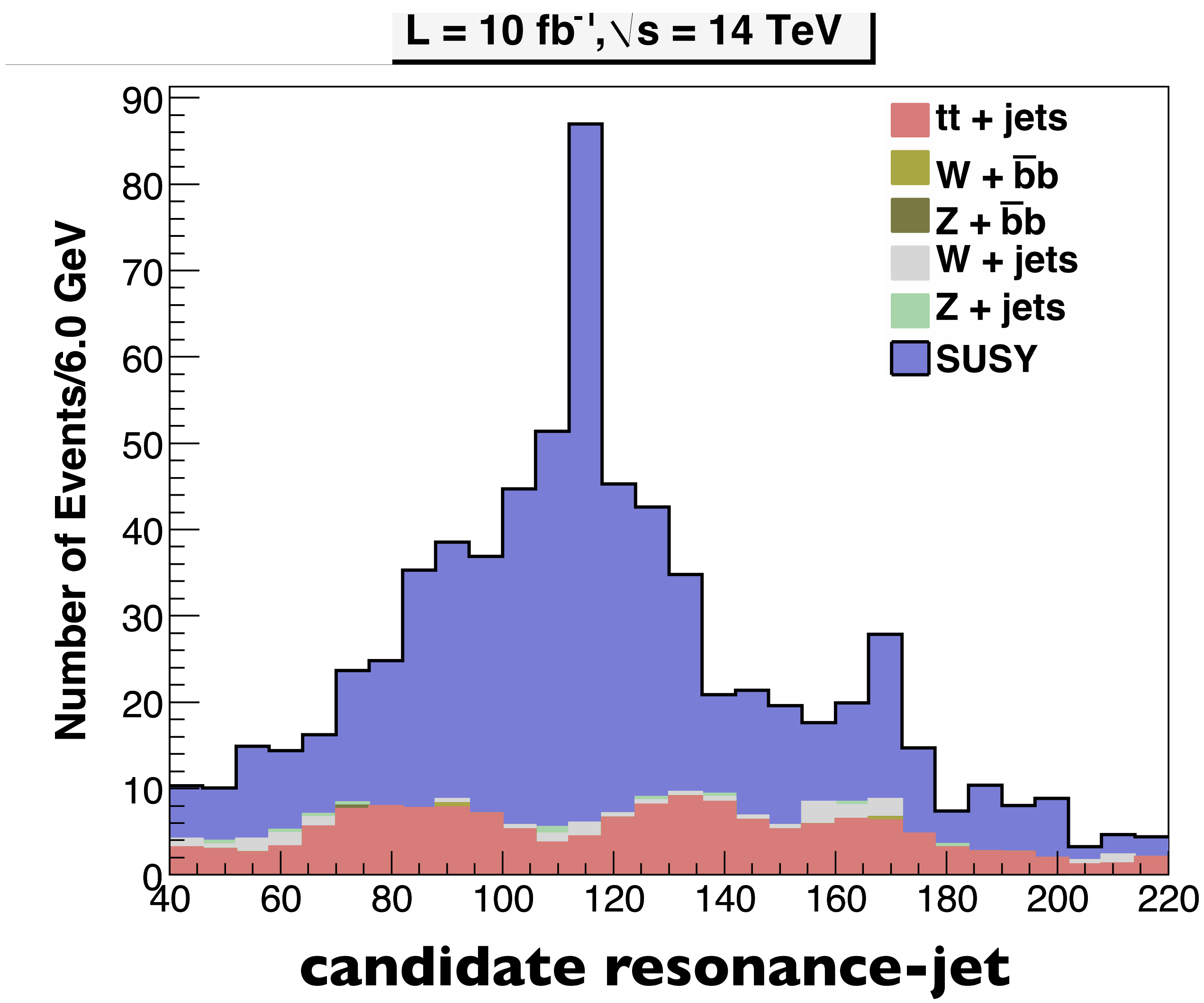
- MSSM Higgs must be light, decays mainly to b-bbar
- Higgses from sparticle cascades have potentially large rate, high boost --> ideal for substructure
- For a wide range of SUSY parameters, cascade-Higgs discovery channels can easily be as significant (or more so !) than conventional $h \to \gamma\gamma$, $h \to \tau\tau$ (H/A discovery too!)
- plenty of room for optimization
- Busy final states are challenging, ideas?

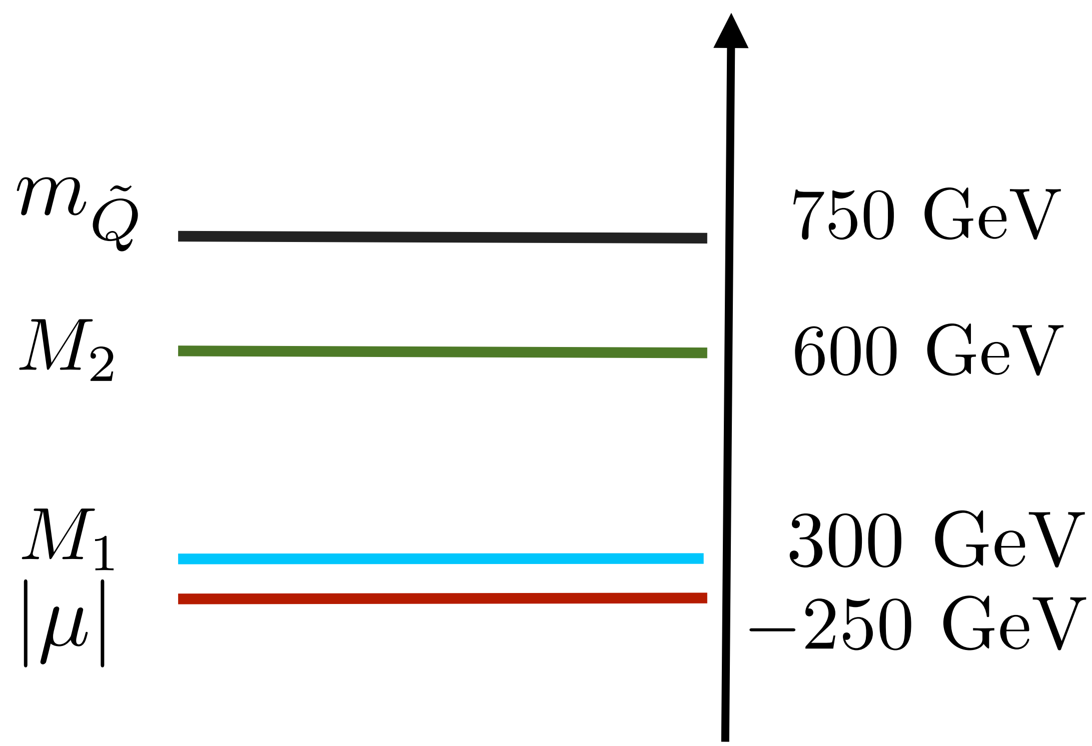
BACKUP SLIDES

Gravitino LSP Results:

$$pp \rightarrow \text{SUSY} \rightarrow \chi_0\chi_0 \rightarrow h + \gamma + \not{E}_T + X$$

High-p_T photon makes things easier...
No need for large H_T, jet mult. cuts





1 jet with substructure +

$$\not{E}_T > 100 \text{ GeV}$$
$$p_{T\gamma} > 80 \text{ GeV}$$

Substructure for SUSY

One idea: don't stop at the first mass drop

Specifically:

1. undo clustering: $j \to j_1 + j_2$

2a. if a mass drop (BDRS):

- keep j_2 = constituent
- $j_1 \to j$, goto 1.)

2b. otherwise, $j_1 \to j$, goto 1.

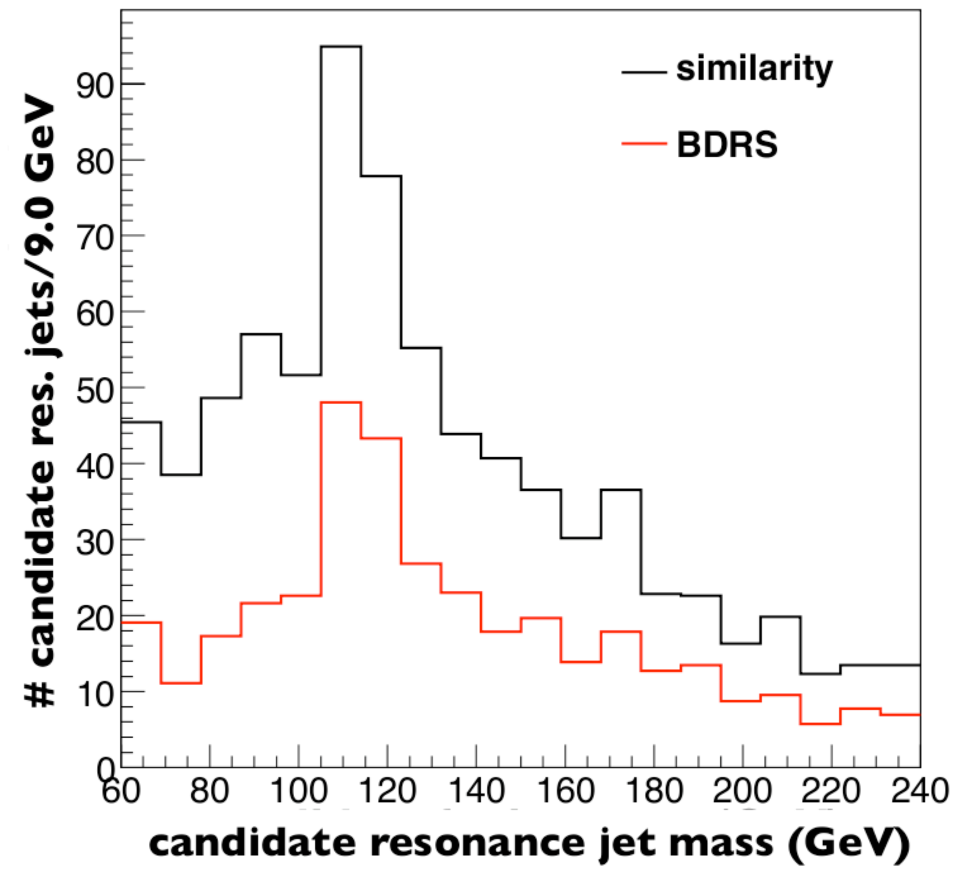
3. continue until $p_{T,j} < 30$ GeV

take pair of constituents with maximum p_T similarity, S_i

$$S_i = \frac{\min(p_{T_{j_1}}^2, p_{T_{j_2}}^2)}{(p_{T_{j1}} + p_{T_{j_2}})^2} \Delta R_{j_1 j_2}$$

if both b-jets, filter --> candidate Higgs

extra (hard) partons introduce a new scale into the jet..



better efficiency, not much improvement in accuracy

Results: Details

Background: ALPGEN → PYTHIA6.4
Signal: SUSPECT2 → PYTHIA6.4

underlying event: ATLAS tune

- All final-state hadrons grouped into cells of size $(\Delta\eta \times \Delta\phi) = (0.1 \times 0.1)$
- Each cell is rescaled to be massless

this models detector response (Thaler, Wang '08)

jet gymnastics performed using FastJet (hep-ph/0512210)

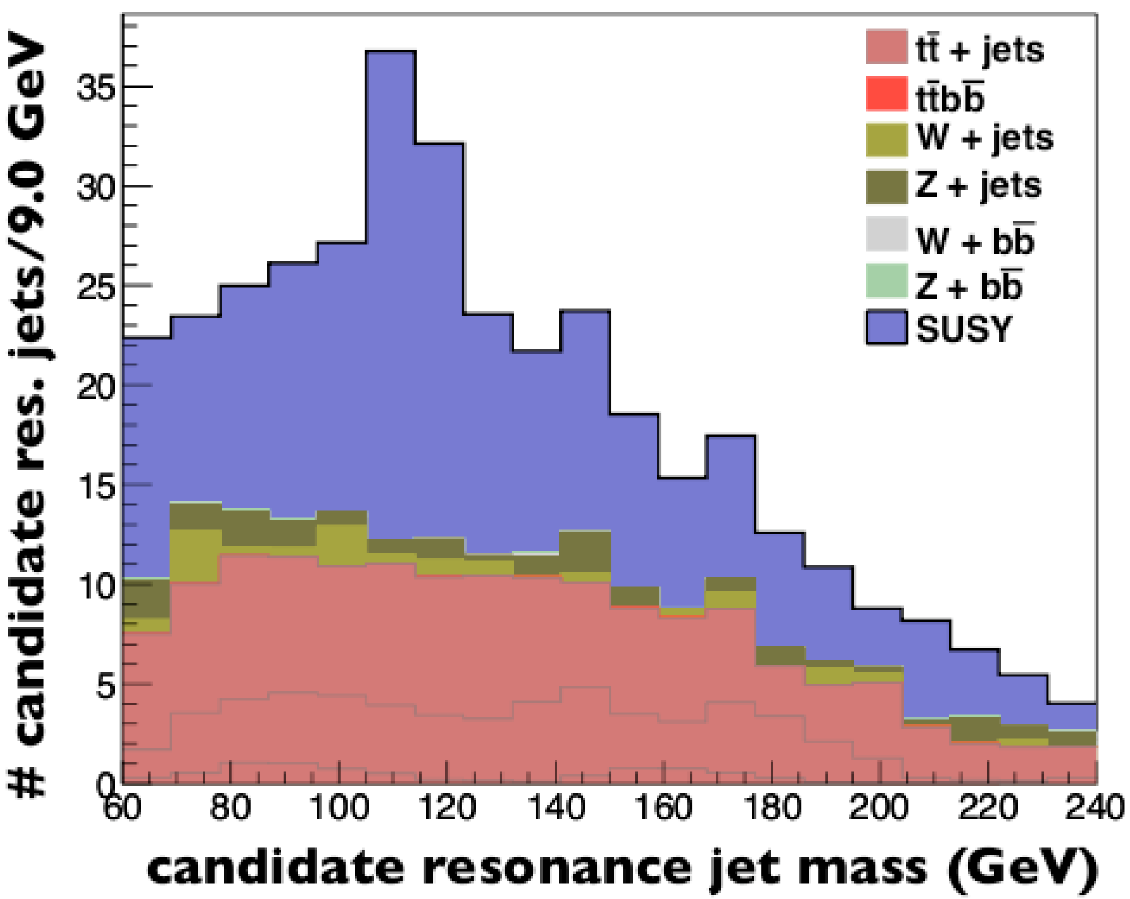
b-tagging: 60% efficiency, 2% fake rate

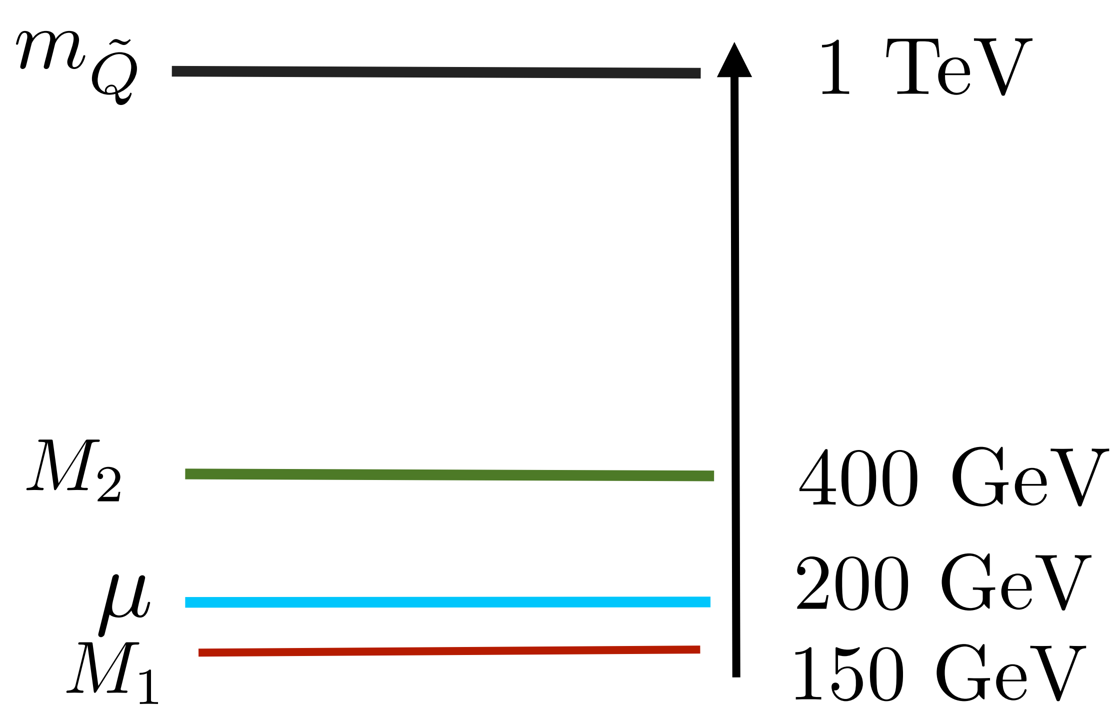
jet-photon fake rate: $.1\%$

Neutralino LSP Results: Point #4

Though we typically have too little DM

permitting $M_1 \lesssim \mu$, we can get consistent Ω_{DM} without losing all our Higgses





Improved Jet Substructure on BSM:

1. cluster particles into jets, $R = 1.2$

2. for each fat jet, undo clustering step by step, looking for mass drop and even splitting of energy between daughters.

   If conditions met, record $\Delta R_{sub,i}$ and S_i. Keep unclustering until no more parent jets

3. Determine which splitting n has most even p_T splitting

4. Resolve the fat jet into subjets at the scale $\cong \Delta R_{sub,n}/2$

5. if two of the three hardest subjets are tagged as b-jets

→ candidate Higgs jet ←