Boosting BSM Higgs searches with Jet Substructure

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Fermilab

Introduction & Motivation

light Higgses are traditionally difficult to find

H-> bb decay mode revived for boosted Higgses via jet substructure (BDRS)

But:

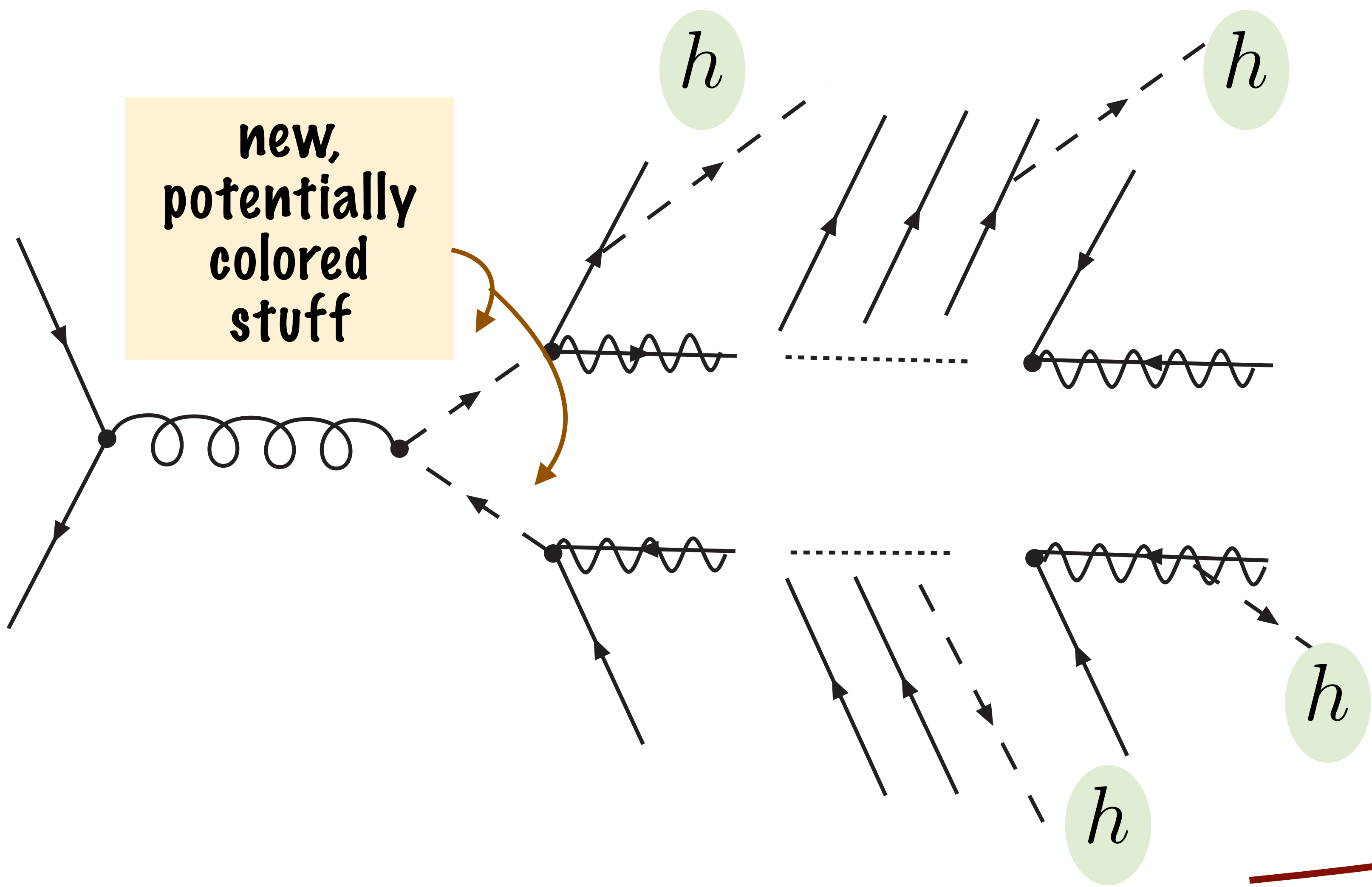
sufficiently boosted (p_T > 200 GeV) Higgs in SM are rare (~5%)

so... what about boosted Higgses from BSM?

Higgs from BSM

BSM stuff often talks to the Higgs

∴ BSM particles can decay to Higgses



initial states are heavy
while Higgs can be light

$(\sim \mathrm{TeV})$

high fraction of boosted Higgses

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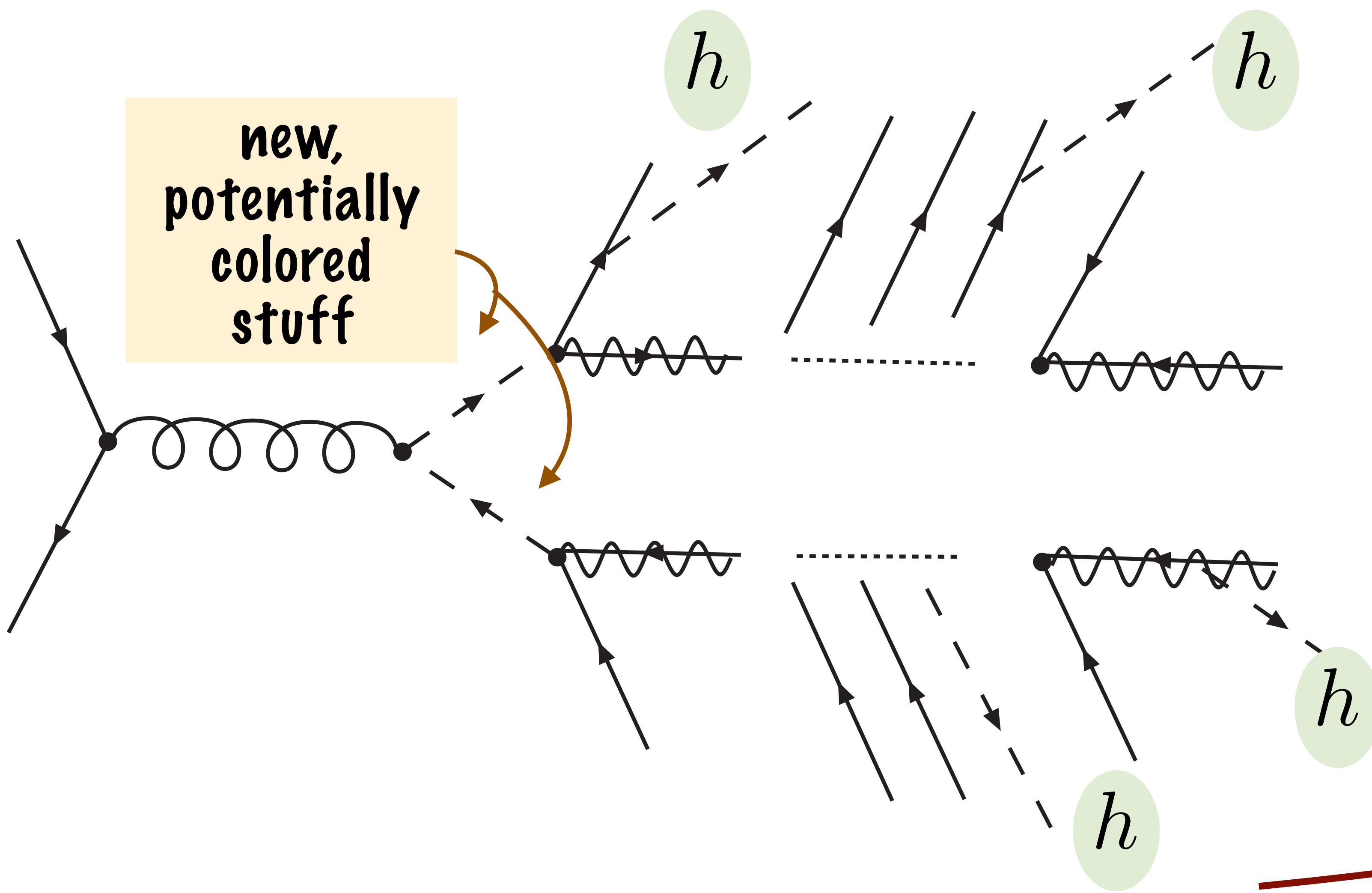

= a new source of Higgses

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while Higgs can be light

$(\sim \mathrm{TeV})$

high fraction of boosted Higgses

Higgs from BSM

If BSM contains new colored states, production at LHC is easily in the $\sim$ few pb range

comparable to or greater than SM EW Higgs production

BSM production often comes with new, effective handles for suppressing SM backgrounds

$$\not{E}_T, \mathrm{high} - p_T \text{ jets}, \ell, \gamma, H_T, \cdots$$

Higgses from BSM have all of the important ingredients for a successful substructure analysis

Outline

- Higgses from the MSSM

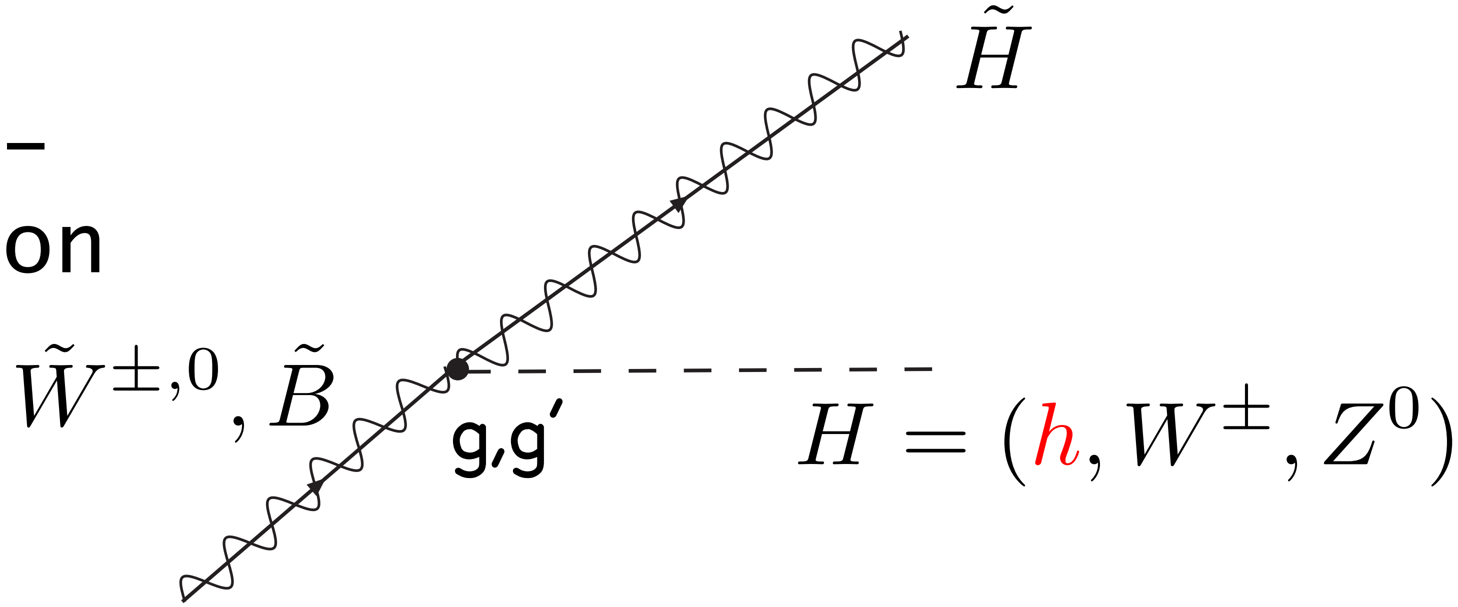
see arxiv: 0912.4731, 1006.1656
Kribs, AM, Spannowsky, Roy

- Higgses from Top-partners

see arxiv: 1012.2866
Kribs, AM, Roy

MSSM + boosted Higgses

Higgs-Higgsino-
Gaugino interaction



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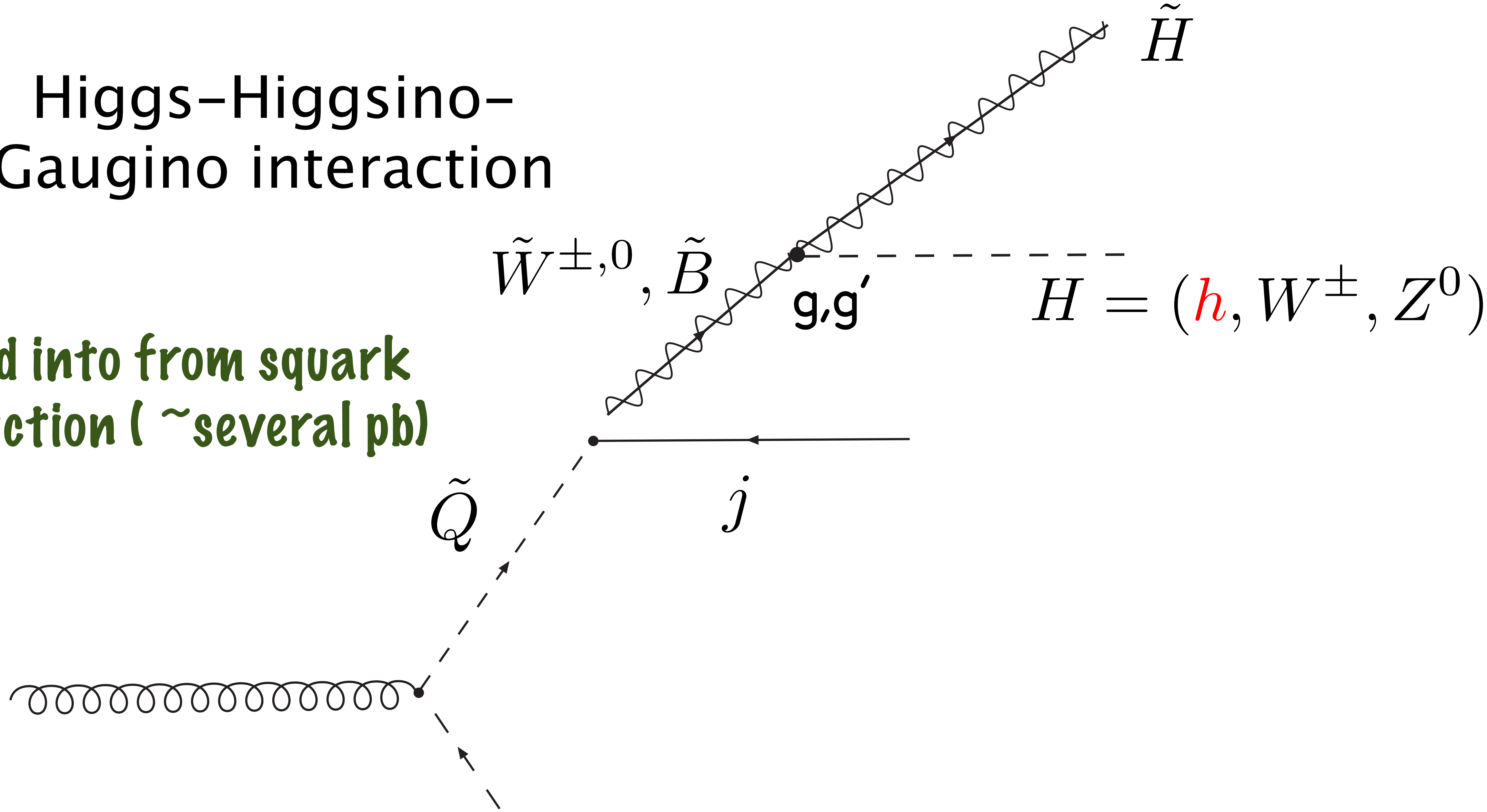
... fed into from squark
production (~several pb)



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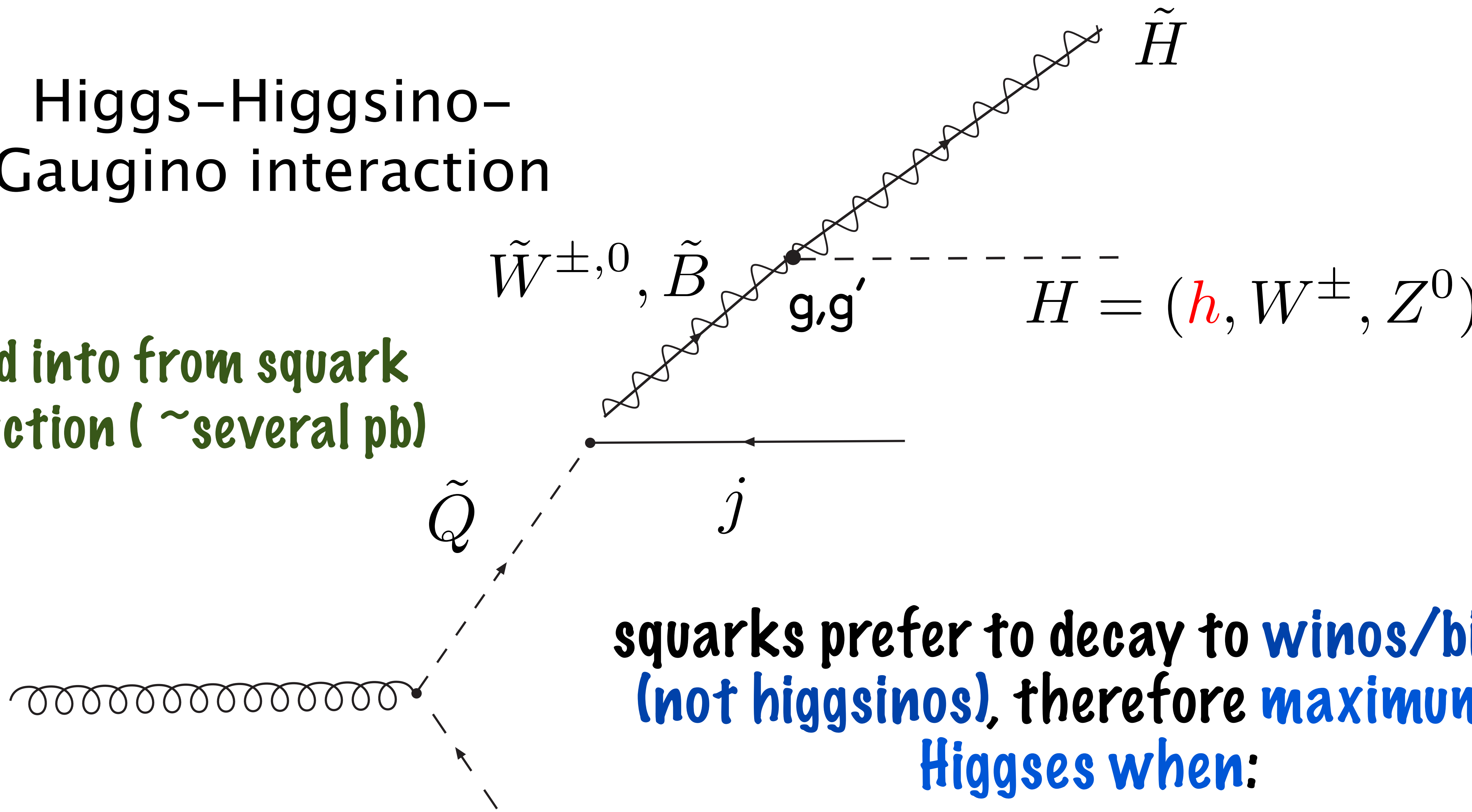

squarks prefer to decay to winos/binos (not higgsinos), therefore maximum # Higgses when:

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

MSSM + boosted Higgses

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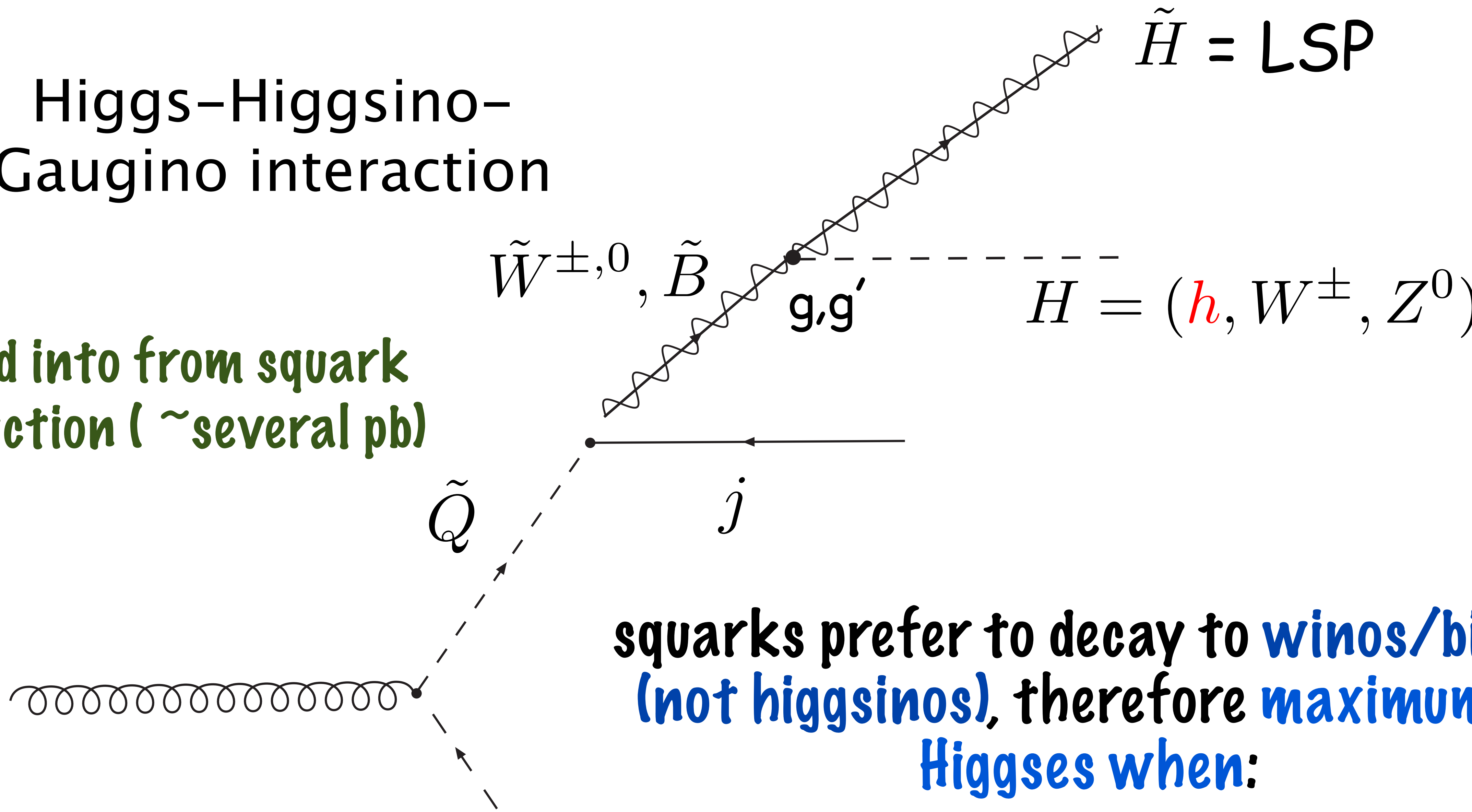

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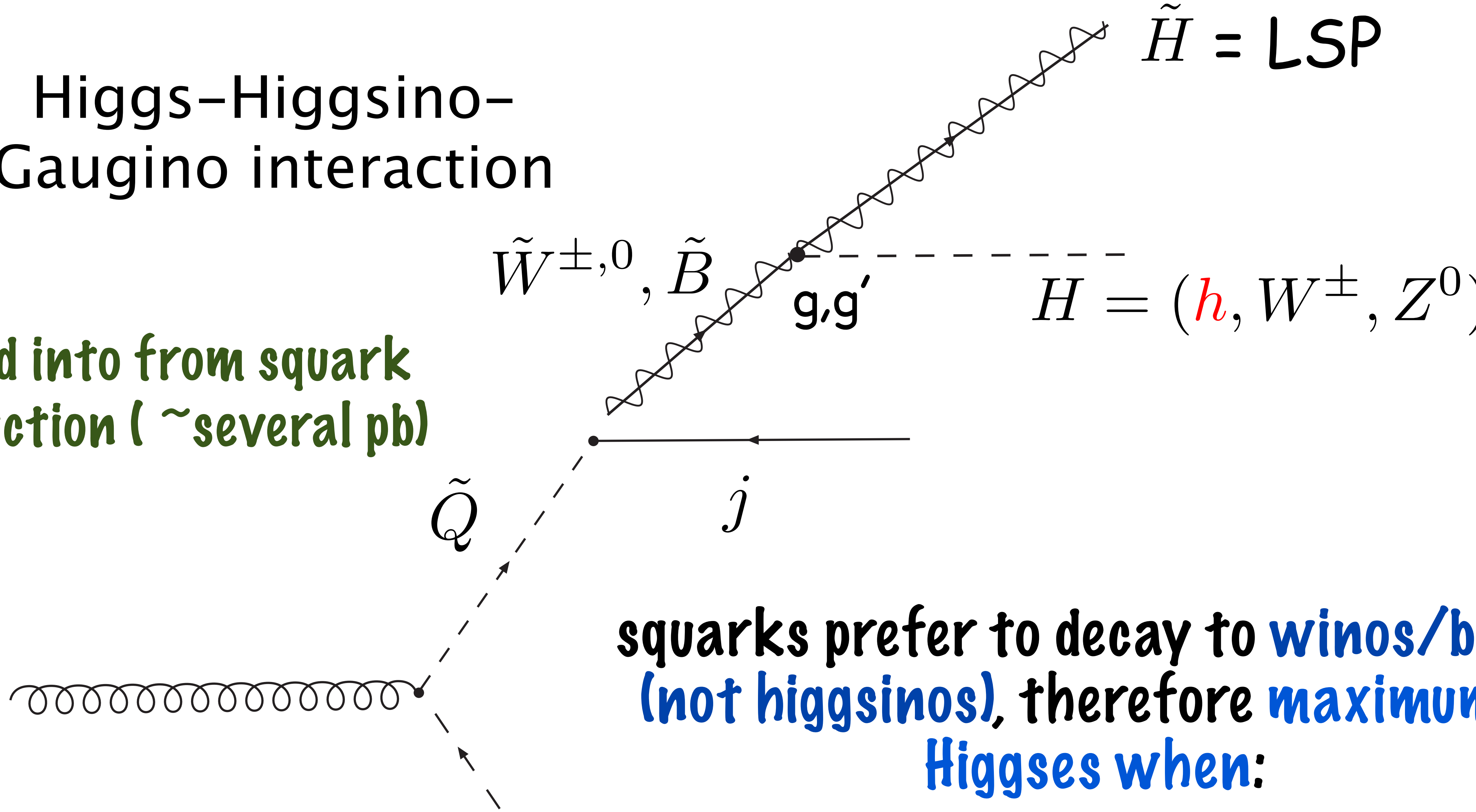

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all events have large BSM MET

the plan

1.) Consider inclusive SUSY production

2.) Impose some typical SUSY cuts (MET, H_T, ..)

3.) find fat-jets, R=1.2, C/A, p_T > 200 GeV and search for substructure via BDRS --> candidate Higgs

4.) look for bump in $M_{cand.\ h}$

conventional cuts kill SM background, substructure cleans up new physics background

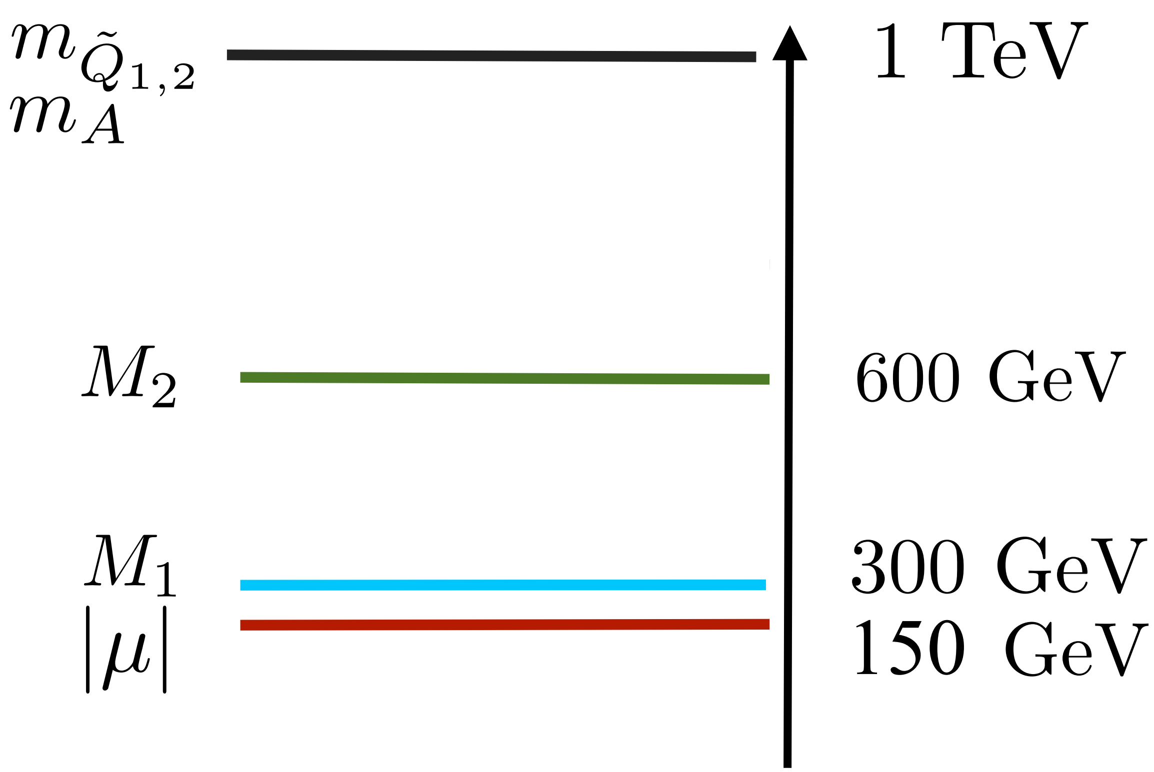
SUSY events are a lot more complicated than W/Z + H

Can improve slightly (~10-20%) with more complicated substructure algorithms (see 1006.1656), but BDRS does just fine

Neutralino LSP Results: #1

MET > 300 GeV, H_T > 1 TeV, 3+ jets,

no lepton, + 1 “tagged” Higgs

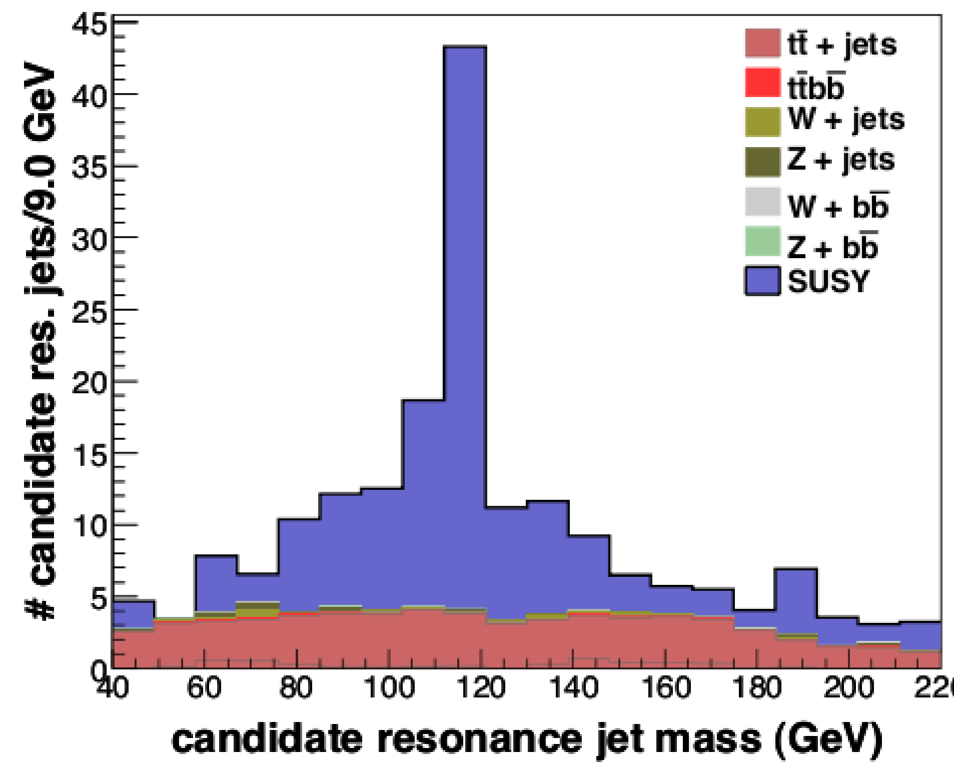


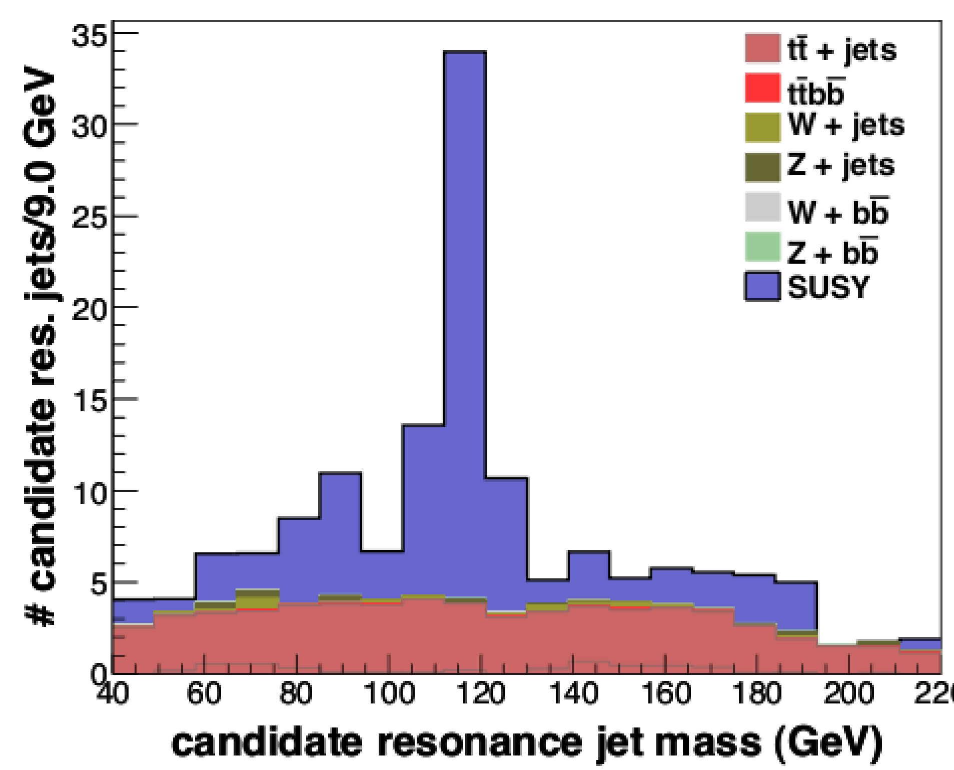
all results: ALPGEN -> PYTHIA6.4

-> 0.1 x 0.1 granularity

b-tagging: flat 60%/2% assumed

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





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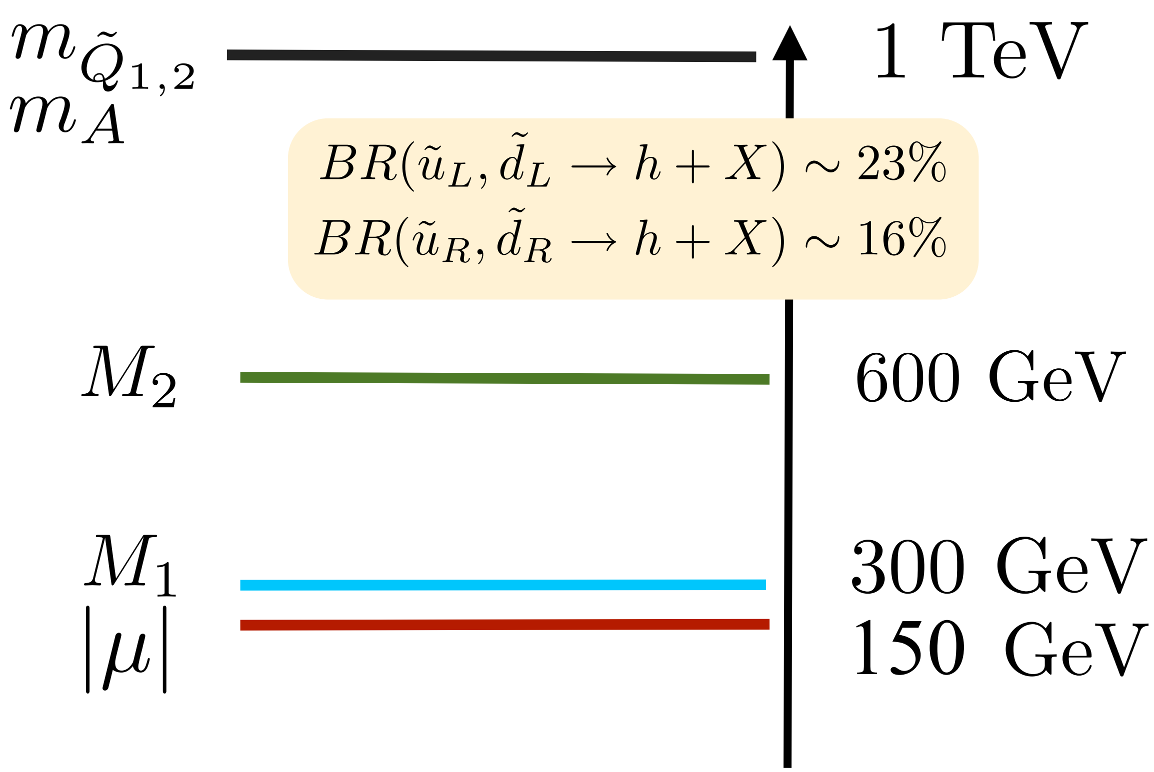

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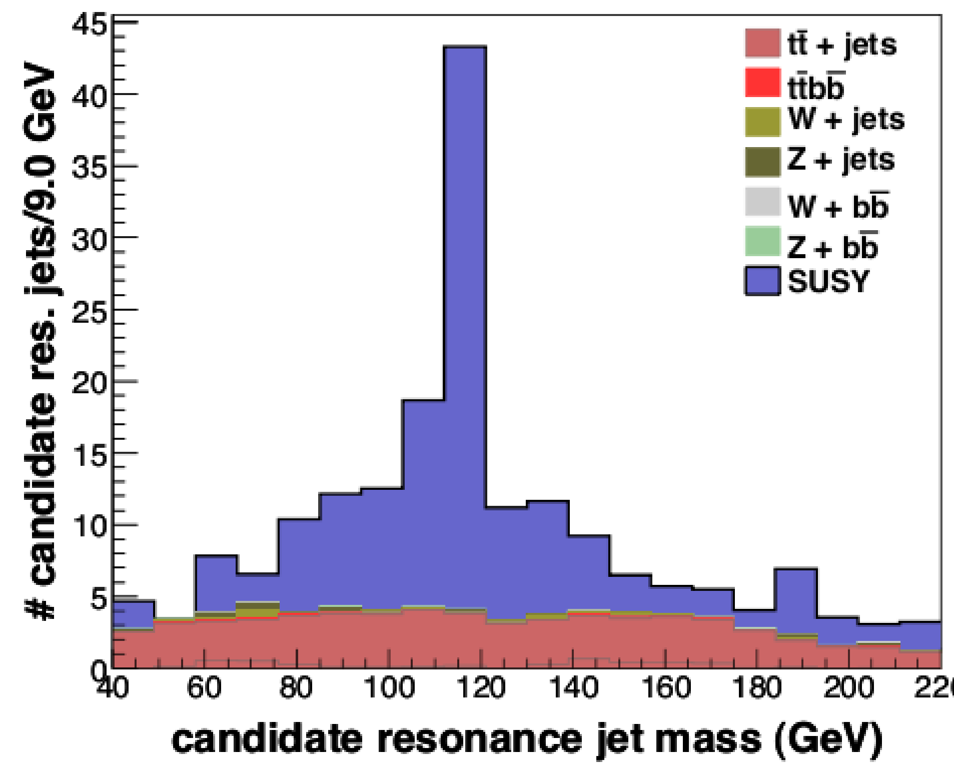

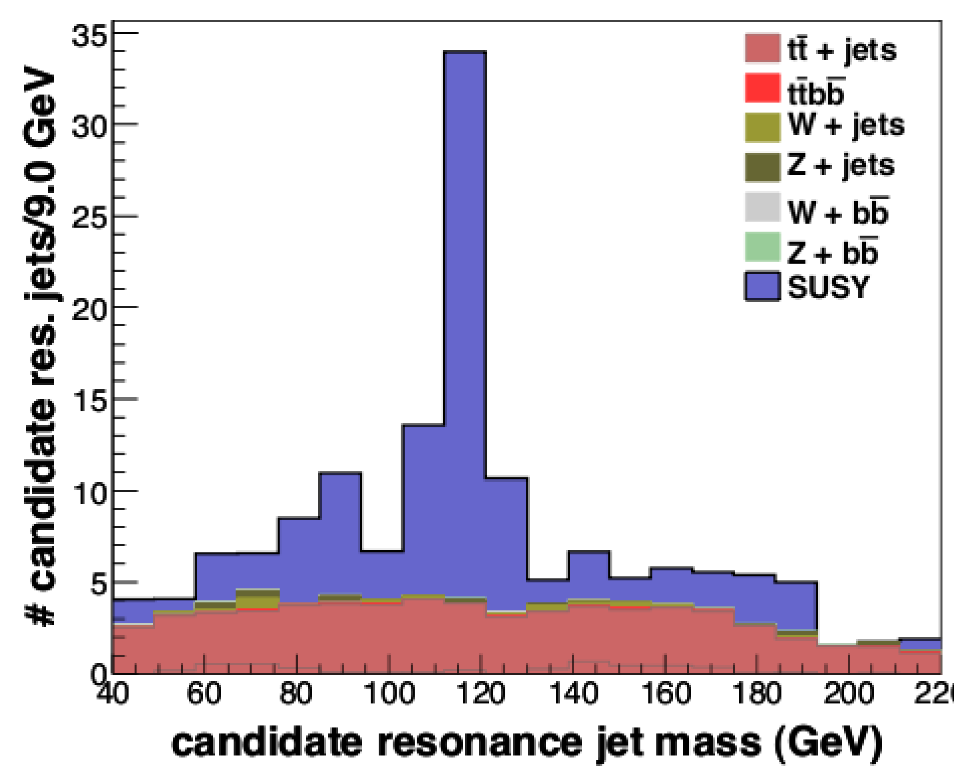

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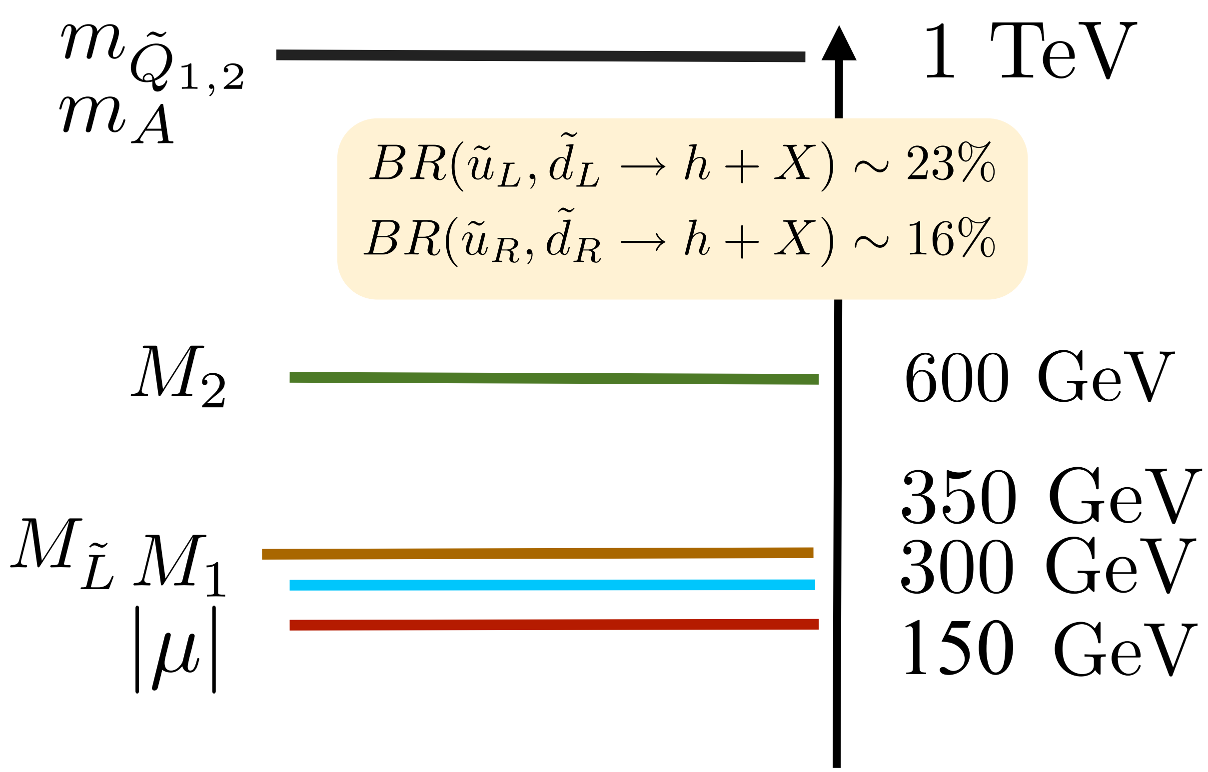

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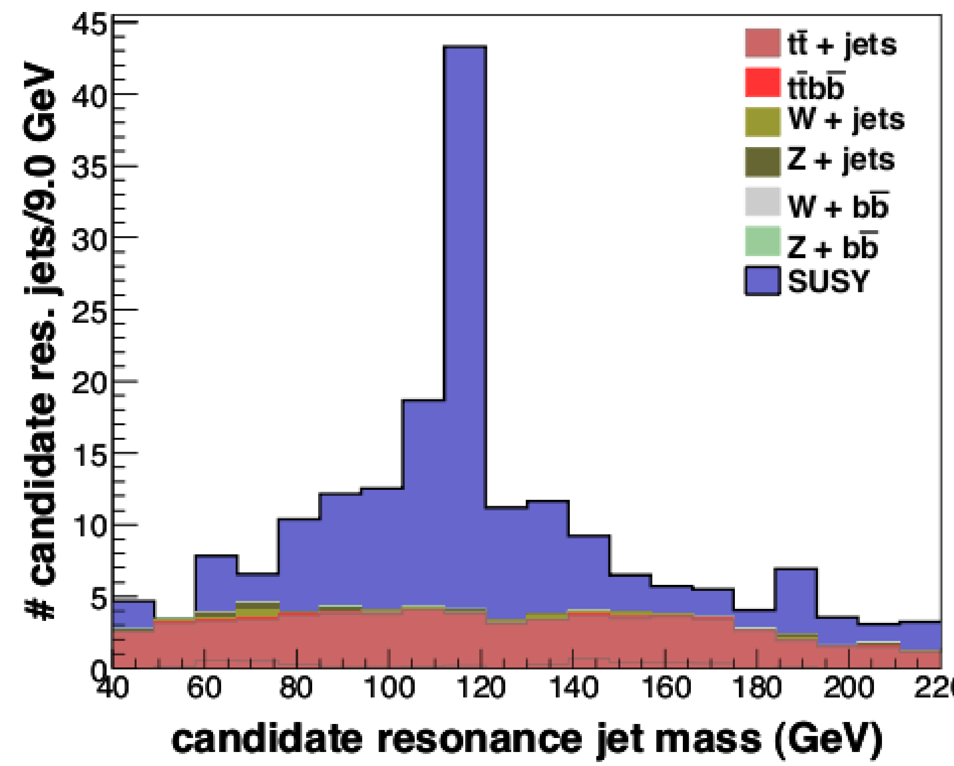

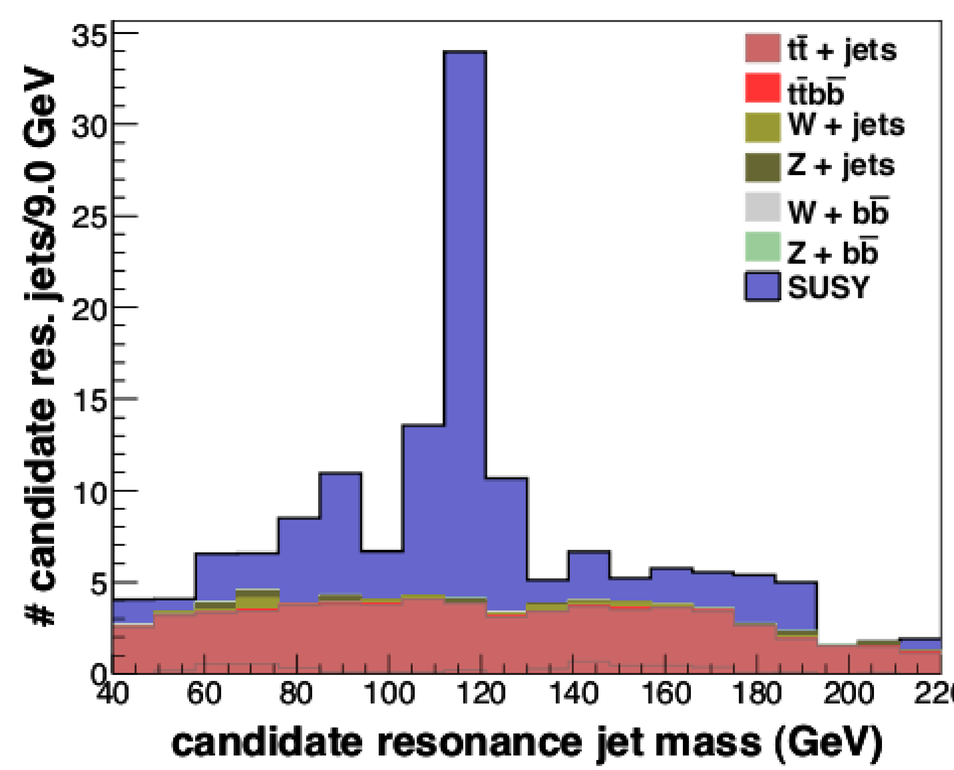

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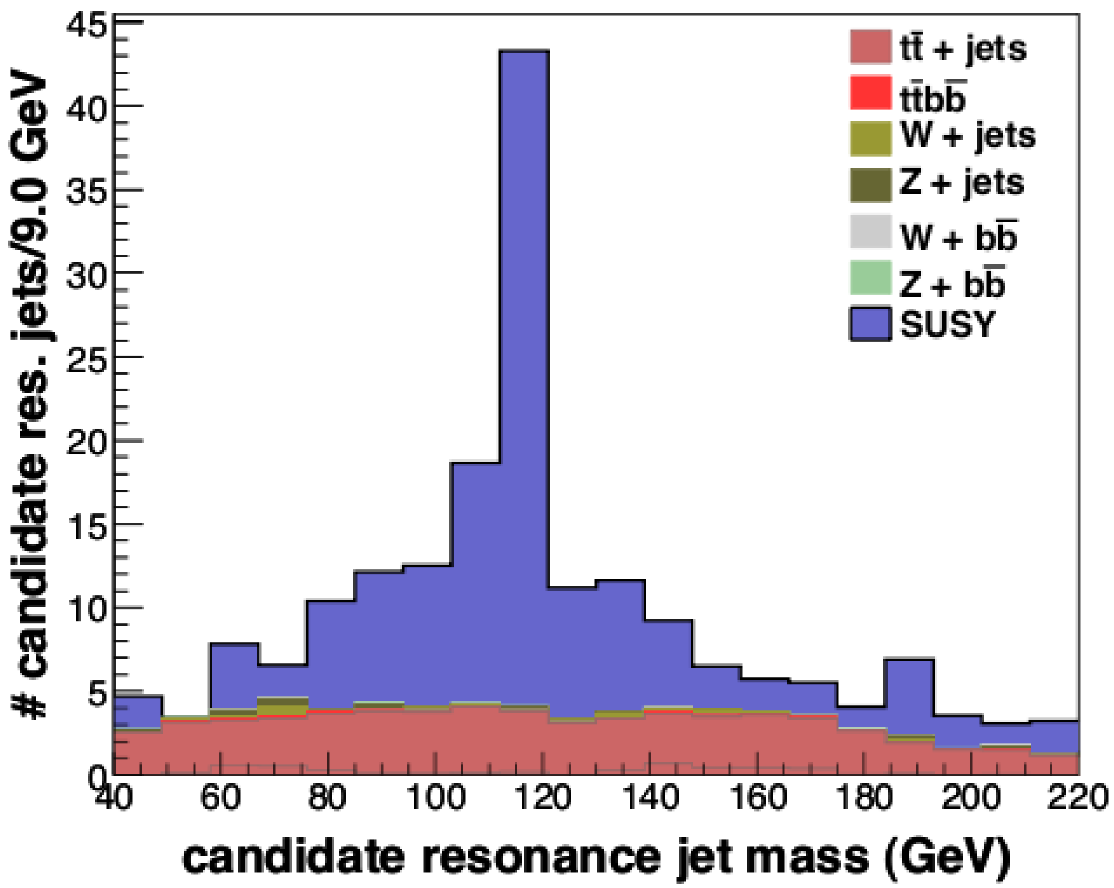
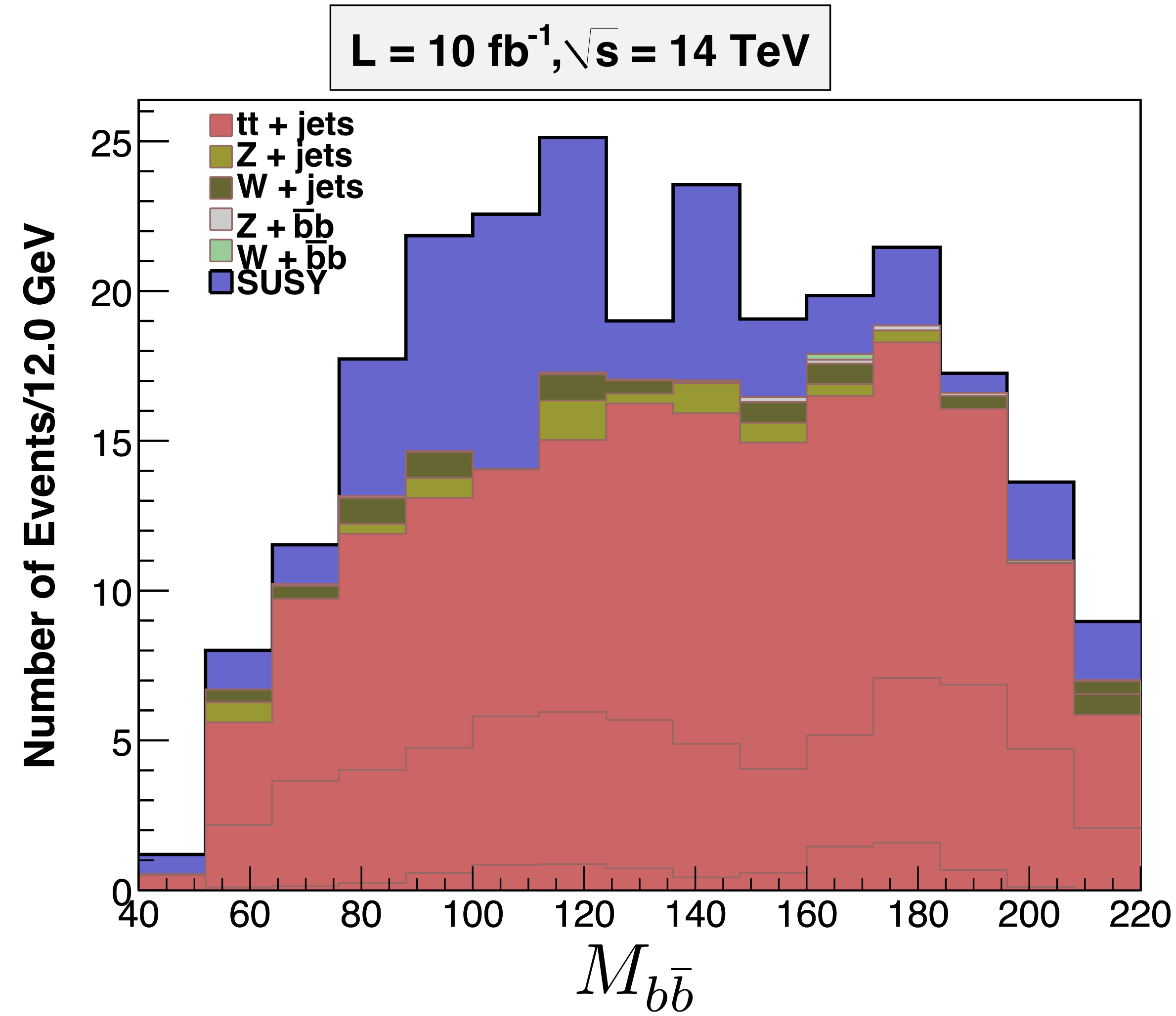
“What good is that fancy substructure?”

Comparison*: with substructure analysis vs. with PGS



$$H_T > 1\ \text{TeV}, \not{E}_T > 300\ \text{GeV}$$
$$3^+\ \text{high-}p_T\ \text{jets, no leptons}$$
$$1\ \text{candidate Higgs}$$

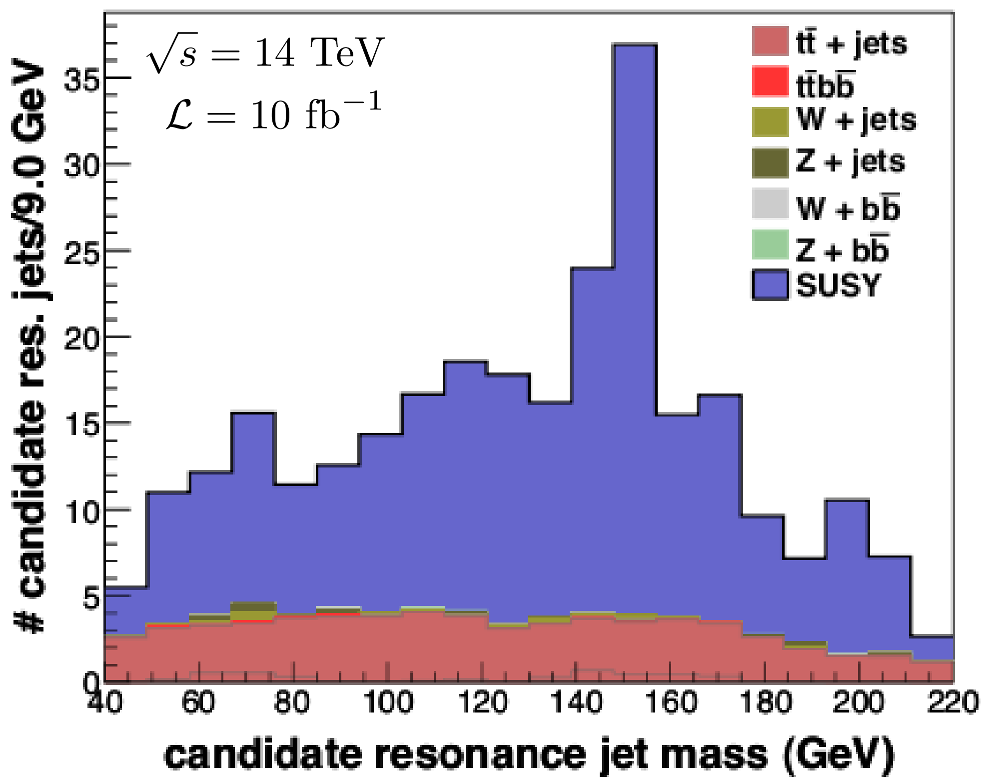


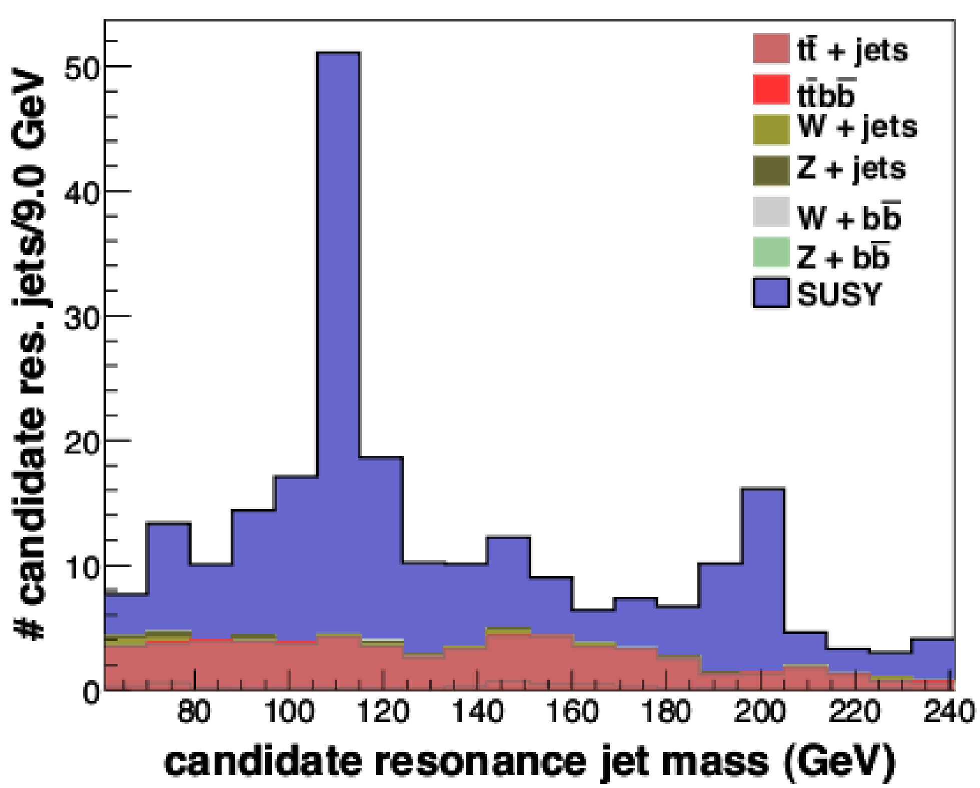
$$H_T > 1\ \text{TeV}, \not{E}_T > 300\ \text{GeV}$$
$$4^+\ \text{high} - p_T\ \text{jets, no leptons}$$
$$2^+\ \text{b-tags}$$

*not totally fair

Neutralino LSP Results: #2

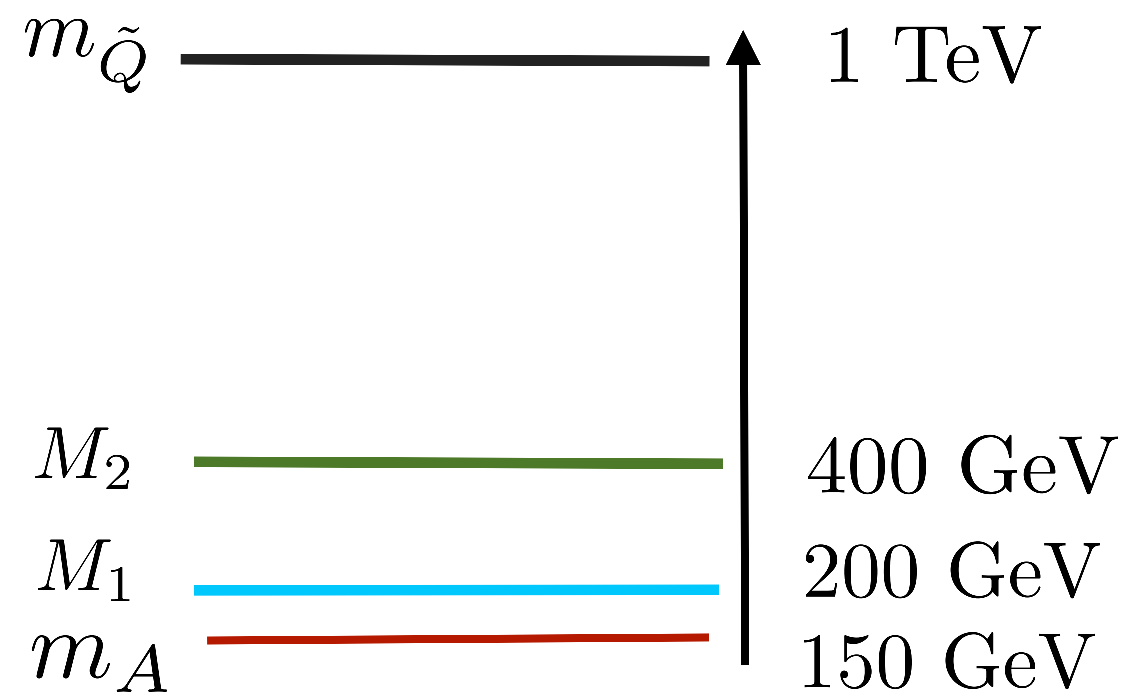
$\mu = -150\ \mathrm{GeV},\ \tan\beta = 6.5$





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

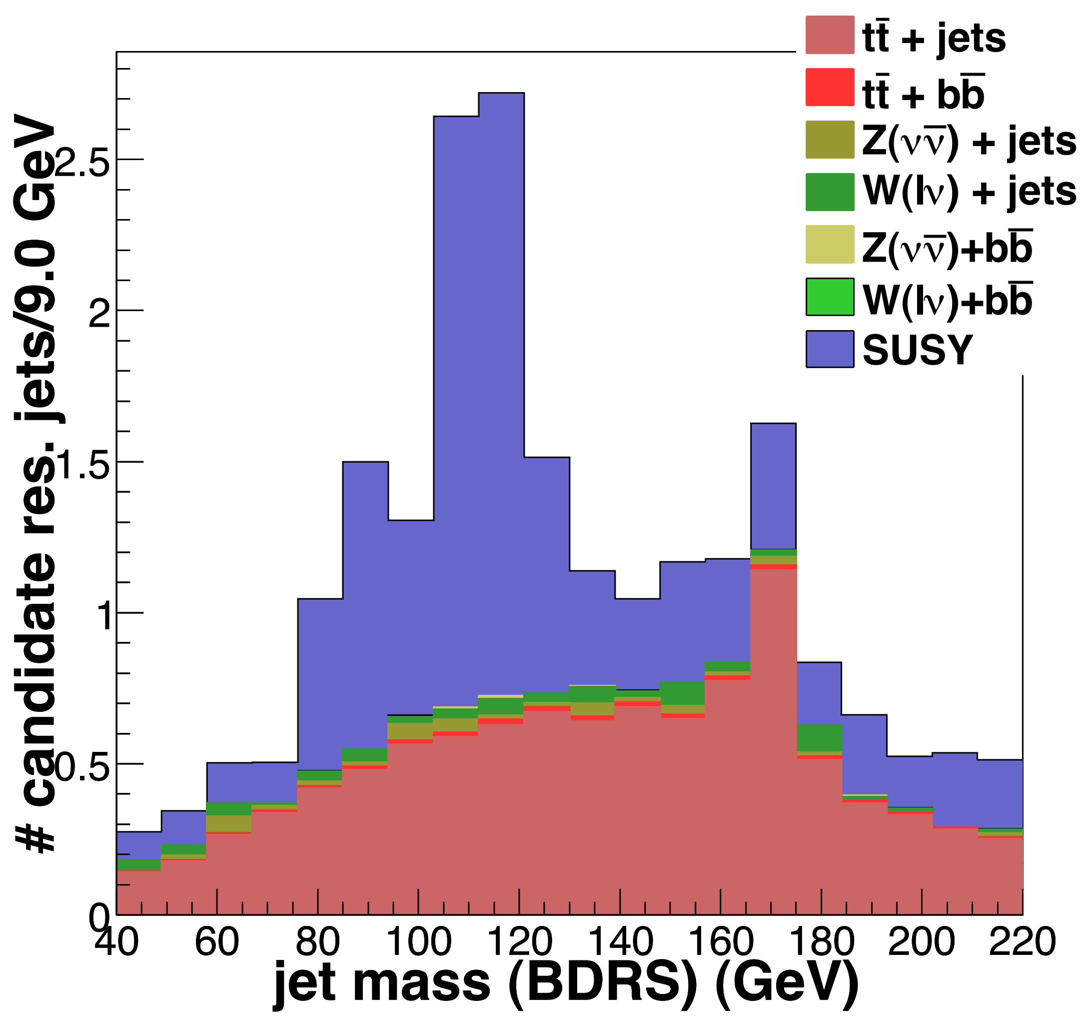
technique holds up at low m_A and $\tan\beta$, where traditional approaches have the most trouble

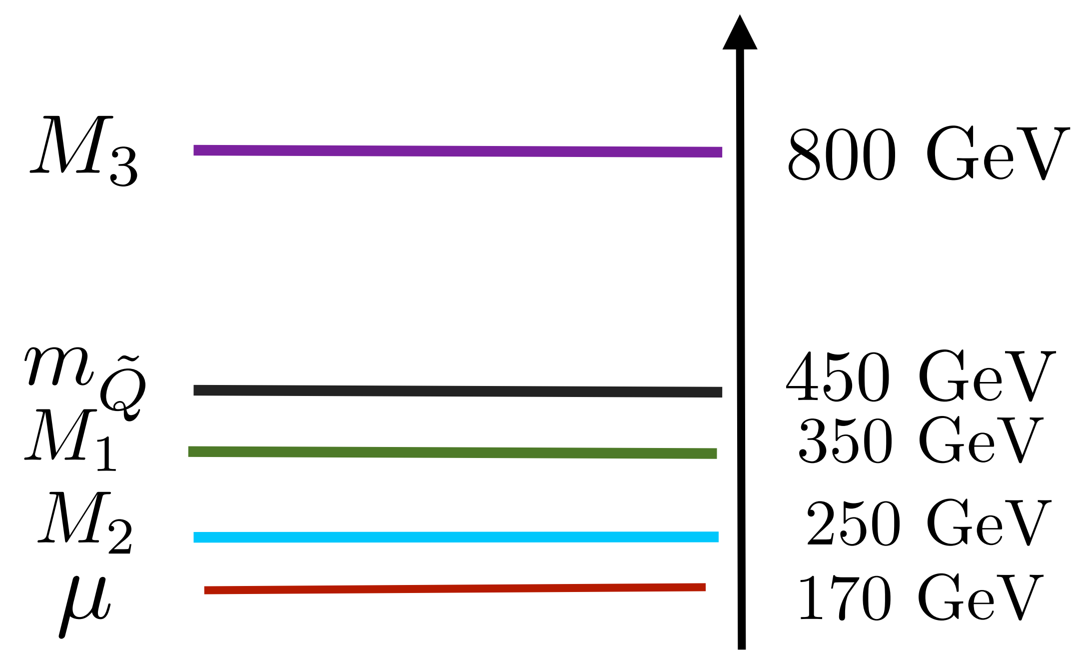


Can even discover heavier A,H states!

"What about at 7 (or 8) TeV?"

Neutralino LSP, squished spectrum:





substructure +

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

$H_T > 600$ GeV

avoids all Tevatron/LEP/LHC1.0 bounds

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

vector-like T can mix with SM

$$y_t\, Q_3\, H\, t^c + M\, T\, T^c + \delta\, T\, t^c + h.c.$$

$$(t \;\; T)\begin{pmatrix} m & 0 \\ \delta & M \end{pmatrix}\begin{pmatrix} t^c \\ T^c \end{pmatrix}$$

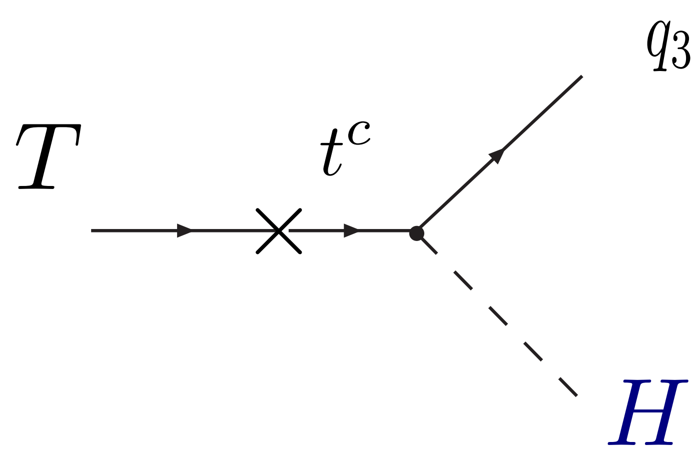
$$\begin{aligned}\mathcal{L} \supset\ & \frac{m_t\ \cos^2\theta_l}{v} h\ \bar{T}_D(\tan\theta_r\, P_L + \tan\theta_l\, P_R)\, t_D \\ & + \frac{g_2 \sin\theta_l\ \cos\theta_l}{2\ \cos\theta_W} Z_\mu\left(\bar{T}_D\gamma^\mu\, P_L t_D + \bar{t}_D\gamma^\mu\, P_L T_D\right) \\ & + \frac{g_2 \sin\theta_l}{\sqrt{2}}\left(W^+_\mu \bar{T}_D\gamma^\mu P_L b_D + W^-_\mu \bar{b}_D\gamma^\mu\, P_L T_D\right)\end{aligned}$$

this simple extension is part of most Little Higgs scenarios, composite models (topcolor) and their 5D counterparts

we are still assuming the Higgs is light

Higgses from Top-partners

new interaction



Branching ratio, up to small corrections,
set by Goldstone equivalence:

Higgses from Top-partners

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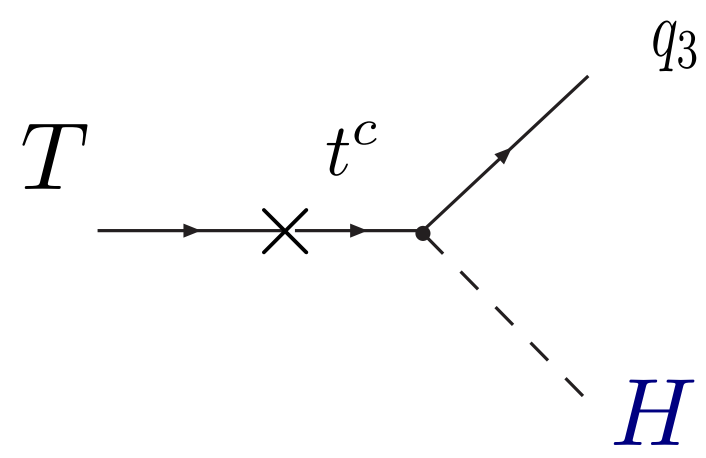

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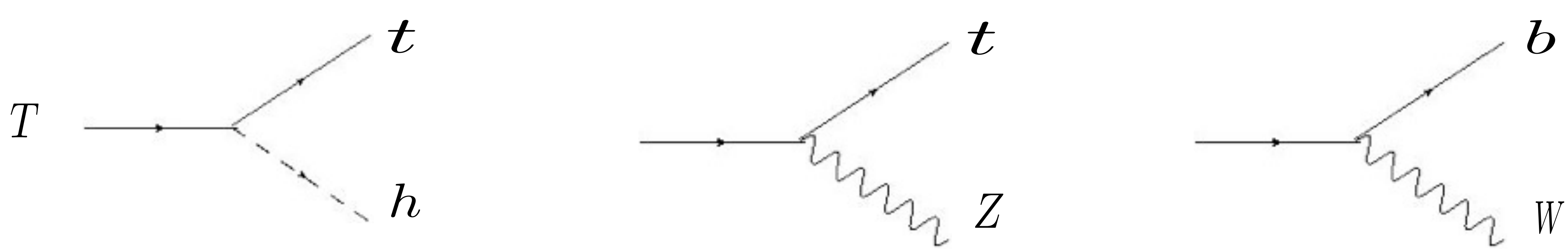
T decay modes



$\sim 25\%$ $\sim 25\%$ $\sim 50\%$

Higgses from Top-partners

Searching for Higgses from T decay seems tricky because:

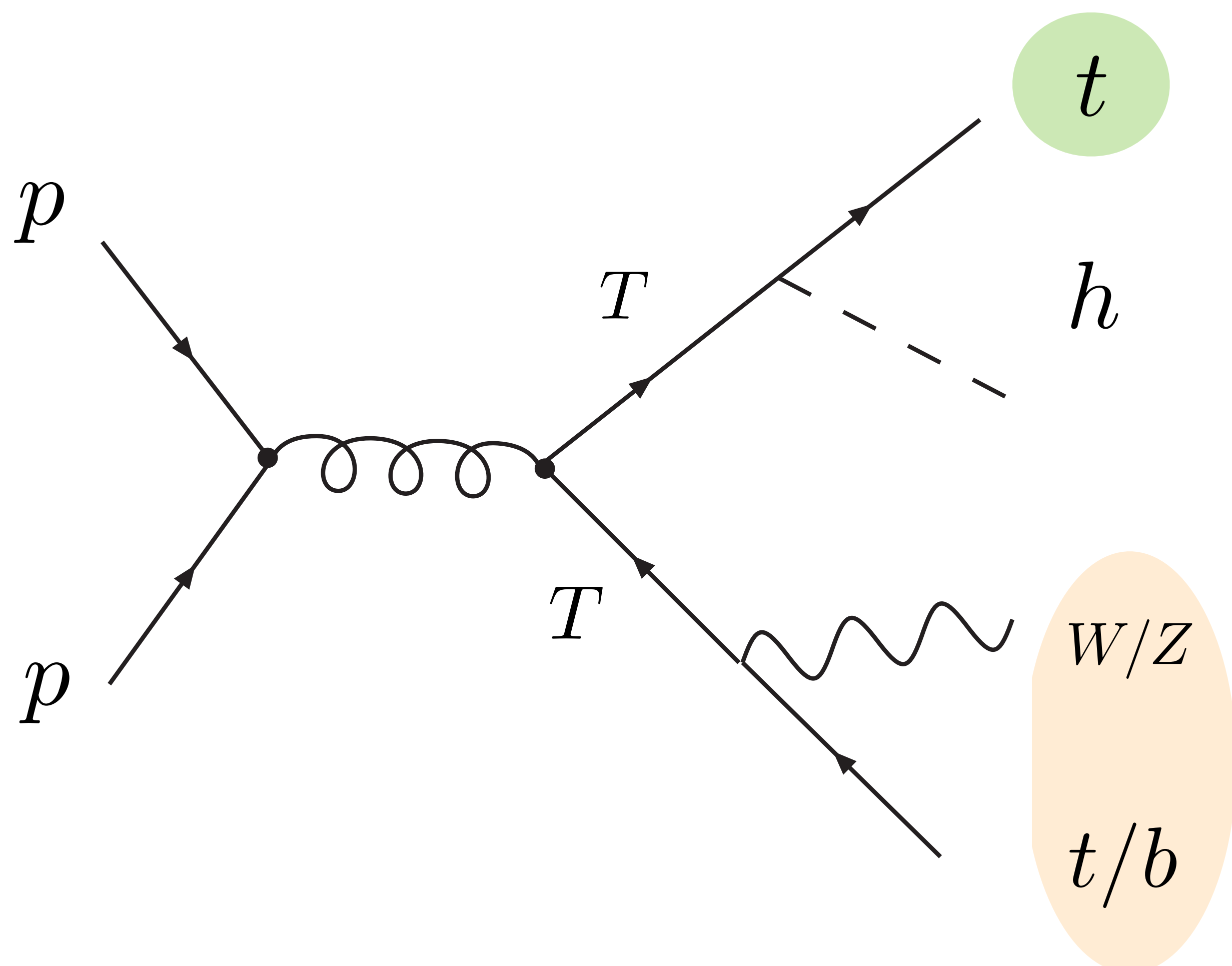
- final state contains only SM particles
- minimal extension -> relatively small cross section
- many combinatoric problems

(Aguilar-Saavedra)

But, well suited to substructure techniques:

- lots of Higgses (~50% of T Tbar events)
- Higgses are efficiently boosted
- Higgses are produced in association with other 'taggable' particles (W/Z/t)

Higgses from Top-partners



always one top quark

short cascade:

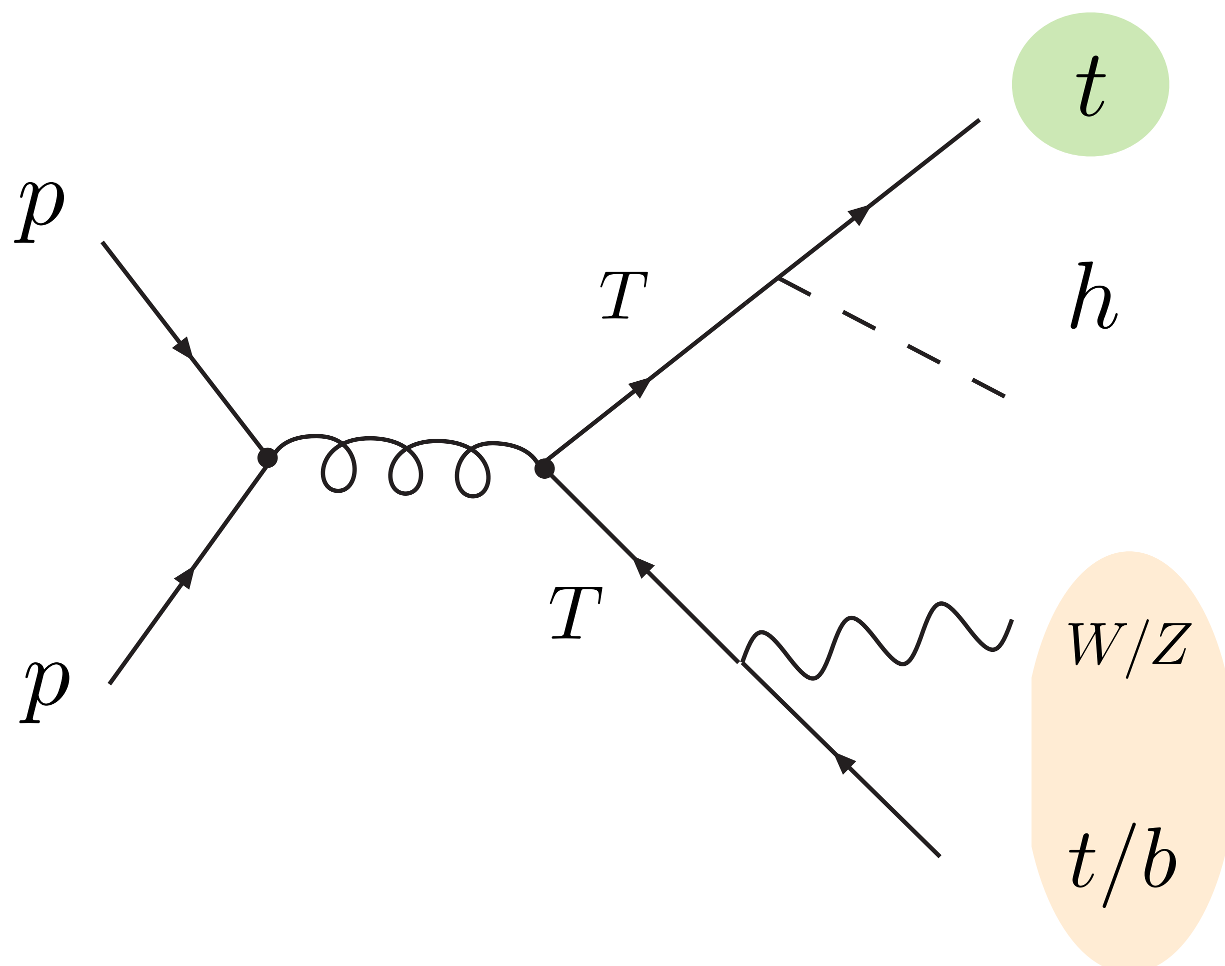
Higgs $p_T \sim M_T/2$

(vs. $\sim M_T/4$ for MSSM)

+ additional gauge boson/top

4^+ bs, many jets!

Higgses from Top-partners



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short cascade:
Higgs $p_T \sim M_T/2$
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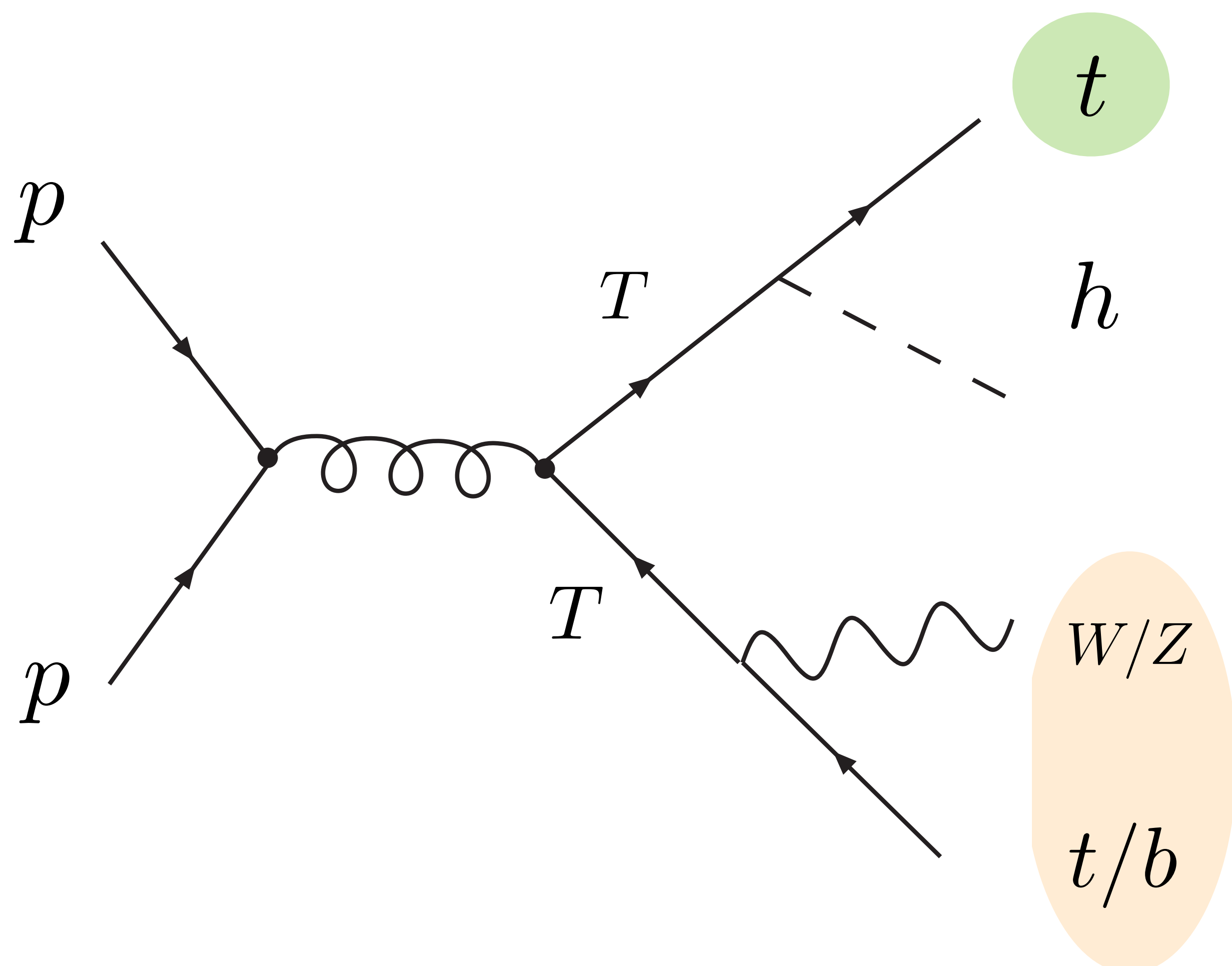
final state characterized by multiple, highly boosted resonances

Higgses from Top-partners



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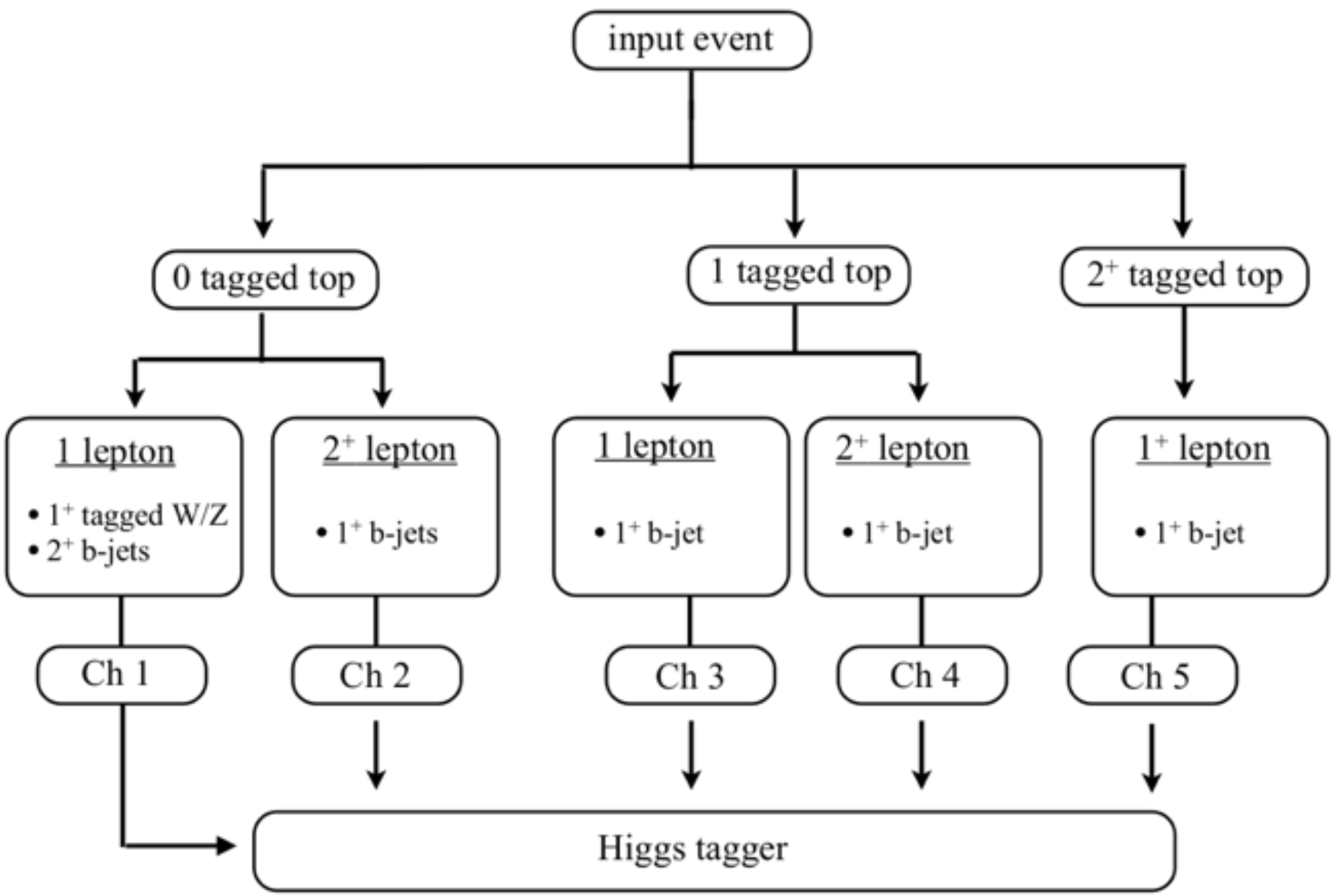
+ additional gauge boson/top

4^+ bs, many jets!

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

Analysis strategy:



1.) always require:

1^+ lepton, 1^+ jets w/ substructure

2.) look for tops (HEP-tagger,0910.5472)

"No event left behind"

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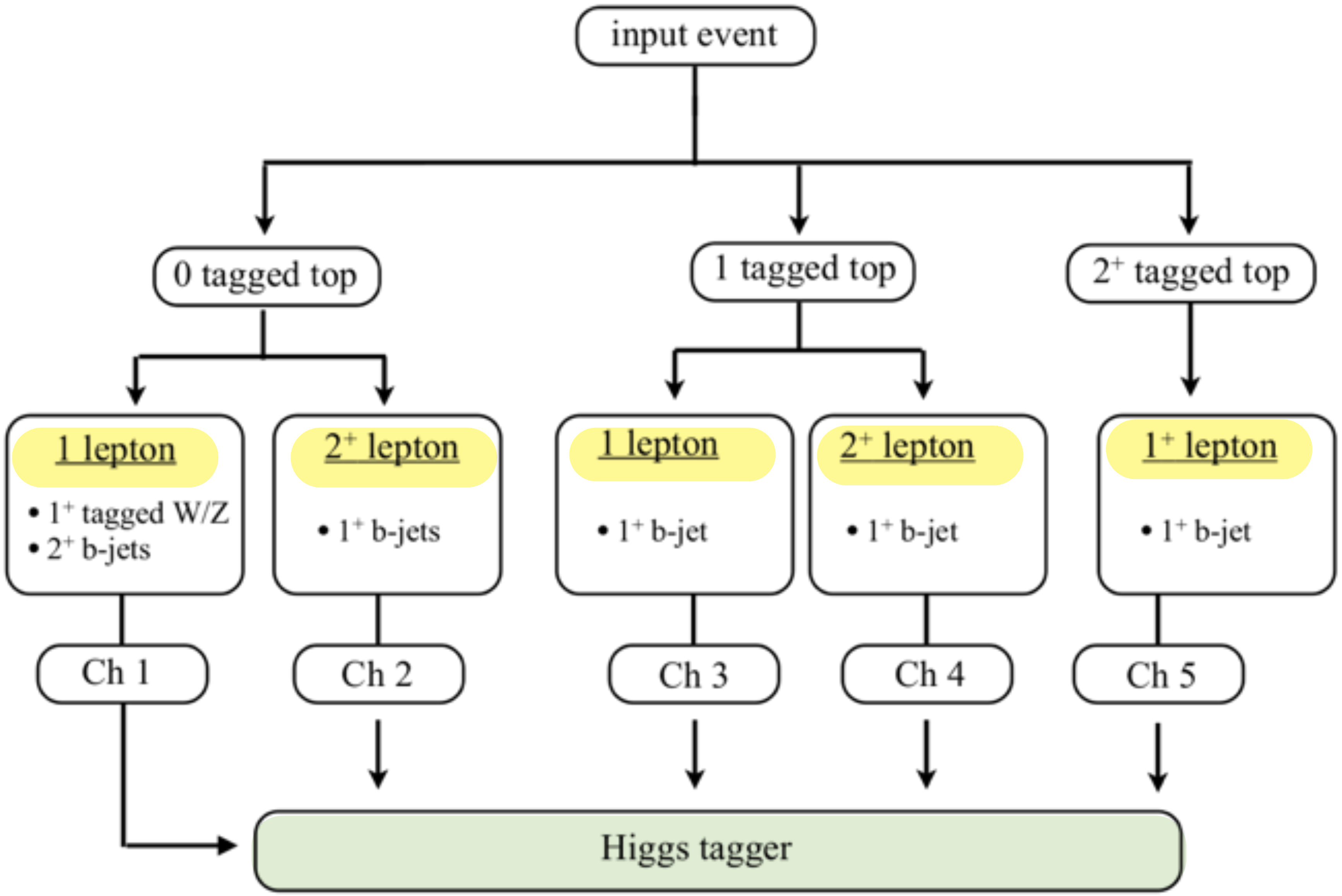

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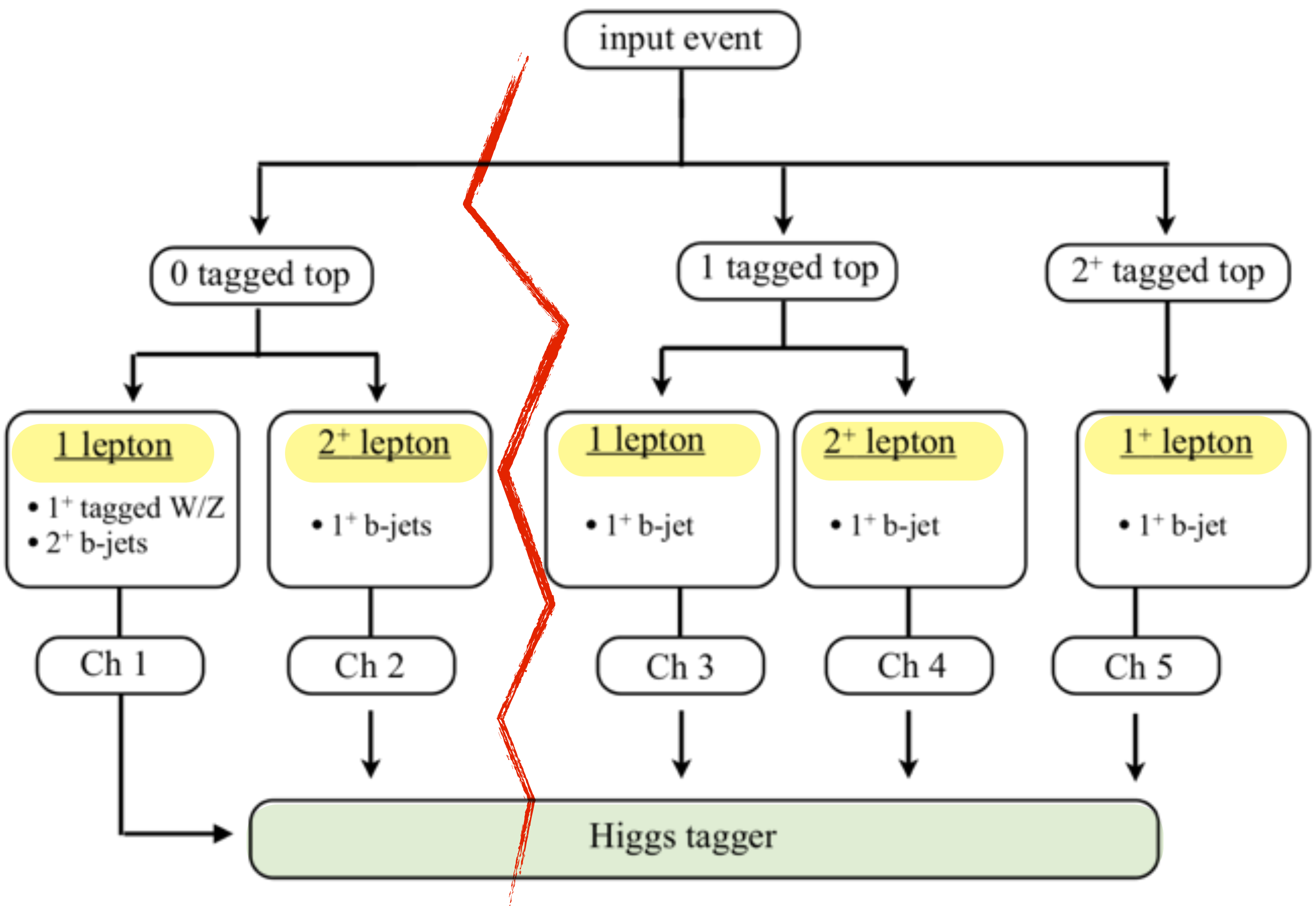

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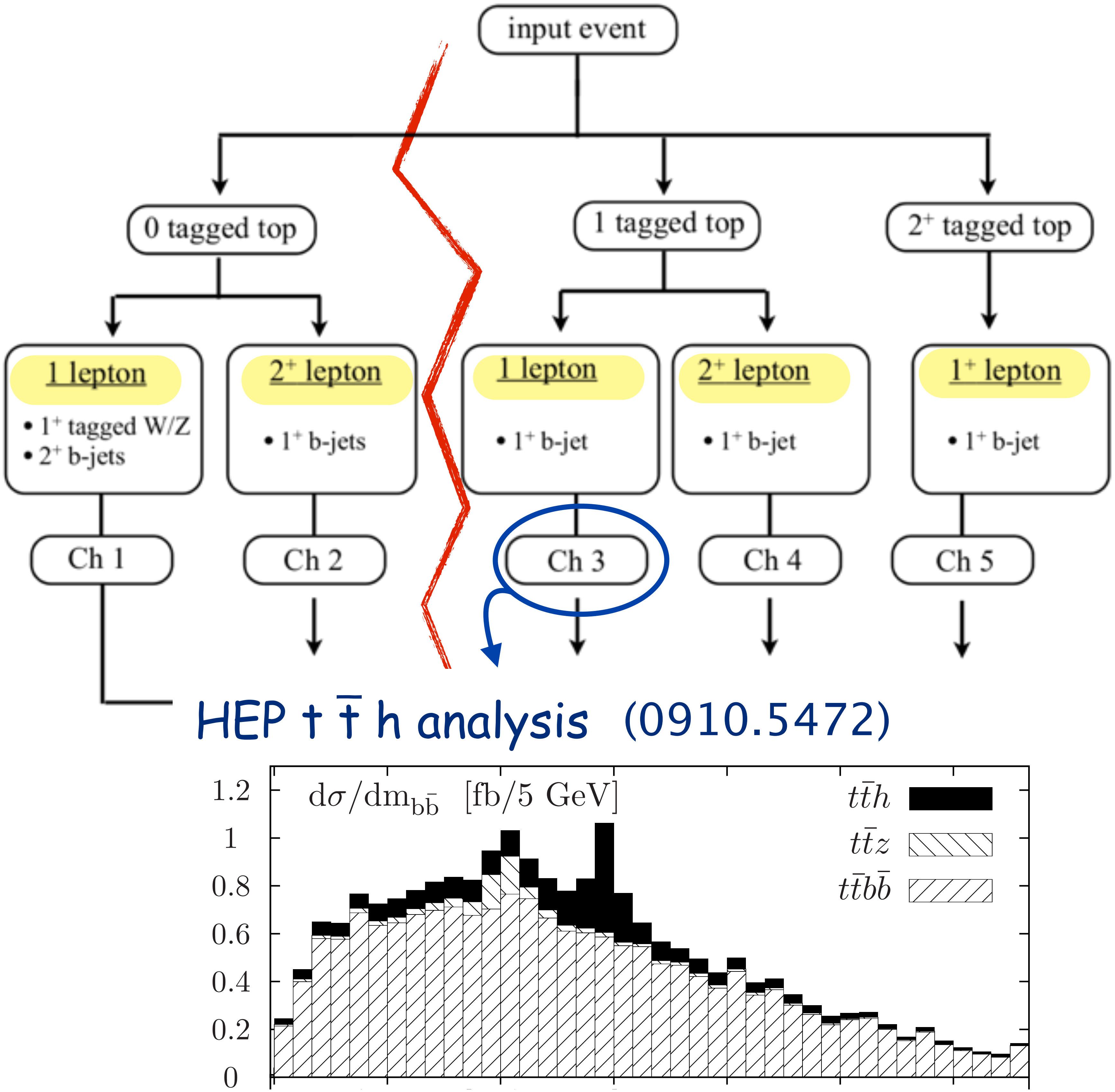

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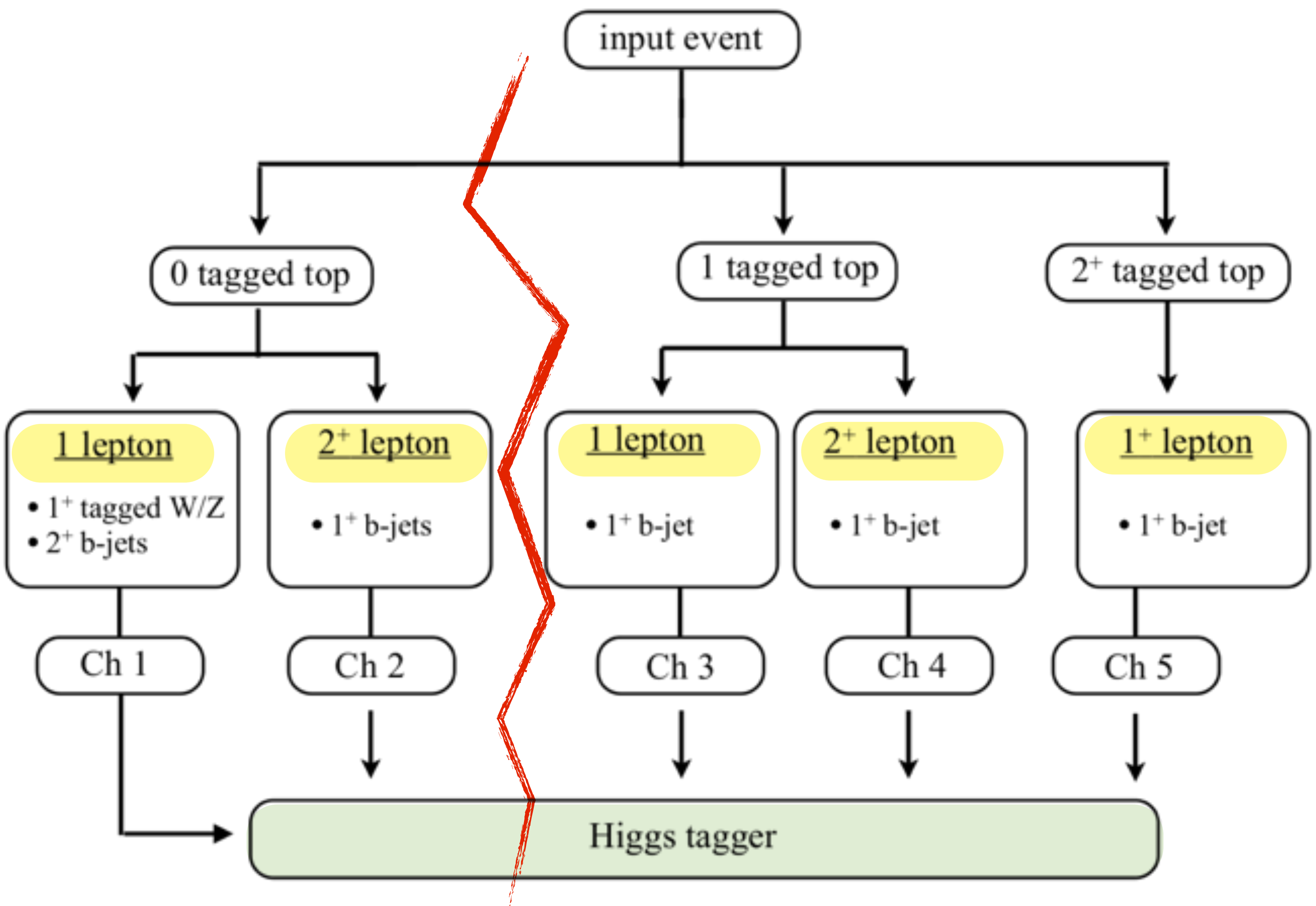

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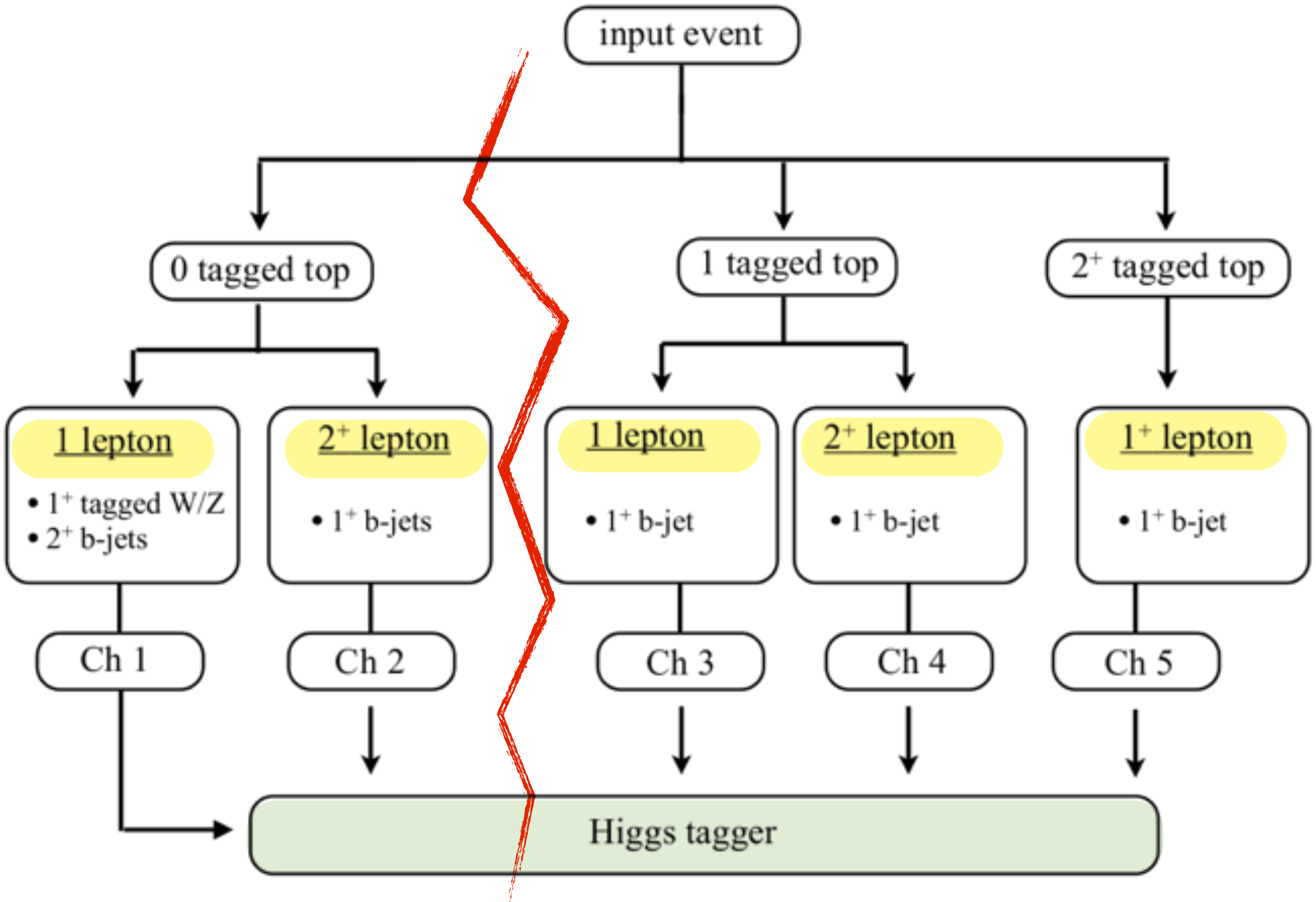

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low background:

further divide 1+ top, 1+ lepton sample to isolate states $t\bar{t}$+jets can't mimic

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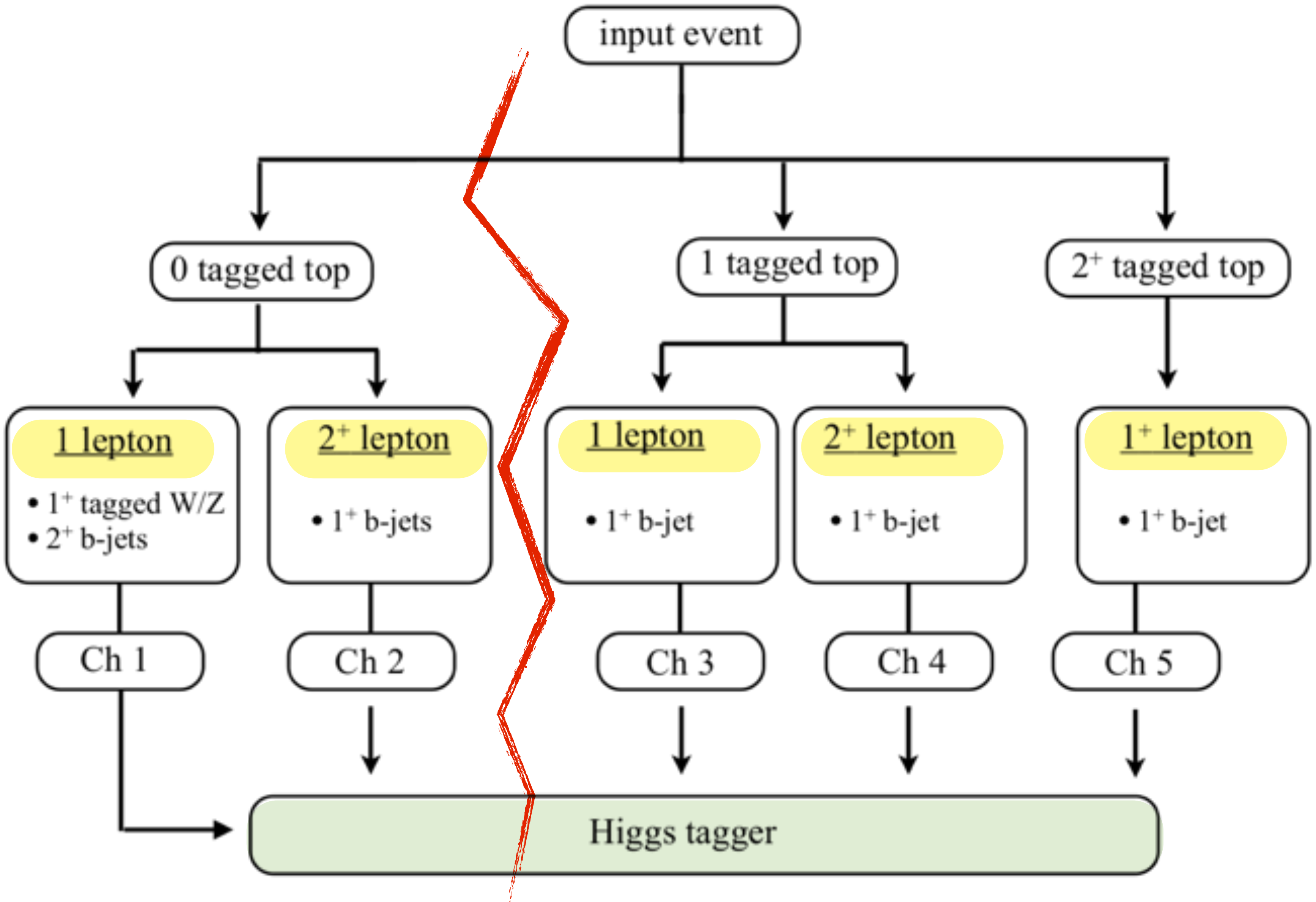

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low background:

further divide 1+ top, 1+ lepton sample to isolate states $t\bar{t}$+jets can't mimic

high-background:

require extra objects b/W-candidate/lepton to remove W/Z + jets

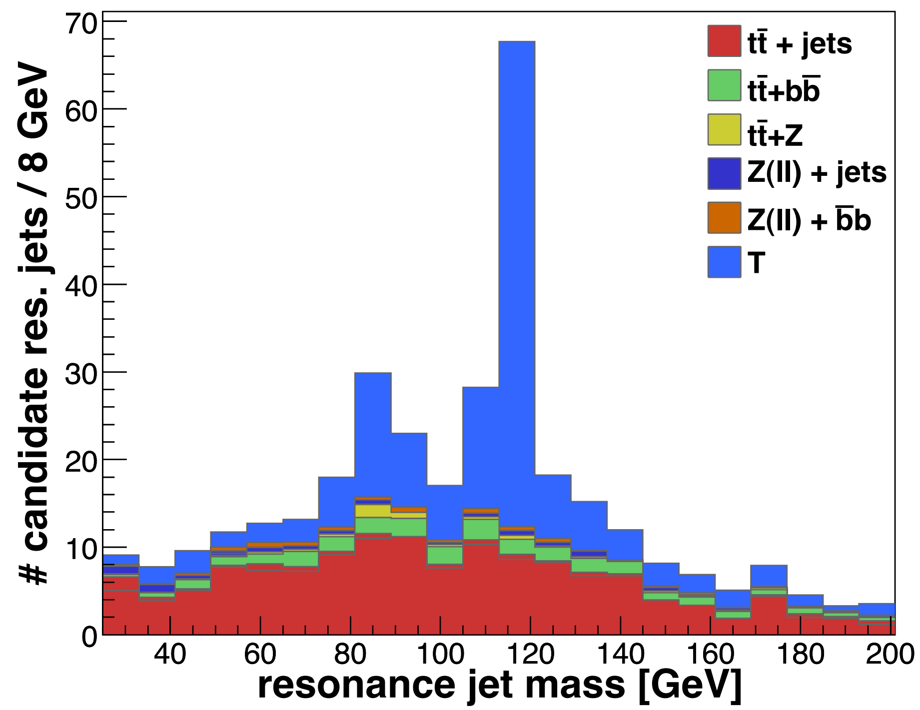
"No event left behind"

Higgses from Top-partners: results

M_T ~ 500-600 GeV, all channels work well

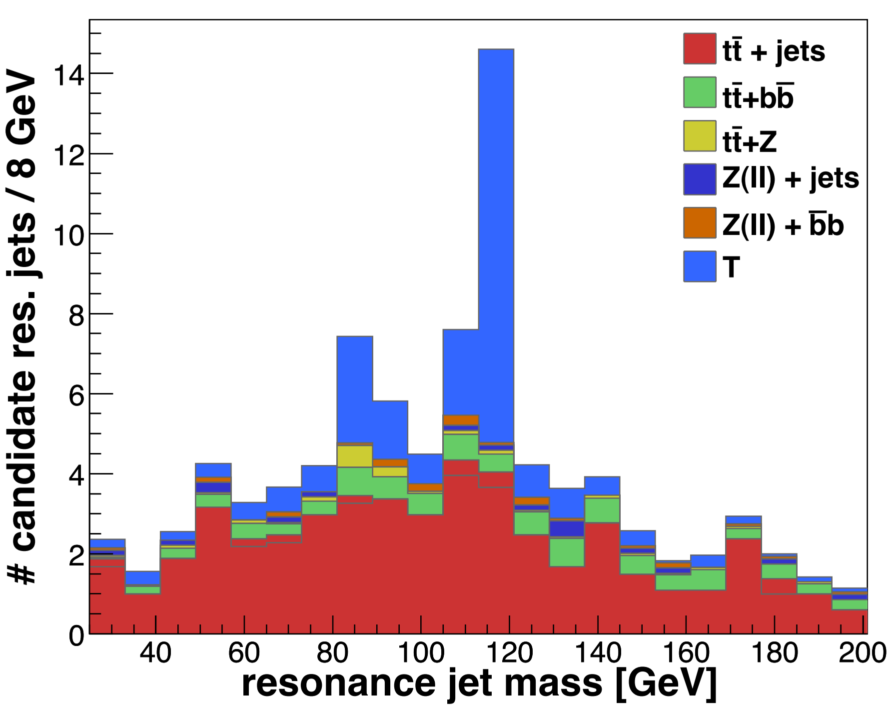
(plots: $\sqrt{s}$ = 14 TeV, 10 fb^{-1})

$$M_T = 600 \text{ GeV}$$



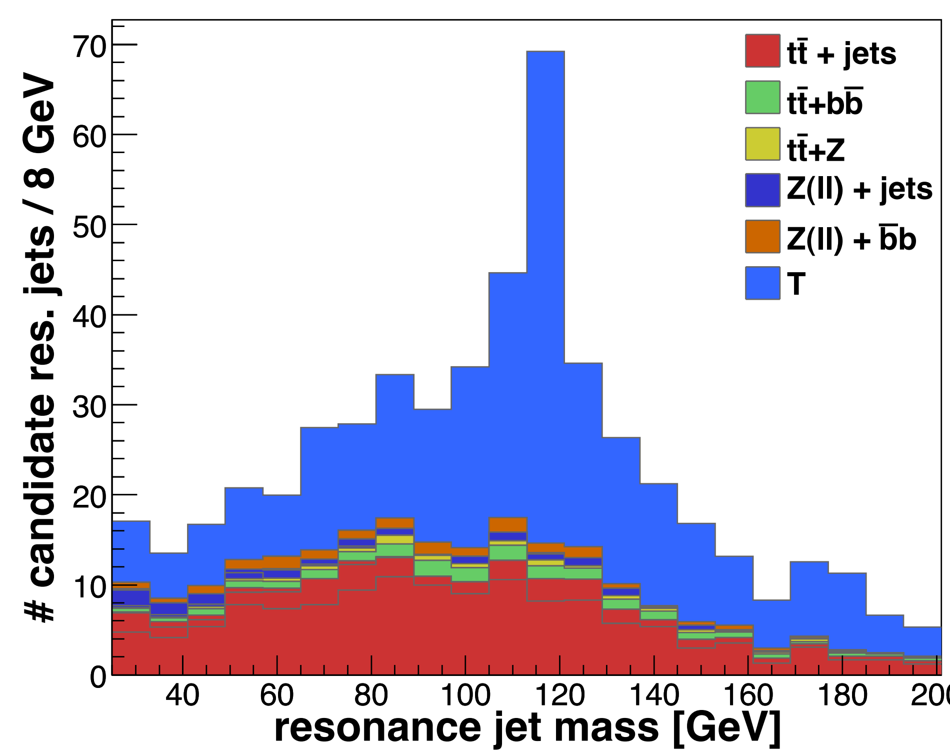
lighter M_T: higher rate, but less boost -> multi-lepton channels work better

$$M_T = 800 \text{ GeV}$$



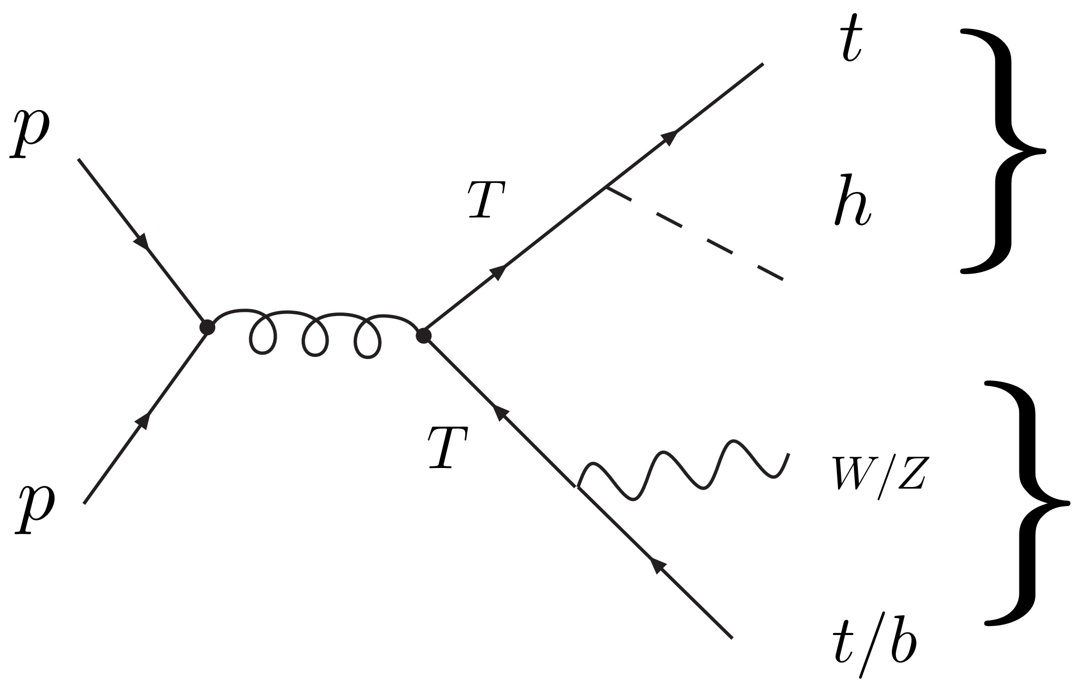
opposite is true for higher M_T: channels w/ multiple boosted resonances work best

$$M_T = 400 \text{ GeV}$$



Comments

1.) Substructure (h/W/Z) can also dramatically improve T detection prospects:



using substructure, more readily reconstructable

(Holdom '07, Skiba + Tucker-Smith '07)

2.) $M_T \geq 1.5$ TeV, Higgs from single T?

3.) Extending the minimal setup:

B, bottom-partner: different signals, but same strategy will work

G, gluon partner: new production mode, $pp \to G \to T\bar{T}$

bigger rate -> better signal

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 $h \to \gamma\gamma$, $h \to \tau\tau$

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

EXTRA SLIDES

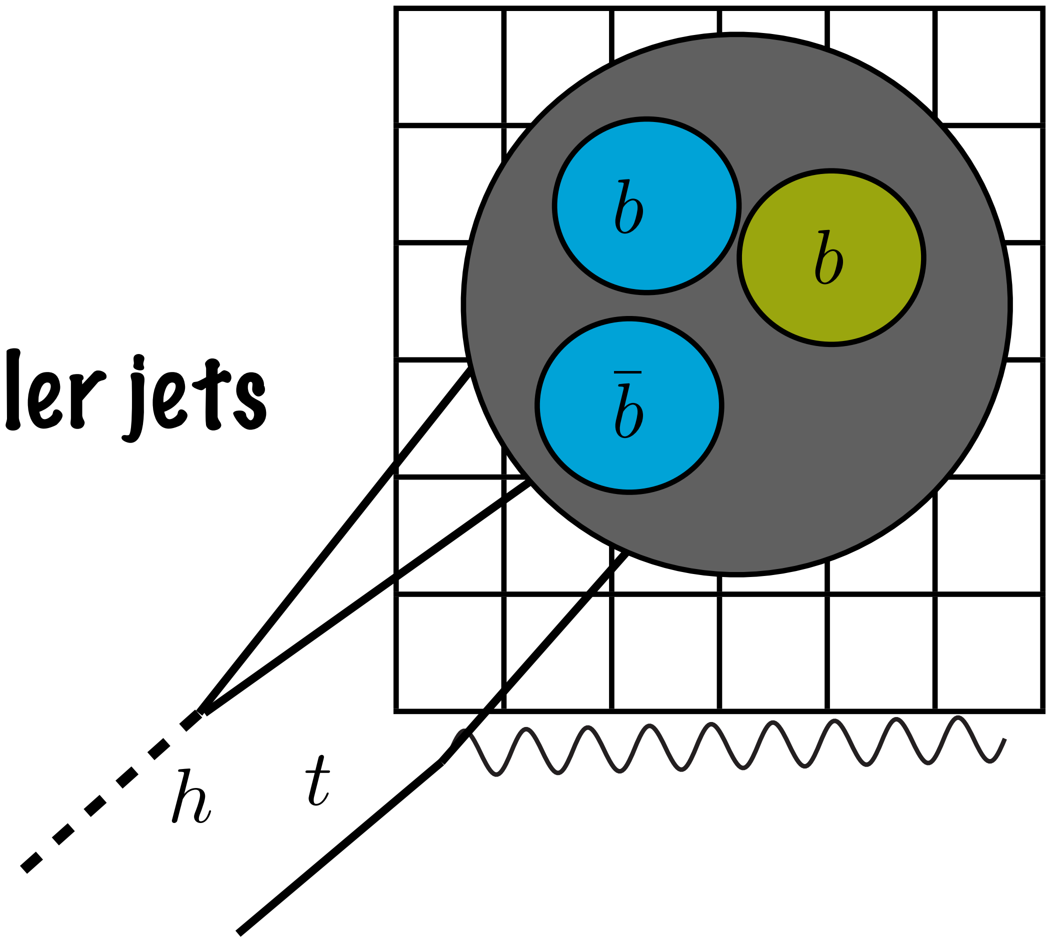
Substructure for SUSY

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

We could:

1. Focus on higher boost = smaller jets

2. Adapt substructure routine



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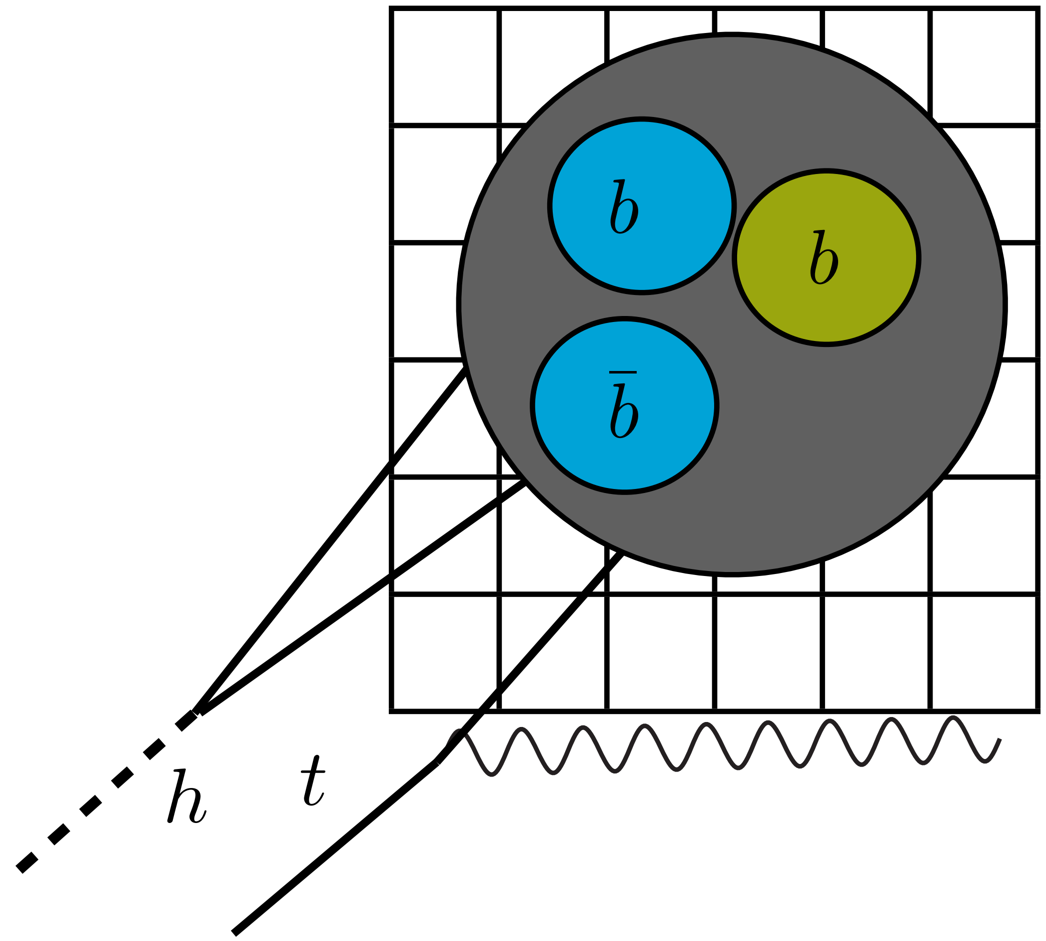

Specifically:

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

2a. if a mass drop (BDRS):

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

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

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

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

→ **candidate higgs**

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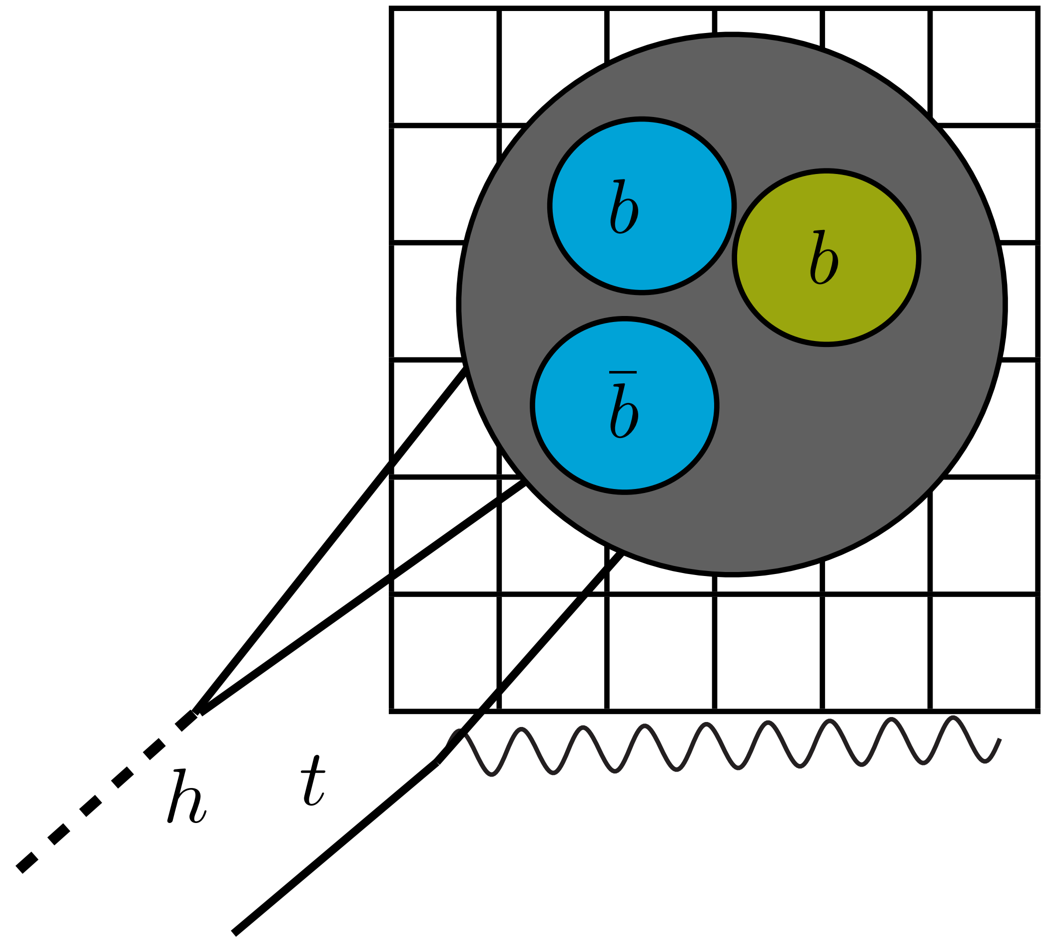
2b. otherwise, $j_1 \to j$, goto 1.

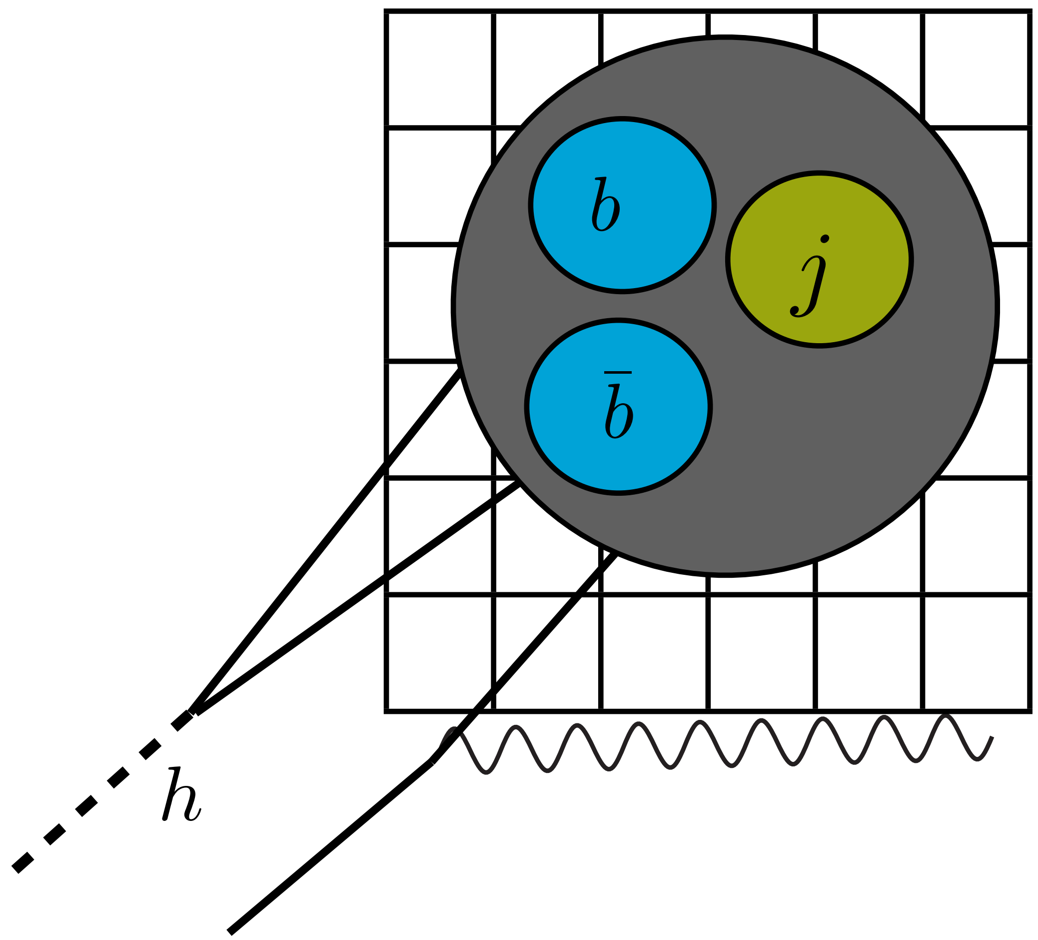
3. continue until $p_{T,j} < 30$ GeV



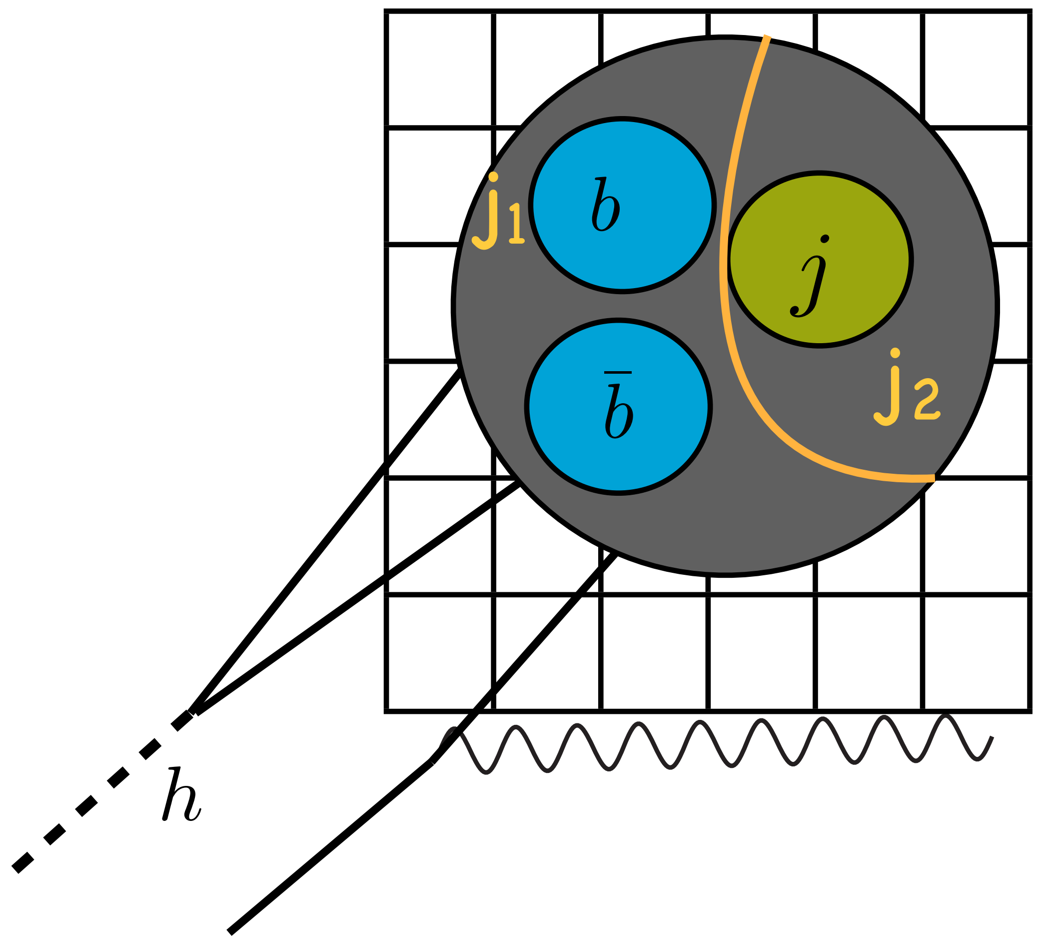
take 2 b-tagged constituents with most similar p_T, filter → **candidate higgs**

similar method to t tbar h tagger (Plehn, Salam, Spannowsky '09)

Substructure for SUSY

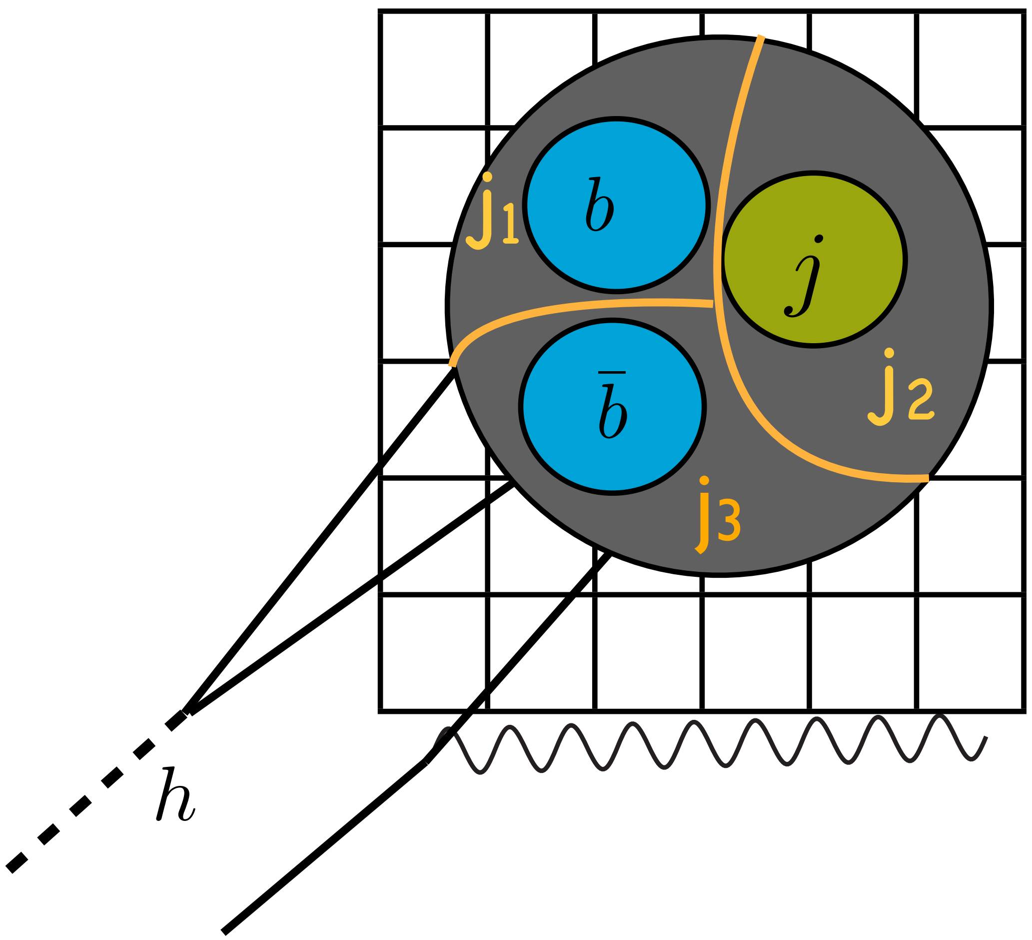


Substructure for SUSY



BDRS stops here

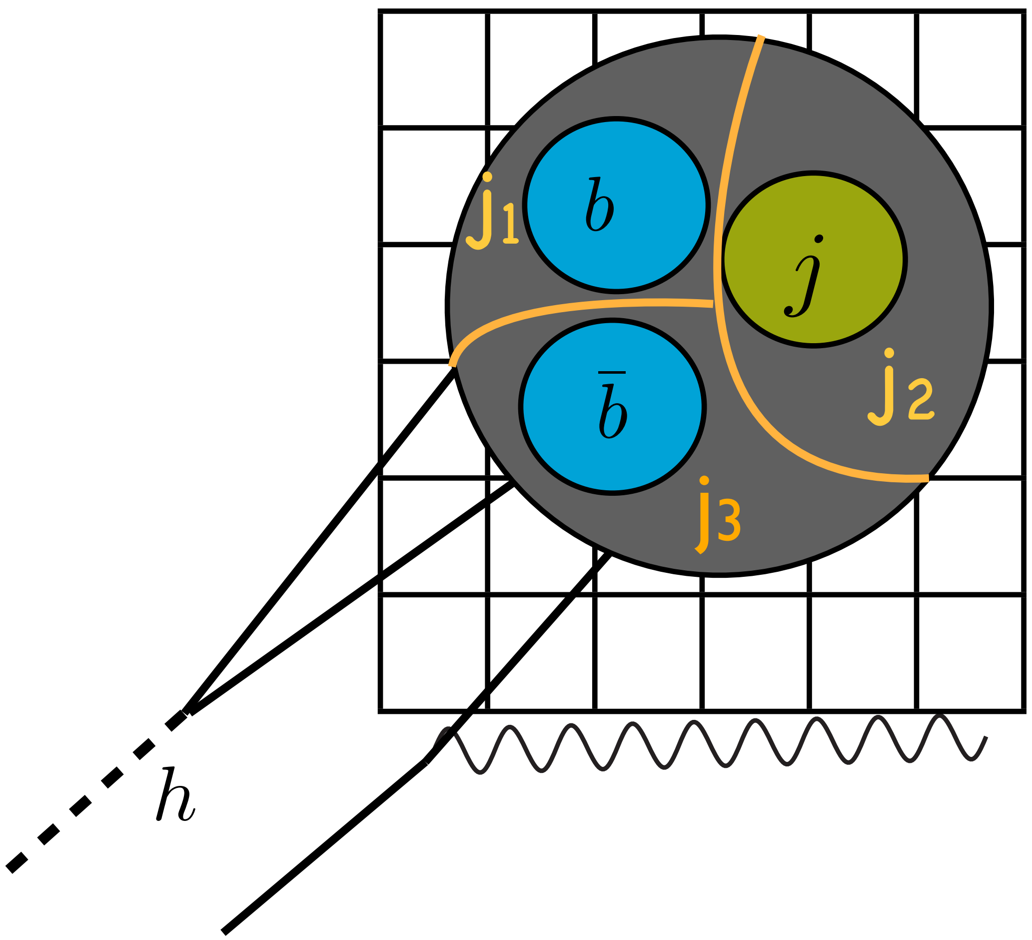
Substructure for SUSY



BDRS stops here

'similarity' method keeps going

Substructure for SUSY

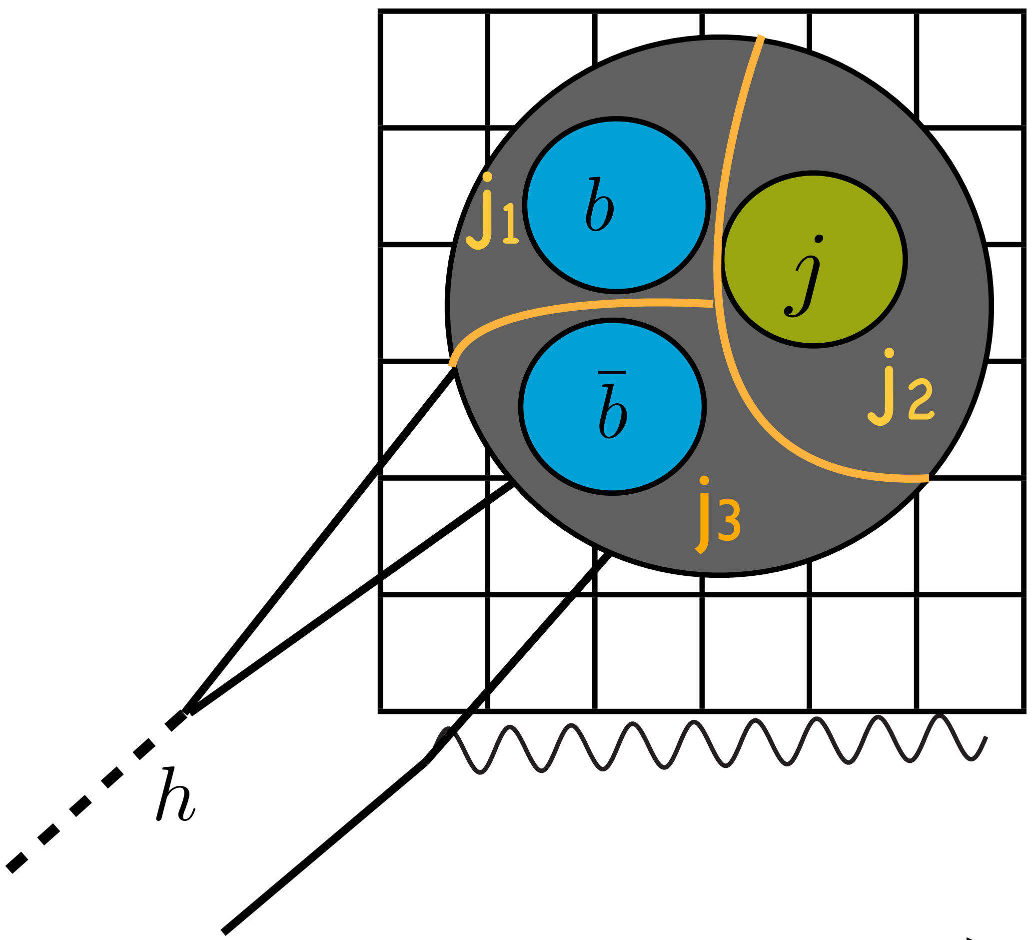


BDRS stops here

'similarity' method keeps going

Higgs is spin-0 -> more symmetric decay products

Substructure for SUSY



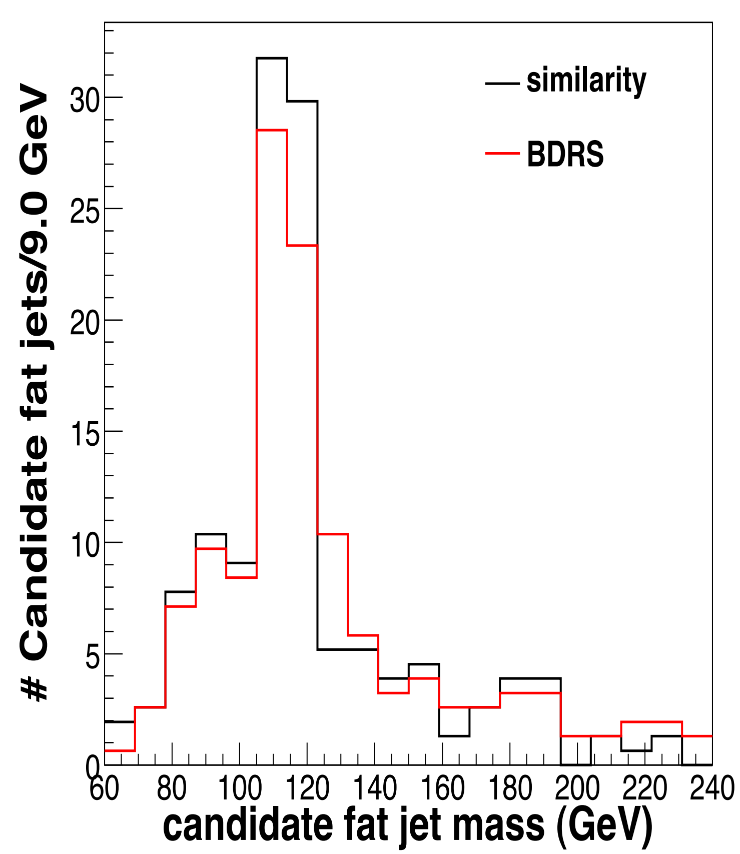
BDRS stops here

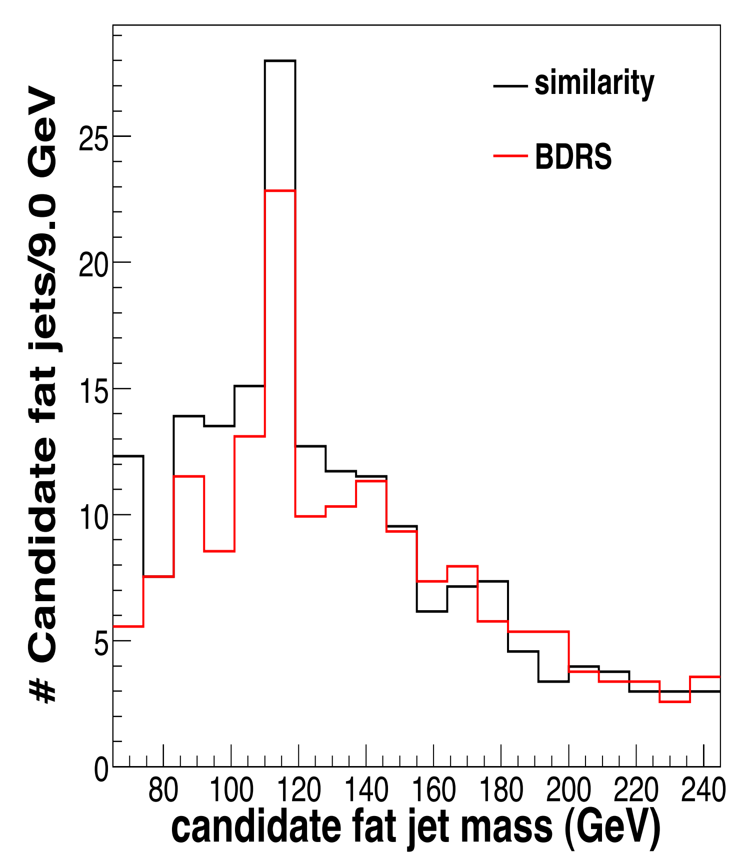
'similarity' method keeps going

Higgs is spin-0 -> more symmetric decay products

more efficient in busy environments

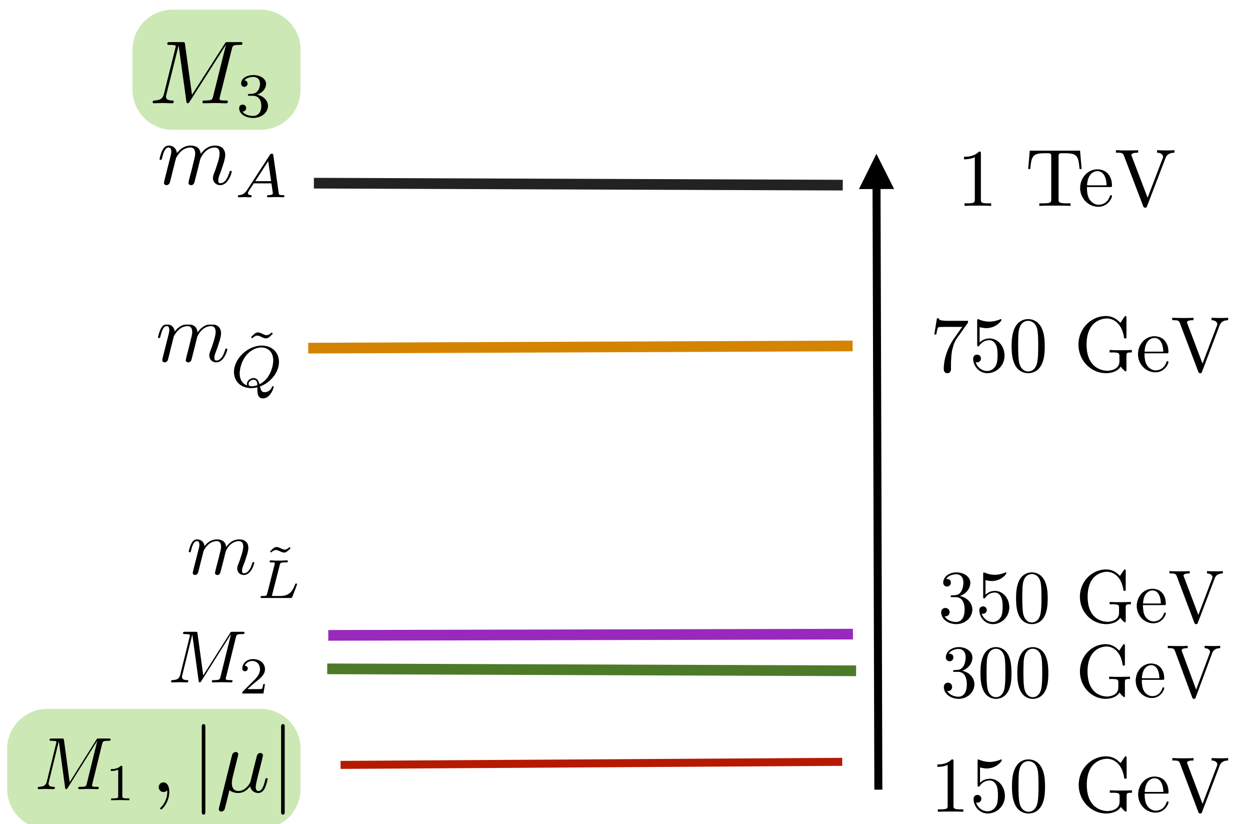
now, results..

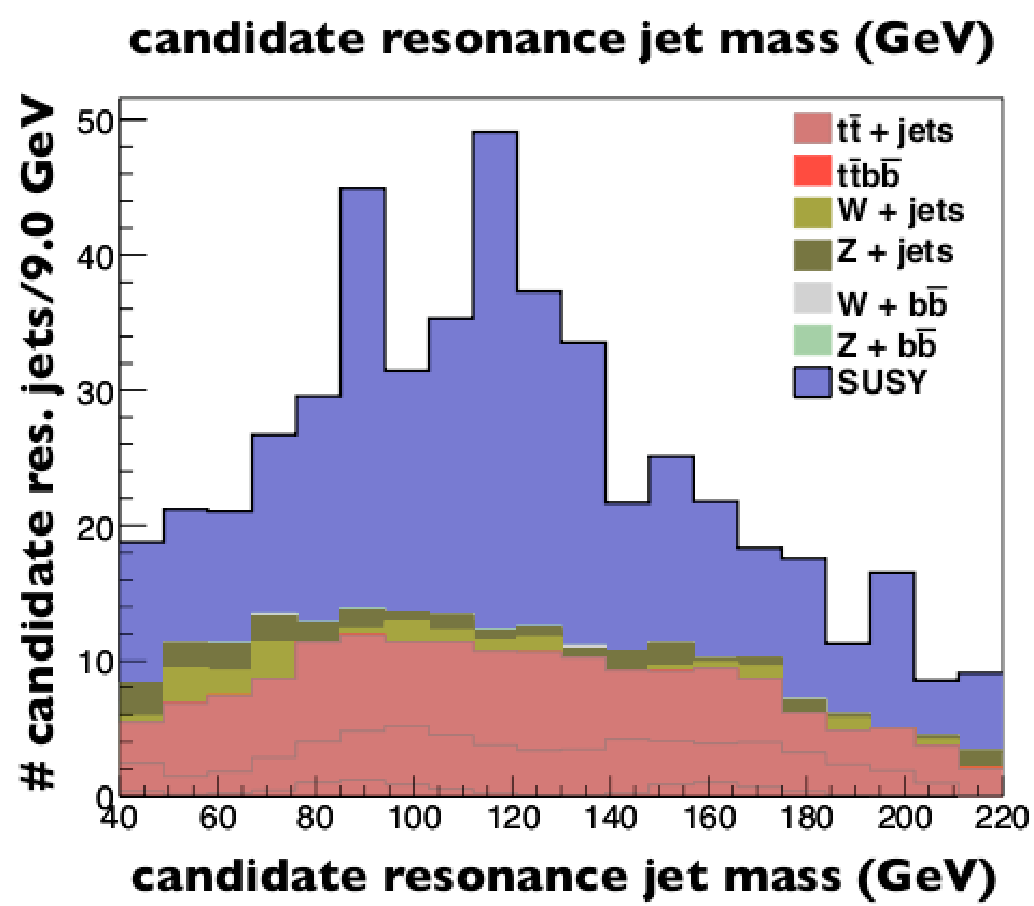




Neutralino LSP Results: #2

busier final states...





contamination from extra partons, but Higgs peak still visible

improvements?

HEPTopTagger - a low-pT Tagger

(Plehn, Salam, MS, Takeuchi)

1. Start with 'fat jet' (C/A, R=1.5, pT>200 GeV)

2. Reverse merging procedure
with the condition

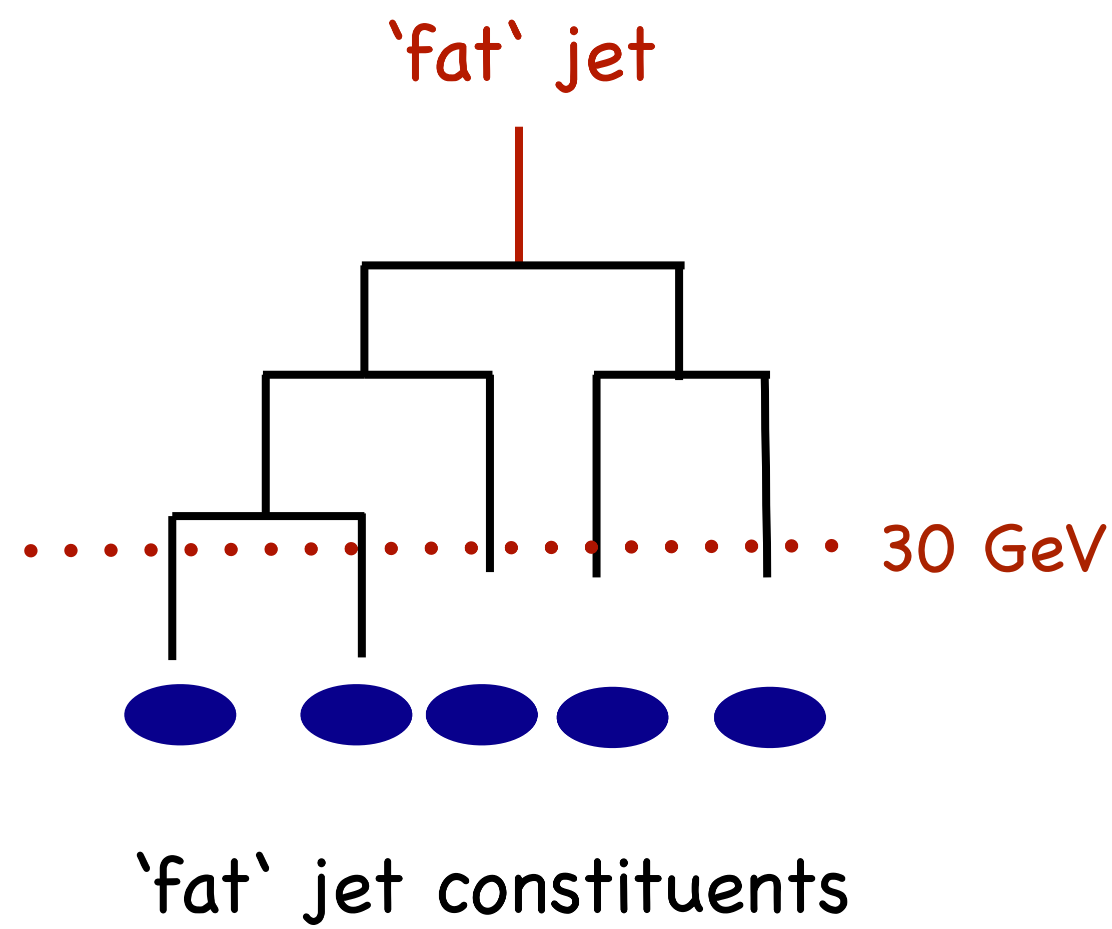
$$\max m_j^{\text{soft}} < 0.8\, m^{\text{hard}}$$

3. If condition is full-filled proceed with

$$m_j^{soft} \to m^{hard}$$

if not

$$m^{\text{hard}} \equiv \max m_j^{\text{soft}}$$



4. Repeat 2. and 3. or stop if mass below 30 GeV

5. Take 3 constituents which give best top mass and filter them

(stolen from Spannowsky, FNAL talk 12/3/10)