# Boosting BSM Higgs searches

Adam Martin (aomartin@fnal.gov)


based on work with:

Graham Kribs, Tuhin Roy,
Michael Spannowsky

arXiv: **0912.4731, 1006.1656, 1012.2866**

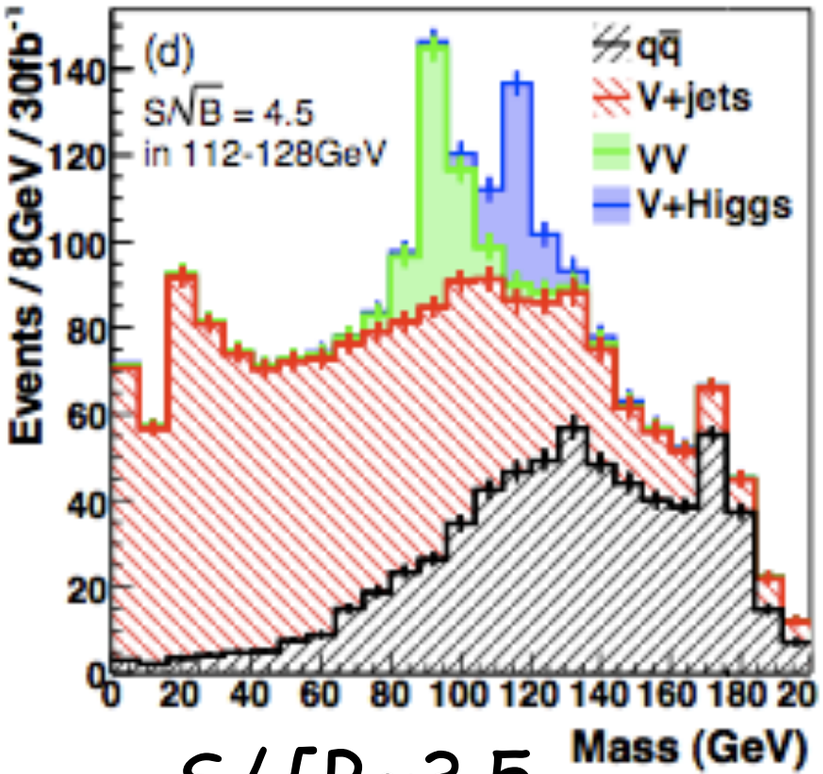
DIS, April 12th, 2011

Fermilab

# Introduction & Motivation

light Higgses ($m_H$ < 130 GeV) are traditionally difficult to find

h -> $b\bar{b}$ decay mode revived for boosted Higgses via jet substructure (see **BDRS**, 0802.2470)




S/√B~3.5

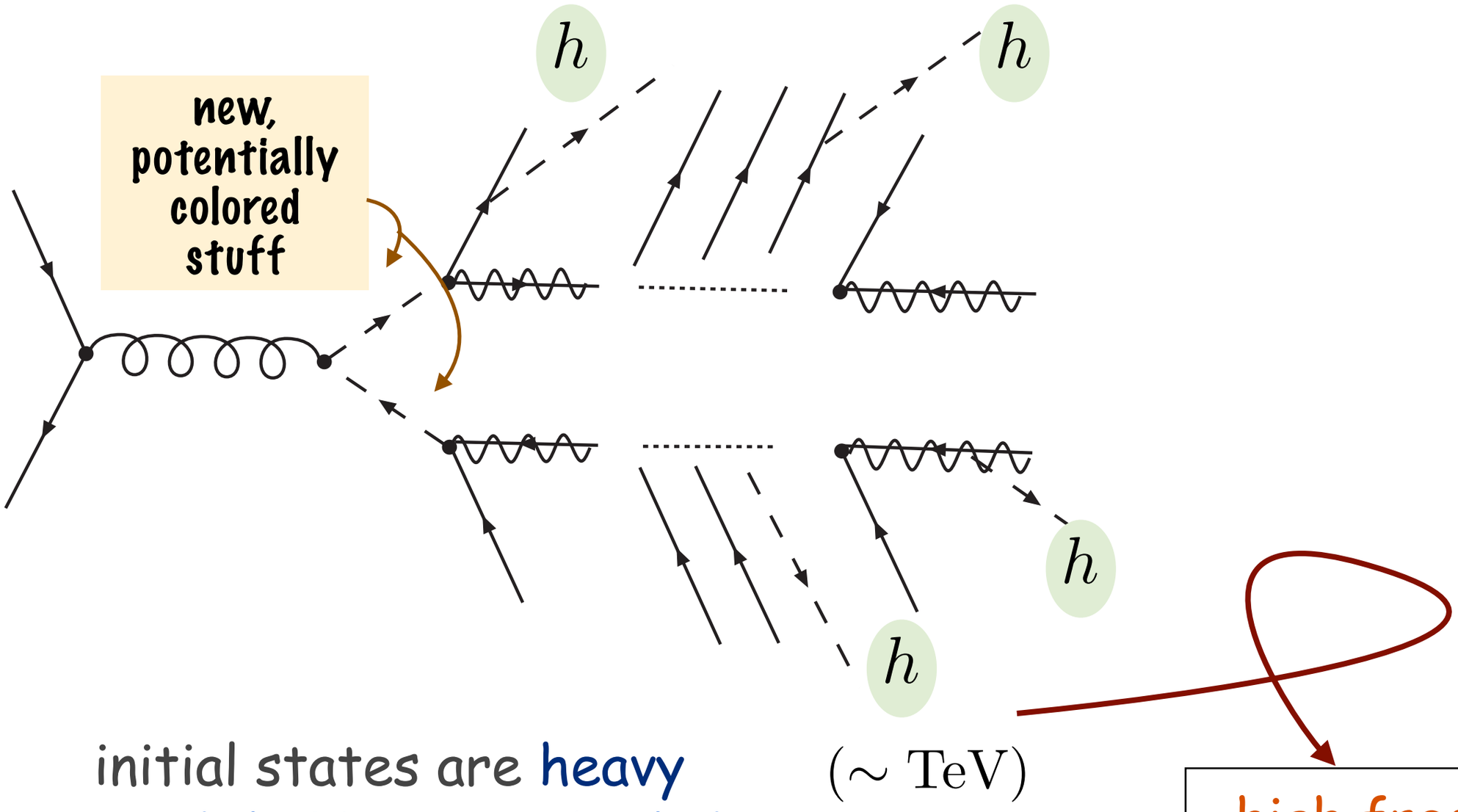

**In this talk:**

... what about boosted Higgses from BSM?

# Higgs from BSM decays

BSM stuff often talks to the Higgs

$\therefore$ BSM particles can decay to Higgses

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high fraction of boosted Higgses

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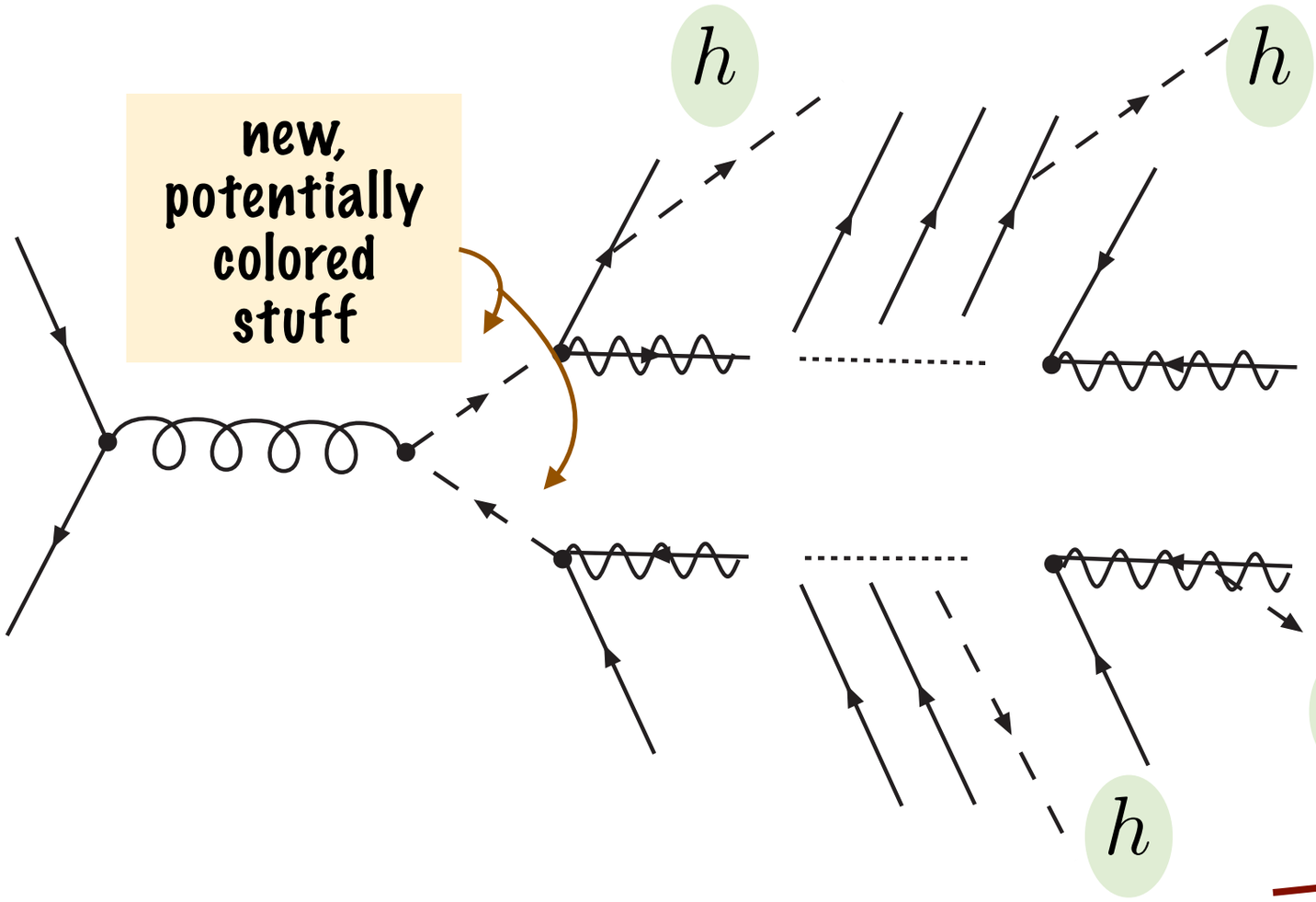


$=$ a new source of Higgses

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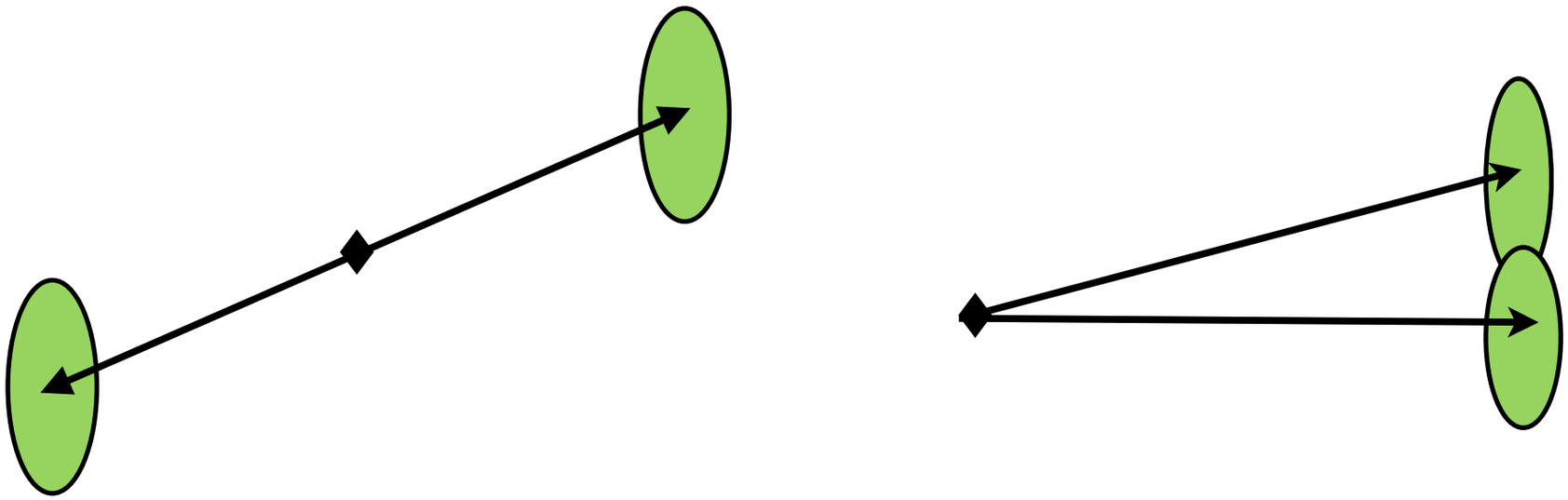
# Boosted Higgses:

when a heavy particle (Higgs) is boosted, its decay remnants get closer together in the detector



both decay products (+ associated radiation) can be captured by taking a larger jet cone -- resulting in a single 'fat-jet'

$R_{jj} \sim 2\, m_R/p_{T,R} \sim 1.2$ for $m_H \sim 120$, $p_{T,H} \sim 200$ GeV

these 'resonance fat jets' have several distinct characteristics, which we can use to our advantage

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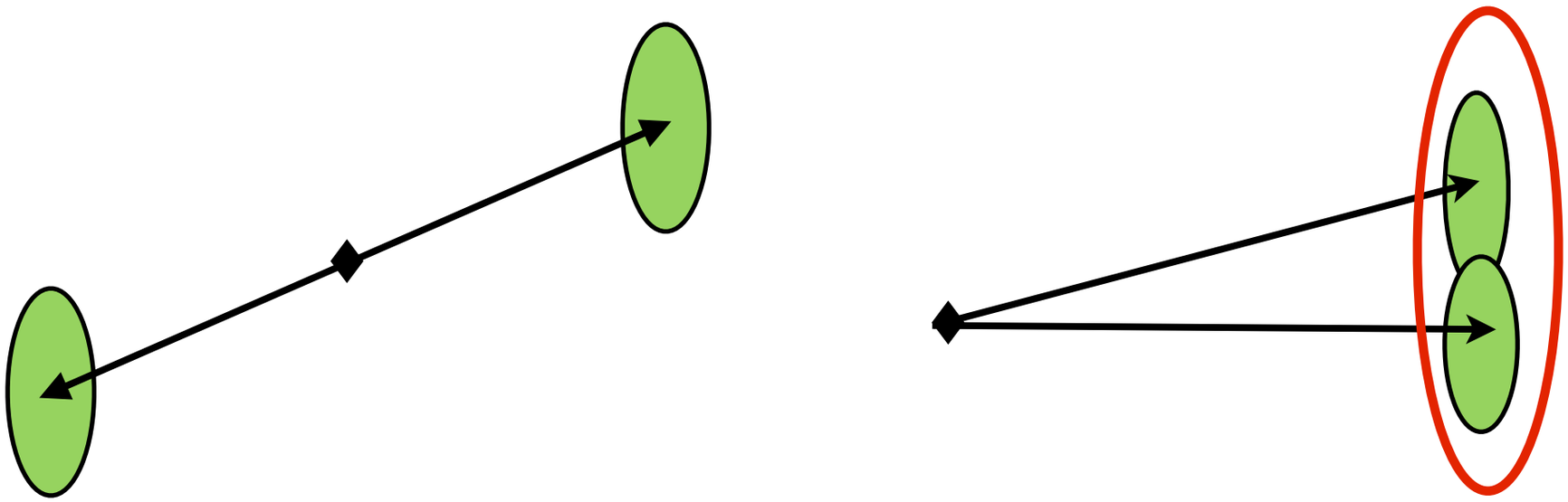

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(BDRS)

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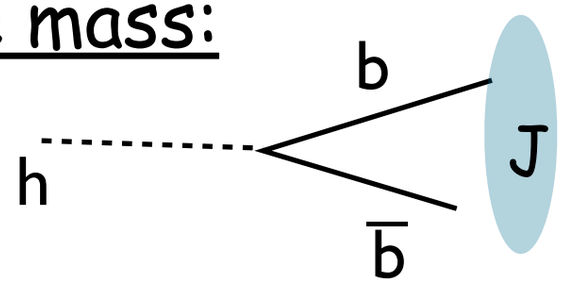


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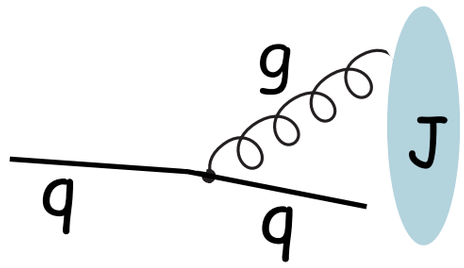


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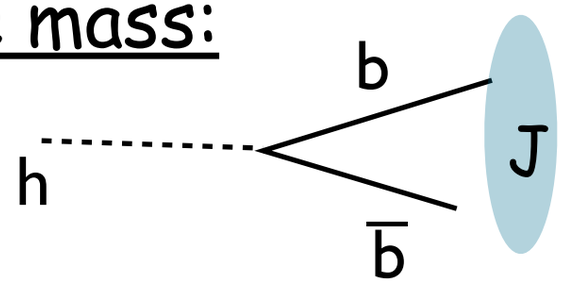


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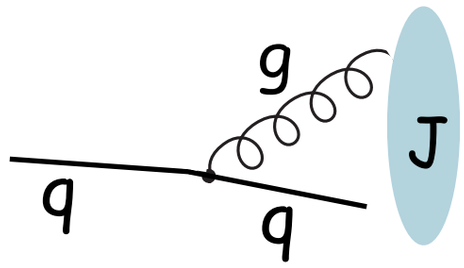


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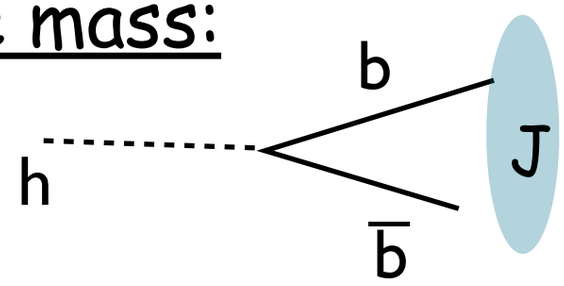


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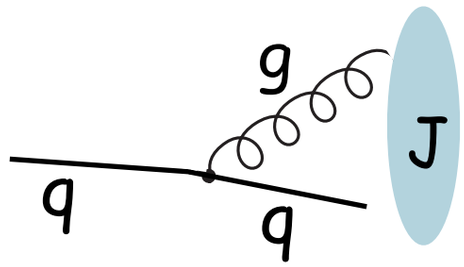


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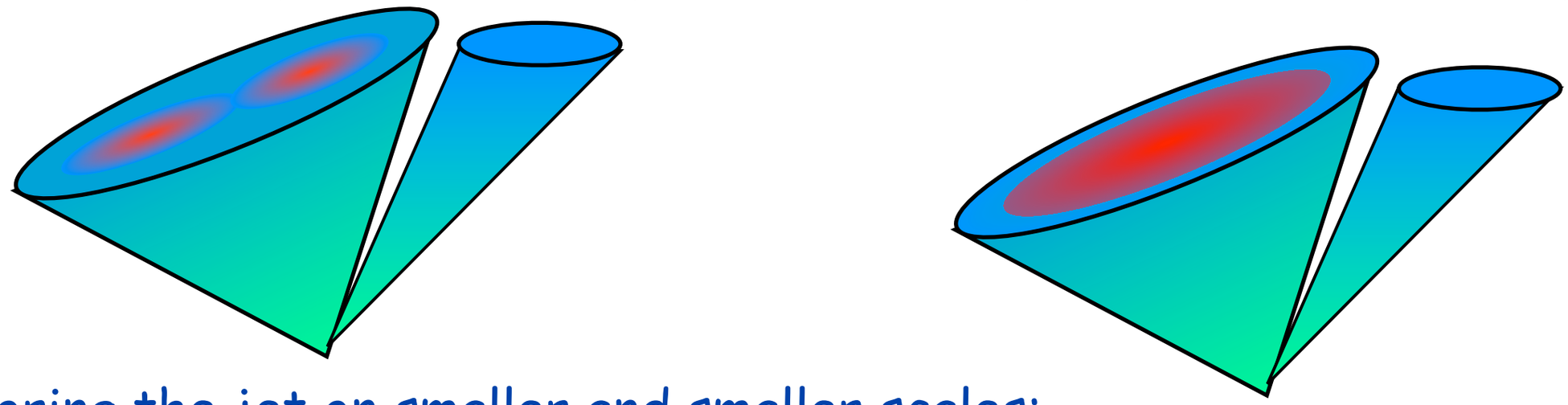

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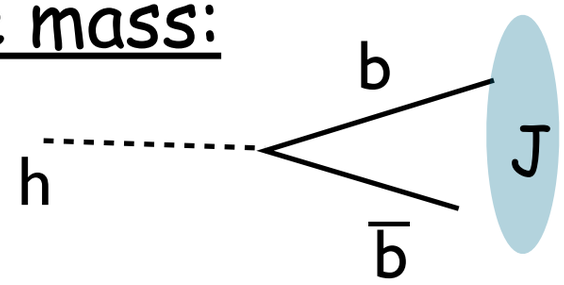


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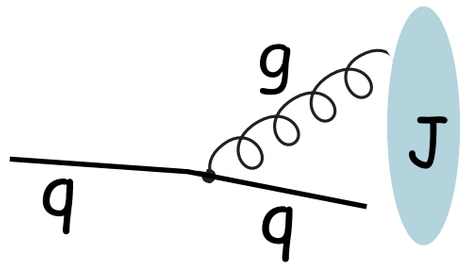


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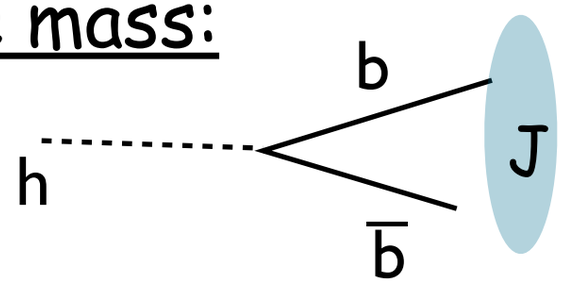


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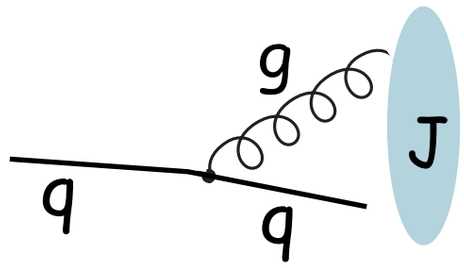


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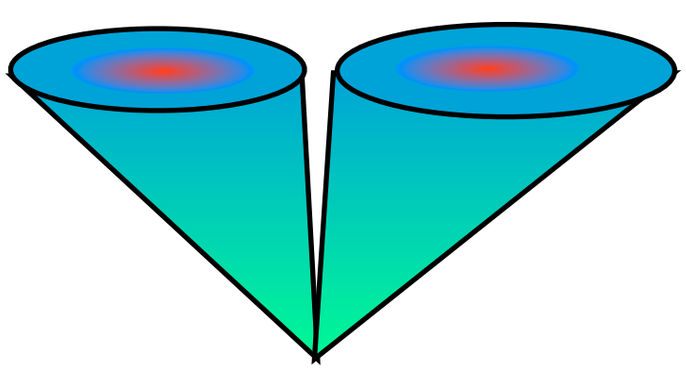

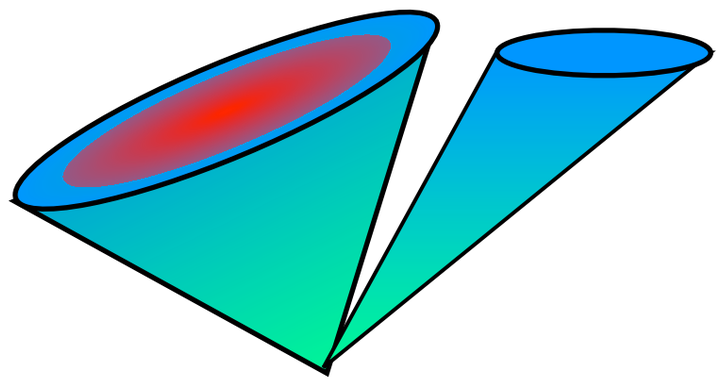

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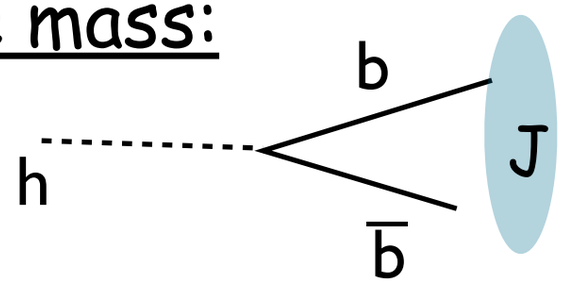


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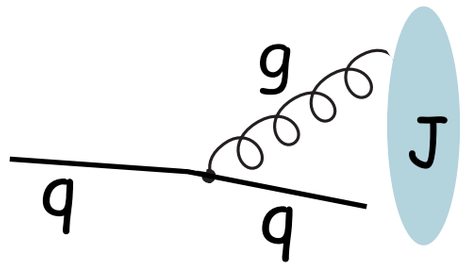


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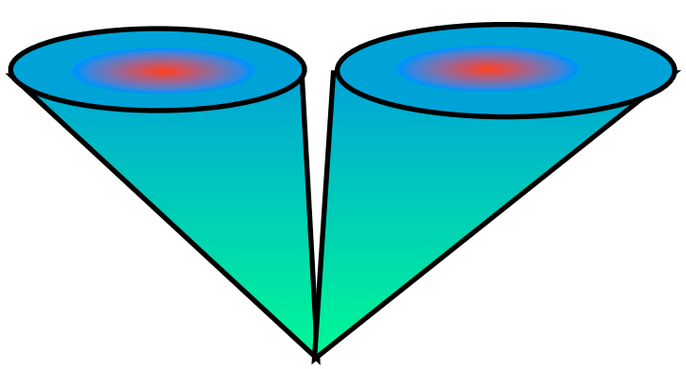

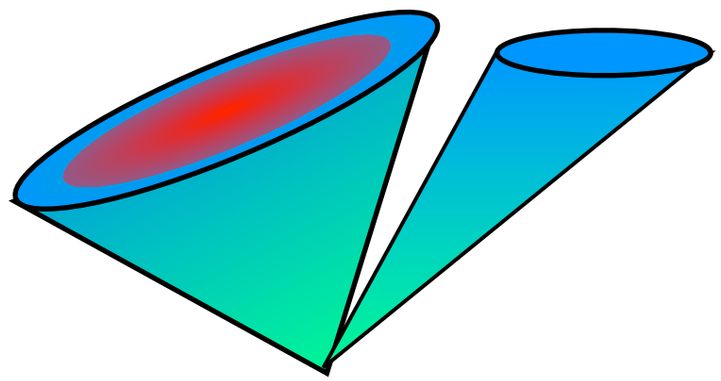

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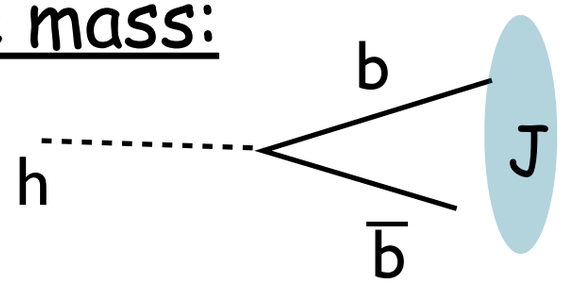


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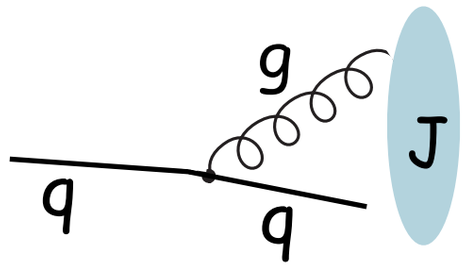


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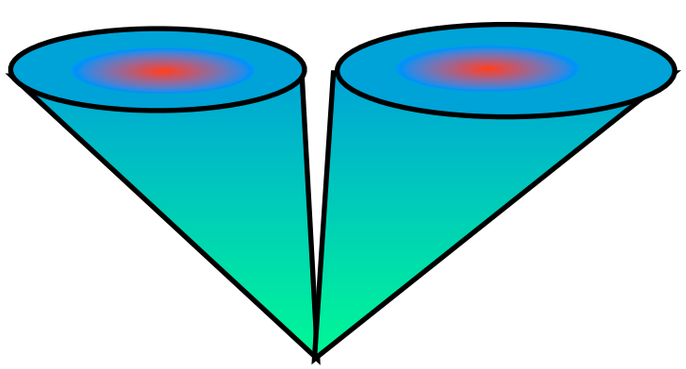

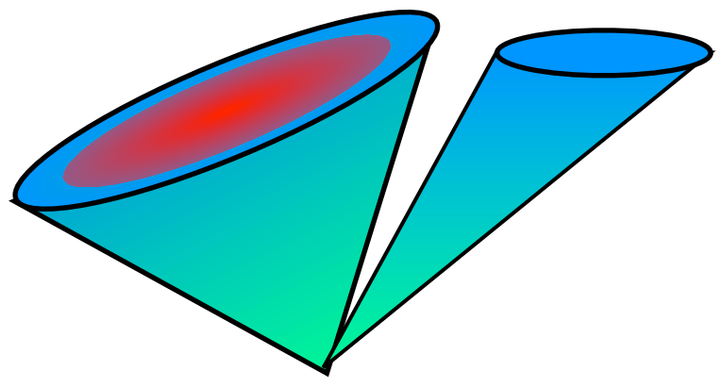

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3. no combinatorics:

look for Higgses within **single 'fat'** jets passing these substructure criteria, **not** between all pairs of jets

# Boosted Higgses:

boosted techniques, while powerful, are limited in the SM by the small fraction of events with sufficient boost/topology: ~2-5% for $W(l\nu)H(b\bar{b})$

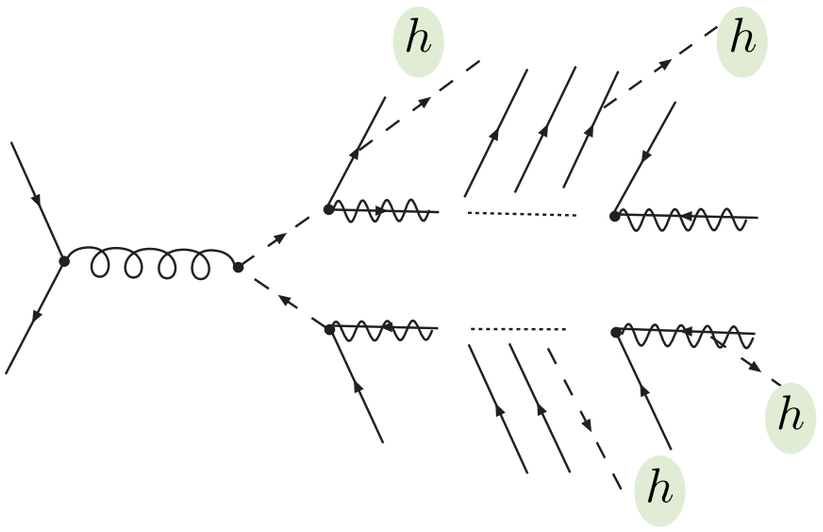
not the case for Higgses from BSM cascades!

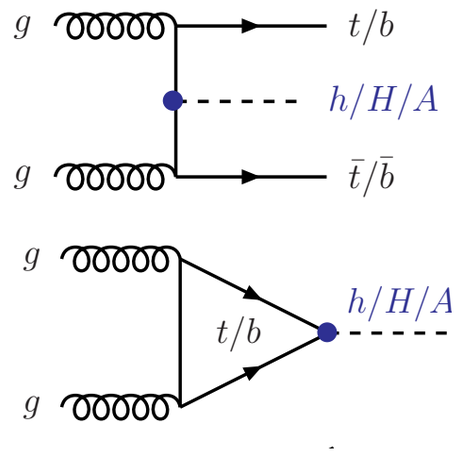
# on to BSM

1. ) Pick your favorite BSM model

- needs Higgs (the lighter, the better)
- needs stuff which interacts with Higgs

2.) Look in all BSM events, rather than just ~few channels

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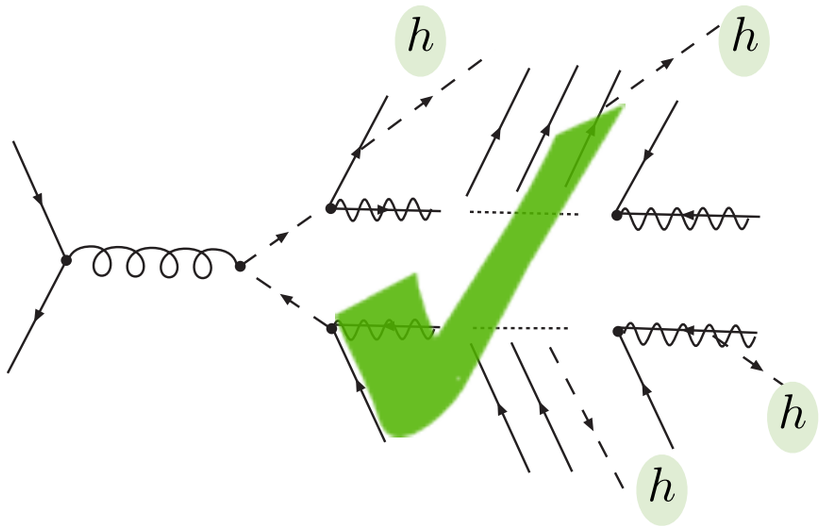


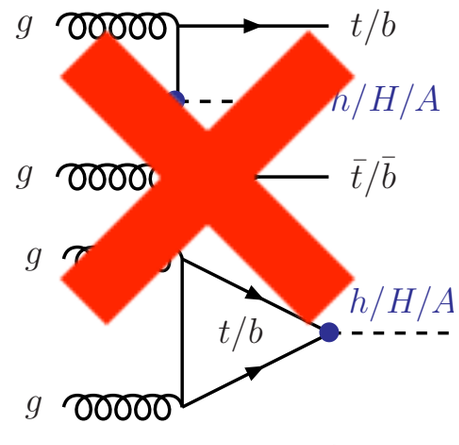


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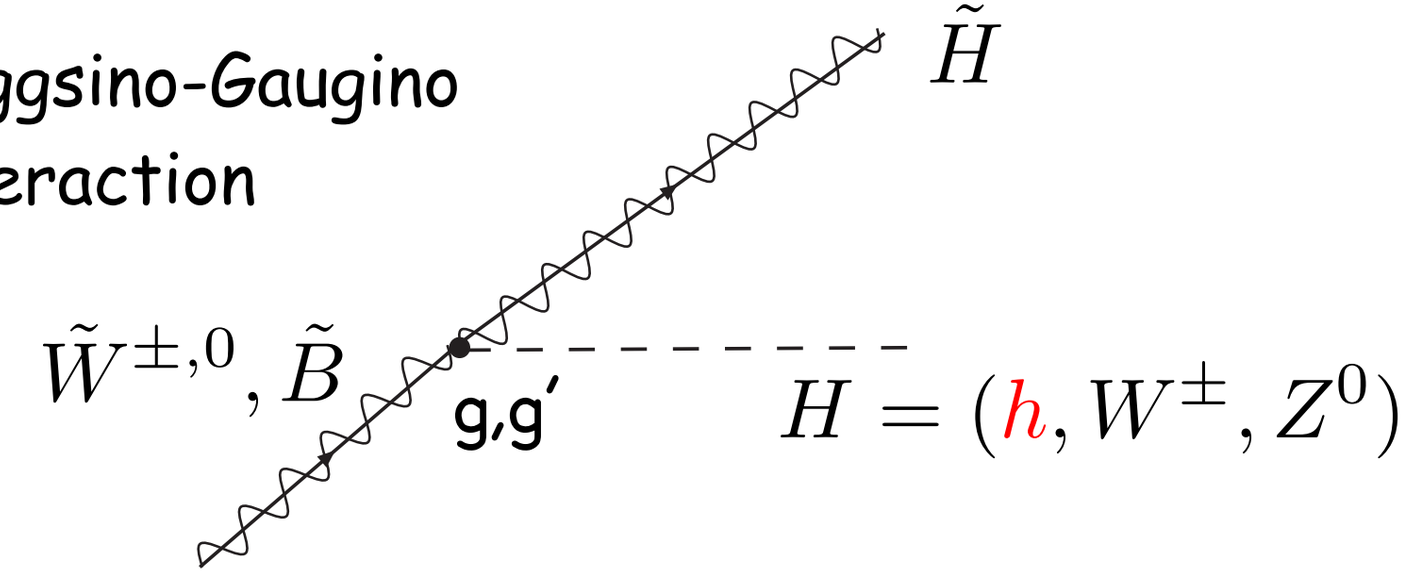

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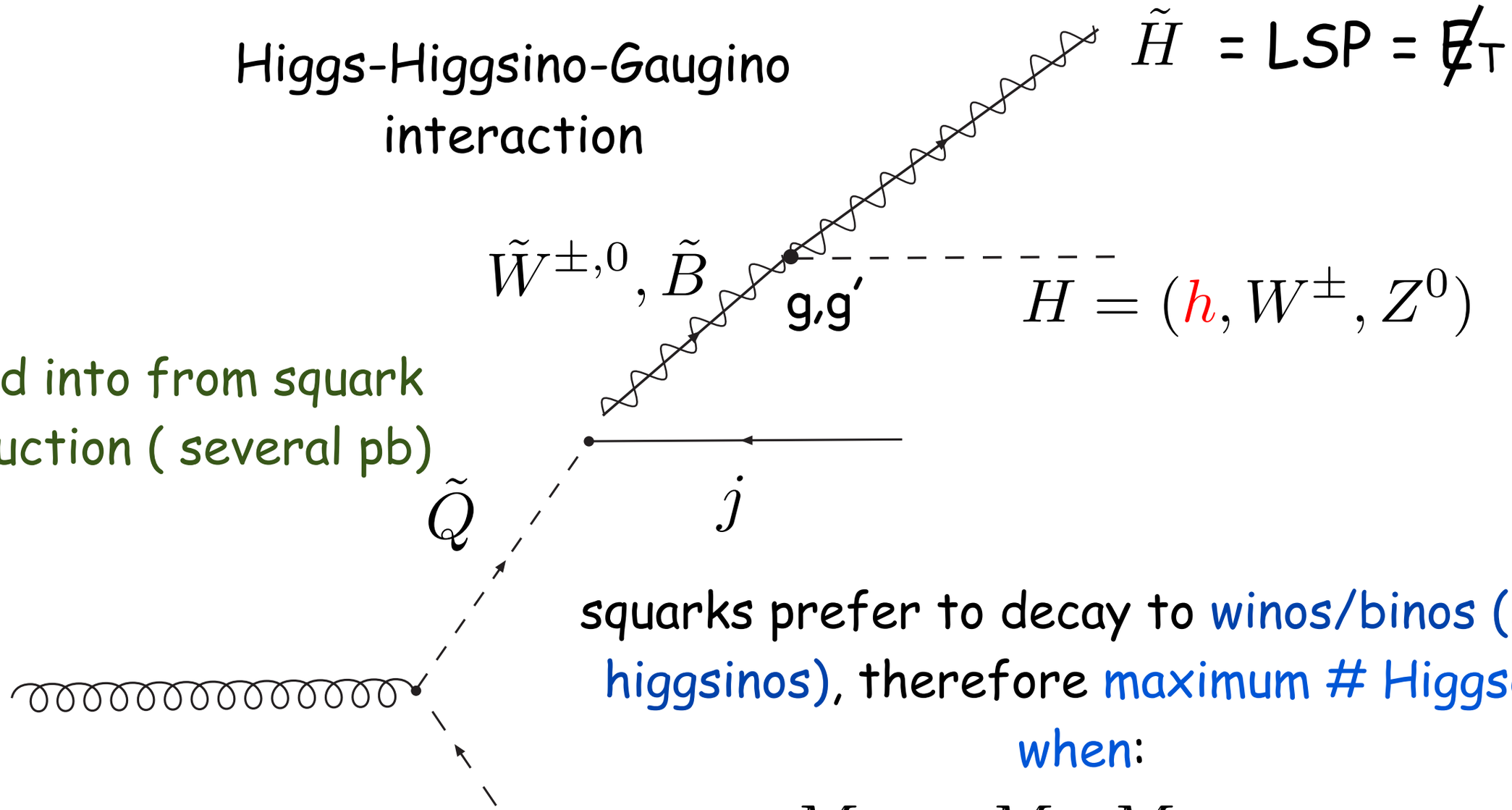


... fed into from squark production ( several pb)

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

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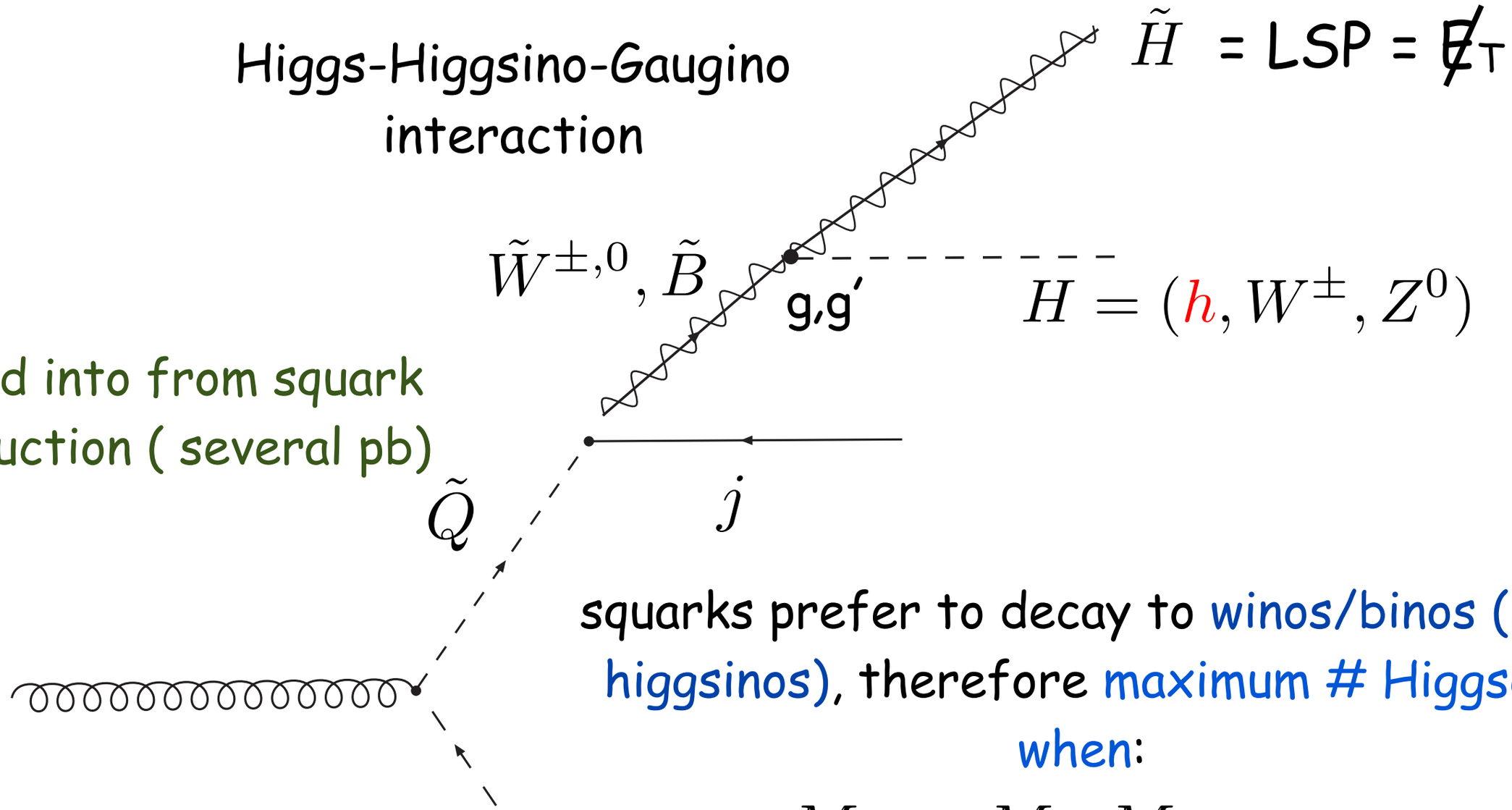


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OR: if gravitino is LSP, can also have Higgses from

$\tilde{\chi}_1^0 \to \tilde{G} + h$ **ex.)** $\tilde{\chi}^0\tilde{\chi}^0 \to h + \gamma + \not{E}_T$

# Boosted Higgs in the MSSM...

- MSSM Higgs has to be light $m_h \lesssim 130\ \mathrm{GeV}$ ,
  decays dominantly to $b\bar{b}$
- All events have $\not{E}_T$

**makes SUSY cascades ideal for Higgs hunting**

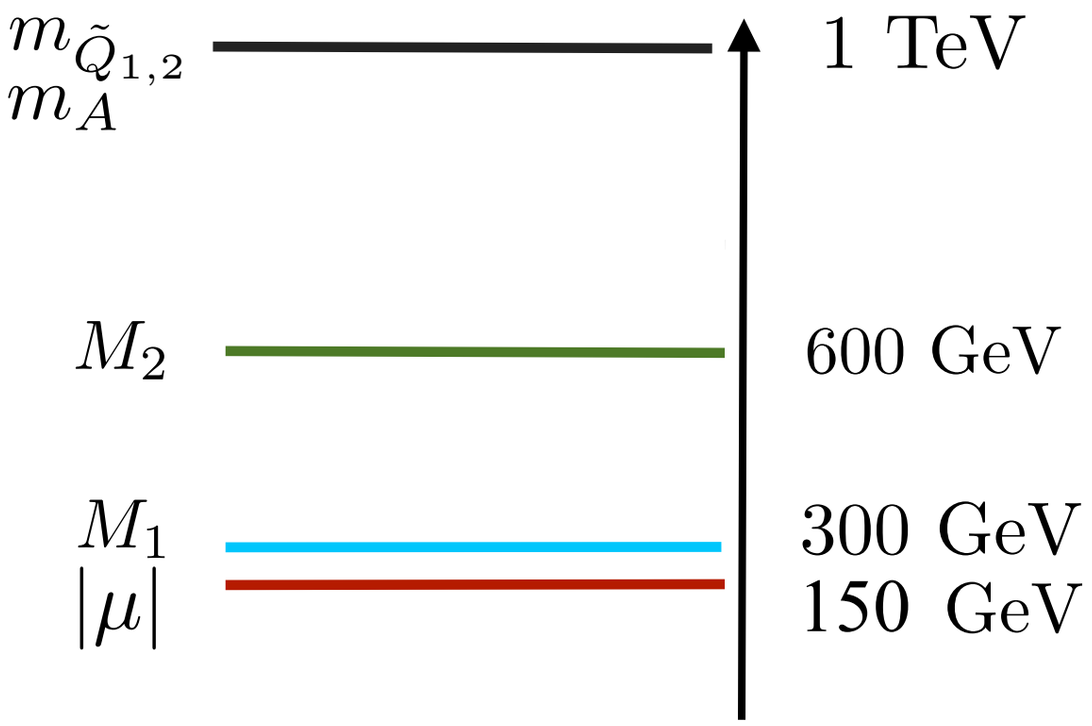
- mass hierarchy requirements are mild

BUT, don't get Higgses in cascades from mSUGRA
(so, rarely studied)

universal BC + EWSB → large μ term → no H in cascades

# Neutralino LSP Results: #1

MET > 300 GeV, $H_T$ > 1 TeV, 3+ jets,
no lepton, + 1 "tagged" Higgs

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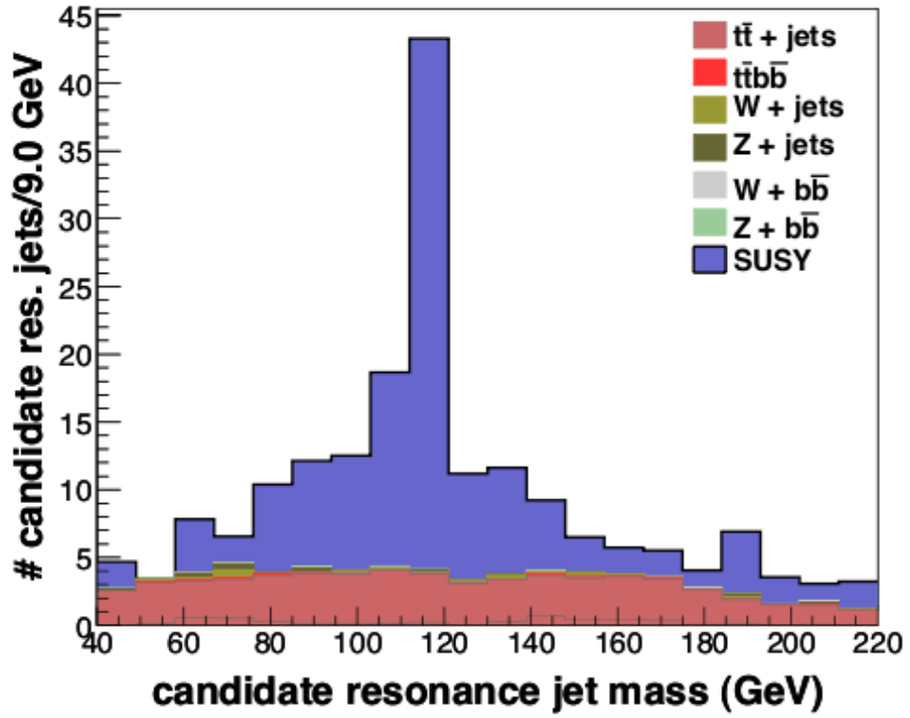


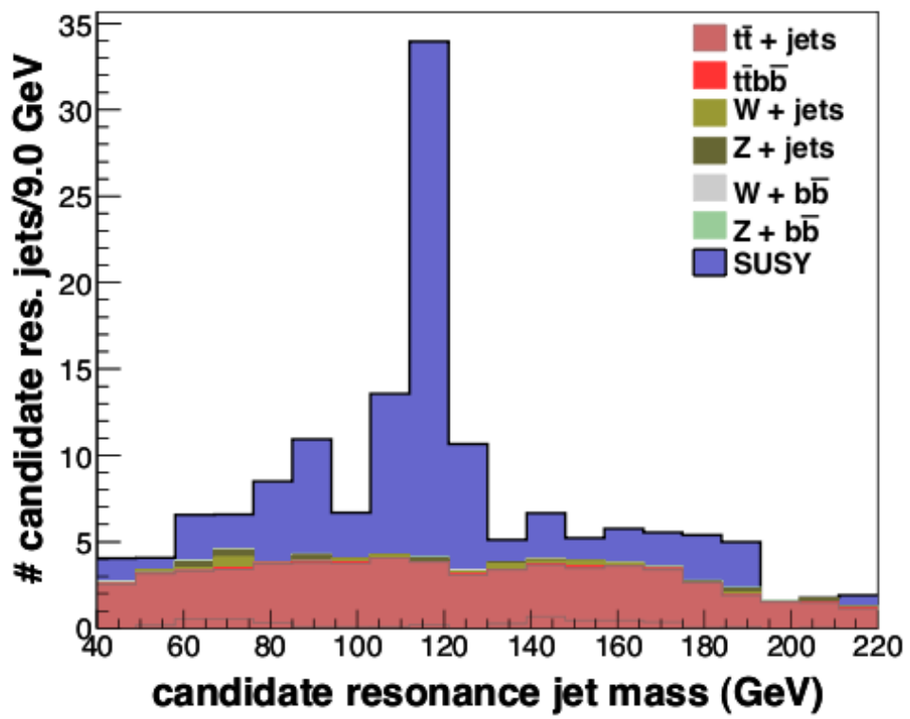

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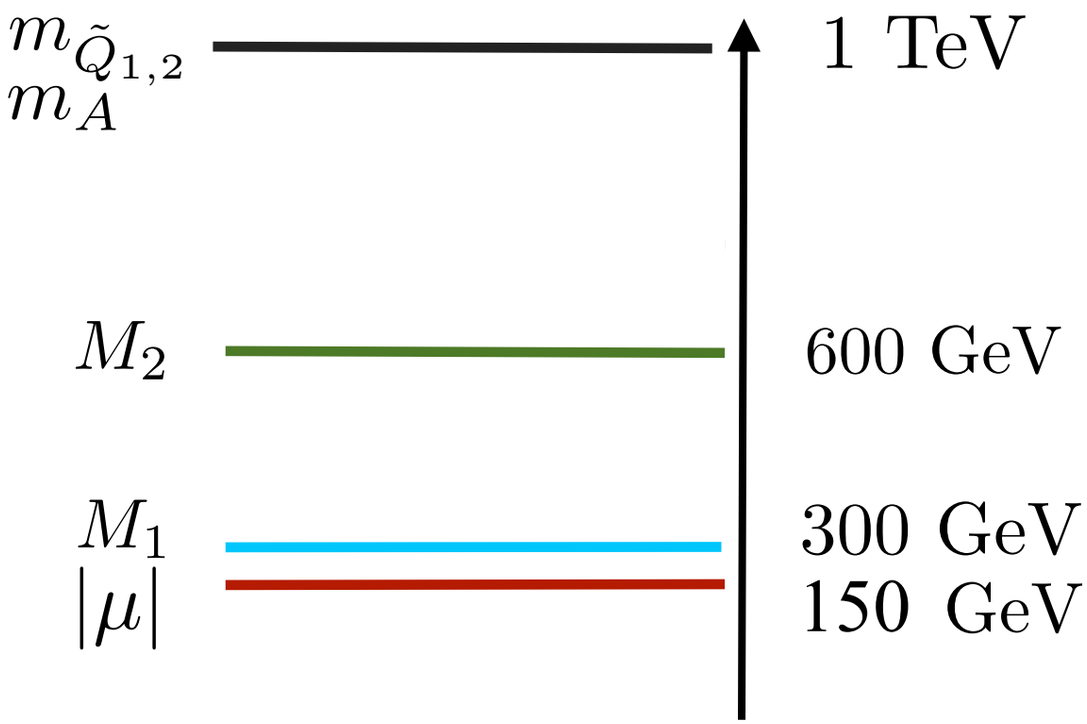


$$BR(\tilde{u}_L, \tilde{d}_L \to h + X) \sim 23\%$$
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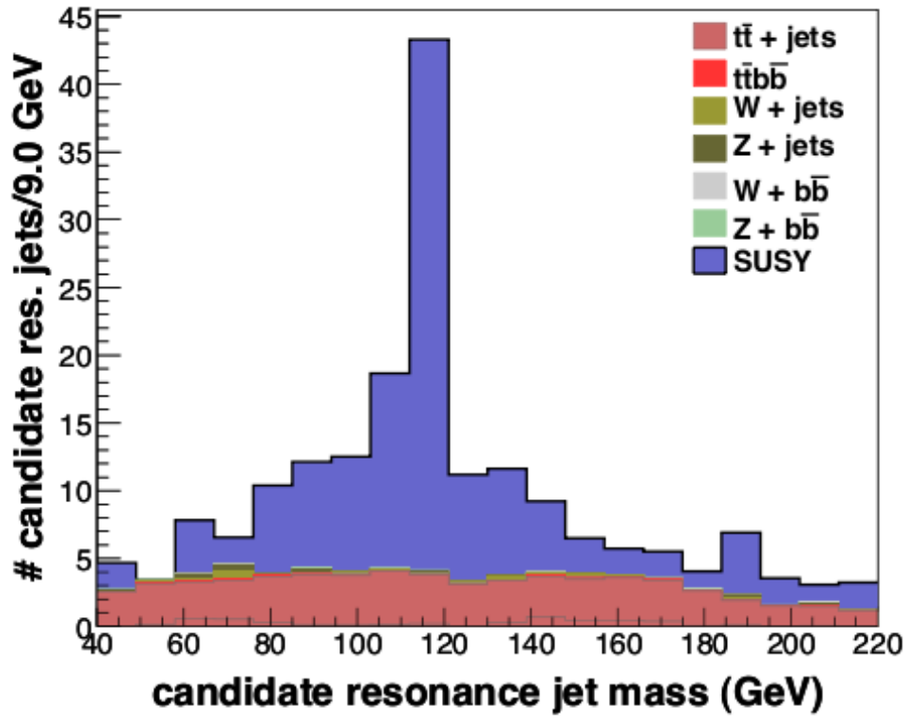


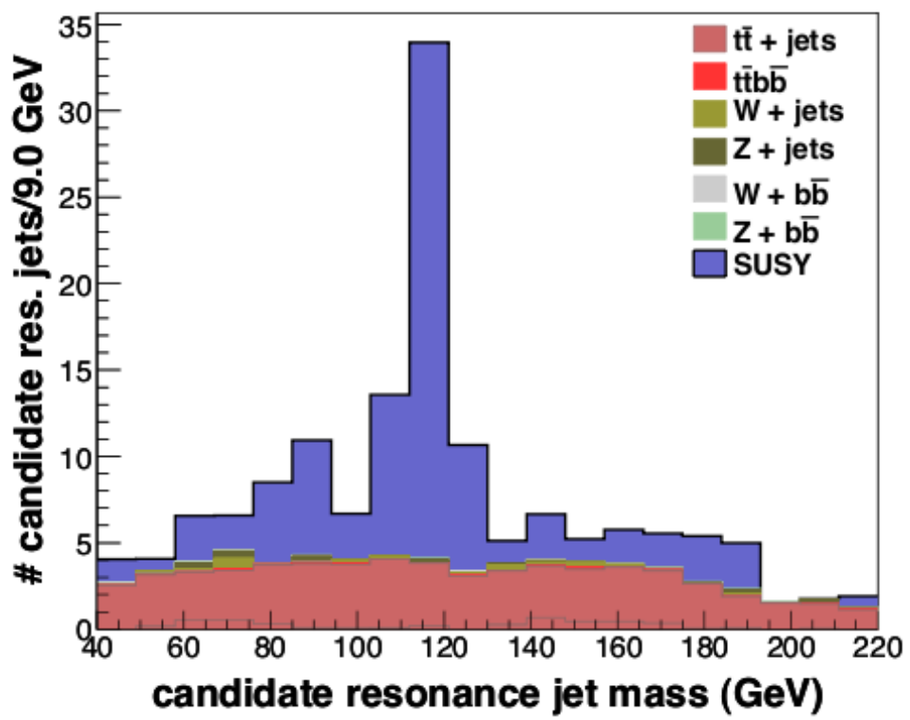

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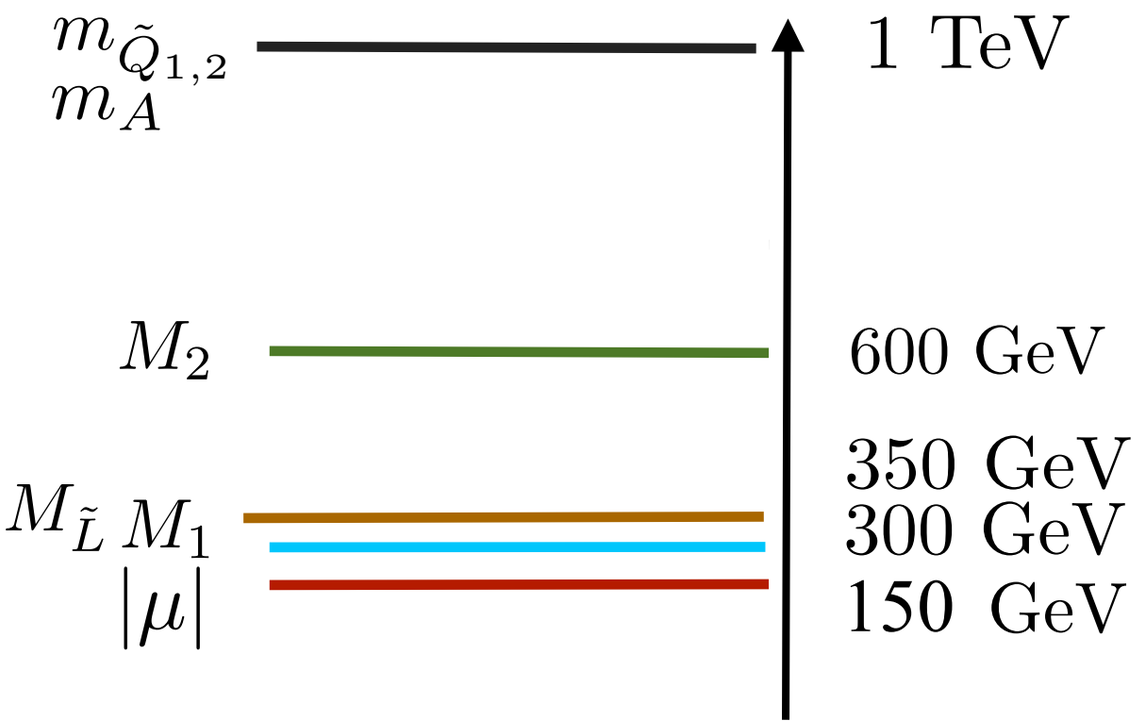


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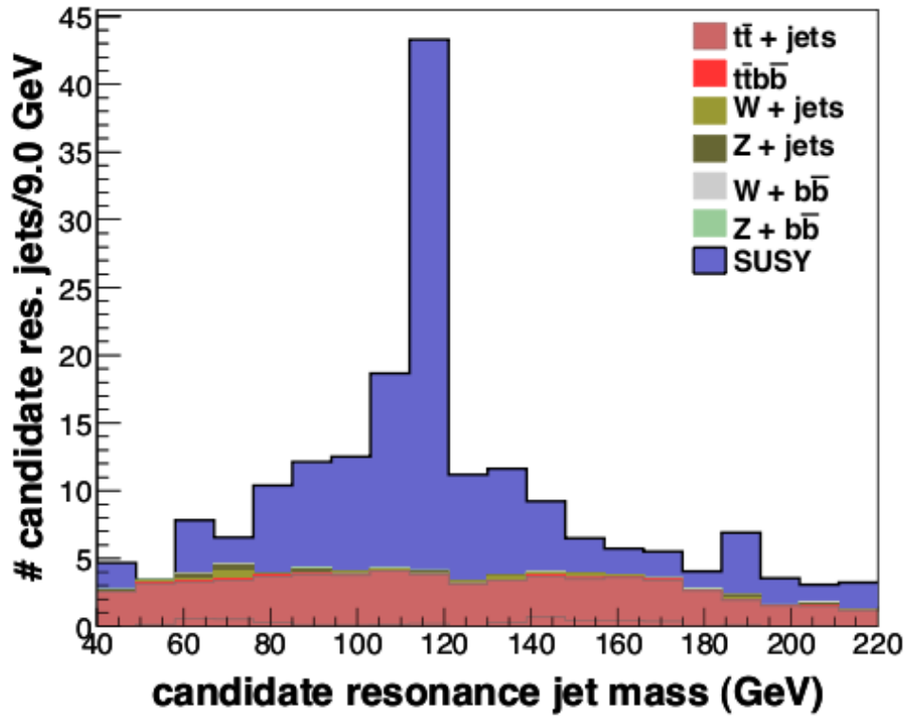
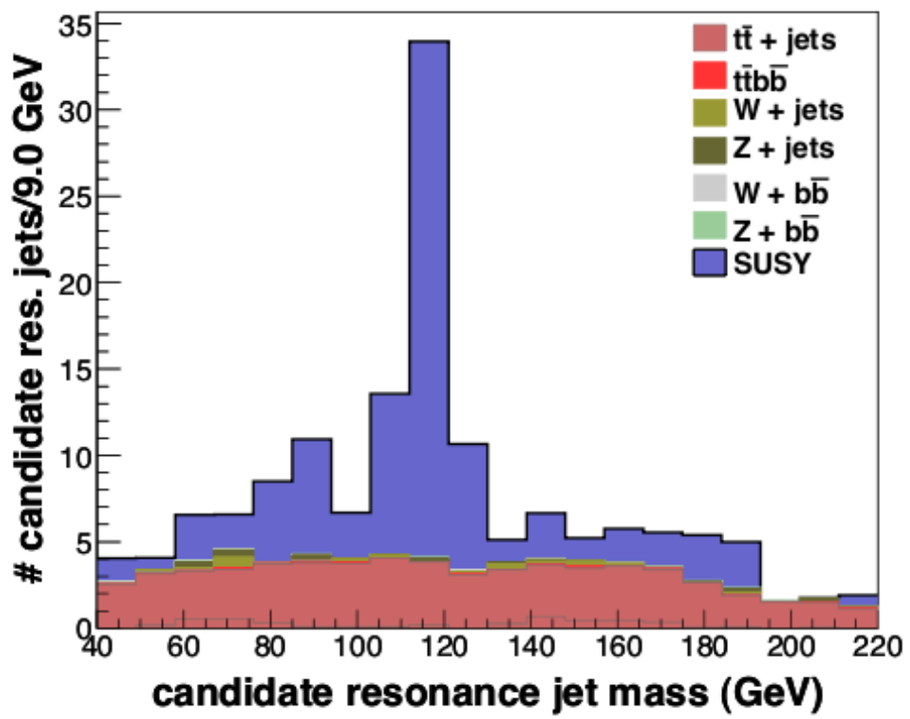
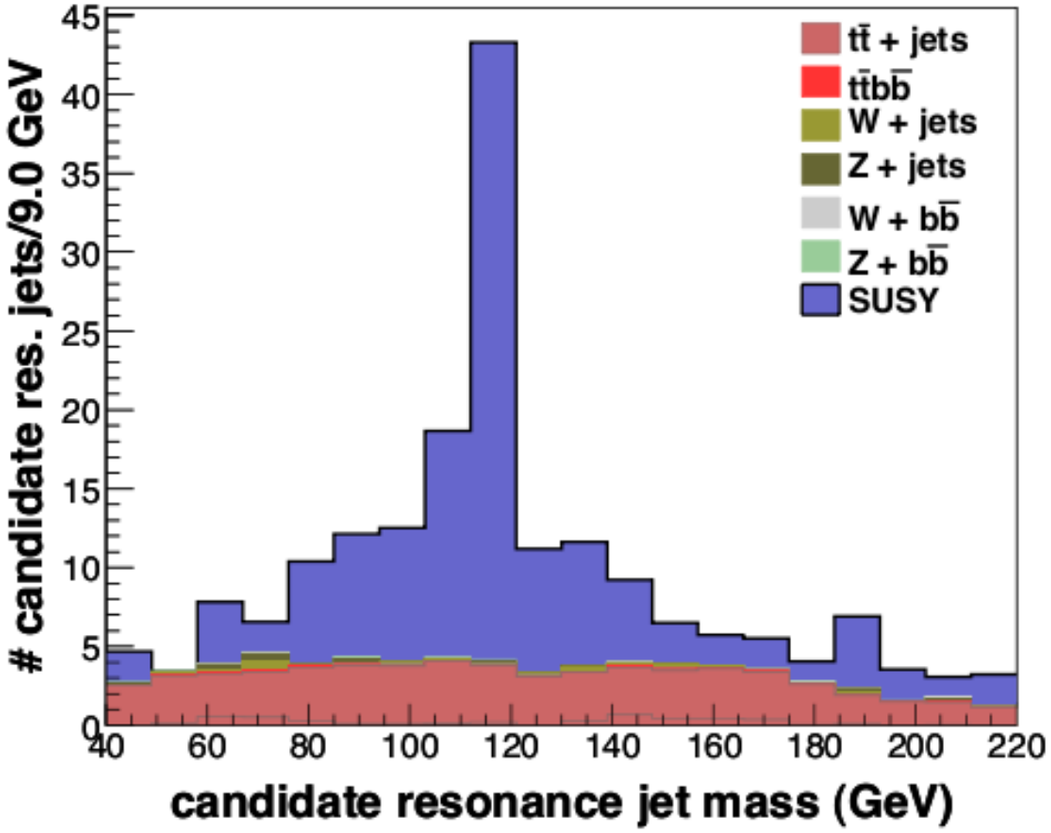


# "What good is that fancy substructure?"

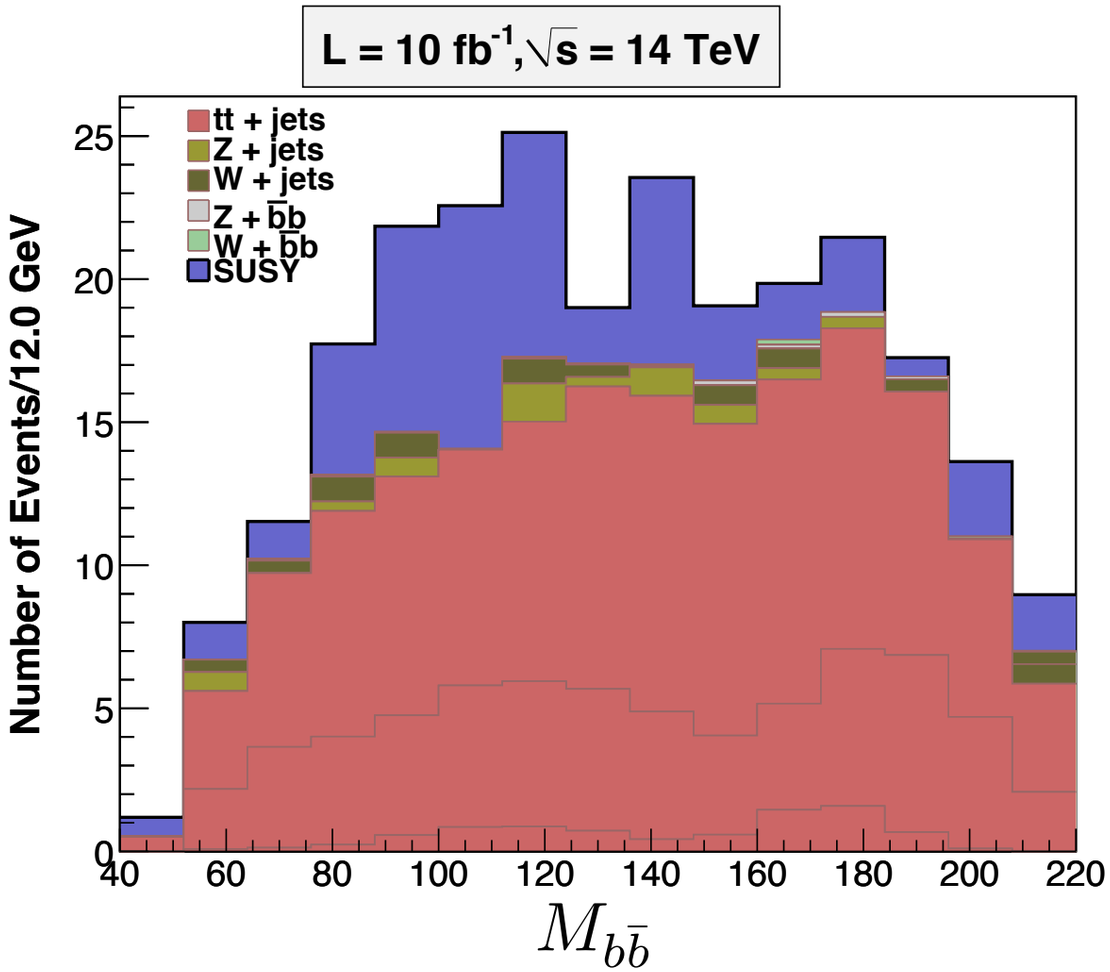
## Comparison*: with substructure analysis vs. with PGS




$H_T > 1$ TeV, $\not{E}_T > 300$ GeV

$3^+$ high-$p_T$ jets, no leptons

1 candidate Higgs




$H_T > 1$ TeV, $\not{E}_T > 300$ GeV

$4^+$ high $- p_T$ jets, no leptons

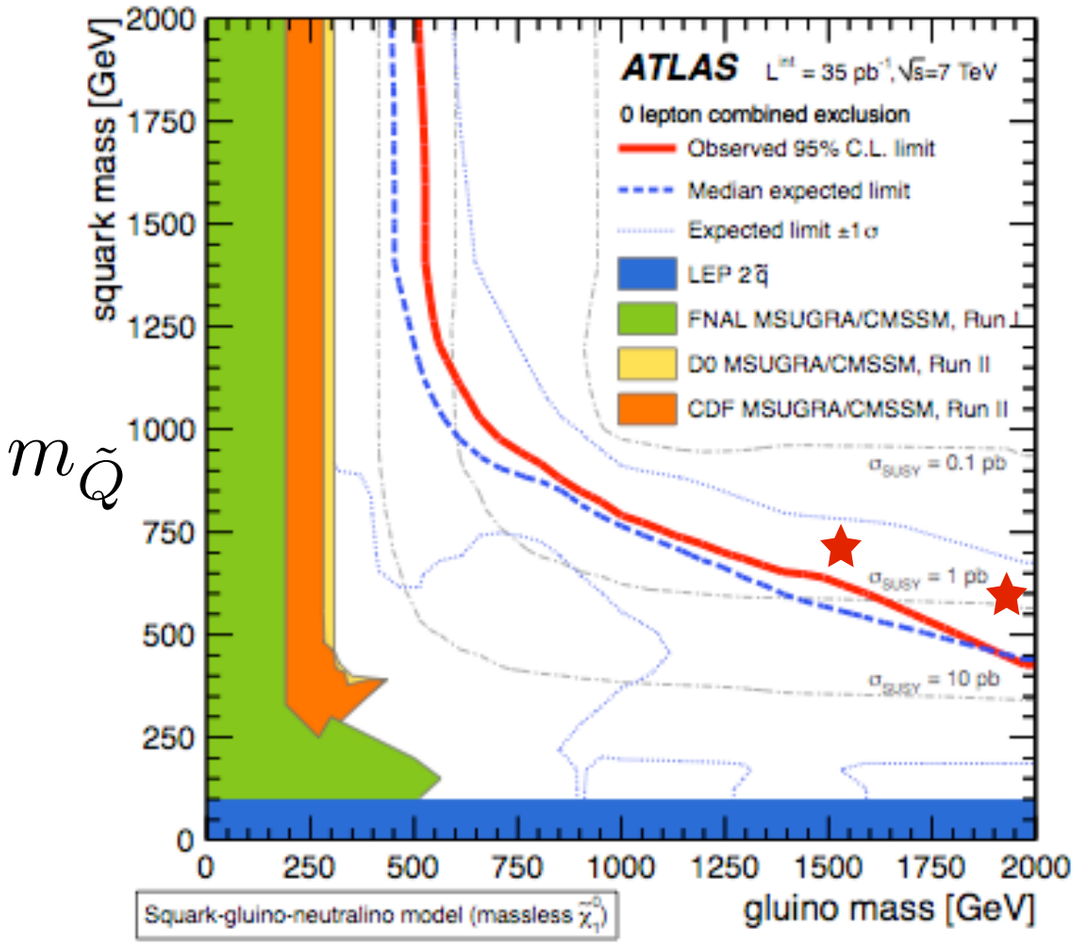
$2^+$ b-tags

***not totally fair**

# "What about at 7 TeV?"

squished spectrum, looser cuts, but same strategy works

$M_1 = 350\,\mathrm{GeV}, M_2 = 250\,\mathrm{GeV}, \mu = 170\,\mathrm{GeV}$




$m_{\tilde{Q}}$

substructure +

$\not{E}_T > 175\ \mathrm{GeV}, 0$ leptons

$H_T > 600\ \mathrm{GeV}$

$M_3$

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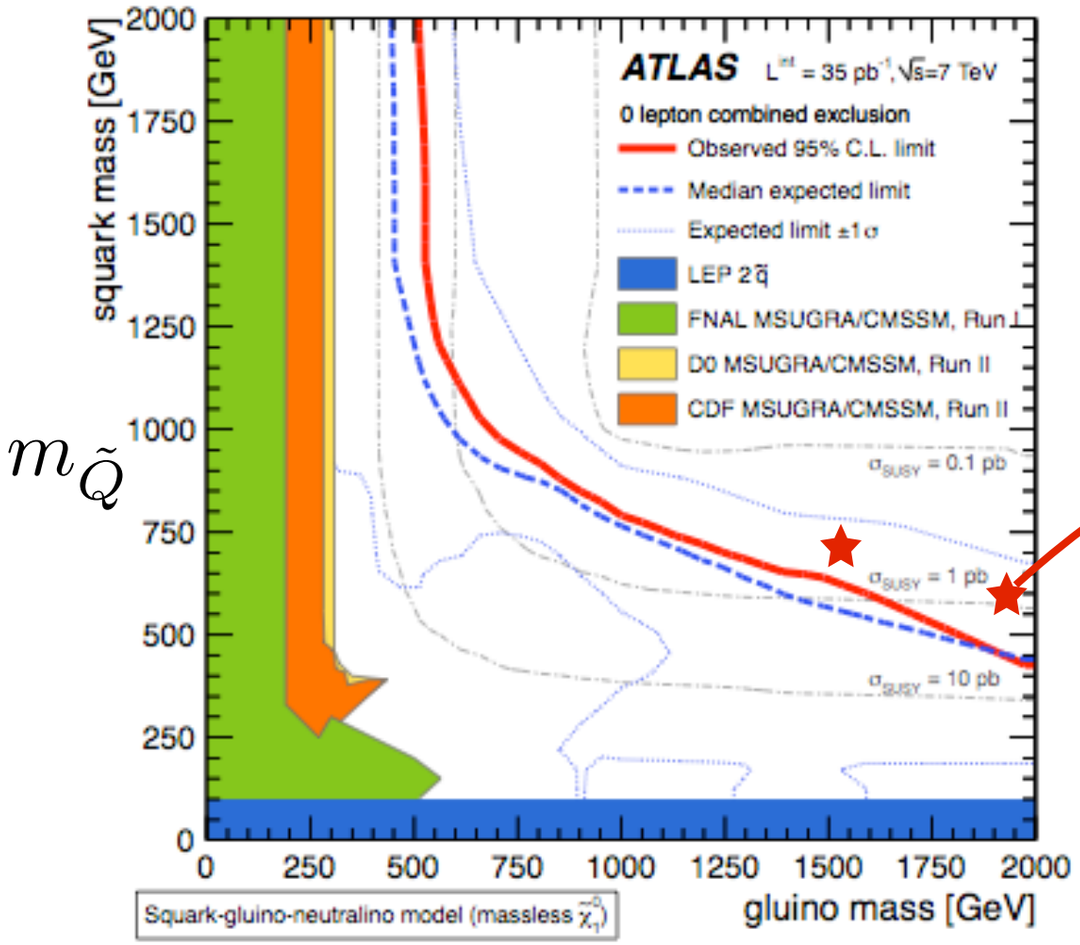


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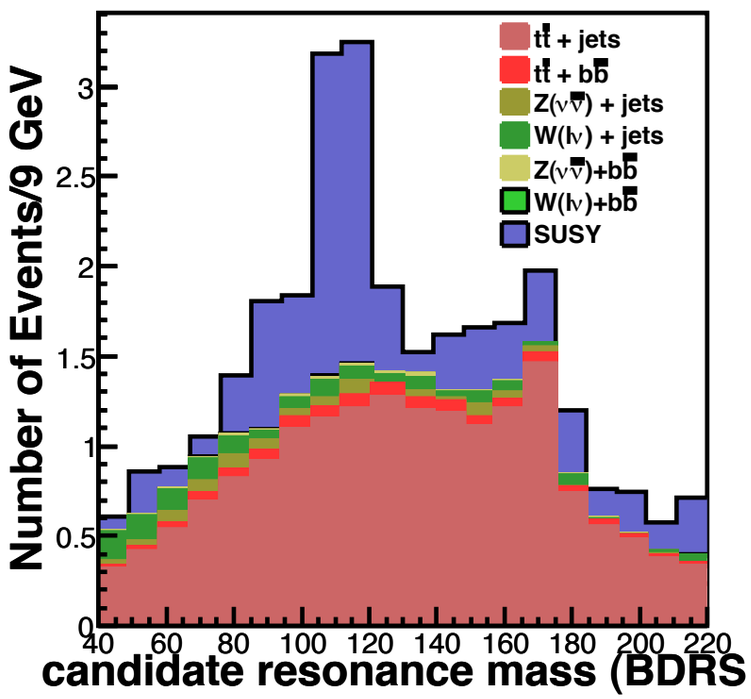

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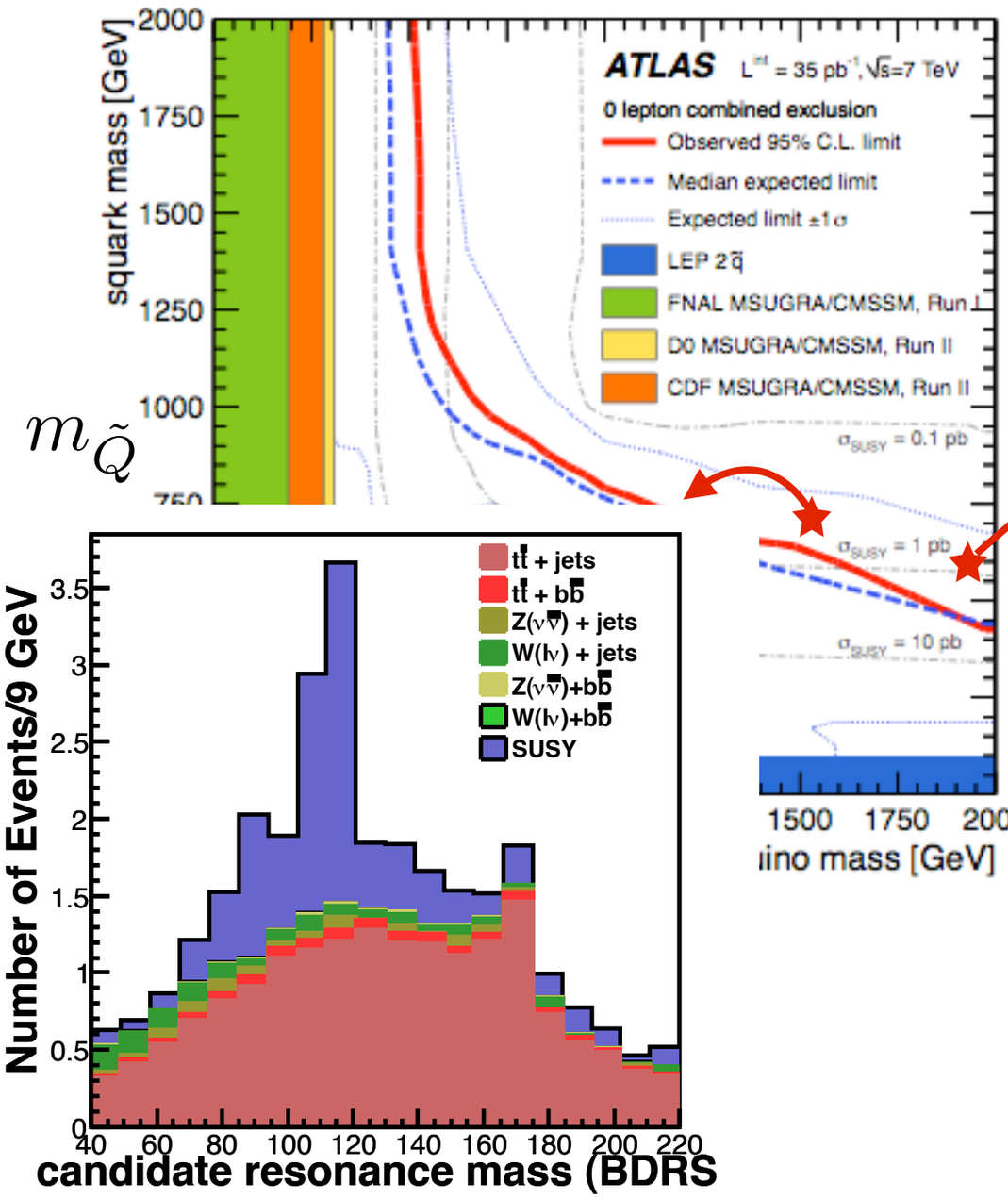


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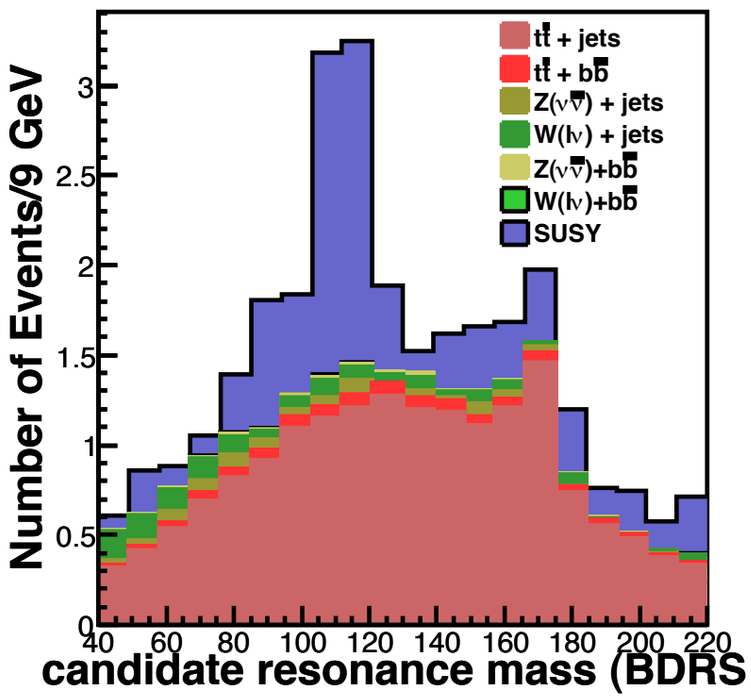
$$H_T > 600\ \text{GeV}$$



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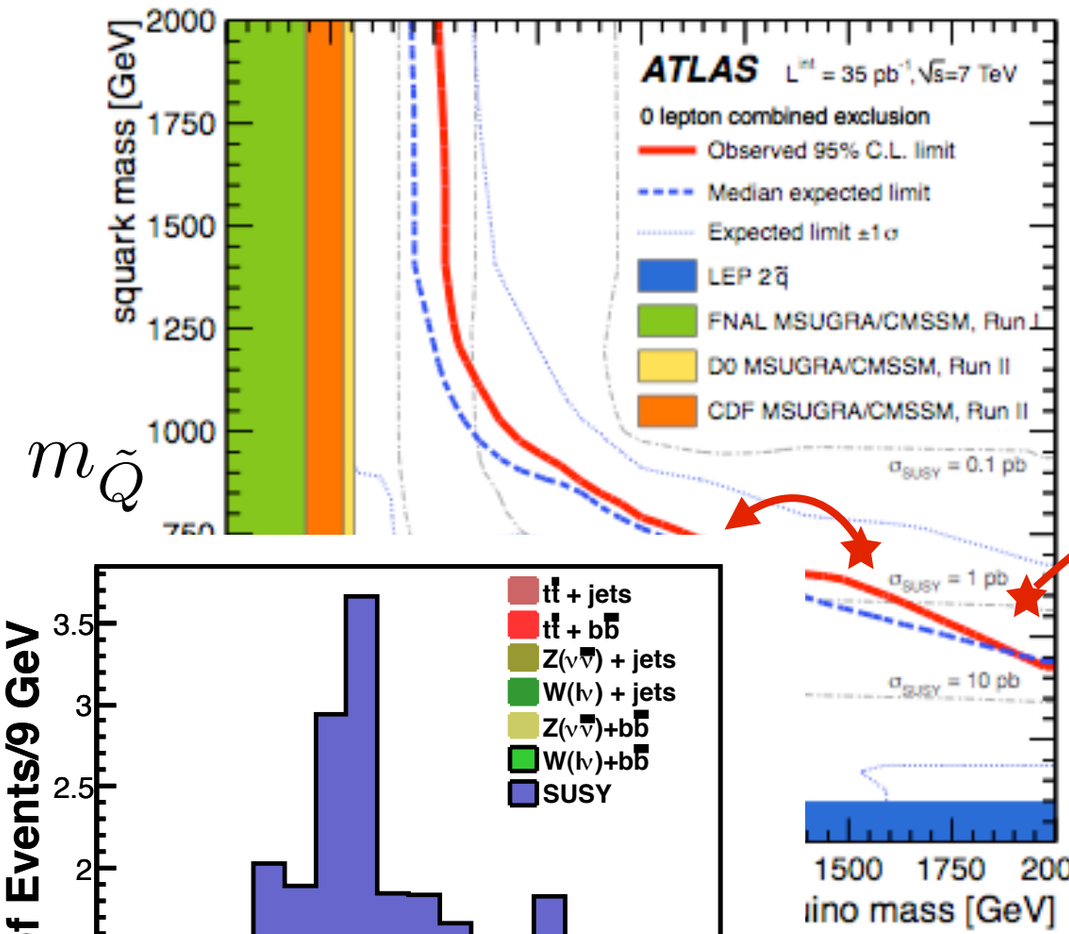


$m_{\tilde{Q}}$

substructure +

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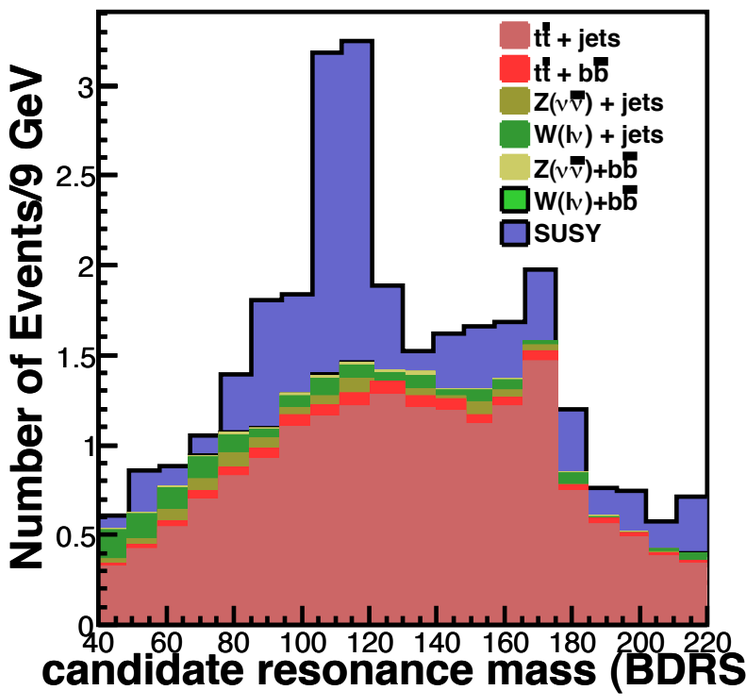
$H_T > 600$ GeV




Higgs discovery < 1 fb$^{-1}$, 7 TeV

# Higgses from Top-partners

In MSSM Higgs searches, the final state always contained two BSM particles (LSPs) -> an automatic handle for suppressing SM background (MET)

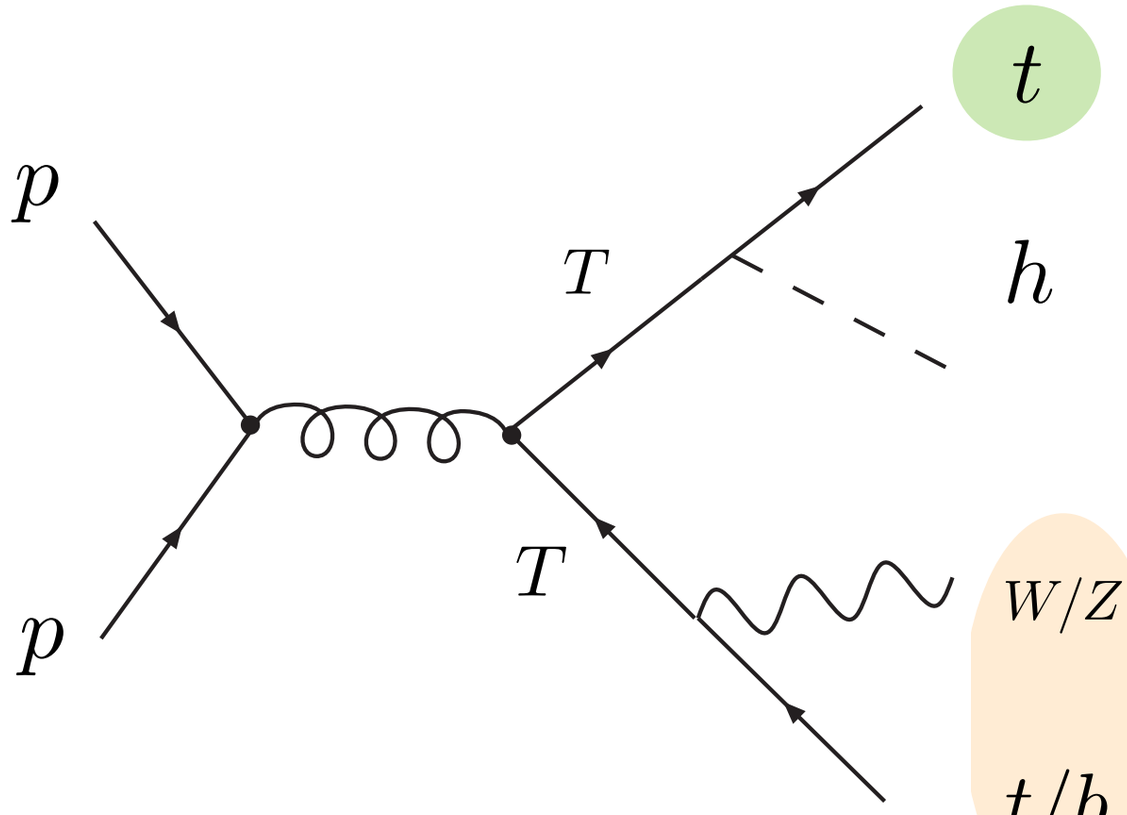
BUT, new physics may not have such a distinct feature

Can we still use BSM-Higgs interactions + substructure to assist Higgs discovery?

To study this, consider a minimal extension of the SM by a new vector-like quark T

$$T = (T_L, T_R) \;\; (3,1)_{2/3}$$ same Q# as $t_R$

# Higgses from Top-partners



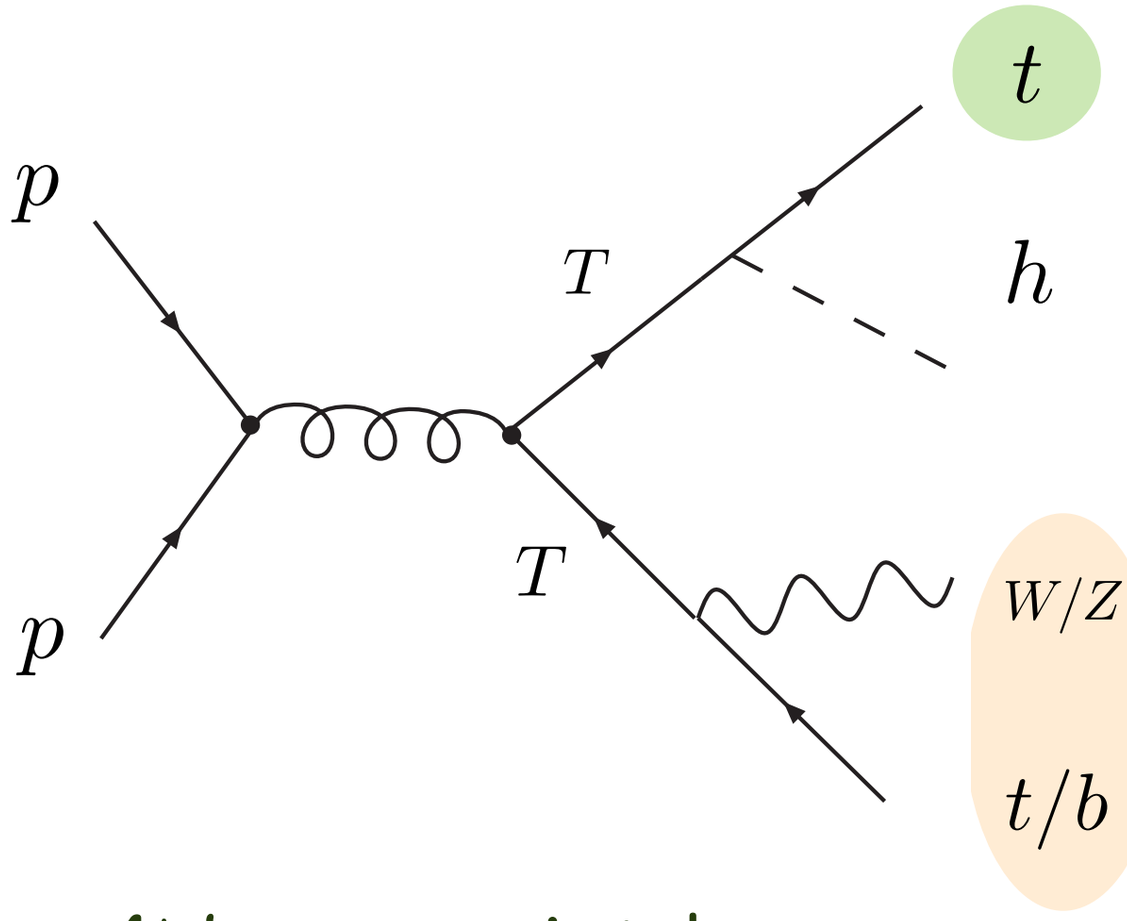

always one top quark

short cascade:
Higgs $p_T \sim M_T/2$
(vs. $\sim M_T/4$ for MSSM)

+ additional gauge boson/top

$4^+$ bs, many jets!

# Higgses from Top-partners




always one top quark

short cascade:
Higgs $p_T \sim M_T/2$
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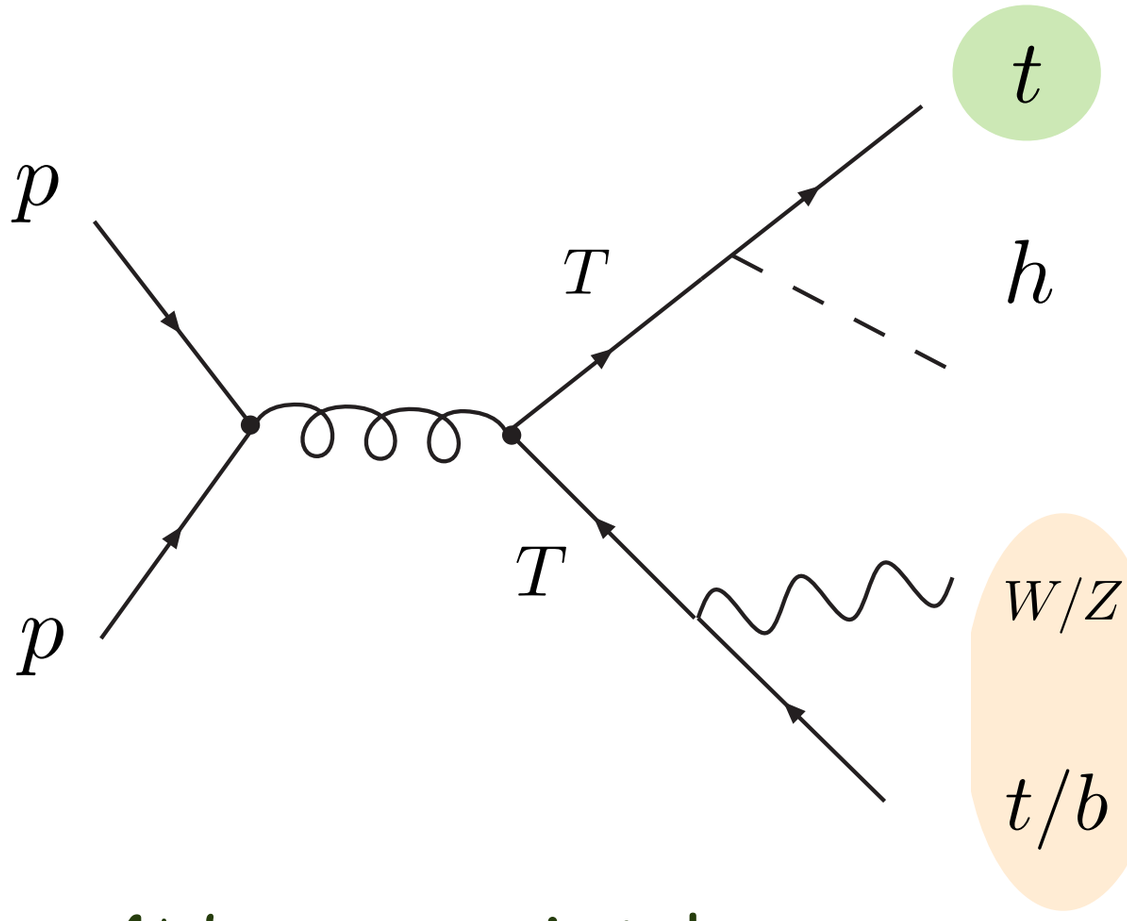
+ additional gauge boson/top

$4^+$ bs, many jets!

final state characterized by multiple, highly boosted resonances

# Higgses from Top-partners




always one top quark

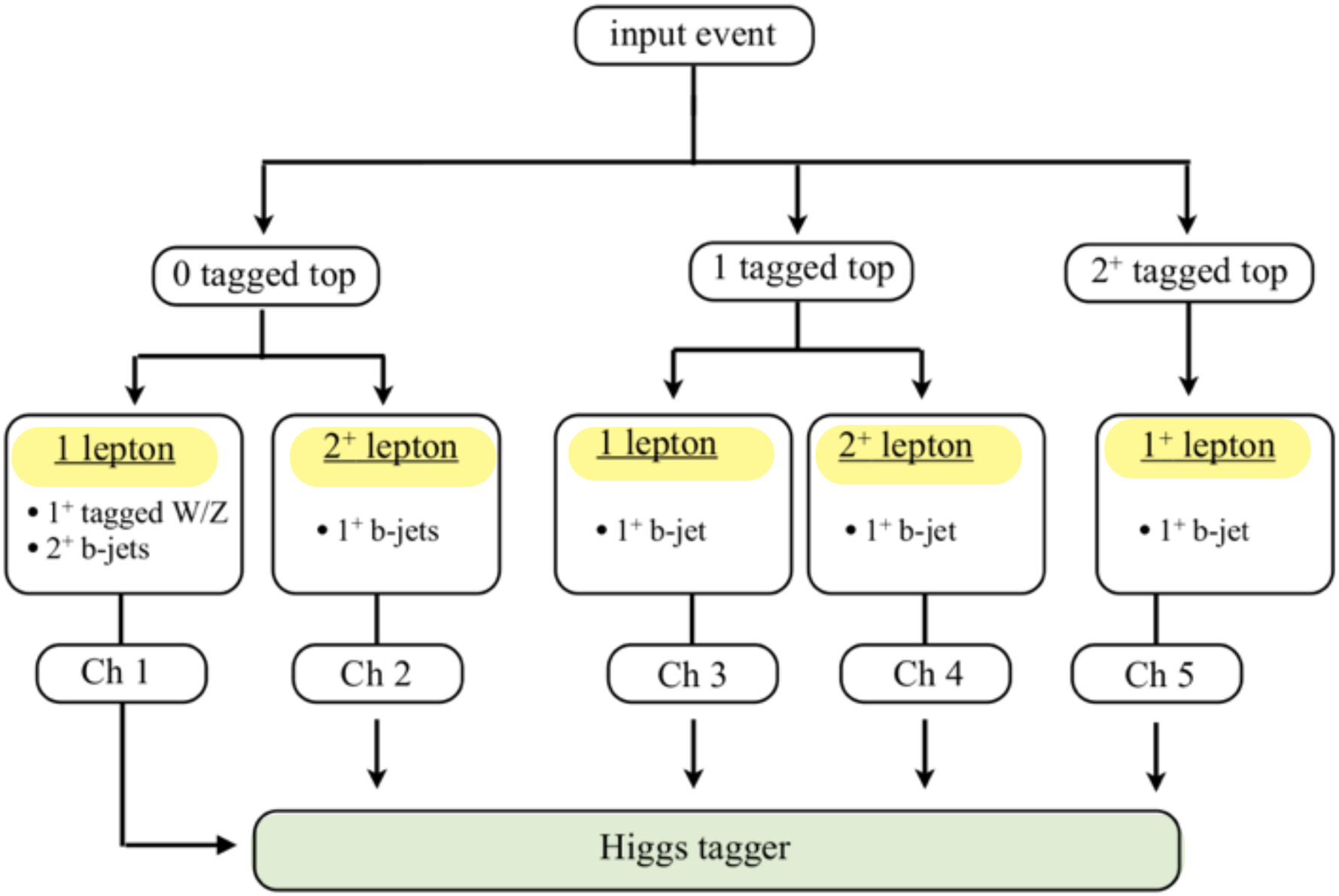
short cascade:
Higgs $p_T \sim M_T/2$
(vs. $\sim M_T/4$ for MSSM)

+ additional gauge boson/top

$4^+$ bs, many jets!

require multiple 'tags' (Higgs + top, Higgs + W, etc.) to suppress SM background, ease combinatorics

# Higgses from Top-partners



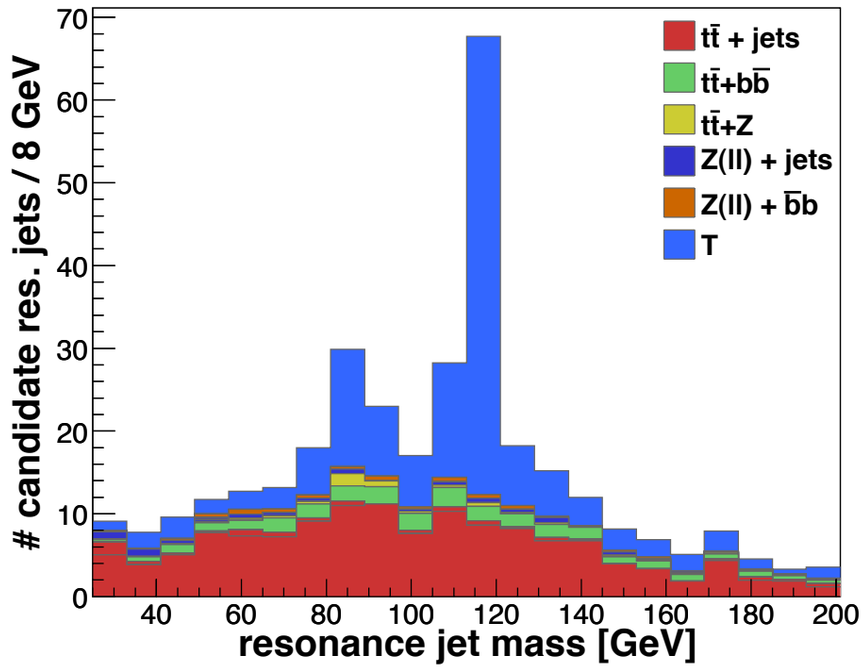

Different analysis pathways for different T masses

# Higgses from Top-partners: results

$M_T = 600$ GeV

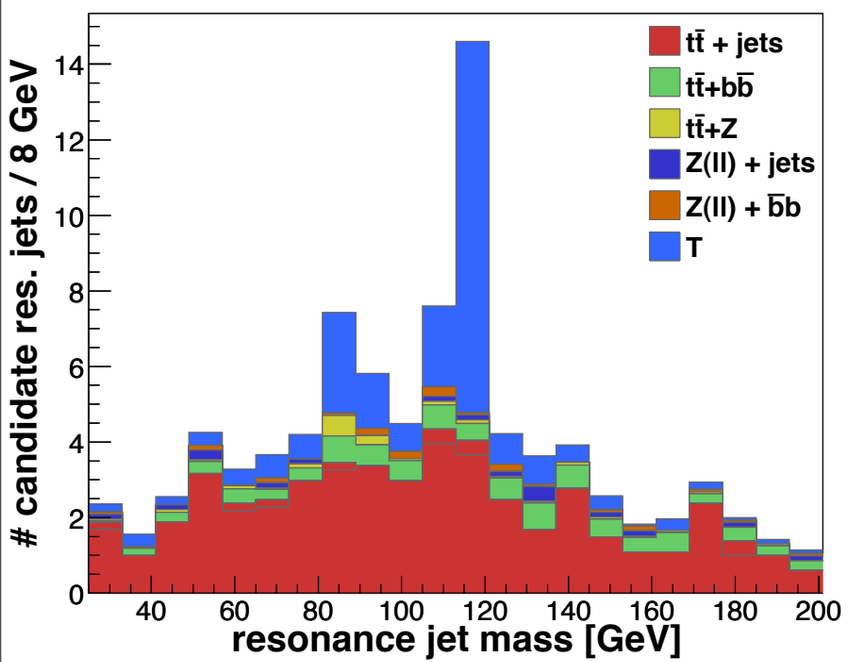
$M_T$ ~ 500-600 GeV, all channels work well

(plots: $\sqrt{s}$ = 14 TeV, 10 fb$^{-1}$ )



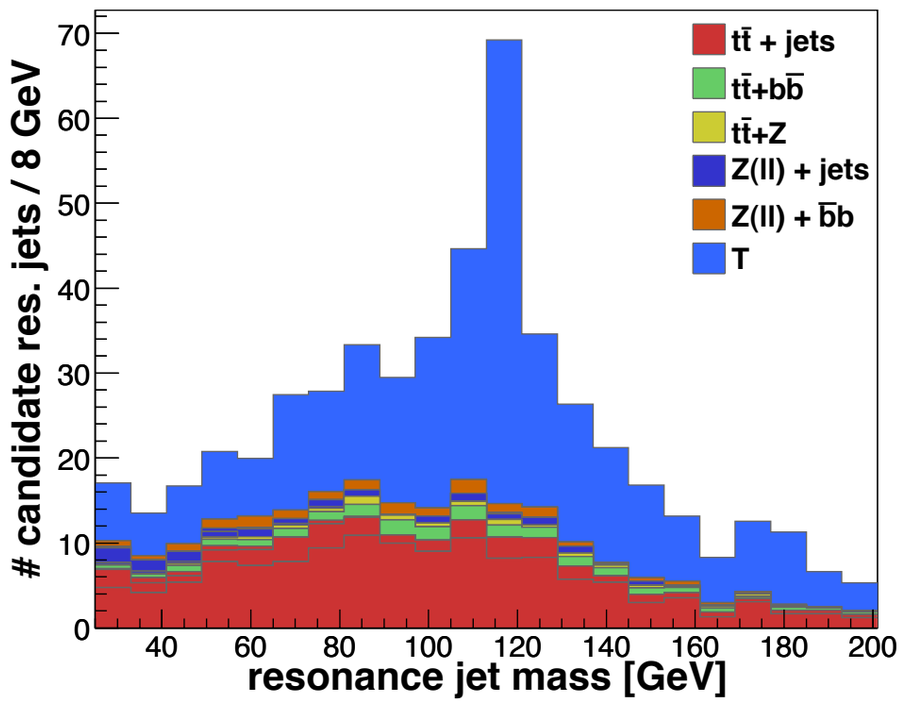

lighter $M_T$: higher rate, but less boost -> multi-lepton channels work better

$M_T = 800$ GeV




opposite is true for higher $M_T$: channels w/ multiple boosted resonances work best

$M_T = 400$ GeV



# Conclusions

BSM particles are often heavy, interact with Higgs
-> decay of BSM stuff to Higgs is a great source of boosted Higgses

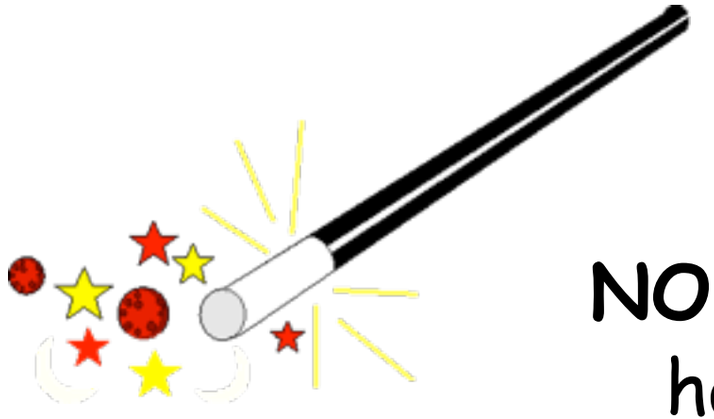
inclusive BSM signal + conventional cuts + BDRS substructure --> fantastic (light) Higgs signals, easily as significant (or more so!) than h -> γγ, h -> ττ

ex.)

- single BDRS-tagged object -- MSSM
- multi-tagged objects, tagged tops + h/W/Z -- Top-partner

plenty of room for more optimization, plenty of other tools to try out

# EXTRAS



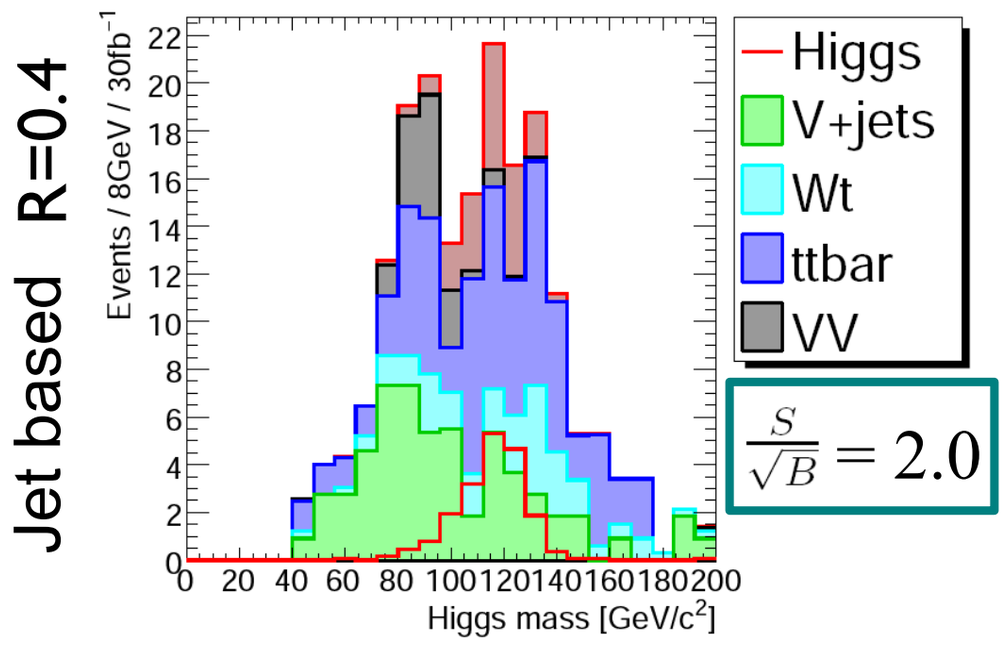
# Substructure = Magic?

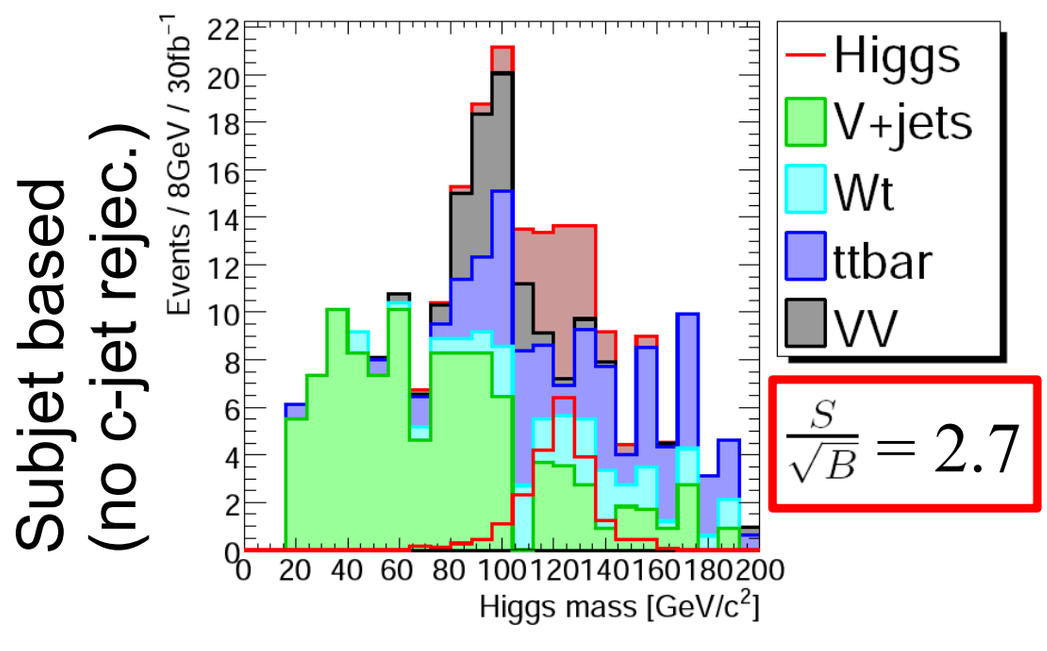
**NO**, but packages together several effective handles which separate decay of high-pT color-singlet resonance from QCD

these handles can be mimicked with fixed-R (more conventional) analysis, to some extent

## fixed R, + 'subjet inspired' cuts vs. subjet based

$L=30\ fb^{-1}$




(from G. Piacquadio, Oregon Jet Workshop 2011)

# 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

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

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

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

# MSSM + boosted Higgses

## Branching ratios and boosted fraction: neutralino LSP

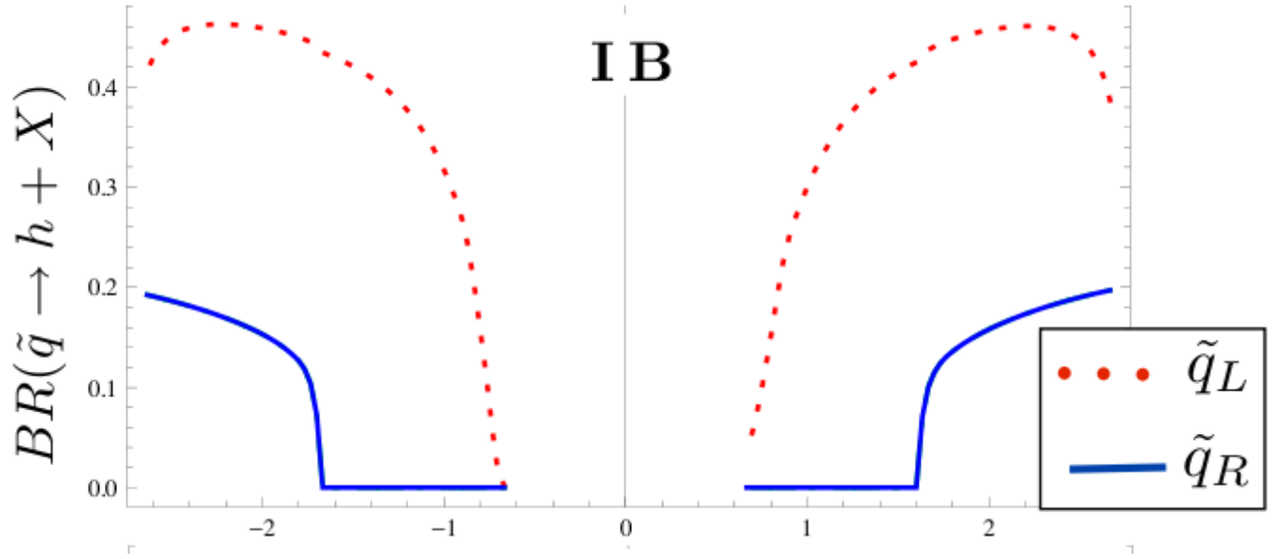
**Ex.)** $M_{\tilde{Q}} = 1 \text{ TeV}$

$\tan\beta = 10$

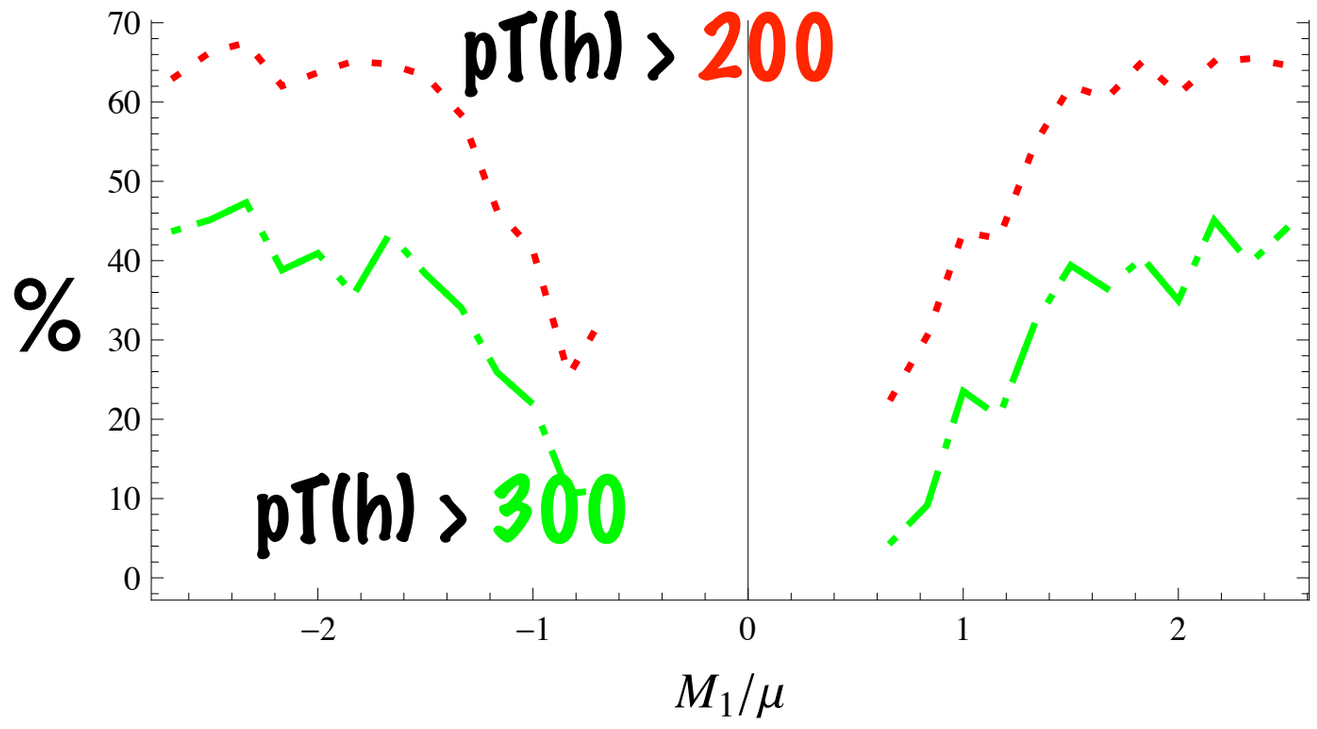
$\mu = 150 \text{ GeV}$

$M_{\tilde{L}} = 1 \text{ TeV}$

$M_2 = 2M_1, M_3 = 7M_1$




## Boosted Fraction

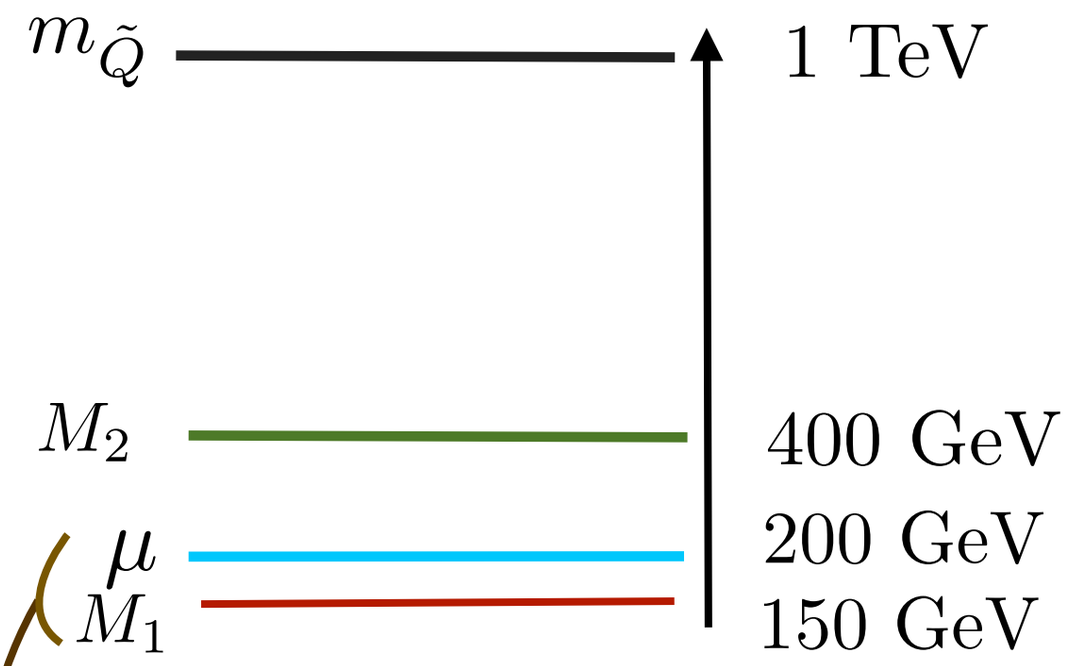


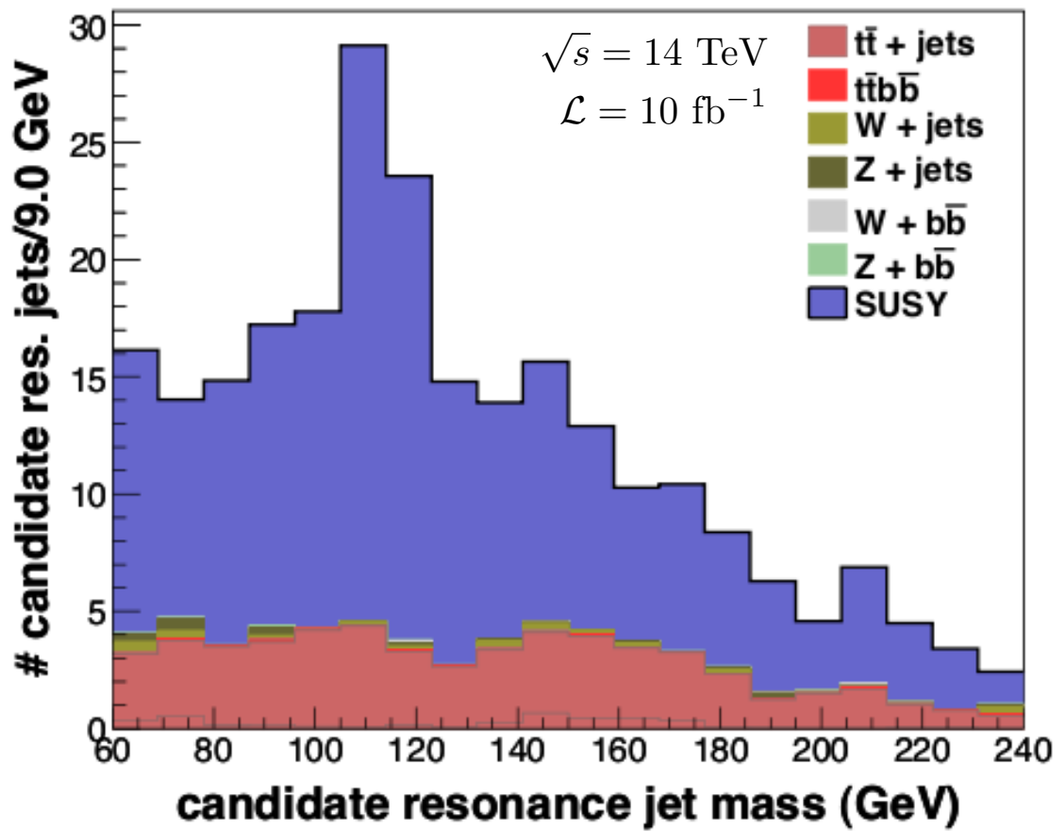
# "But I really liked SUSY Dark Matter..."

Though we typically have too little DM

permitting $M_1 \lesssim \mu$, we can get consistent $\Omega_{DM}$

without losing all our Higgses



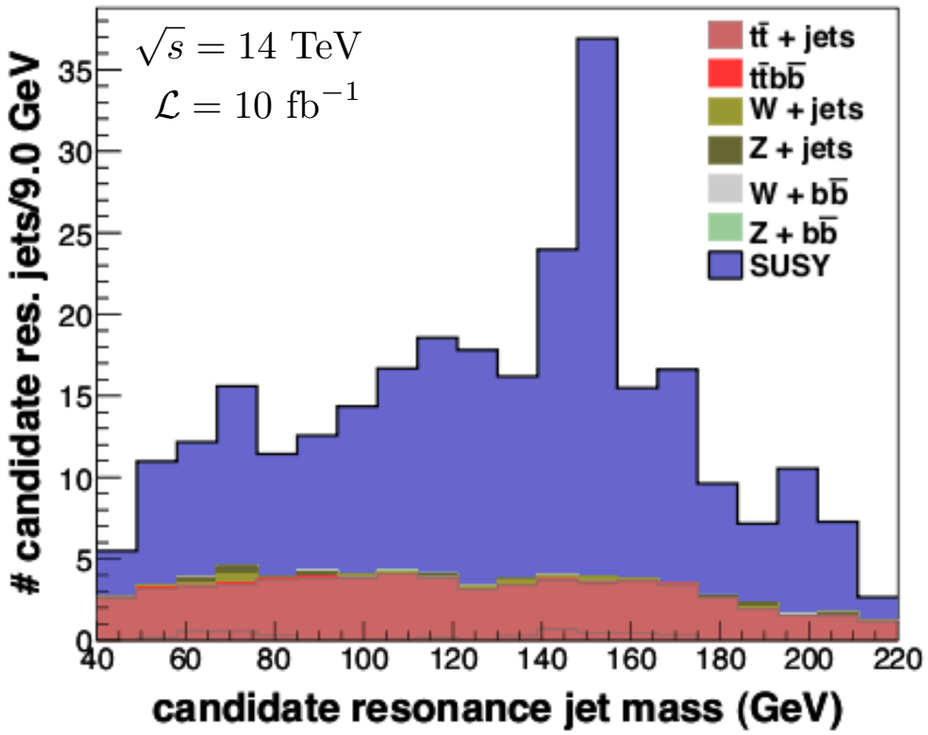



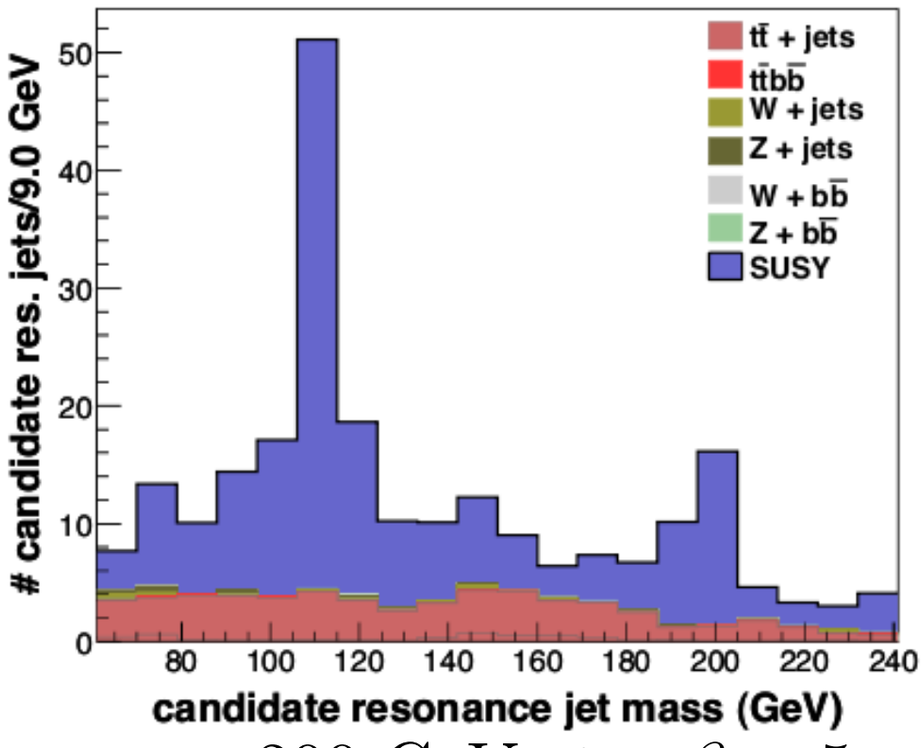

$M_1 \lesssim \mu$ shuts off bino -> Higgsino decays

shuts off RH squark to Higgs cascades, reducing the signal rate

# Neutralino LSP Results: #2

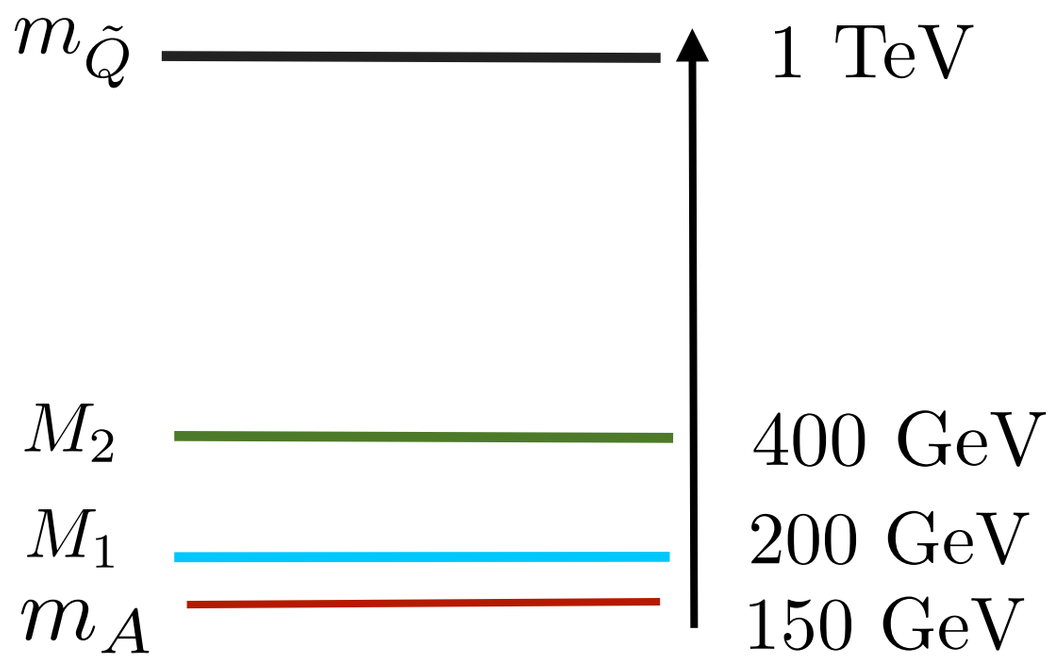
$\mu = -150$ GeV, $\tan\beta = 6.5$




$\mu = 200$ GeV, $\tan\beta = 5$

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




Can even discover heavier A,H states!