Discovering MSSM Higgses with jet substructure

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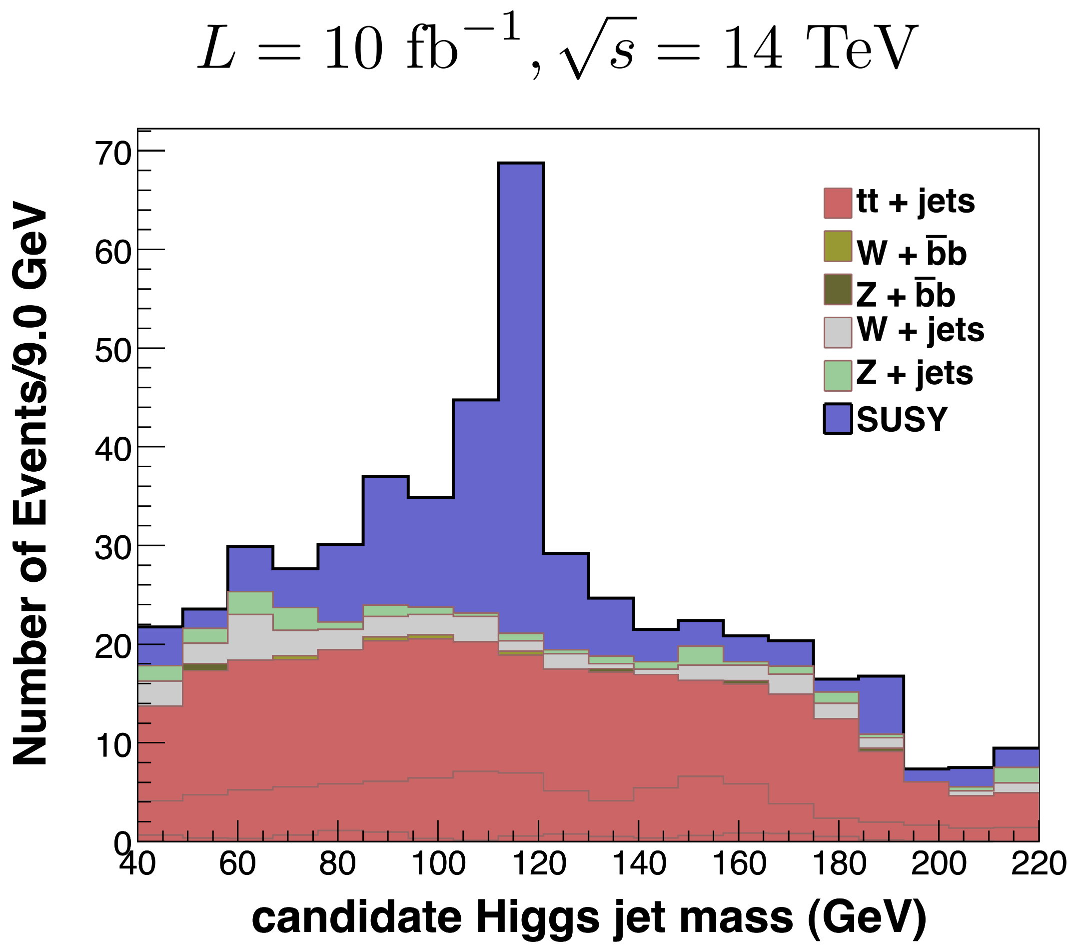
Fermilab

Punchline

Light MSSM Higgses, which decay h -> b bbar, are ideally suited to recently developed jet substructure techniques

this opens up a new way to look for h (& H,H^{+-},A): Higgses from the decays of heavy sparticles

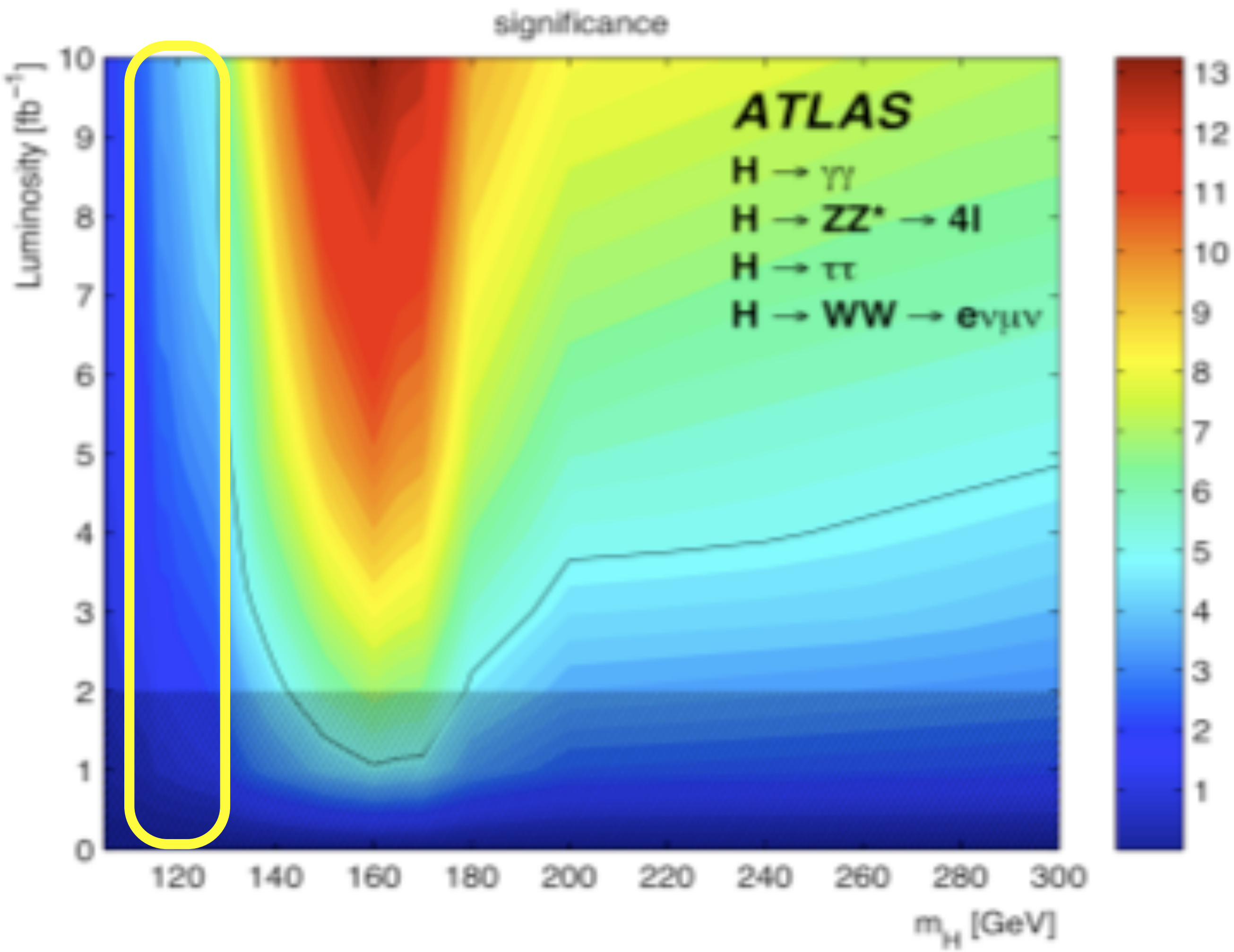
Could be first h discovery mode, before h -> $\gamma\ \gamma$, h -> $\tau\ \tau$!!



Our Motivation:

Despite large LHC cross sections...

a light Higgs $m_h \sim 115 - 130\ \mathrm{GeV}$, **which decays primarily**



$$h \rightarrow \bar{b}b \sim 80\%$$

will be difficult to find

most sensitive channel is

$$h \rightarrow \gamma\gamma + \mathrm{jets}$$

$S/\sqrt{B} \sim 2.5$ **for** $\mathcal{L} = 10\ \mathrm{fb}^{-1}$

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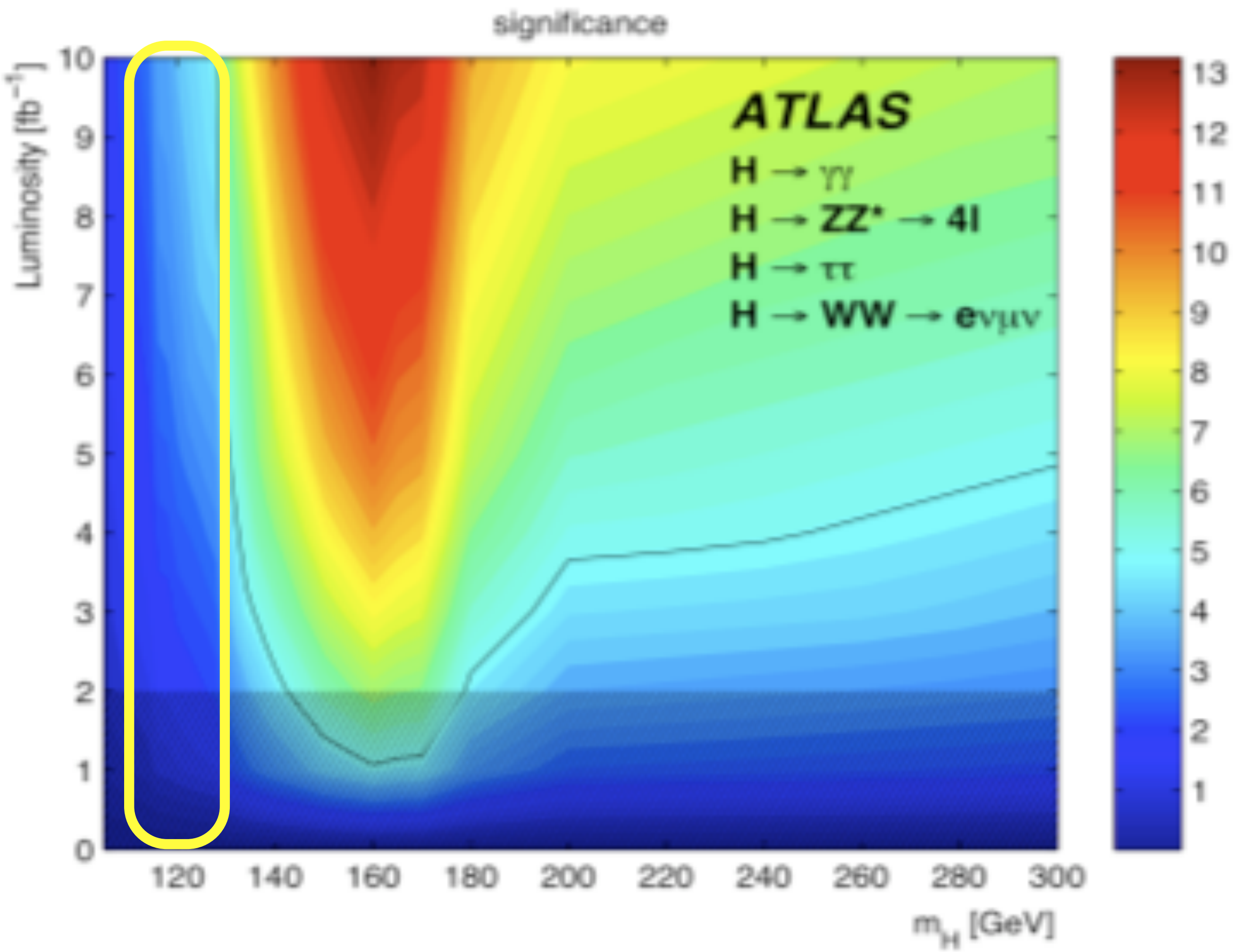

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$h \to \tau\tau$

$BR \sim 5-7\times 10^{-2}$

also contributes, but smaller

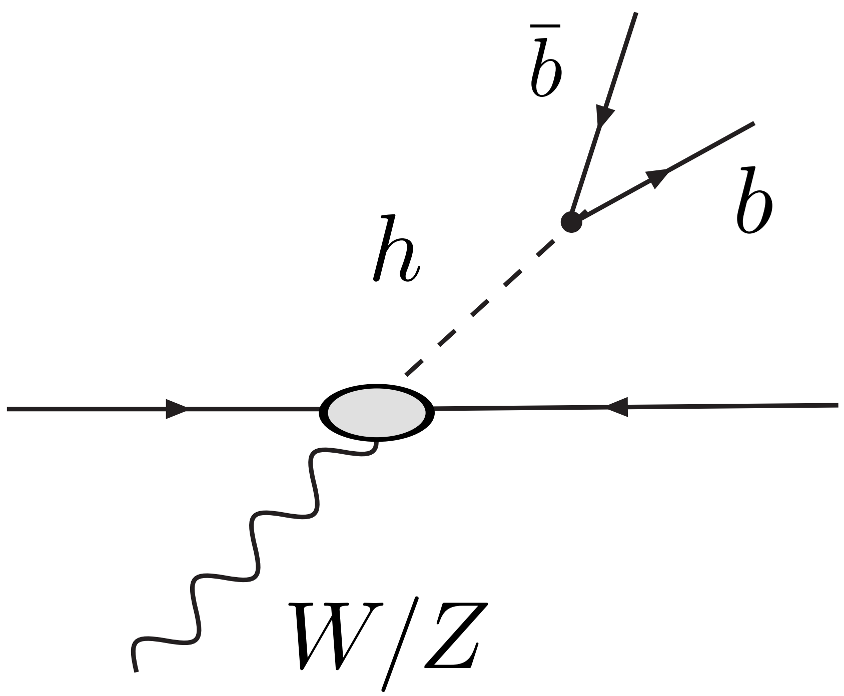
Our Inspiration:

Recently, a NEW TECHNIQUE for light Higgses

(Butterworth, Davison, Rubin, Salam '08)

In associated production: $pp \longrightarrow \; W(\ell\nu)/Z(\ell\ell) + h(\bar{b}b)$

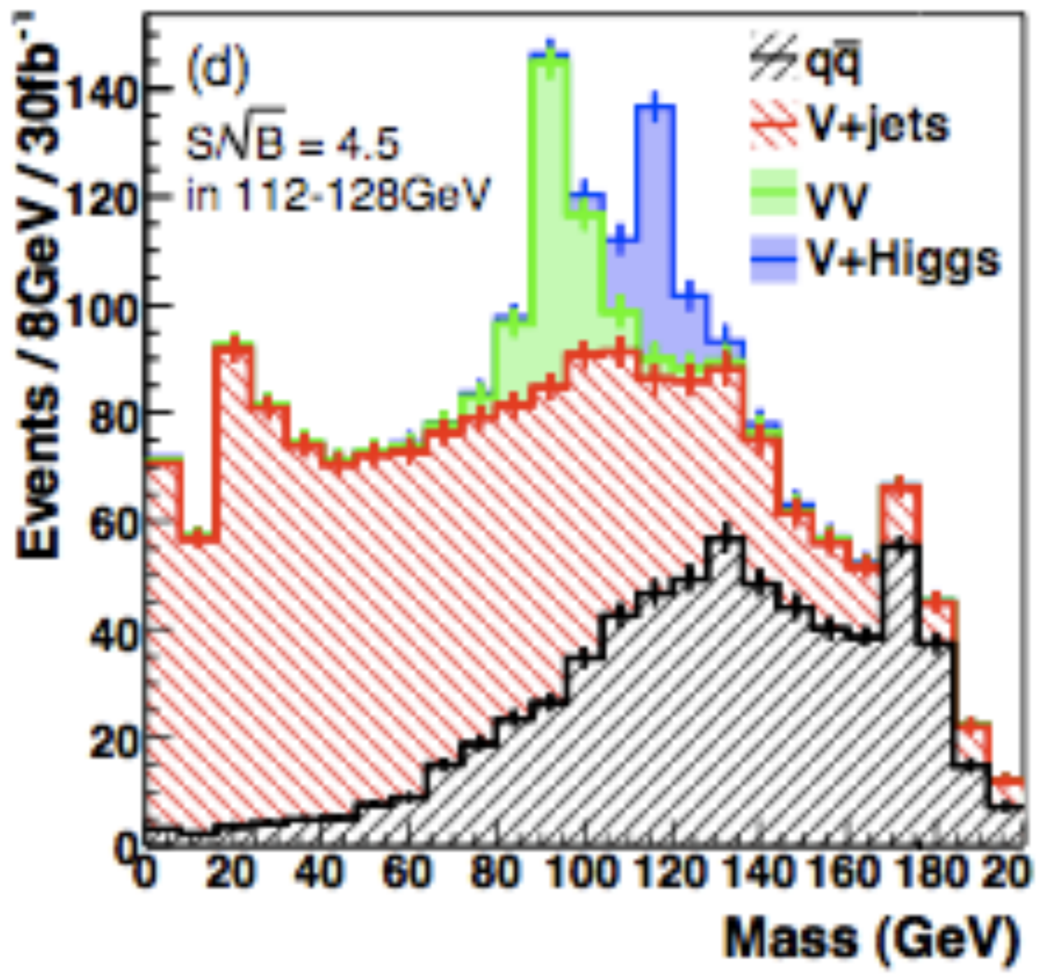
find: significance ~ 4.5 for $\mathcal{L} = 30\ \text{fb}^{-1}$ $\left(\sim 2.6 \text{ for } \mathcal{L} = 10\ \text{fb}^{-1}\right)$!!



by focusing on boosted Higgses:

$$p_{T,h} > 200\ \text{GeV}$$

and requiring jet substructure



(Butterworth et al '08)

brings back a channel that had been thought extremely difficult at the LHC

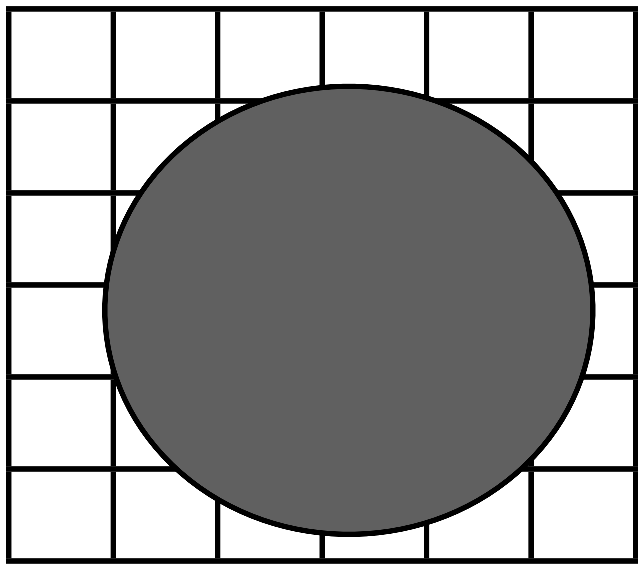
(also investigated by ATLAS ATL-PHYS-PUB-2009-088 (Aug 2009))

substructure basics

a boosted Higgs appears as a single "fat" jet with some distinguishing characteristics

1.) large invariant mass $m_j \sim m_h$

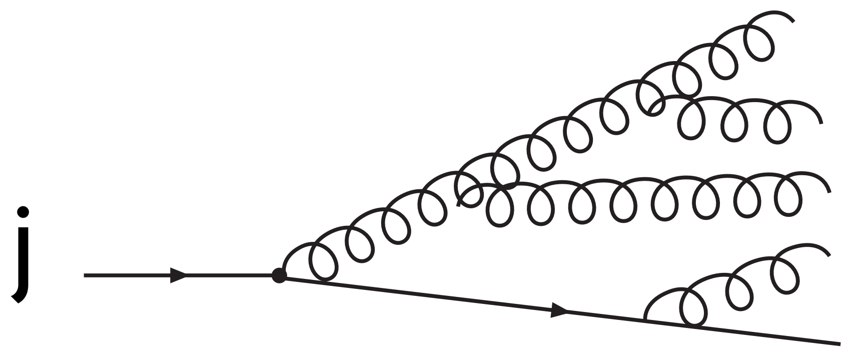
2.) original vertex is a heavy particle decaying to two light particles -- identified by unclustering, looking for "mass-drop", symmetric splitting --> subjets



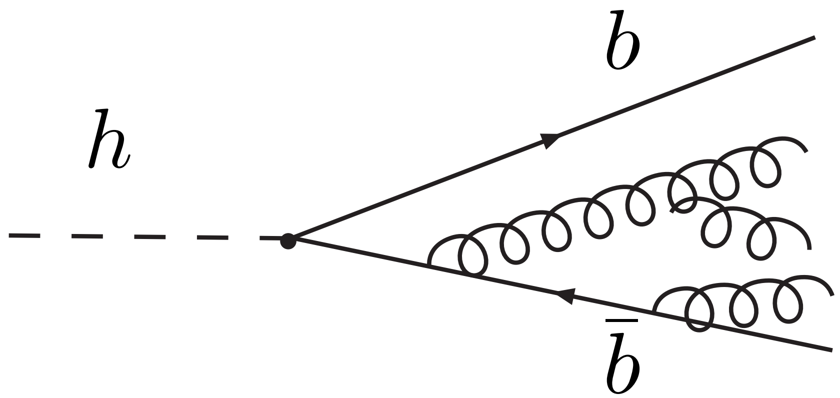
(Butterworth et al '08, Thaler et al '08, Kaplan et al '08, Brooijmans '08, etc.)

3.) subjets are b-jets, can be flavor-tagged

... taken together, effectively suppresses QCD backgrounds



vs.



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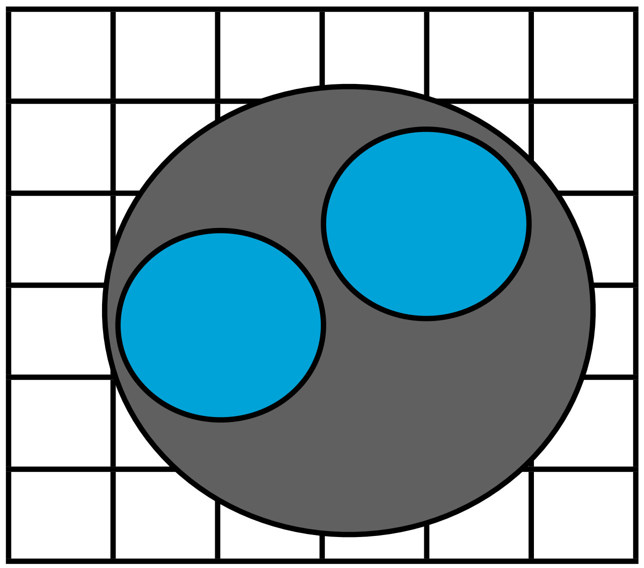

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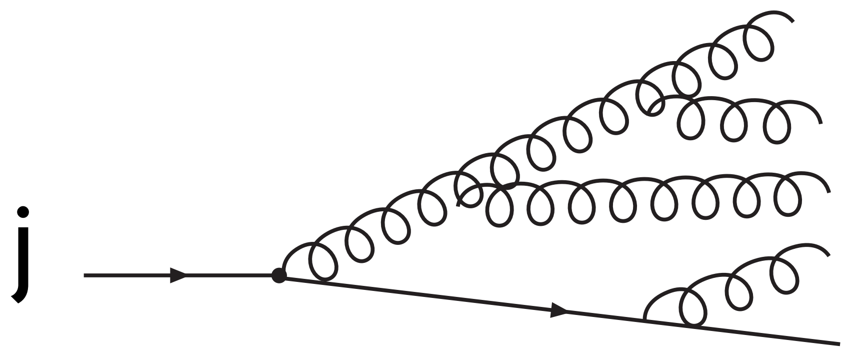

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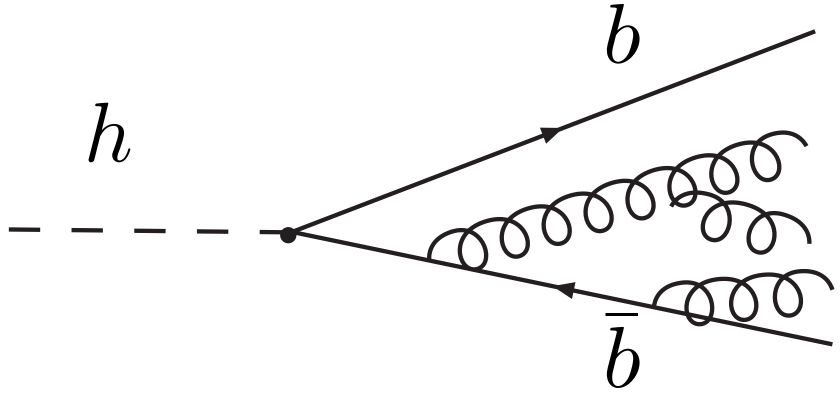

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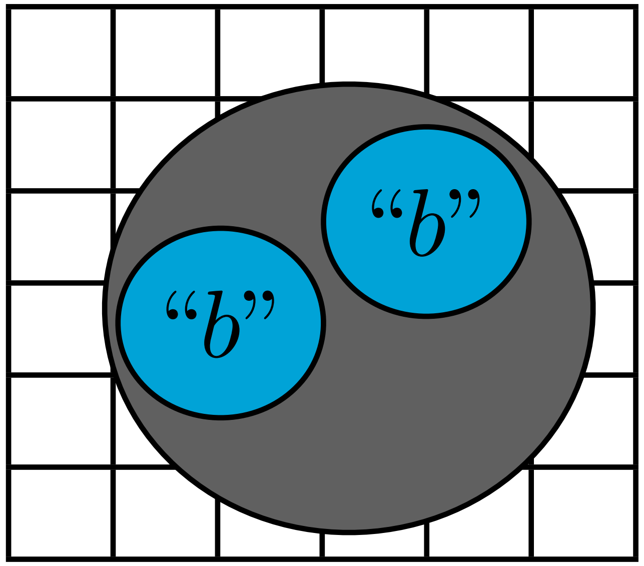

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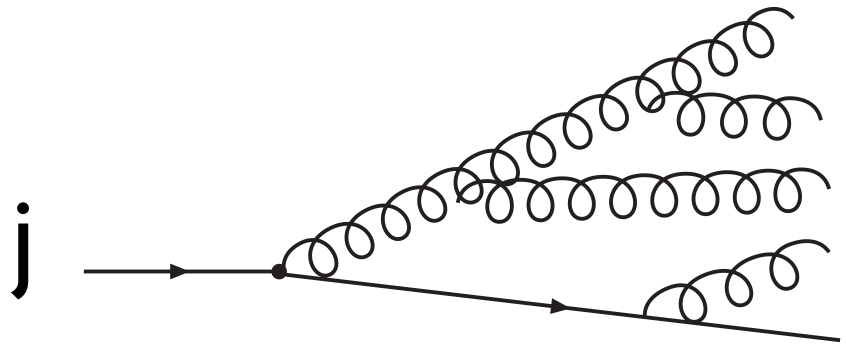

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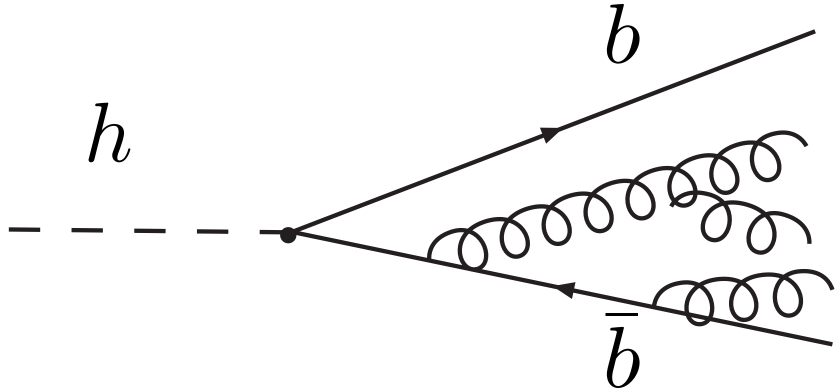


Boosted Higgses

interesting new approach (see talks by Plehn, Spannowsky, Thalapillil, Son)

BUT, a bit limited in SM

* boosted Higgs are rare in the SM: $\sim 5\%$ in $H+W/Z$
* need to trigger & suppress SM backgrounds: limited to W/Z leptonic decay modes

MSSM

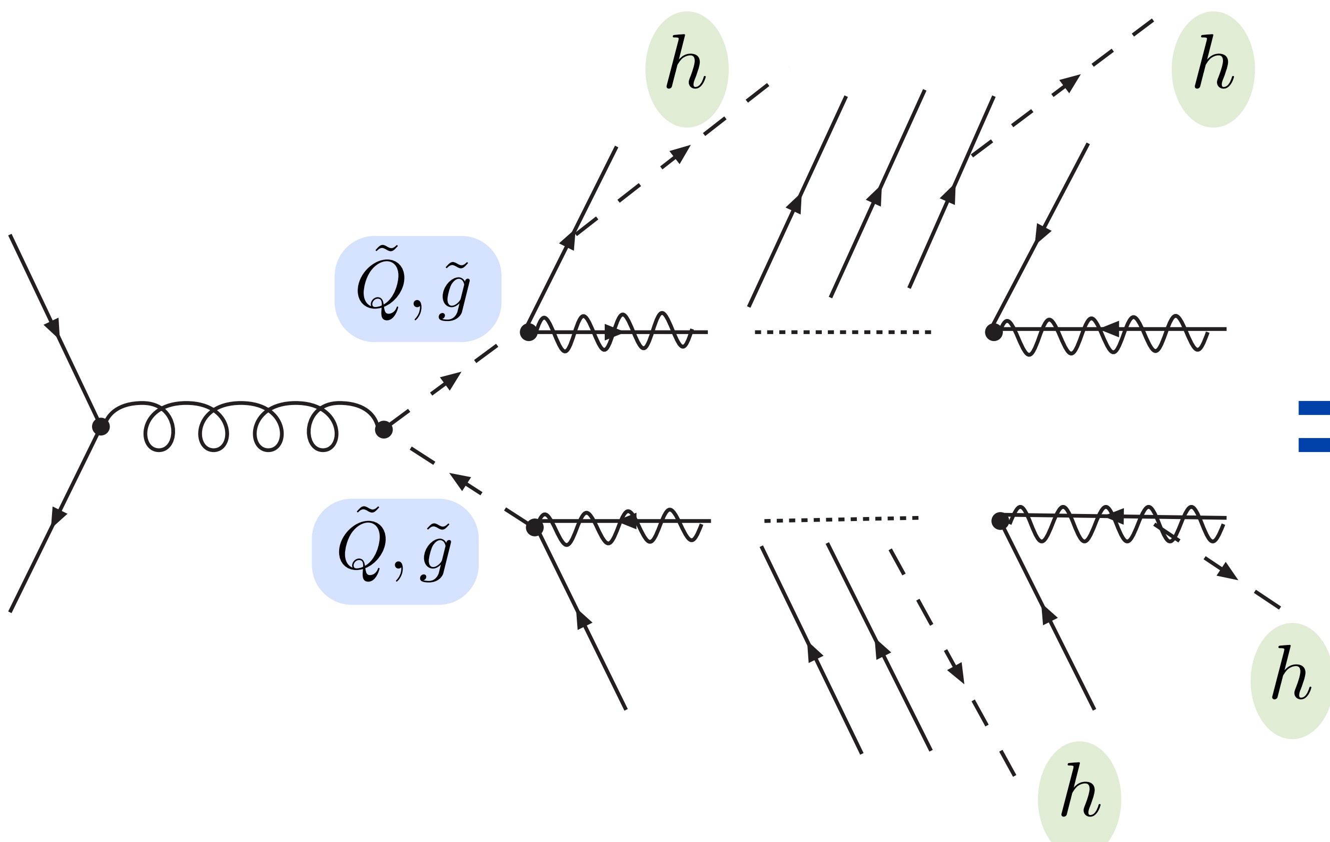
+

substructure =

great opportunity for
Higgs discovery

MSSM + boosted Higgses

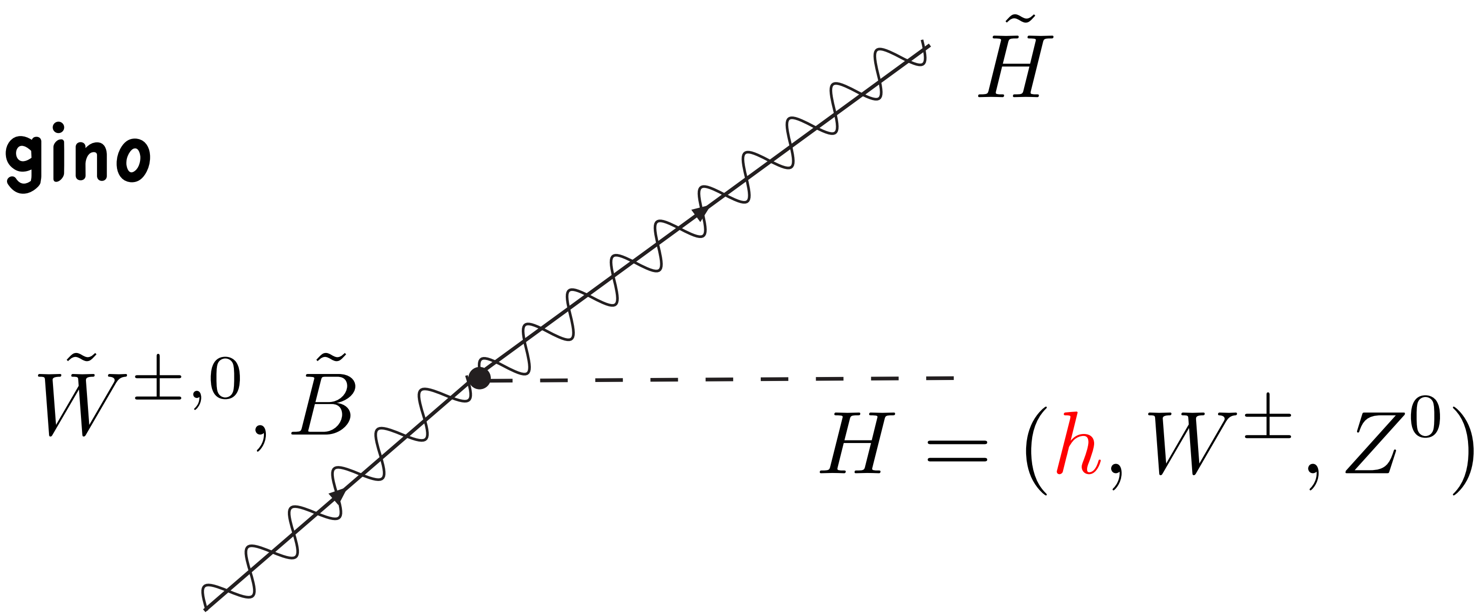
- MSSM Higgs has to be light $m_h \lesssim 130$ GeV, decays dominantly to $b\bar{b}$
- MSSM has new colored particles (squarks, gluinos), which are heavy, but can be produced with large cross sections
- All events have $\not{E}_T$
- Cascade decay products can include Higgses



= a new source of boosted Higgses

MSSM + boosted Higgses

Higgs-Higgsino-Gaugino interaction



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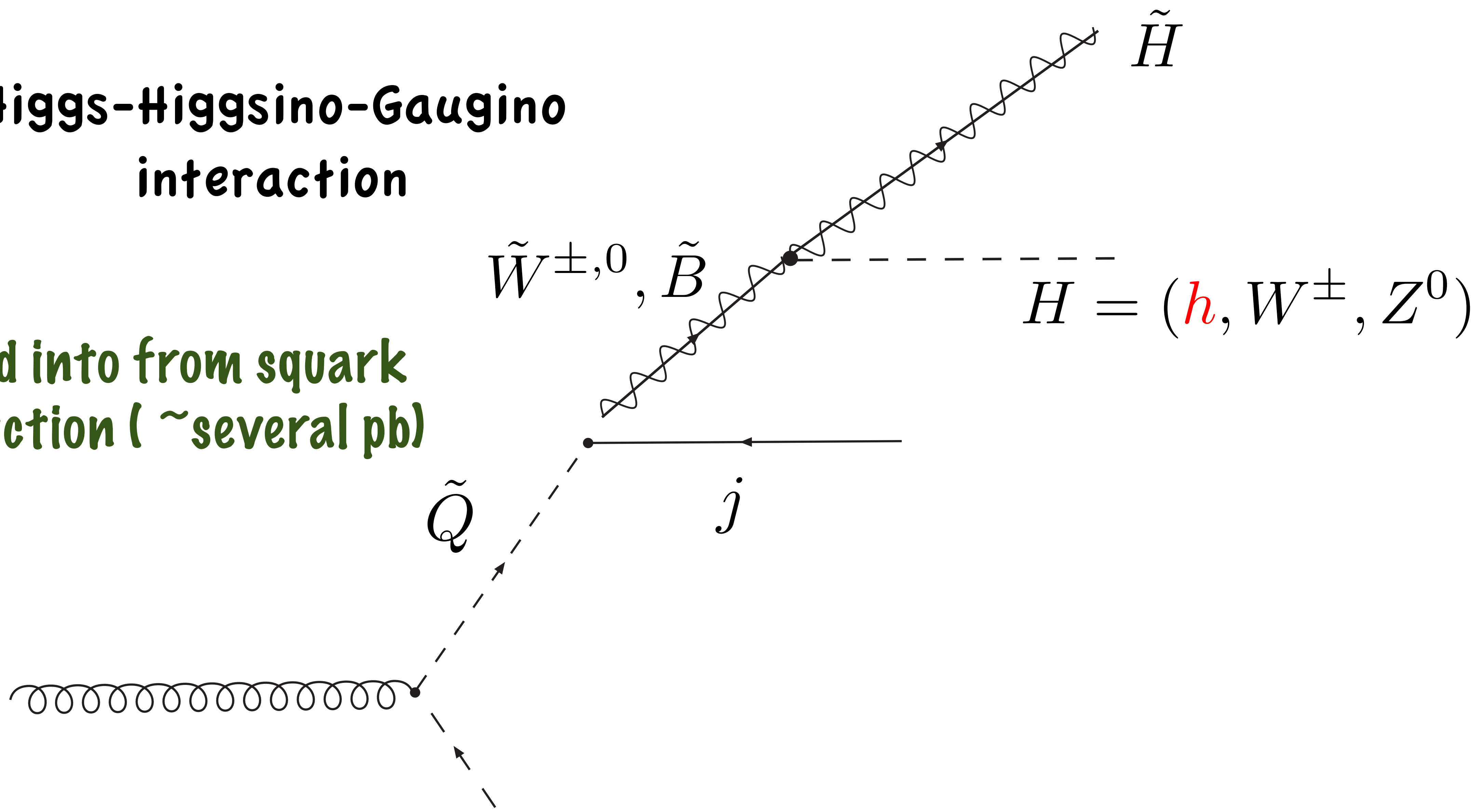
... fed into from squark production (~several pb)



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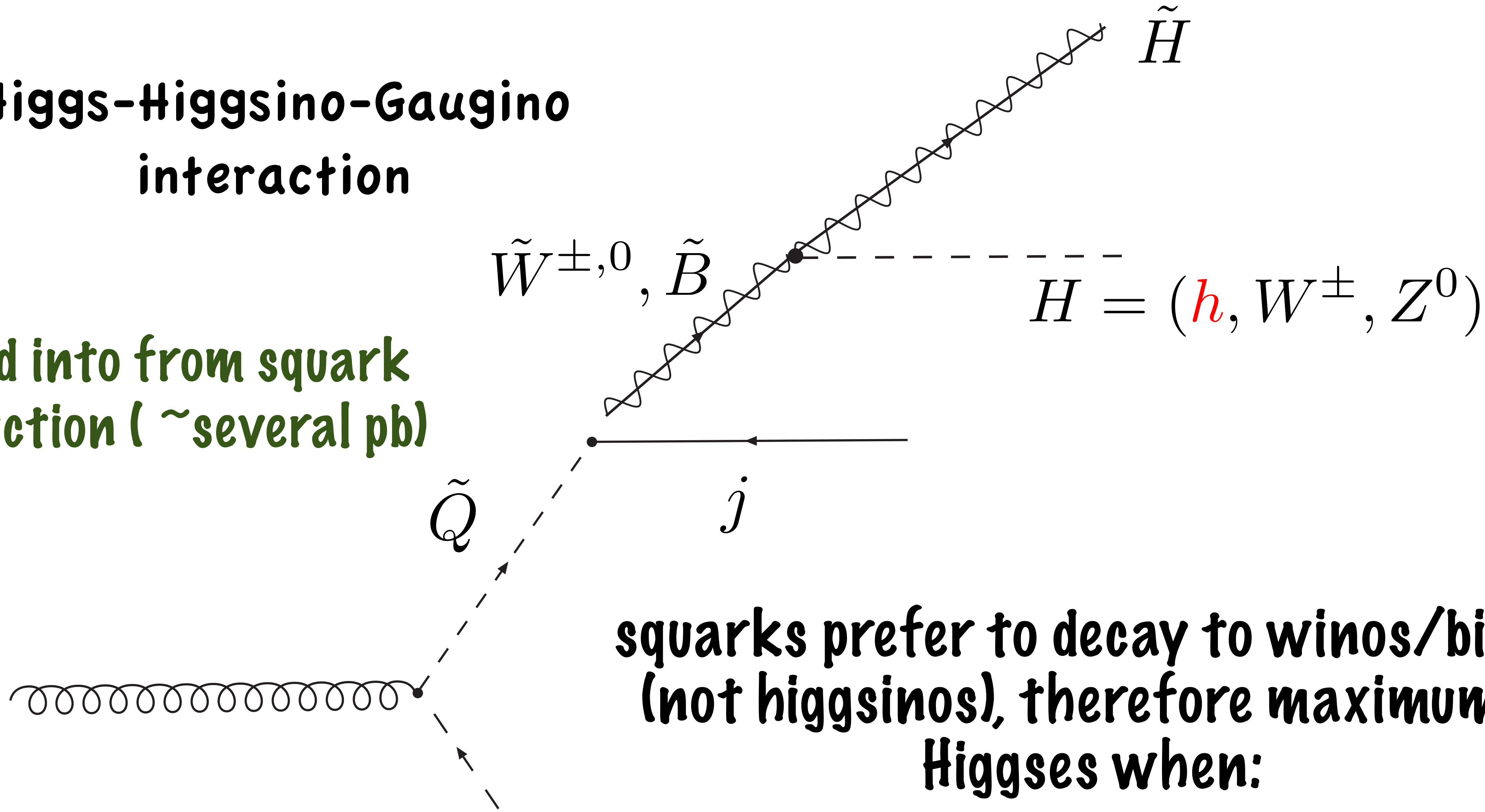

squarks prefer to decay to winos/binos (not higgsinos), therefore maximum # Higgses when:

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

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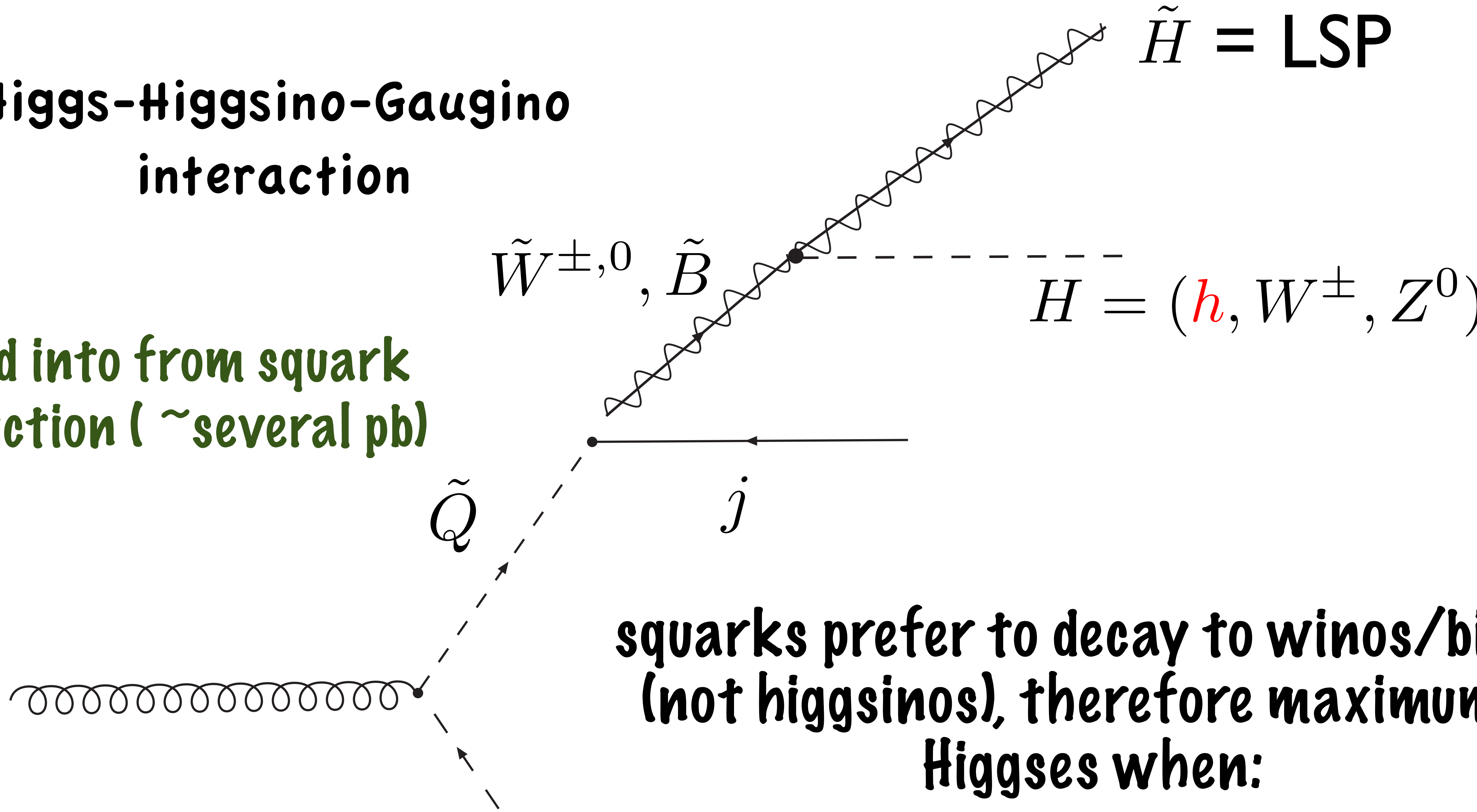

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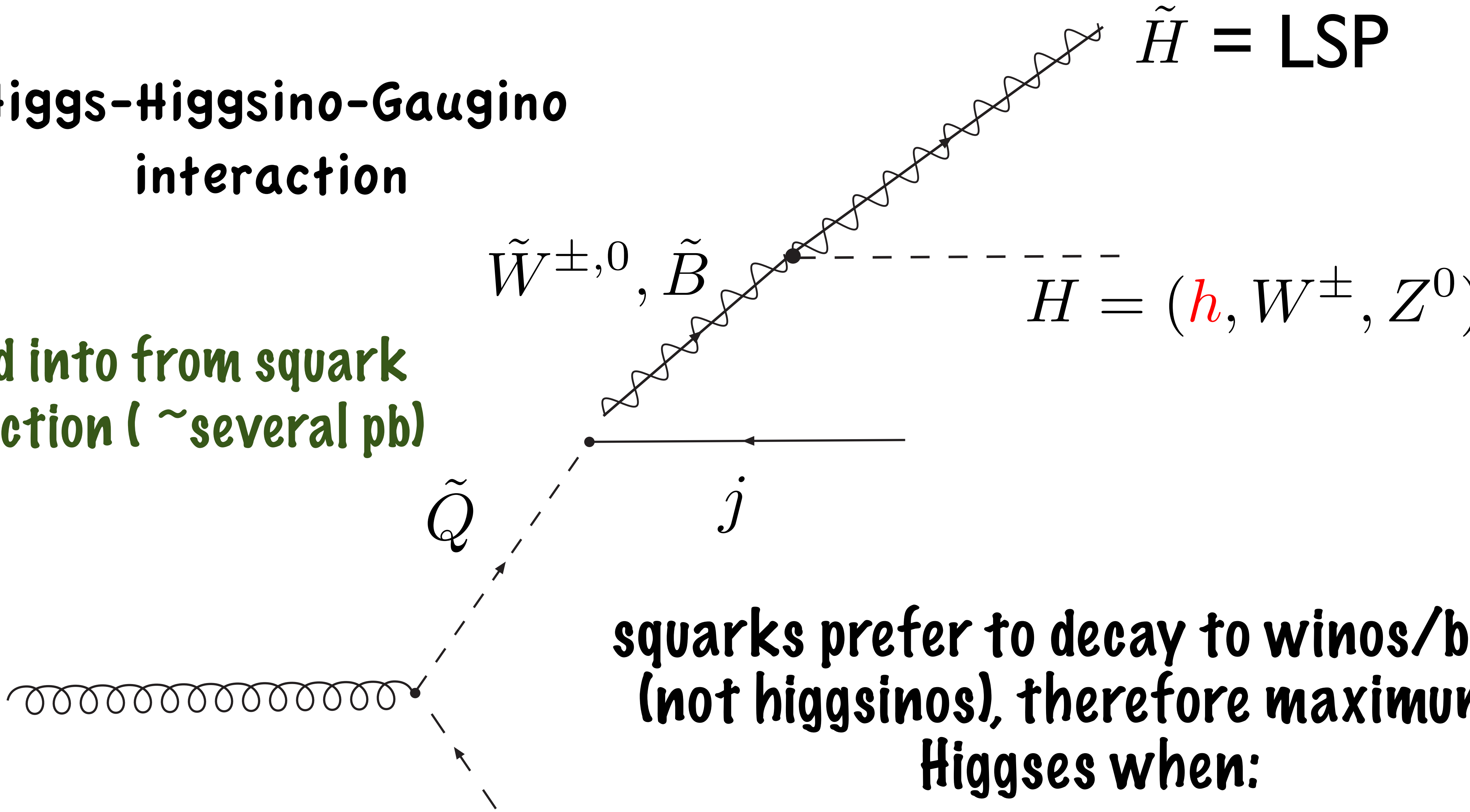

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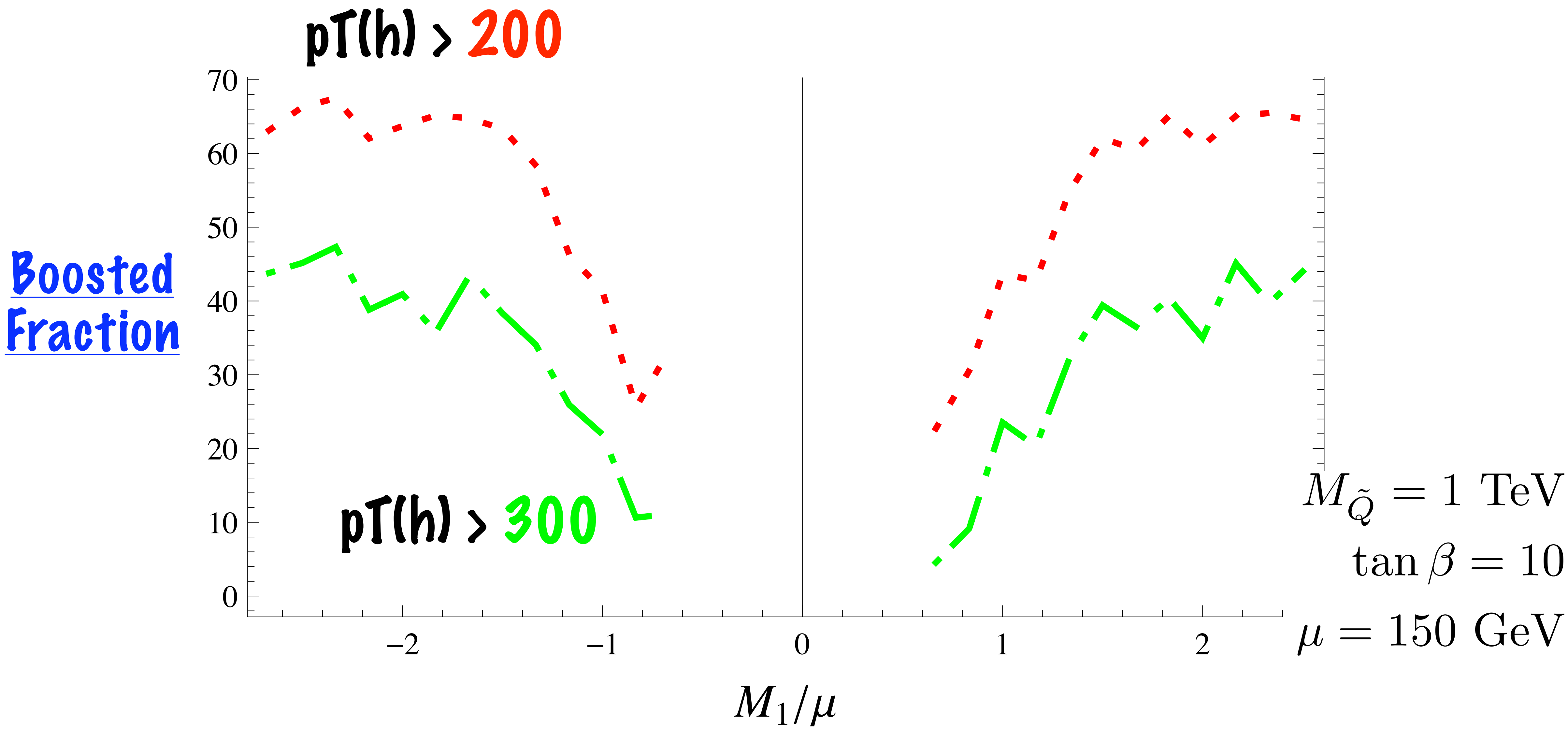
OR: if gravitino is LSP, can also have Higgses from $\tilde{\chi}_1^0 \rightarrow \tilde{G} + h$ ex.) $\tilde{\chi}^0\tilde{\chi}^0 \rightarrow h + \gamma + \not{E}_T$

How boosted?



MSSM Higgses from sparticle decays have all requirements for boosted analysis. Combine with conventional variables (MET, H_T) for best results

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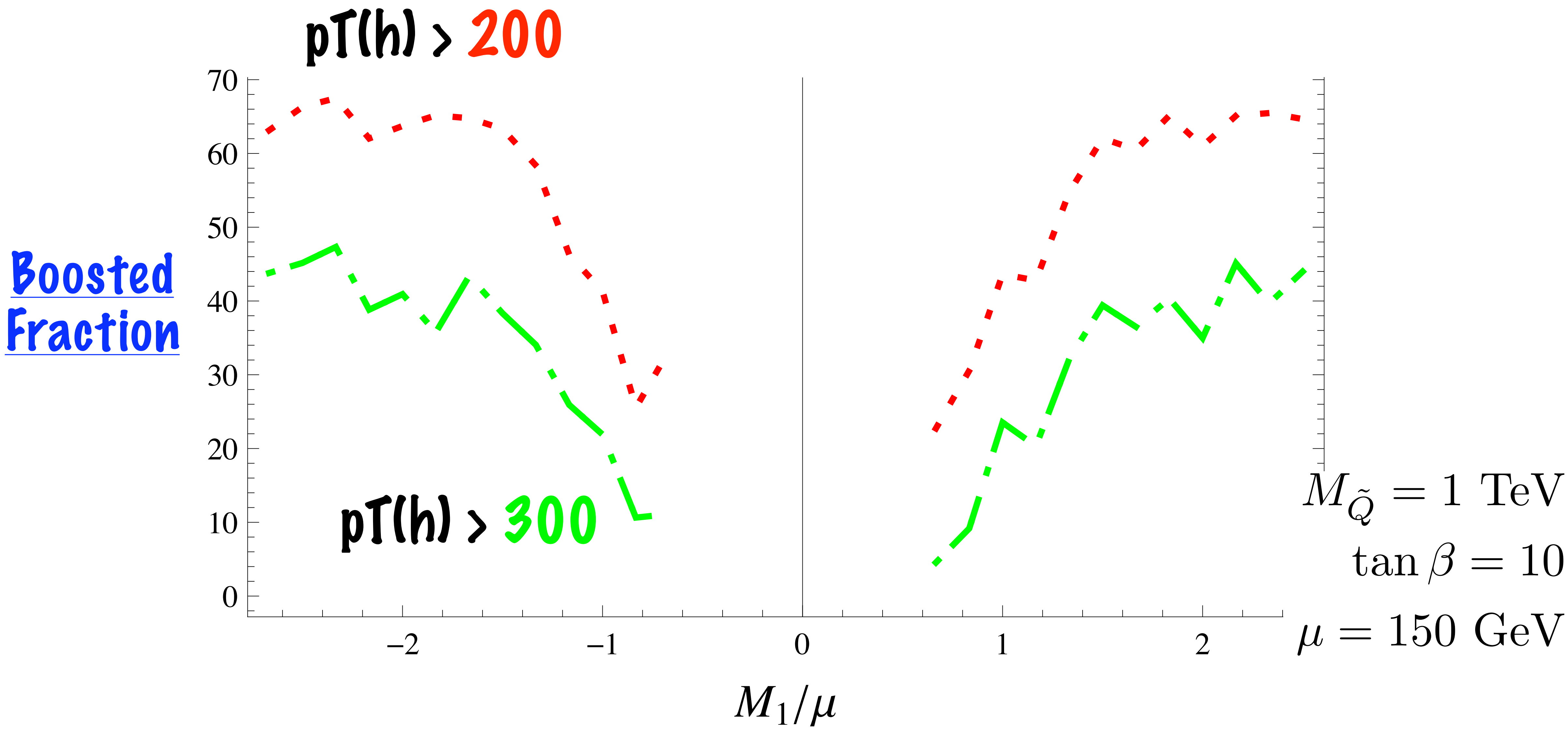

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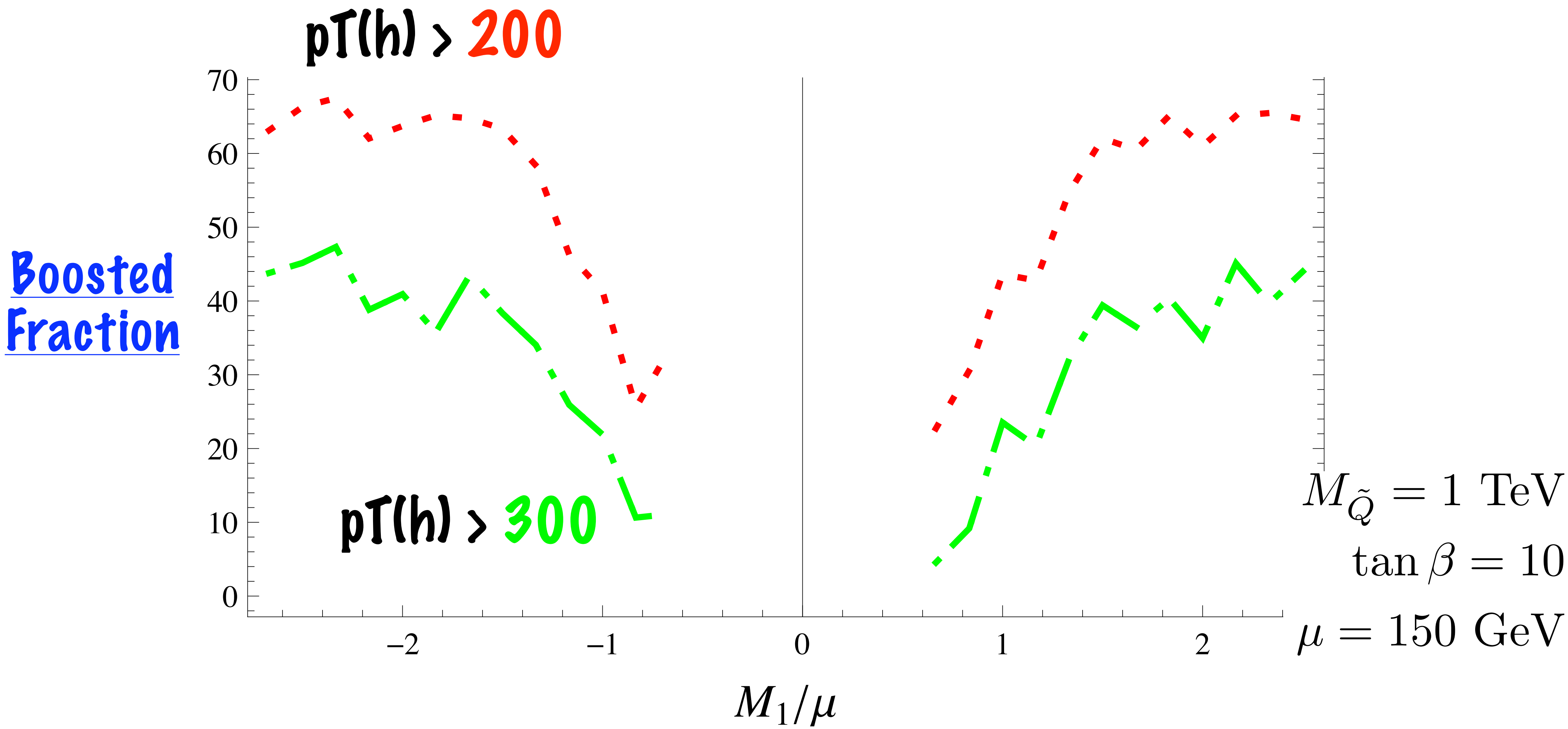


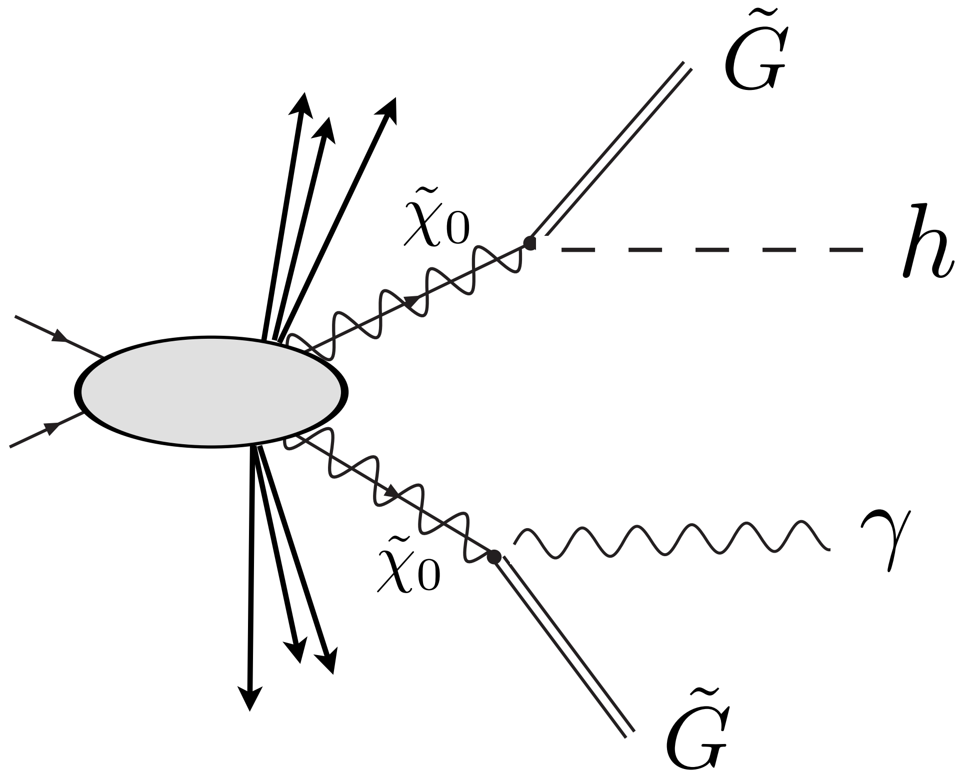
MSSM Higgses from sparticle decays have all requirements for boosted analysis. Combine with conventional variables (MET, H_T) for best results

fights combinatorial SUSY background

fights SM background

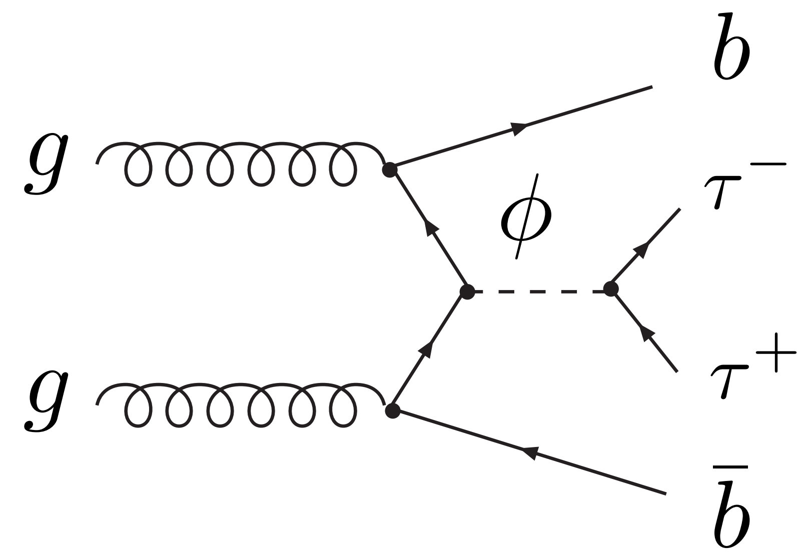
Higgses source comparison

how we want to look for the MSSM Higgs



- Higgses from sparticle decays
- big cross-section (inclusive SUSY prod.)
- all events have $\not{E}_T$, lots of extra jets
- SM and BSM backgrounds

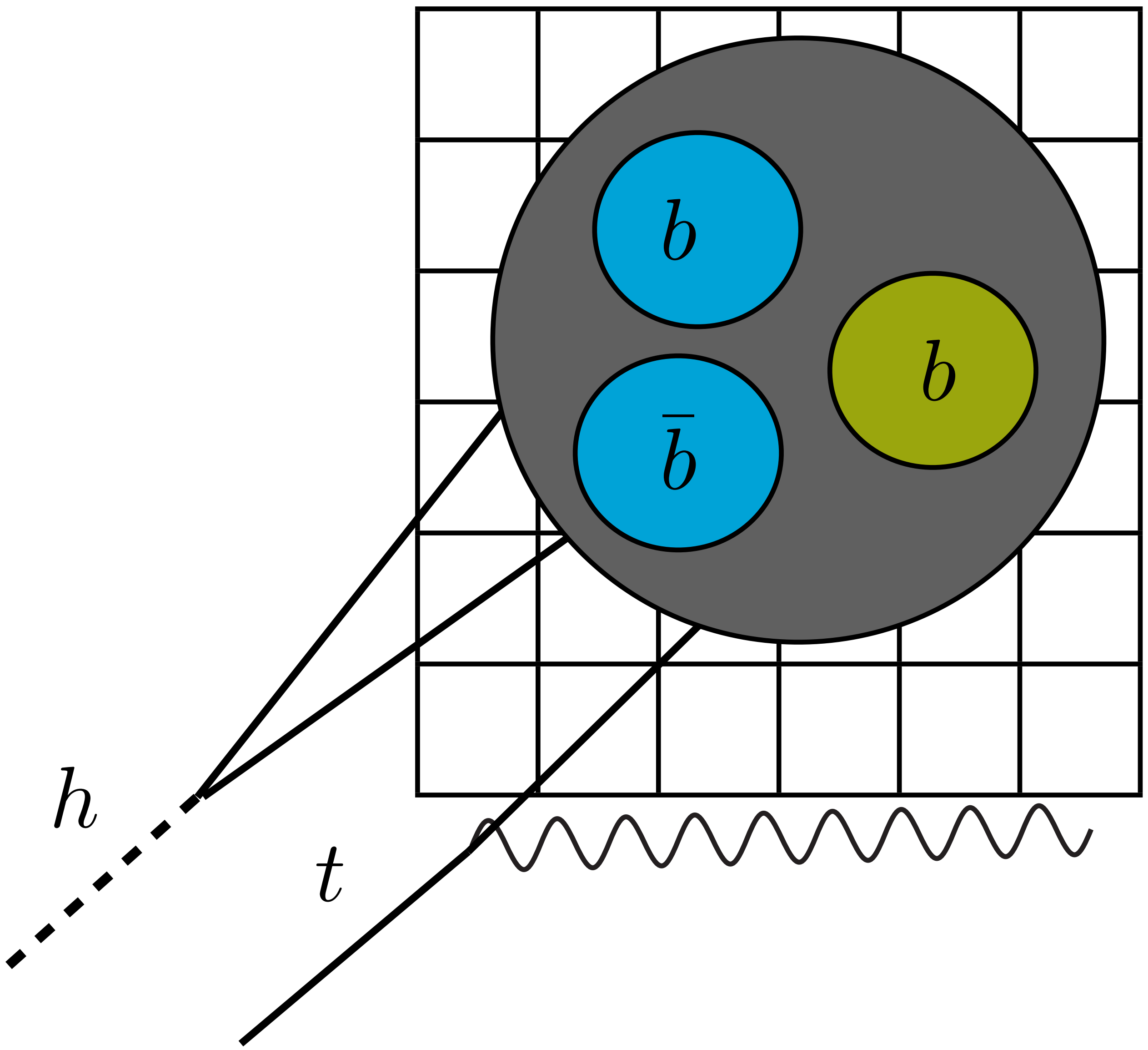
how people usually look for the MSSM Higgs



- Higgs produced in association with SM particles
- smaller cross section (set by y_b)
- no (BSM) $\not{E}_T$
- only SM backgrounds

adapting substructure

SUSY events are busy, many other heavy particles around $(t, \tilde{q}, \tilde{\chi})$ which decay to b



these can end up in the "higgs jet", disrupting things

(as in t tbar h -- Plehn, Salam, Spannowsky)

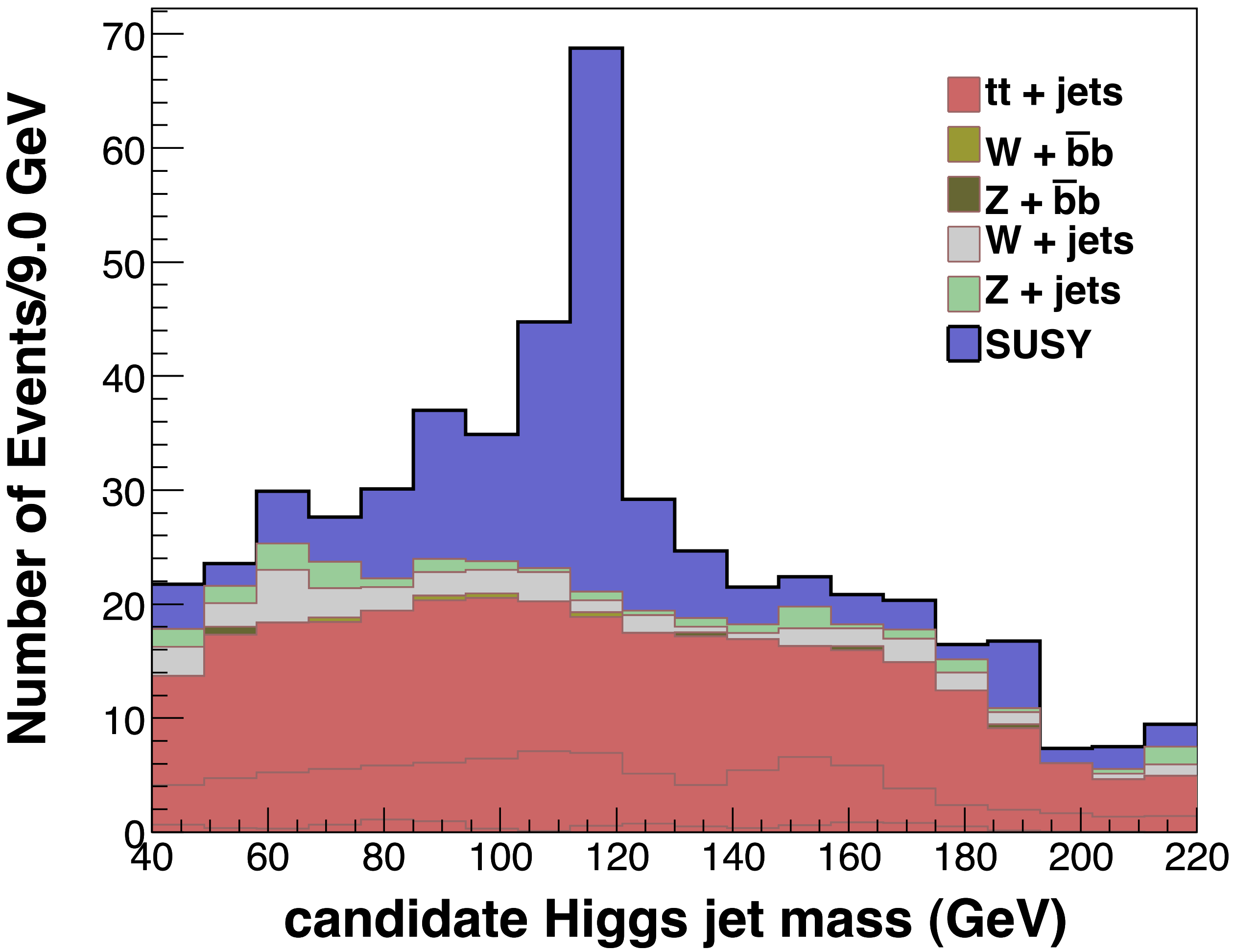
modify substructure algorithm:

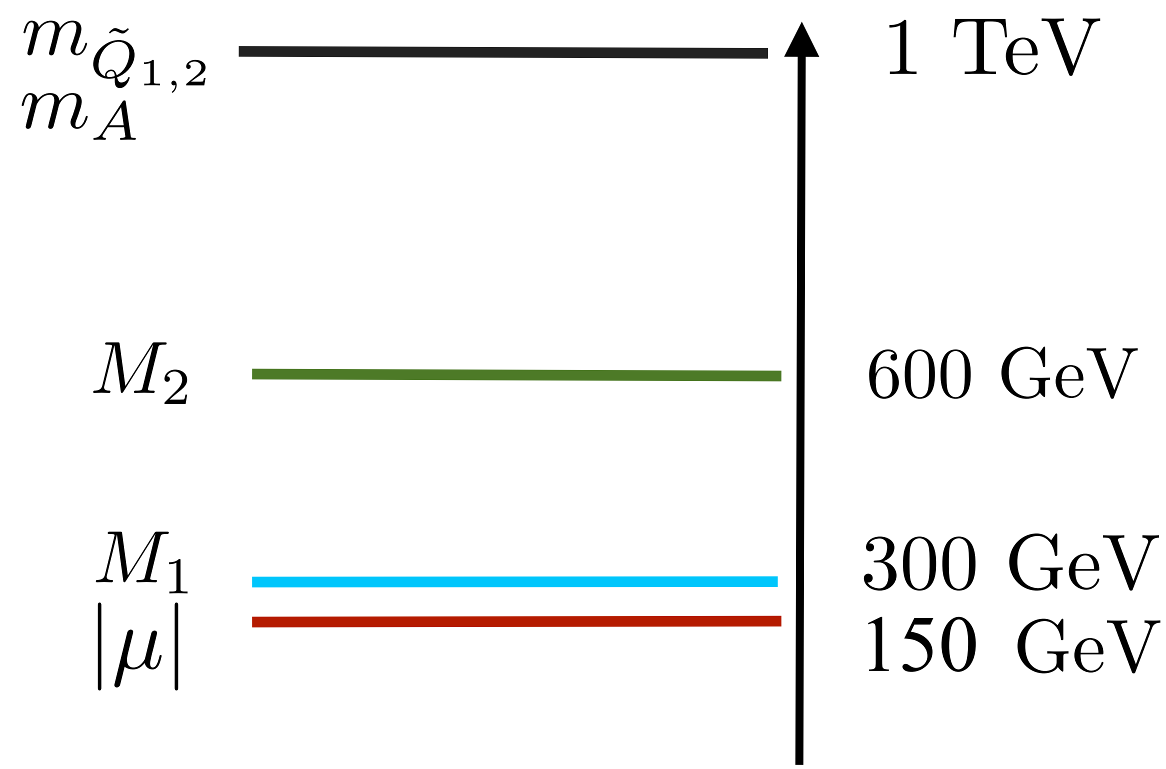
un-cluster fat jet entirely, then keep the two b-subjets which have most similar pT

now ... results

Neutralino LSP Results: Point #1

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

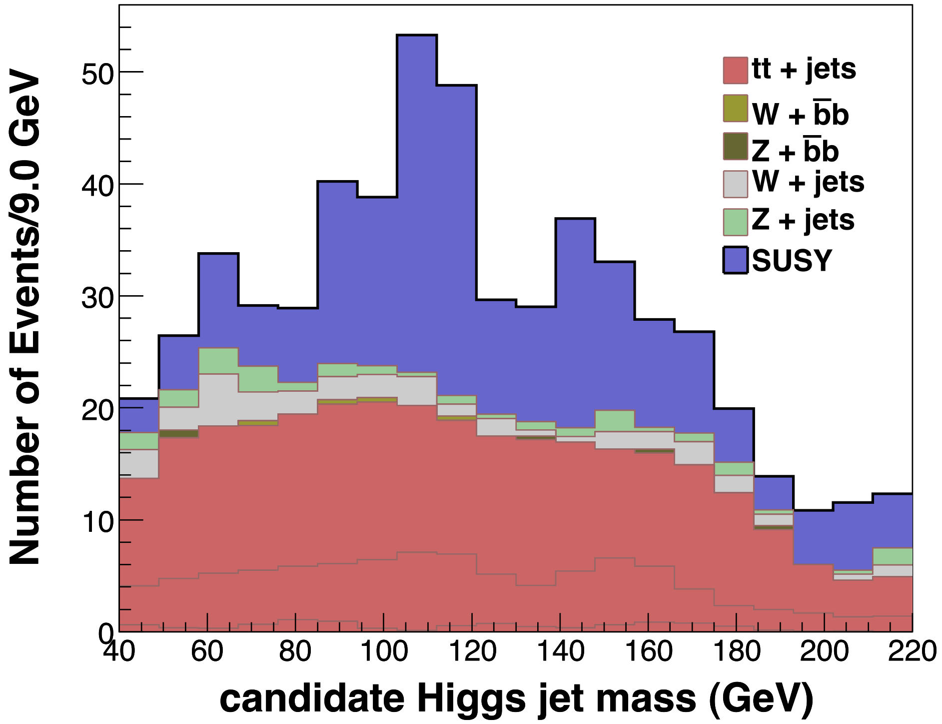




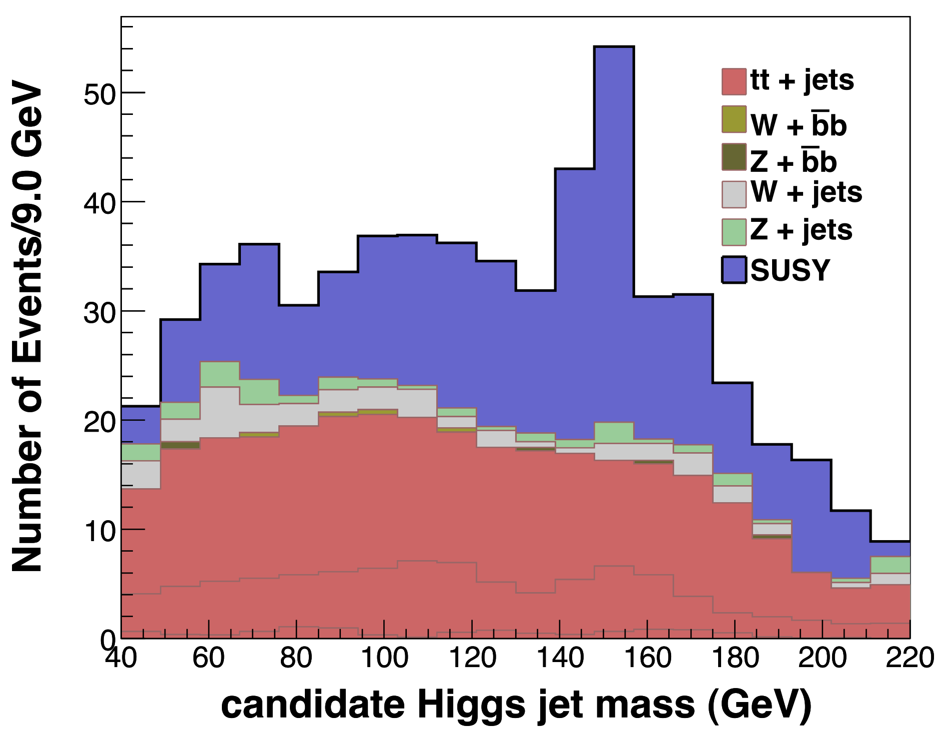
$$BR(\tilde{u}_L, \tilde{d}_L \to h + X) \sim 23\%$$
$$BR(\tilde{u}_R, \tilde{d}_R \to h + X) \sim 16\%$$

$$H_T > 1\ \mathrm{TeV}, \not{E}_T > 300\ \mathrm{GeV}$$
2^+ high-p_T jets + substructure

Neutralino LSP Results: Point #2,3

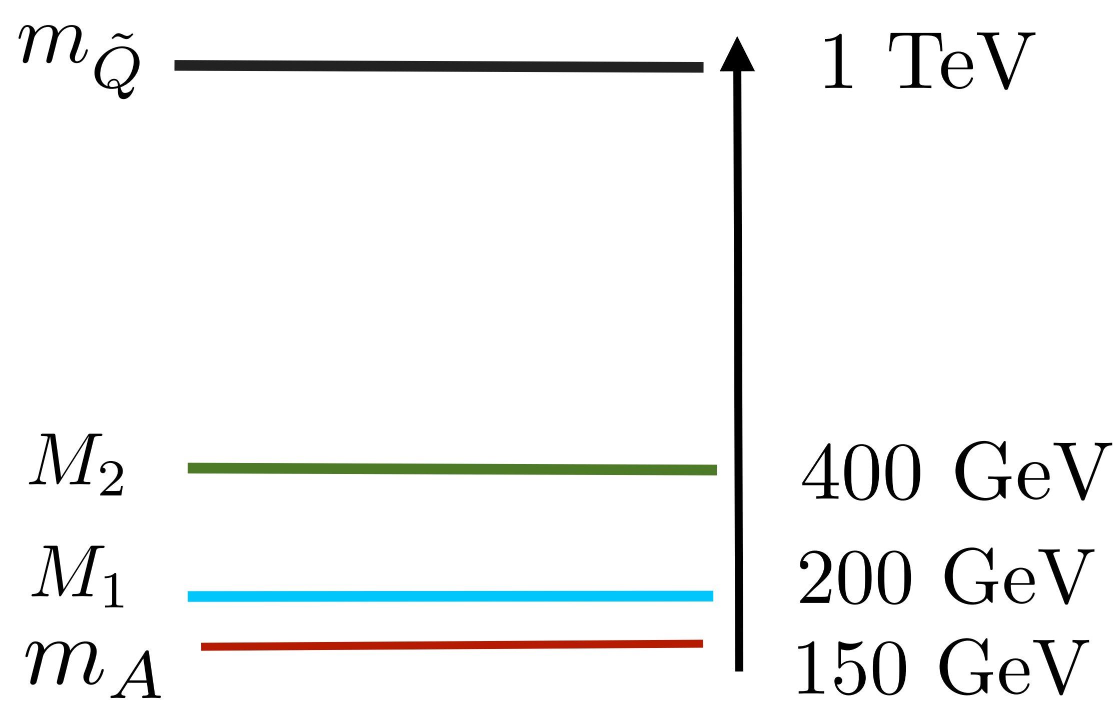


$\mu = 200\ \mathrm{GeV},\ \tan\beta = 5$



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

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



Can even discover heavier A,H states!

Comments

We've used the MSSM as an example source of Higgses from BSM, but the technique is by no means limited to this

Ingredients:

- new, heavy particles who's decays include Higgses
- Higgs which decays primarily to b b-bar
- some handle to suppress SM backgrounds (high-p_T particles, $\not{E}_T$)

* cleanliness of substructure analysis

→ better extraction of underlying parameters

$$\left(\frac{\delta E}{E}\right)_{\rm jets} \cong \frac{0.6}{\sqrt{E/{\rm GeV}}} + 0.03$$

(ATLAS TDR, cone jets.)

Conclusions

Light Higgses are hard to find at the LHC ...

* the decays of MSSM particles offer a new source of Higgses at the LHC, especially boosted Higgses

* The rate is smaller, but MSSM often comes with handles to suppress SM backgrounds

* Using jet substructure analysis to fight combinatorial MSSM backgrounds, result is new channels to discover $h \to \bar{b}b$

  improved substructure extends this to 'b-rich' environments

- Complementary to conventional Higgs searches, smaller jet-resolution effects

- These new Higgs discovery channels can easily be as significant (or more so !) than conventional $h \to \gamma\gamma$

BACKUP SLIDES

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

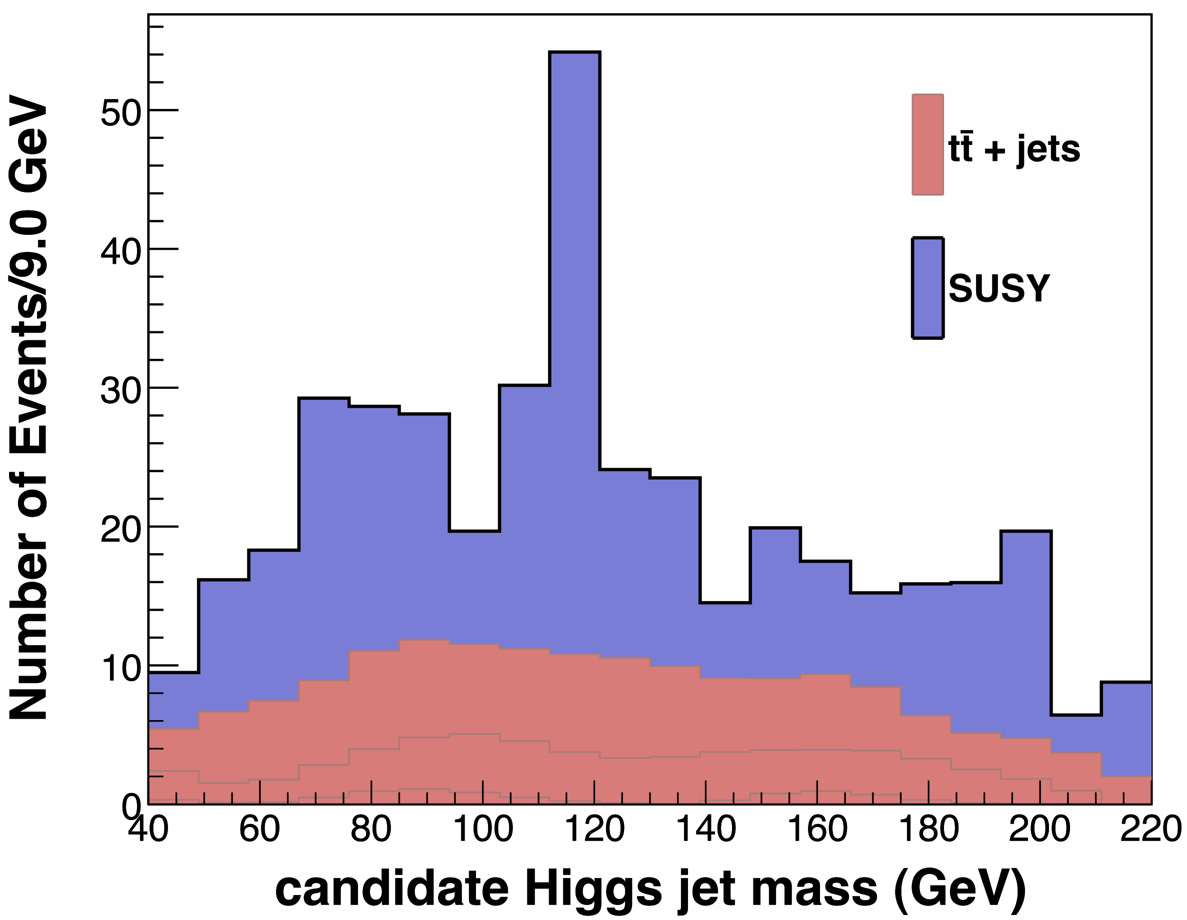
jet-photon fake rate: $.1\%$

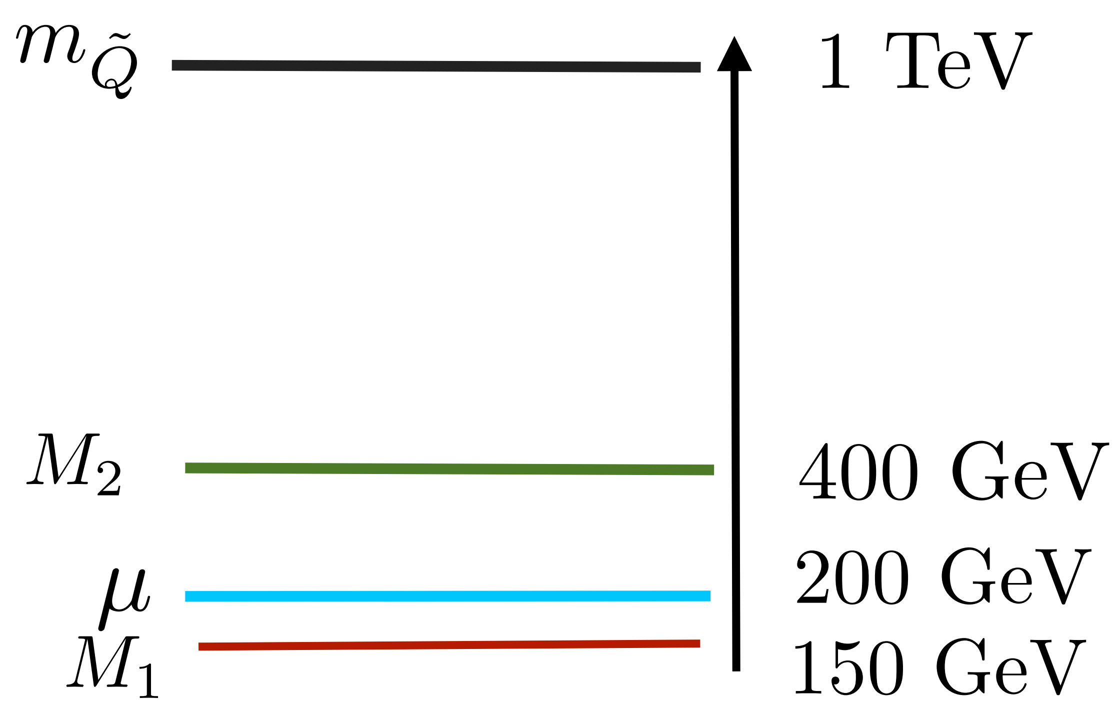
Neutralino LSP Results: Point #4

Higgsino LSP is usually thought to be a bad DM candidate -- annihilates too efficiently through gauge interactions

* too little DM much smaller problem than too much!

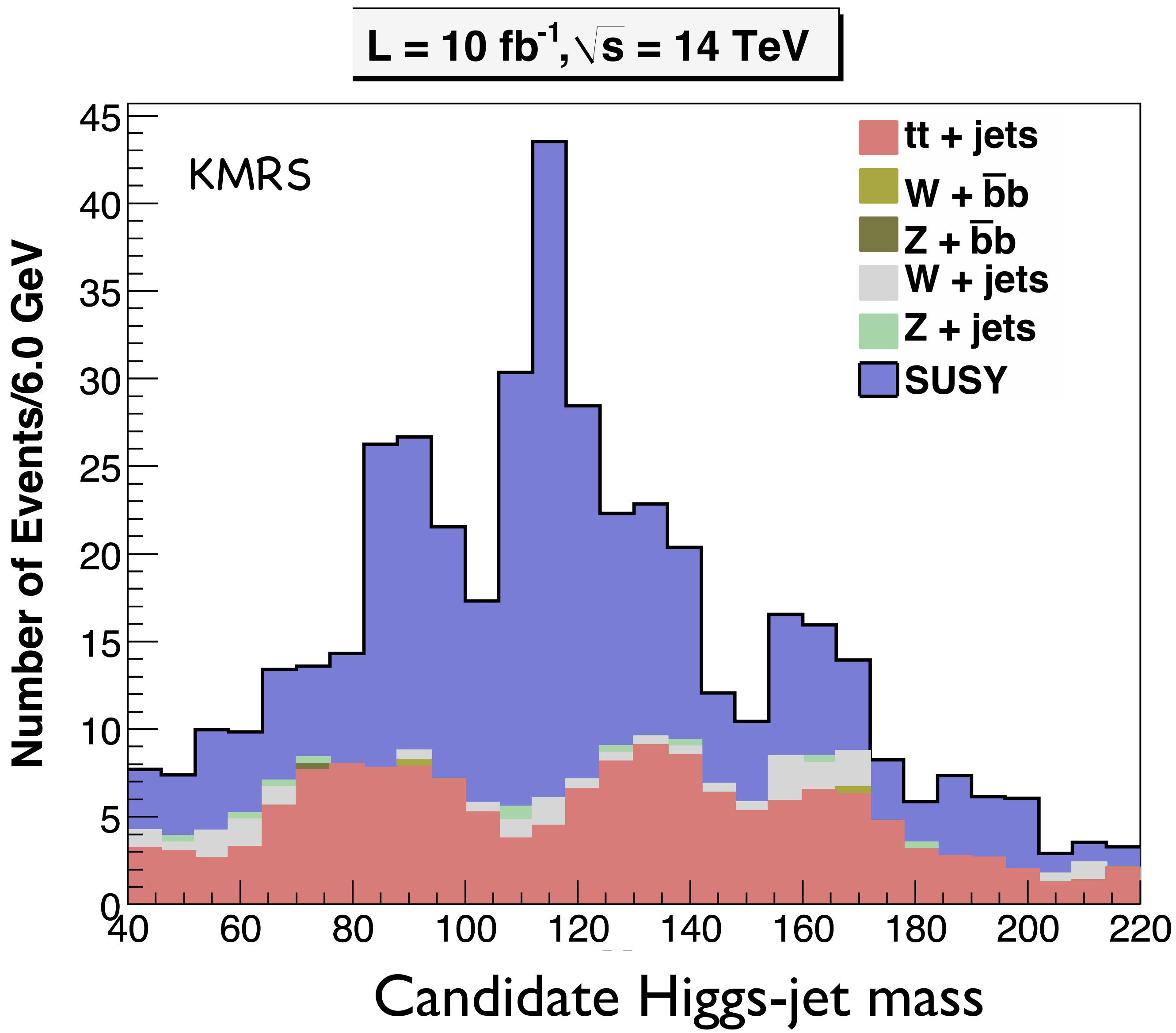
But, permitting $M_1 \lesssim \mu$, we can get consistent Ω_{DM} without losing all our Higgses

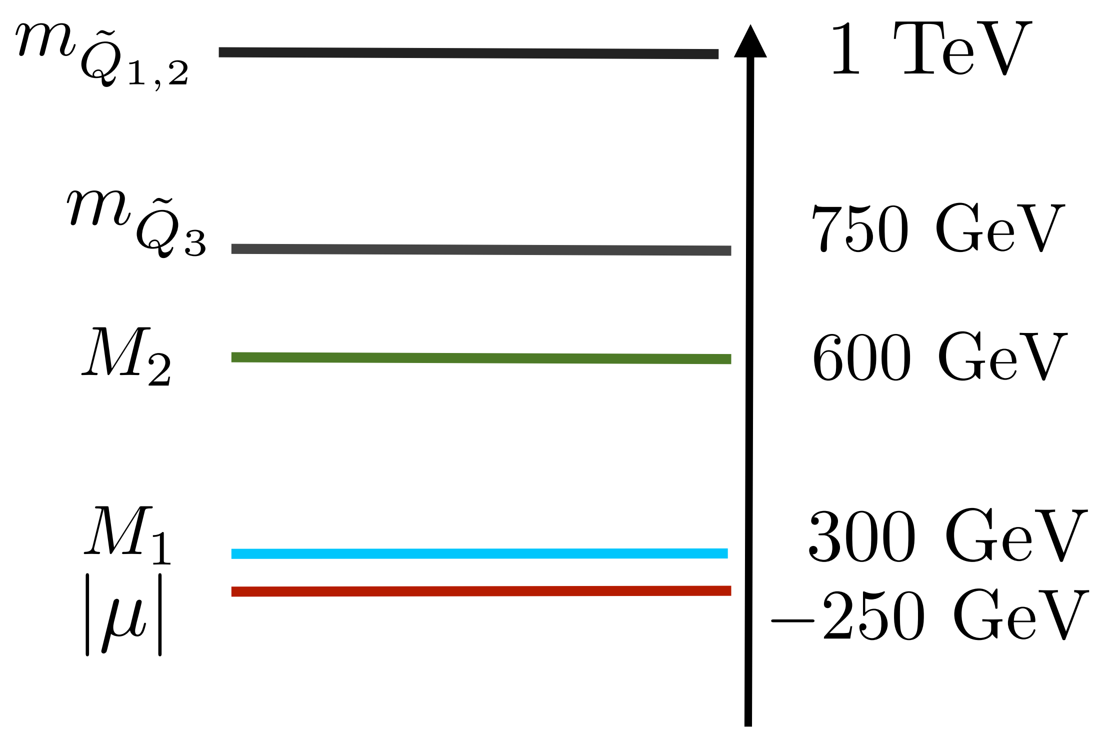




Gravitino LSP Results

high pT photon makes things even easier





cuts:

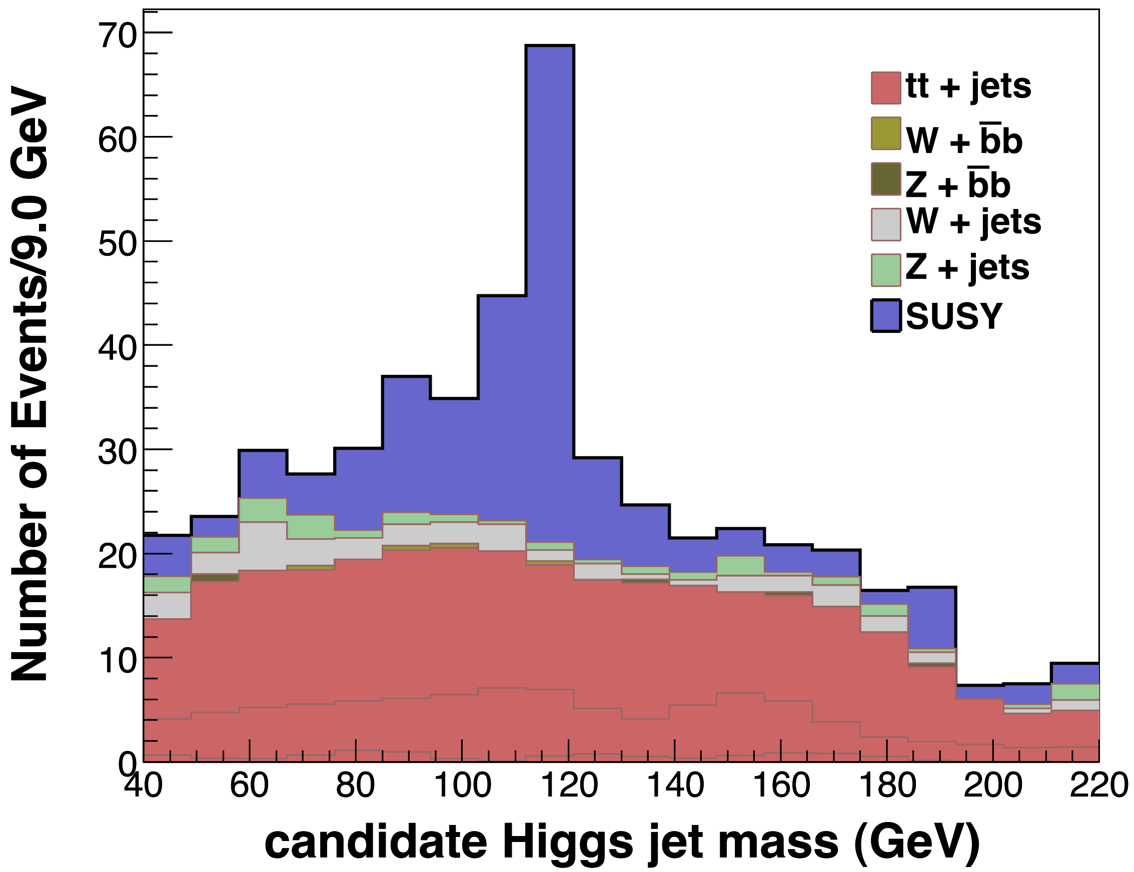
substructure + $\not{E}_T > 100$ GeV, $p_{T\gamma} > 80$ GeV

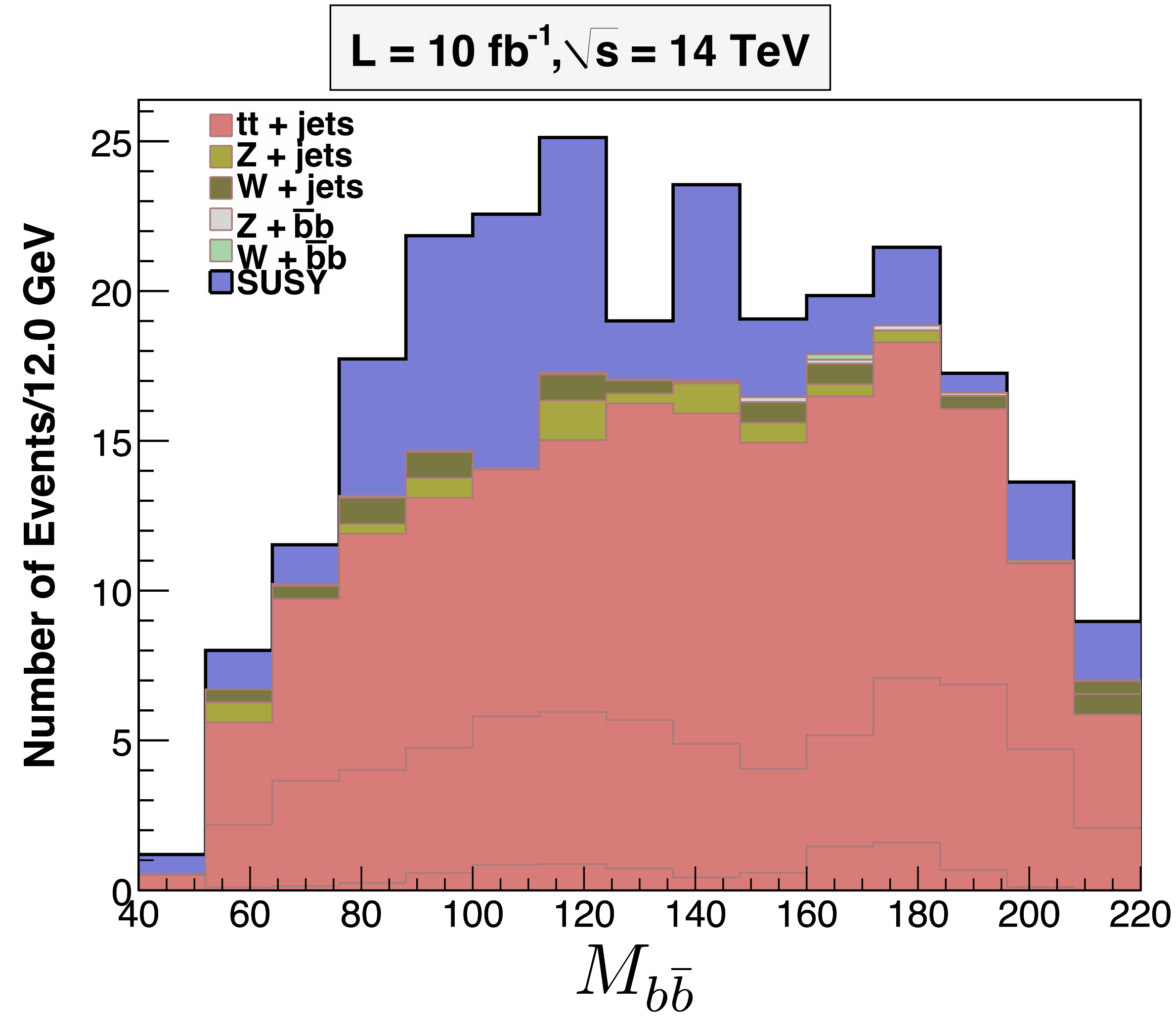
3rd generation squarks and gluinos play a bigger role in SUSY production, more b/t quarks in the events

$$BR(\tilde{\chi}^0 \to \tilde{G} + \gamma) \sim 43\%$$
$$BR(\tilde{\chi}^0 \to \tilde{G} + Z^0) \sim 29\%$$
$$BR(\tilde{\chi}^0 \to \tilde{G} + h) \sim 28\%$$

Neutralino LSP point, analysis comparison

Point #1, with substructure analysis and with PGS



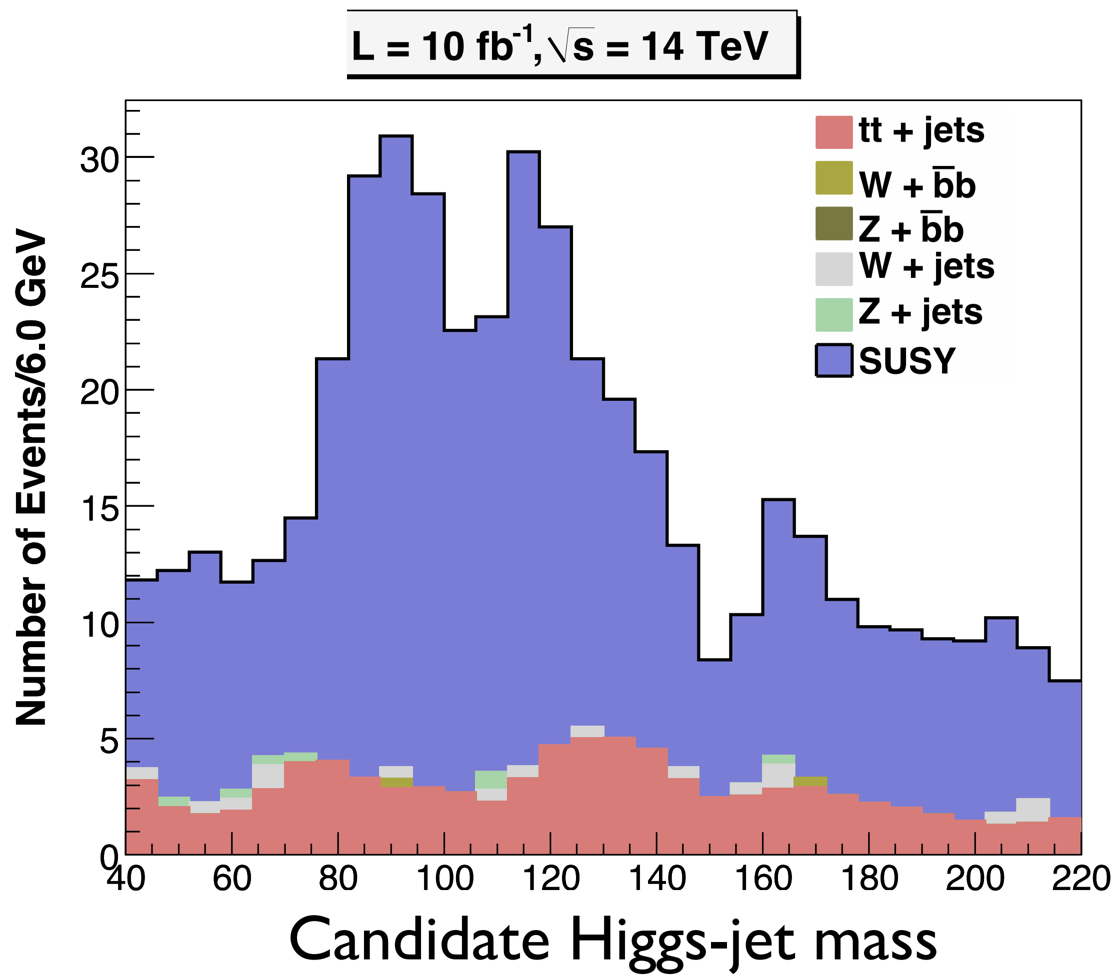


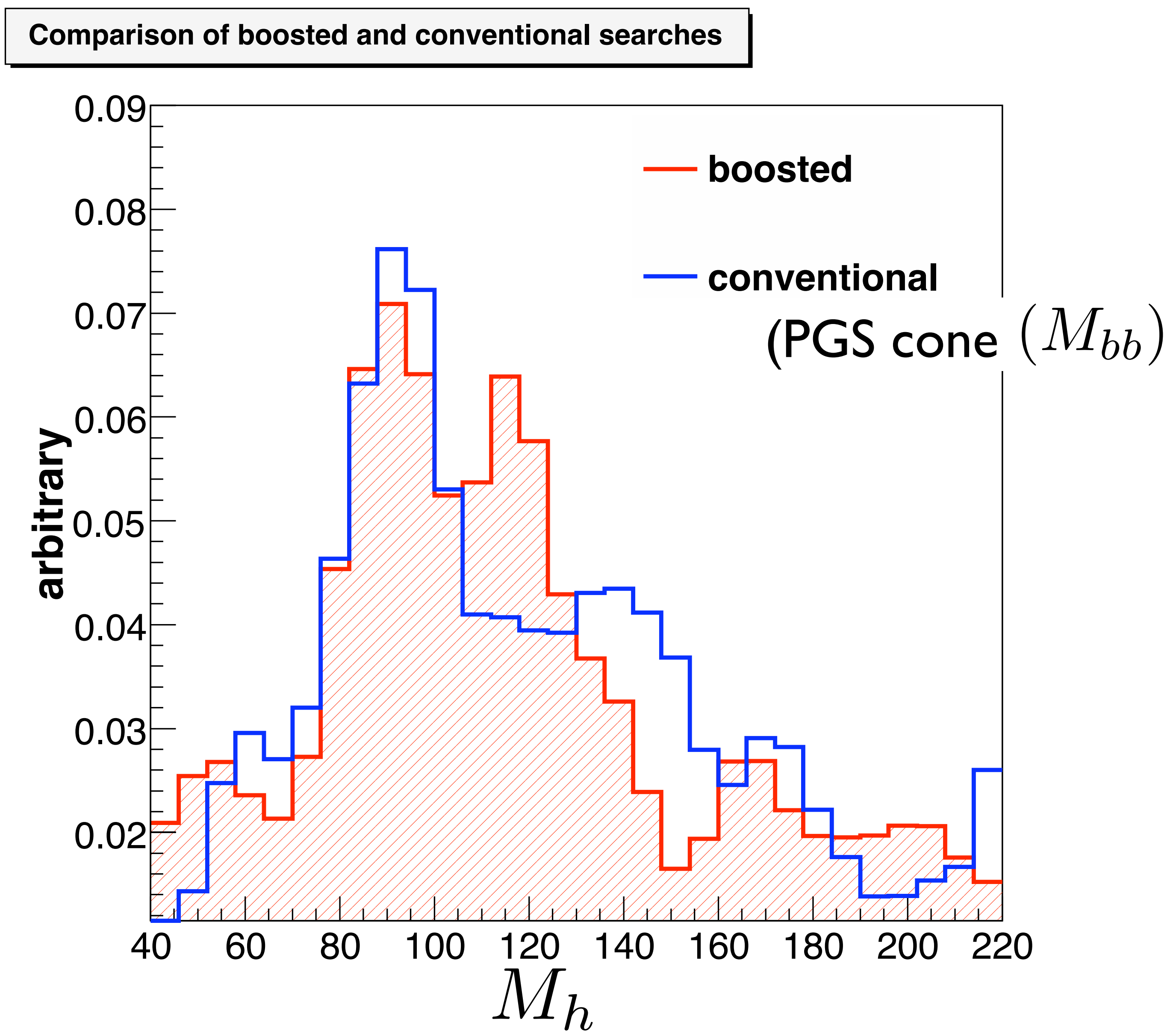
$H_T > 1$ TeV, $\not{E}_T > 300$ GeV
2^+ high-p_T jets + substructure

$H_T > 1$ TeV, $\not{E}_T > 300$ GeV
4^+ high $- p_T$ jets, no leptons

Gravitino LSP point, analysis comparison

boosted analysis finds the Higgs peak even where conventional analysis fails completely or leads to confusing features





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 ←