Boosting BSM-Higgs discovery with jet-substructure

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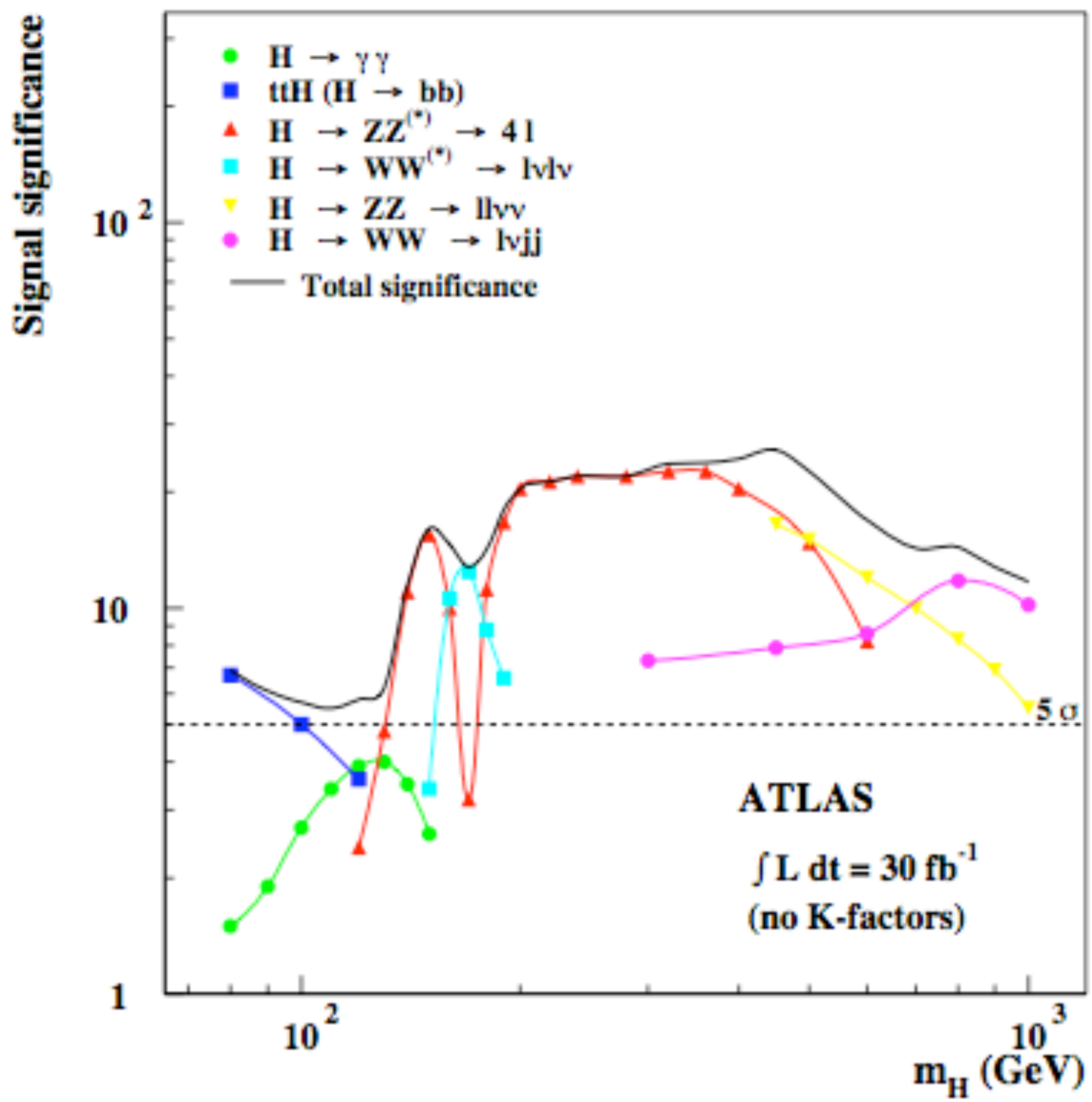
Martin, Kribs,
TR, Spannowsky

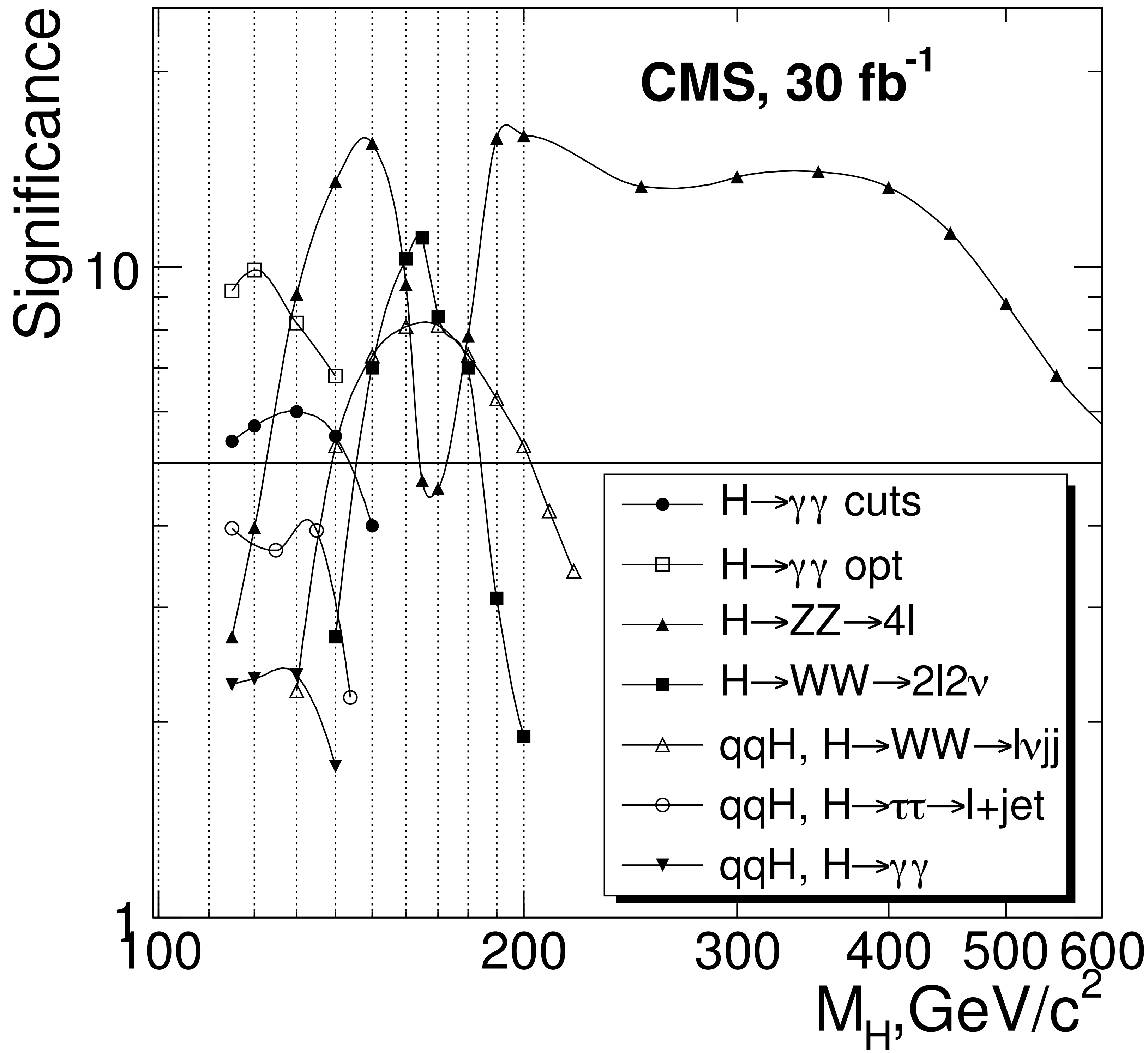
arxiv 0912.4731
in preparation

LHC higgs reach



115-120 GeV higgs
search is challenging

CMS TDR 2006

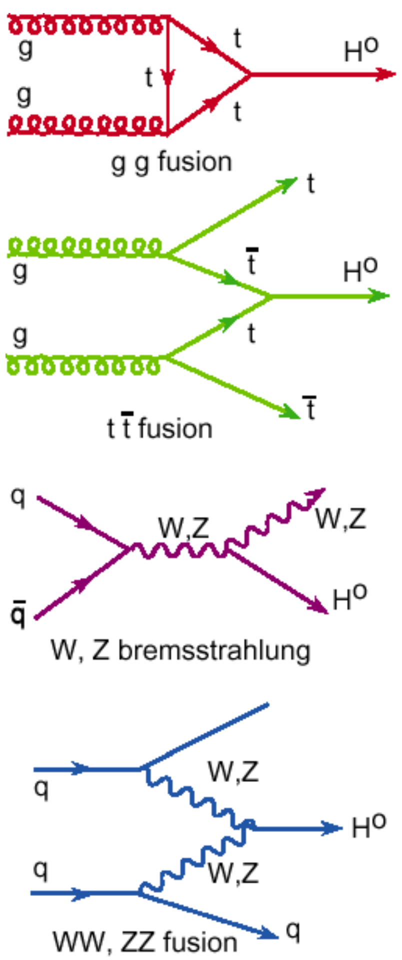


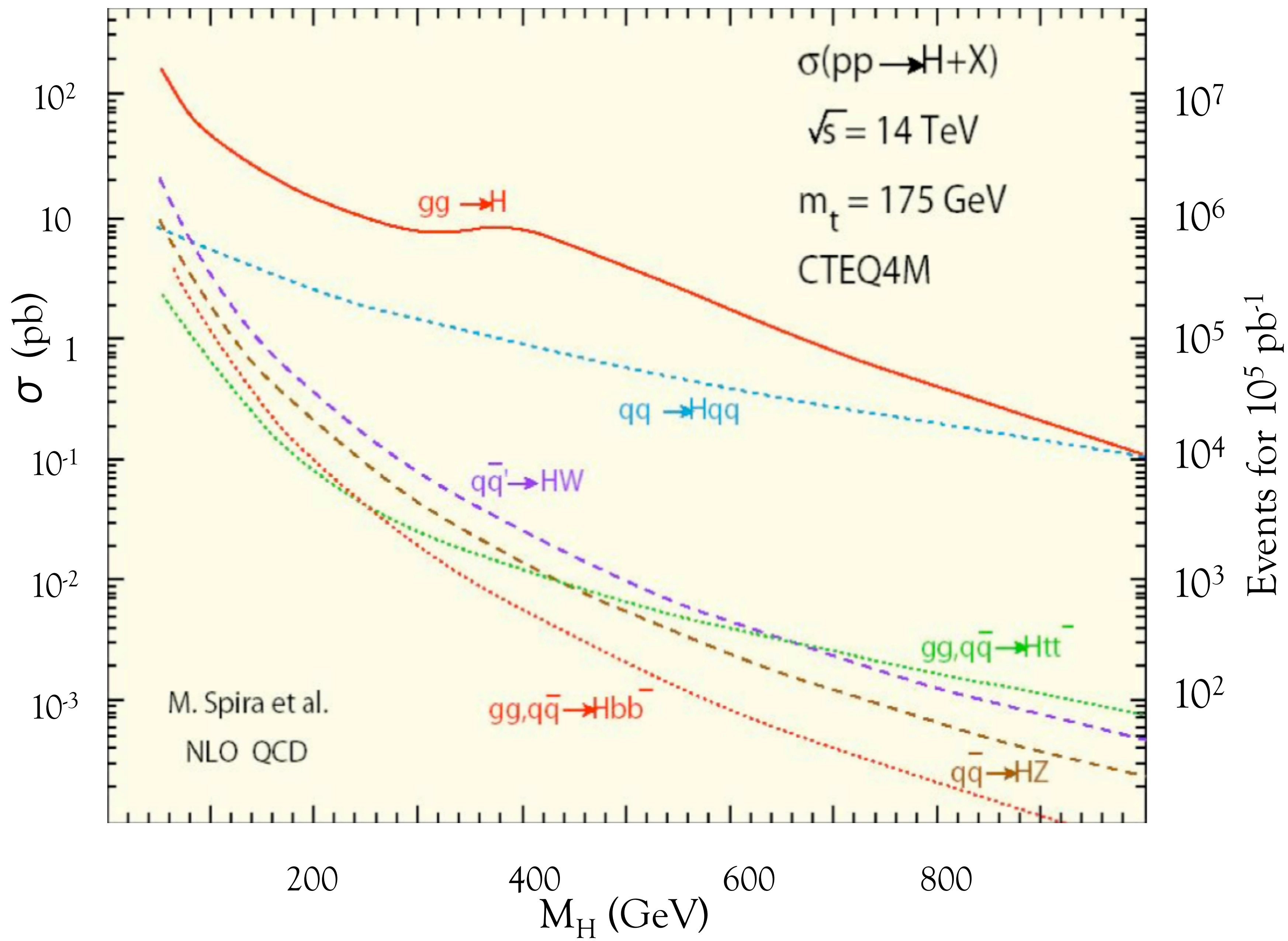
CMS, 30 fb^{-1}
Significance
10
1
100
200
300
400
500
600
M_H,GeV/c^2
H→γγ cuts
H→γγ opt
H→ZZ→4l
H→WW→2l2ν
qqH, H→WW→lνjj
qqH, H→ττ→l+jet
qqH, H→γγ

this is unfortunate

MSSM higgs is most likely to be found
in
115- 130 GeV
window

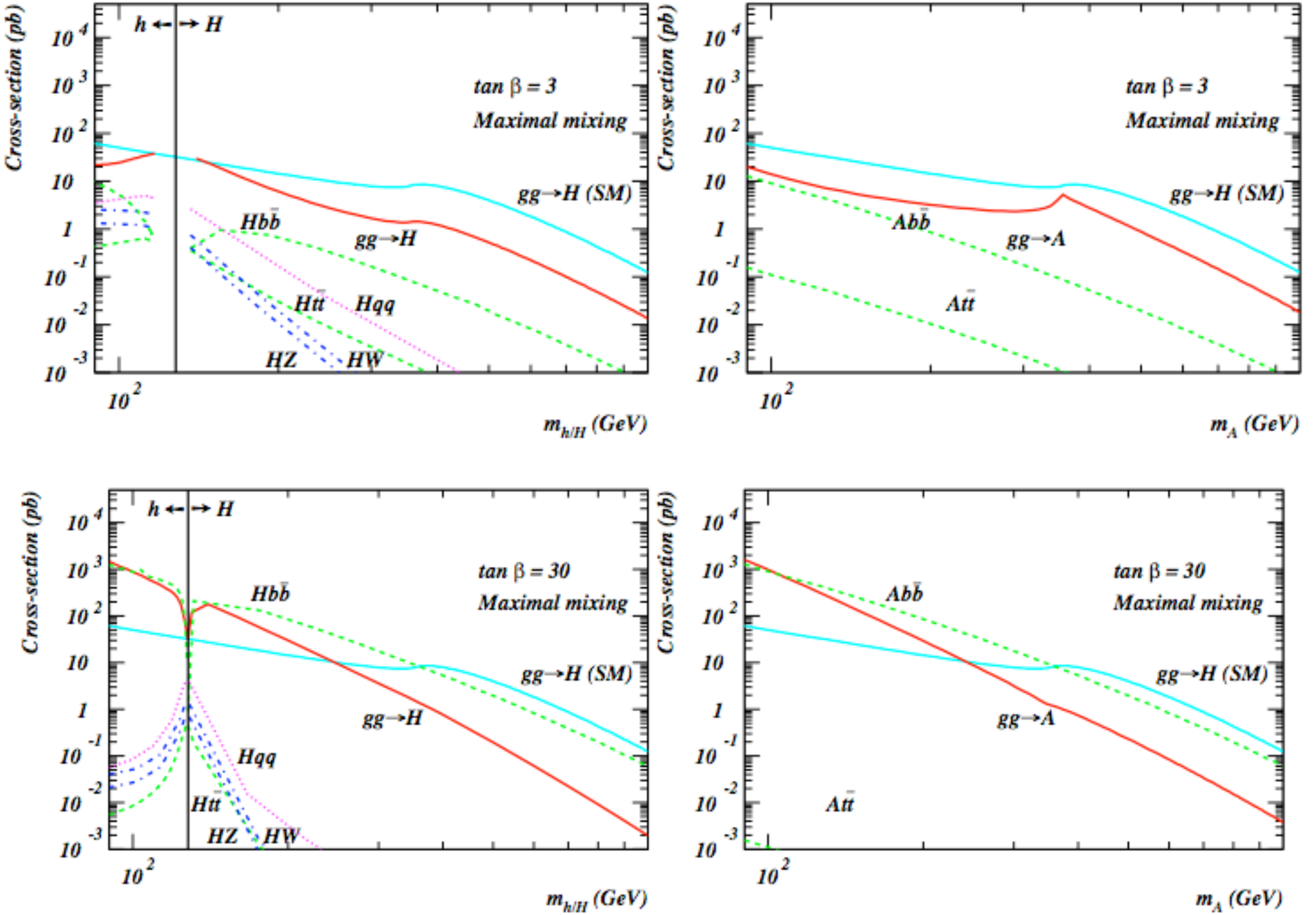
there will be plenty of Higgs at LHC





SM cross-section

source (ATL-PHYS-2008-258)

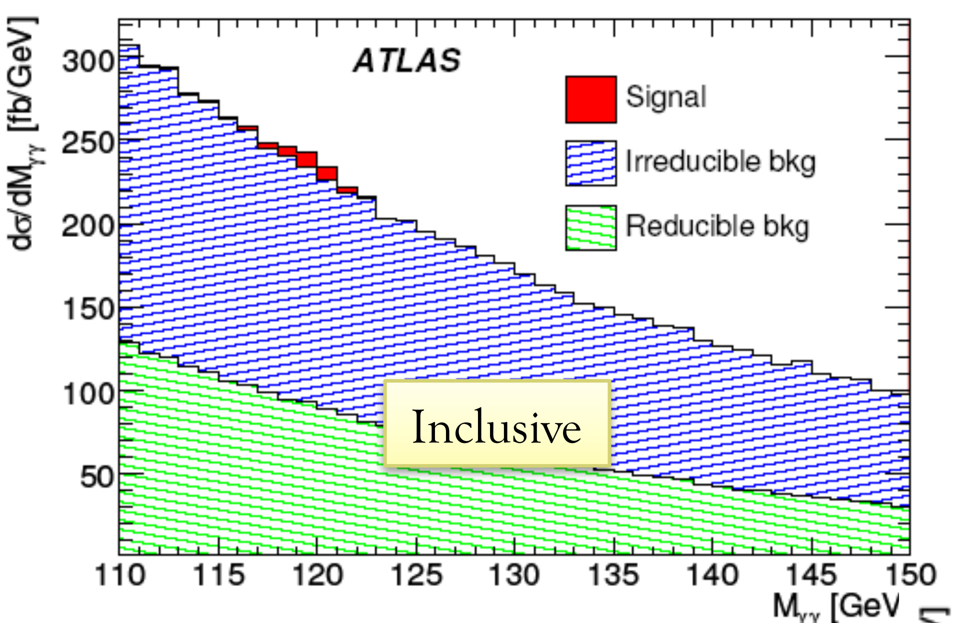


MSSM cross-section

source (ATL-PHYS-2008-258)

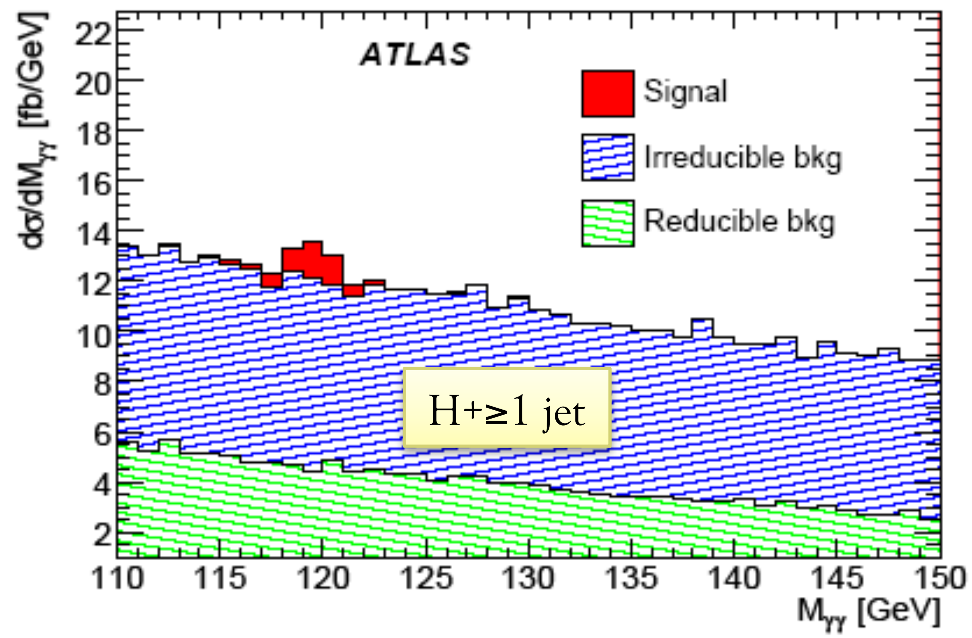
$h \rightarrow \gamma\gamma$

- *Most significant decay channel .*
- *Reconstructed mass peak on top of continuum di-photon bkg.*
- *Atlas: inclusive $\gamma\ \gamma$ and exclusive $\gamma\ \gamma$ +jets searches.*

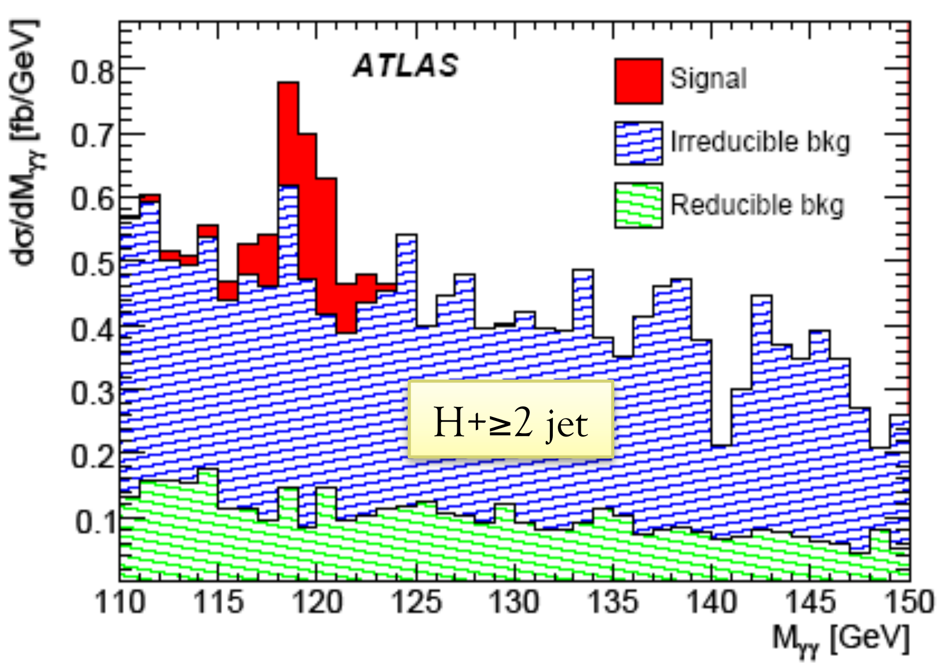


$$S/\sqrt{B} = 2.6$$

$$S/\sqrt{B} = 1.8$$



$$S/\sqrt{B} = 1.9$$



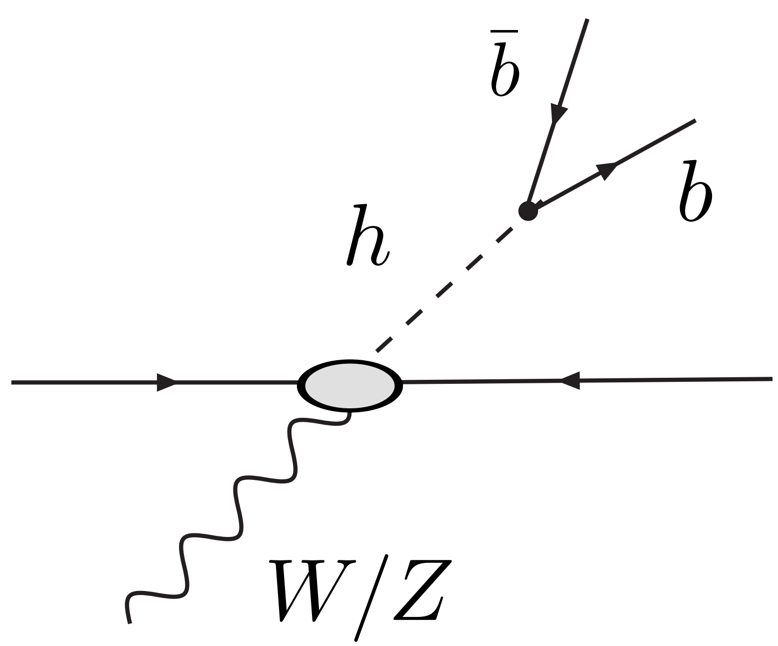
$$\mathcal{L} = 10\ \mathrm{fb}^{-1}$$

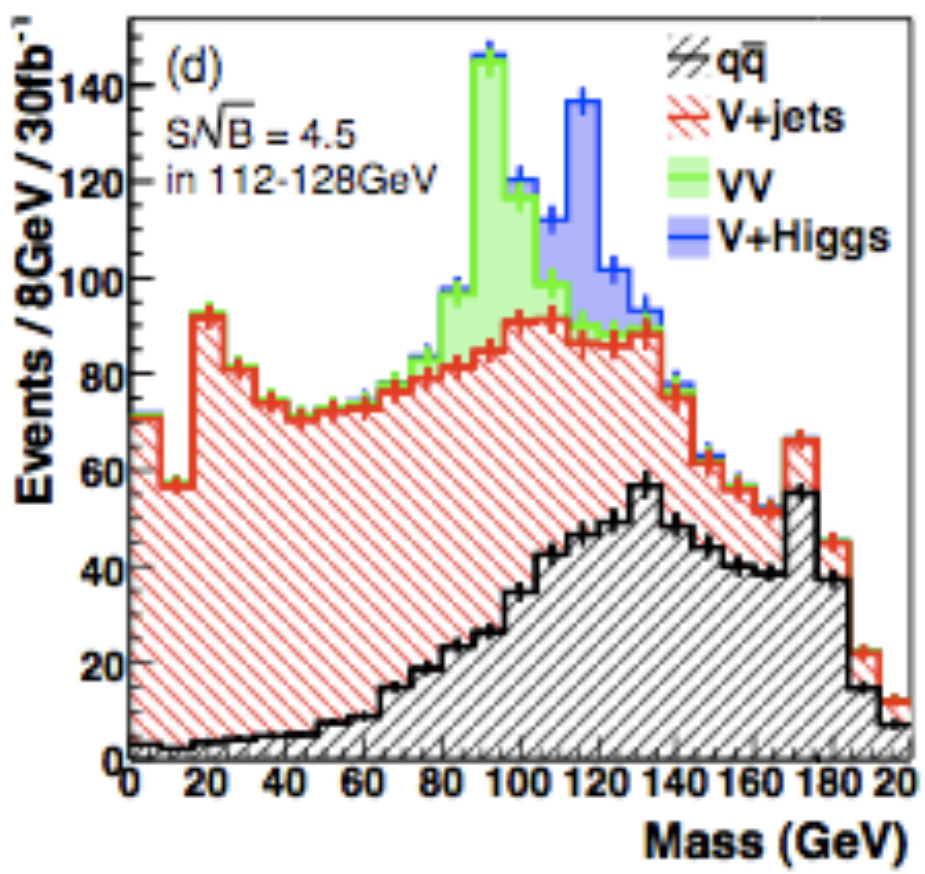
source (ATL-PHYS-2008-258)

LHC higgs search in 115-120 GeV

$$pp \;\rightarrow\; V\; h$$

significance of 4.2 for $\mathcal{L} = 30\ \text{fb}^{-1}$
using jet-substructure for jets with $p_{T,h} > 200\ \text{GeV}$





Butterworth, Davison, Rubin, Salam (2008)

substructure

not an exhaustive list

two-pronged decays

Butterworth, Davison, Rubin, Salam (2008)

Plehn, Salam, Spannowsky (2009)

three-pronged decays

Thaler and Wang (2008)

Brooijmans (2008)

Kaplan, Rehermann, Schwartz and Tweedie (2008)

Butterworth, Ellis, Rakhlev, Salam (2009)

pruning/trimming

Ellis, Vermilion, Walsh (2009)

Krohn, Thaler, Wang (2009)

Search for boosted Higgs

interesting new concept

but a bit limited in the SM

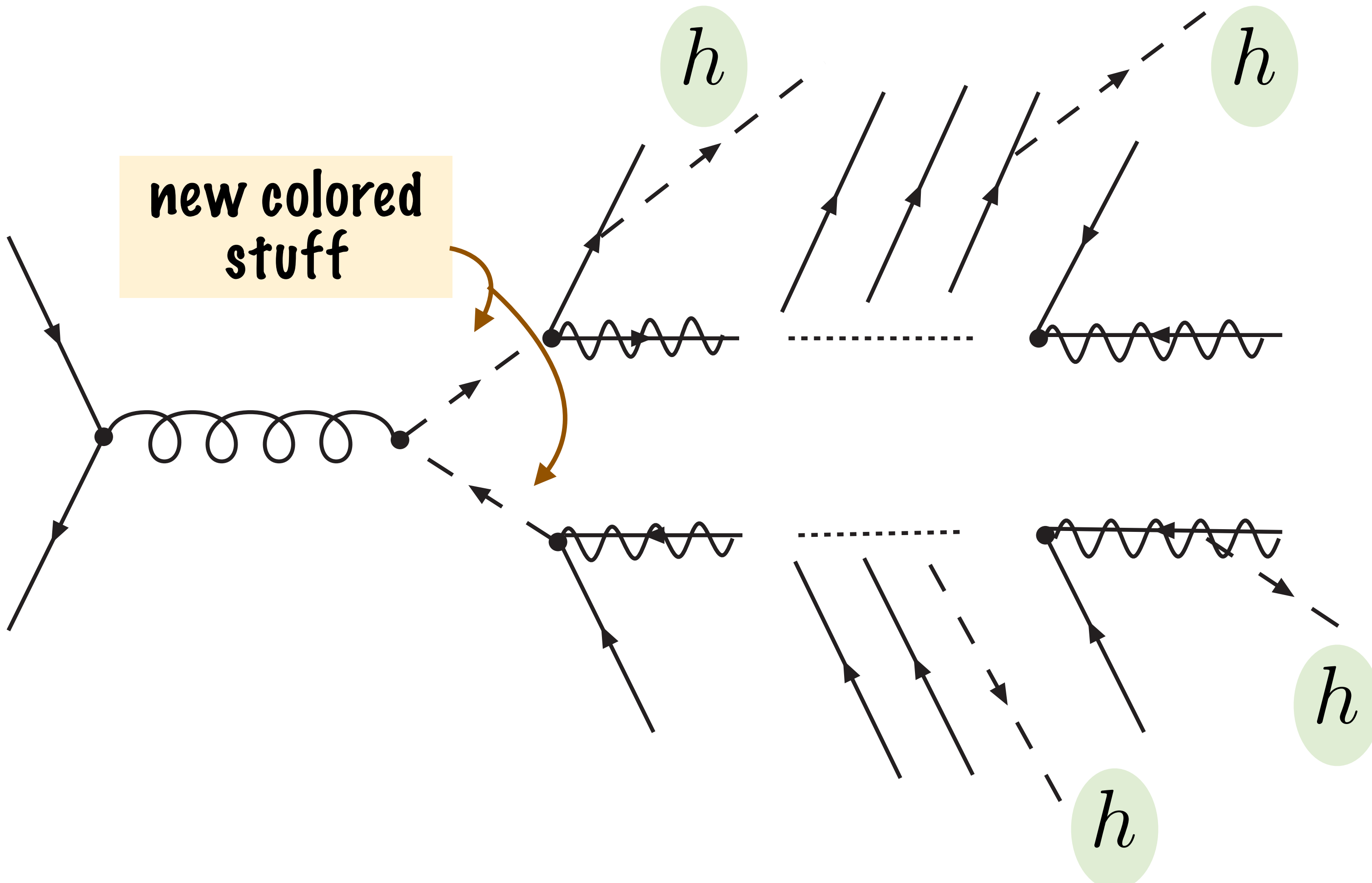
- there are few boosted Higgses in SM:

  only ~ 5% of boosted Higgs in h + W/Z

- need to trigger & suppress SM backgrounds

  search is limited to leptonic decay of W/Z

Higgs in the BSM



new sources of Higgs

initial colored states are heavy
while Higgs is light

much higher fraction of boosted Higgs

Higgs from BSM

- If BSM contains new colored states, production at LHC is easily in the ~few pb range

  comparable to or greater than SM EW production of Higgses

- BSM production often comes with new effective handles for suppressing SM background

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

- Higgses from decays of BSM particles are naturally boosted

BSM-Higgses have all ingredients for a successful substructure analysis

The plan for the talk

Pick new physics scenarios as sources of boosted Higgs.

- MSSM with a gravitino LSP (low scale mediation)
- MSSM with a neutralino LSP (high scale mediation)

Review of jet substructure technicalities:

- briefly discuss clustering
- simple substructure analysis as proposed by Butterworth et.al..
- our algorithm that works in hectic, crowded BSM environments

Results

SUSY sources of boosted Higgs

though our techniques apply to a wide area of BSM scenarios, we'll look at (weak scale) SUSY

Why SUSY ?

- MSSM Higgs is light ($m_h \lesssim 130\ \mathrm{GeV}$)
- it has new colored particles (squarks, gluinos)
- all events include $\not{E}_T$
- Higgs via various decays

$$\tilde{\chi}^0_{3,4} \rightarrow \tilde{\chi}^0_{1,2} + h$$

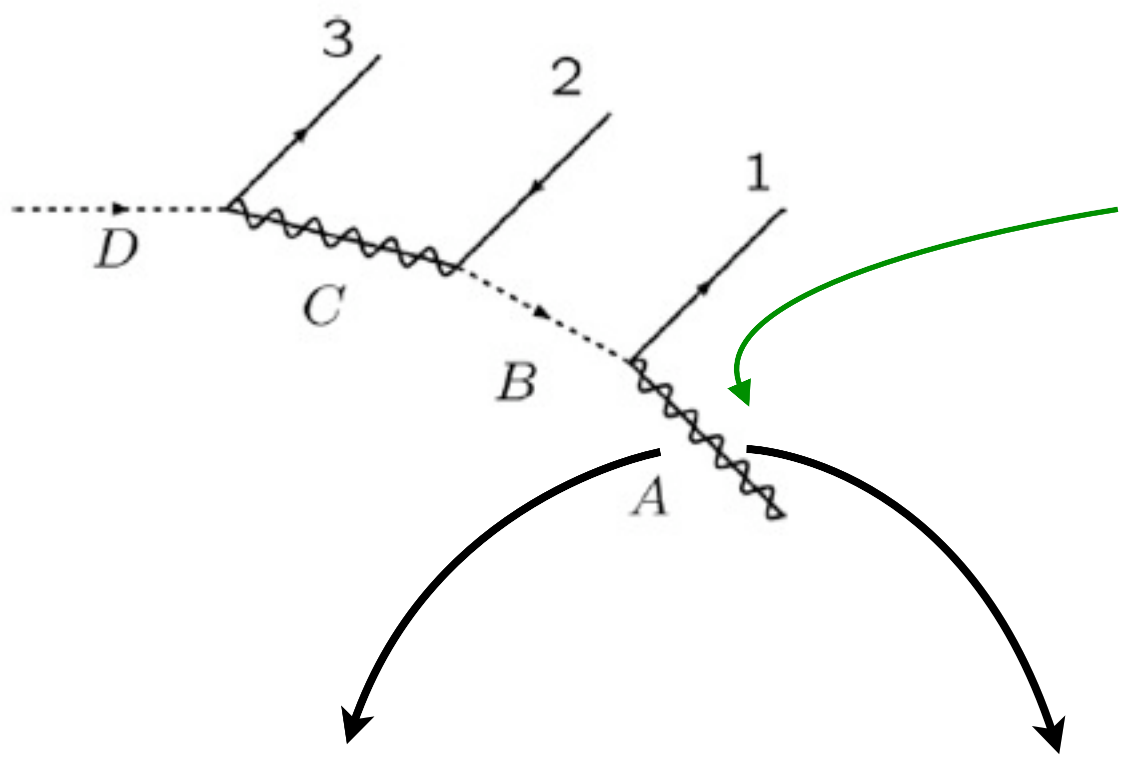
$$\tilde{\chi}^\pm_2 \rightarrow \tilde{\chi}^\pm_1 + h$$

$$\tilde{t}_2 \rightarrow \tilde{t}_1 + h$$

$$\tilde{\chi}^0_1 \rightarrow \tilde{G} + h$$

MSSM with neutralino LSP + gravitino LSP

everything super decays to the NLSP

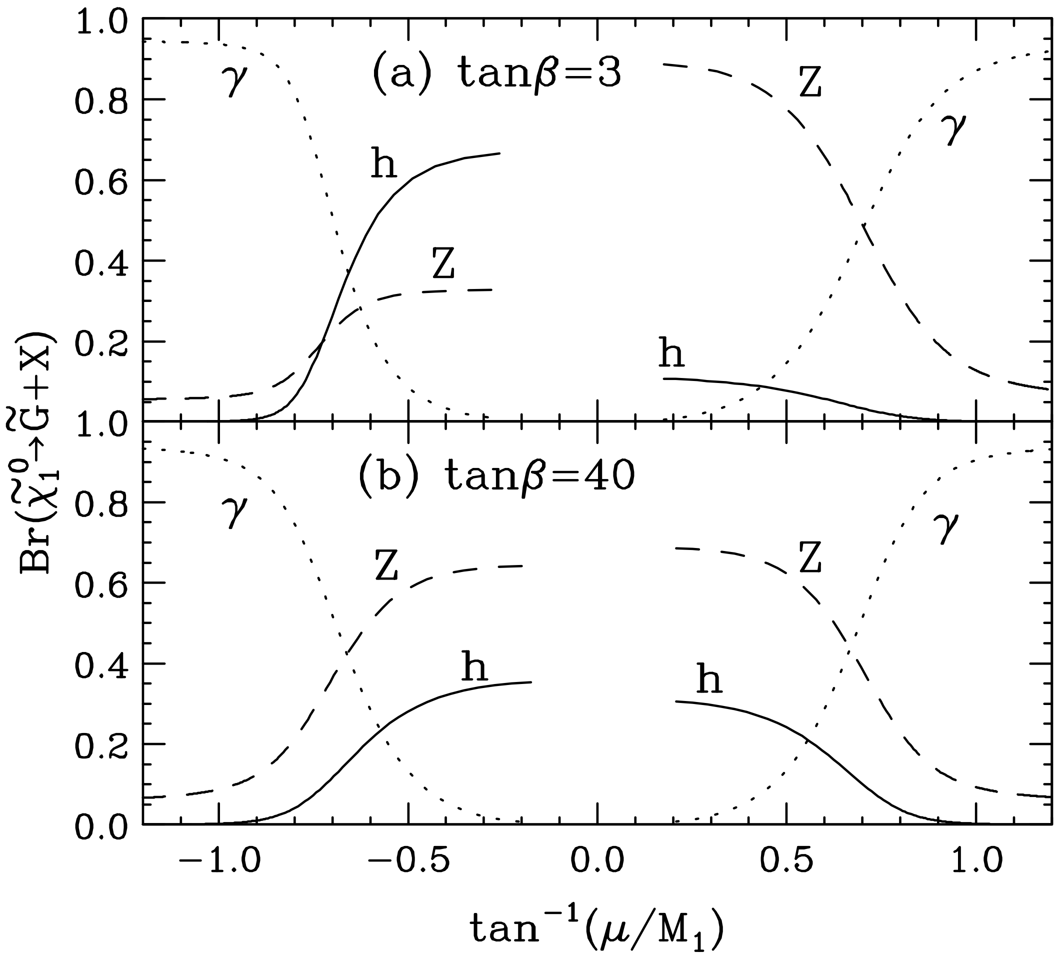


the lightest neutralino

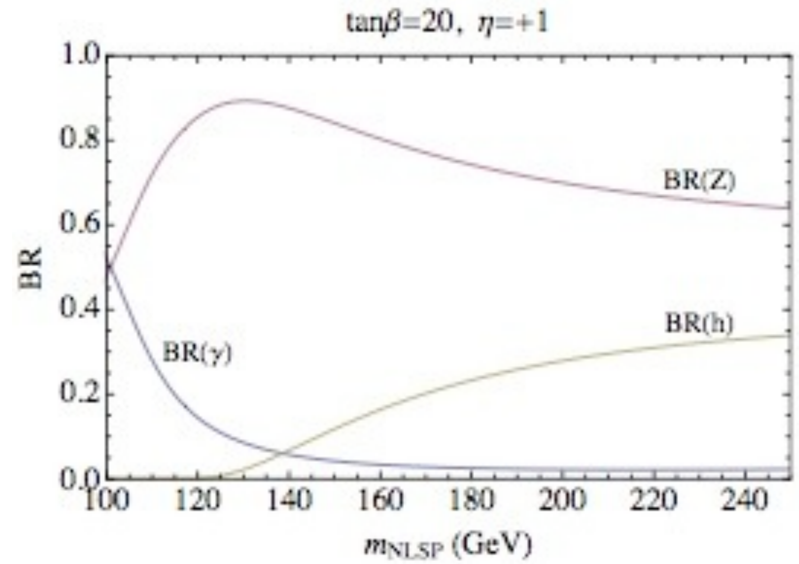
gravitino + γ *or* Z *or* h

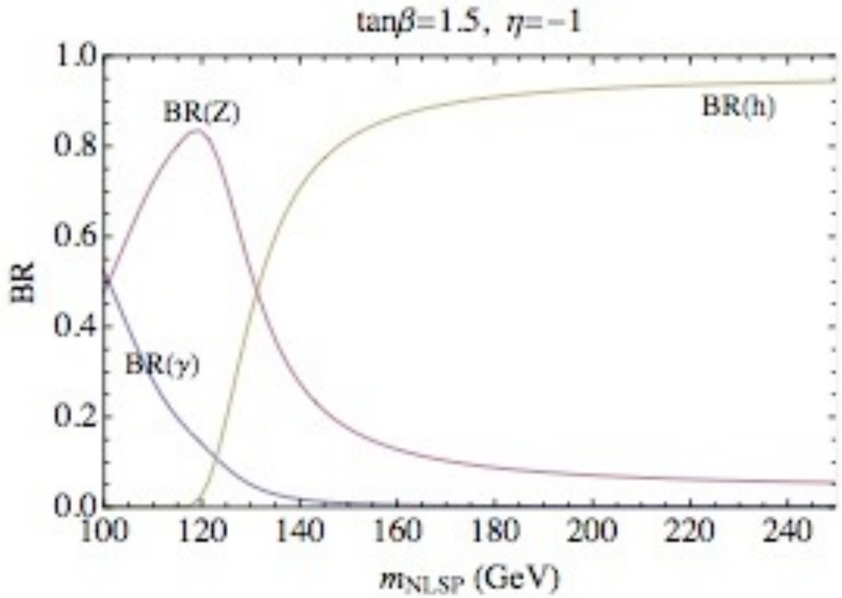
new source of Higgs

neutralino branching ratio:



(Matchev, Thomas '99)

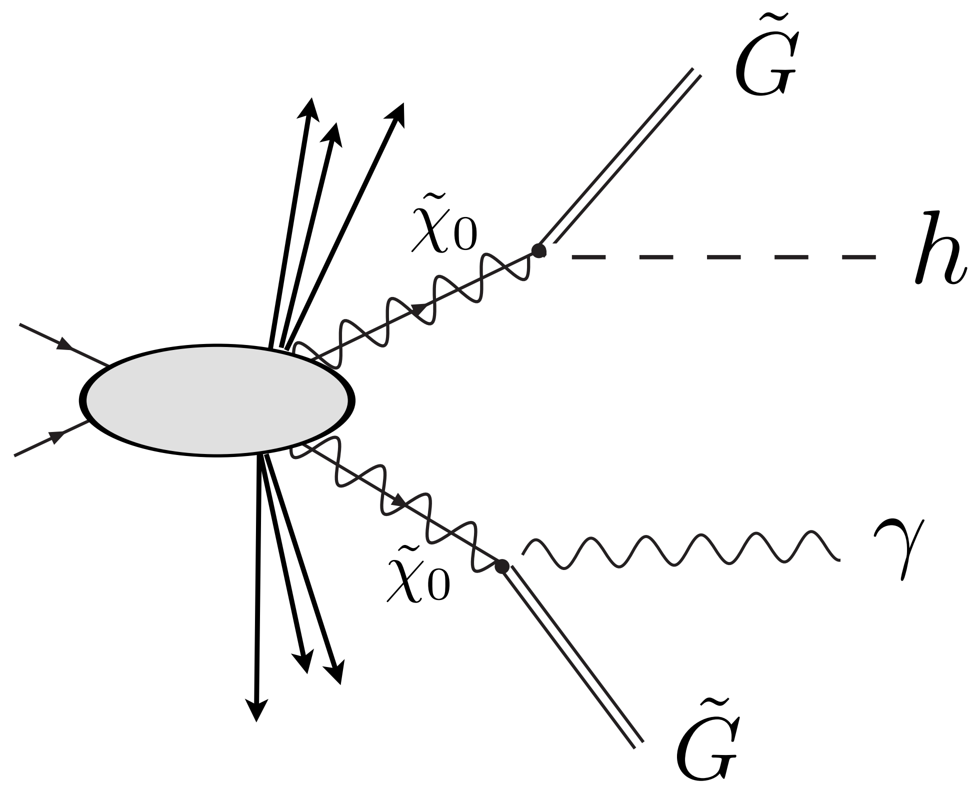




(Meade, Reece, Shih '09)

You can almost make a Higgs factory out of LHC

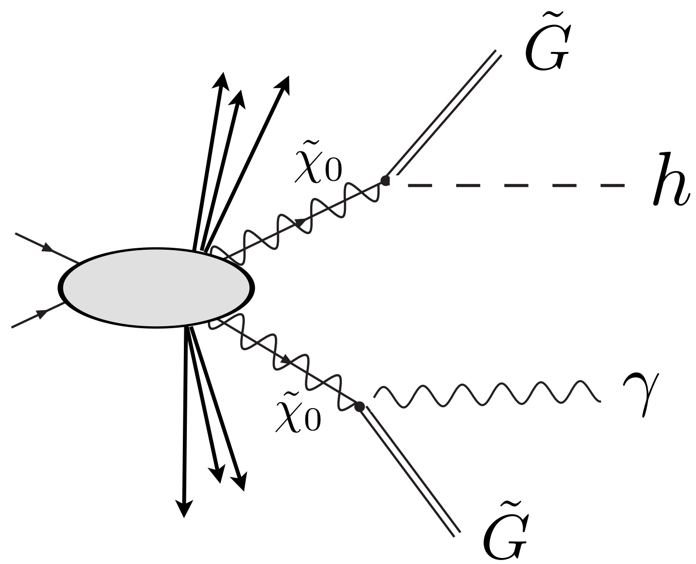
additional handles to get rid of SM backgrounds



1 isolated photon + large missing Et

MSSM Higgs source comparison

how we want to look for



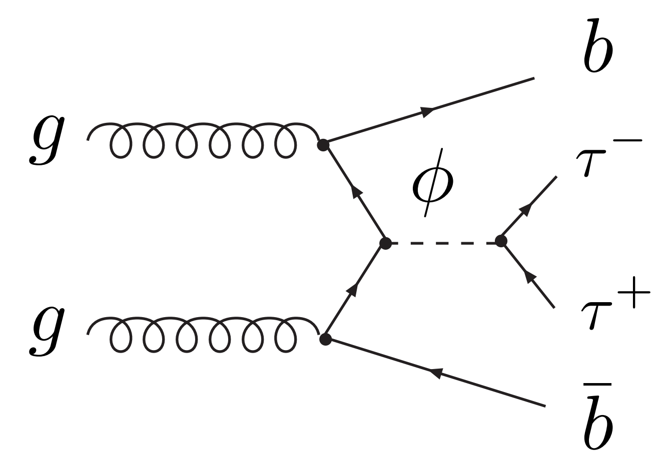
Higgses from sparticle decay

big cross-section (inclusive susy prod.)

all events have $\not{E}_T$

SM and BSM bkg

how people usually look for



Higgses produced in association with SM particles

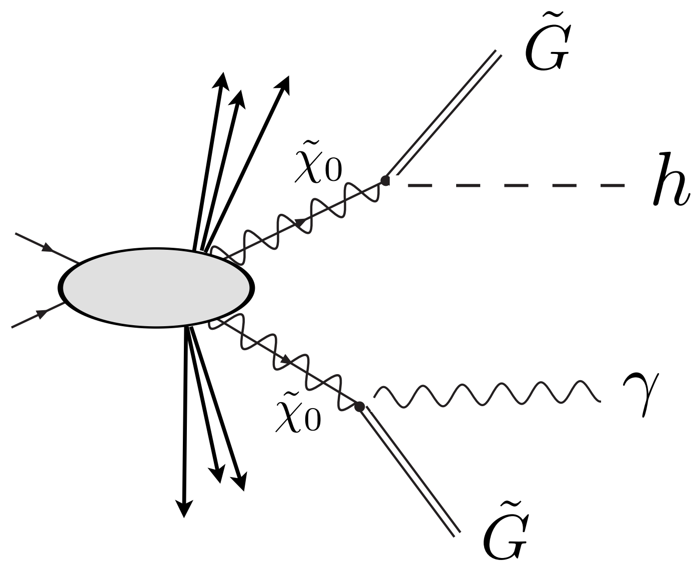
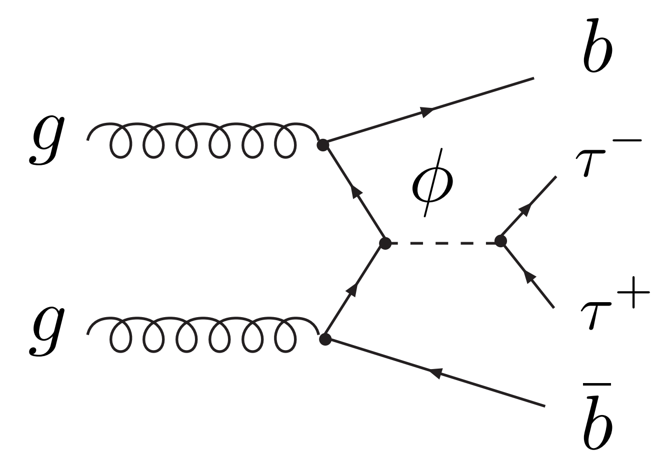
smaller cross-section (set by y_b)

no BSM $\not{E}_T$

only SM bkg

with so much is going on in inclusive SUSY events.. how can we do better than traditional search

MSSM Higgs source comparison

how we want to look for	how people usually look for
	

How we want to look for:

Higgses from sparticle decay

big cross-section (inclusive susy prod.)

all events have $\not{E}_T$

SM and BSM bkg

How people usually look for:

Higgses produced in association with SM particles

smaller cross-section (set by y_b)

no BSM $\not{E}_T$

only SM bkg

use Jet substructure

substructure

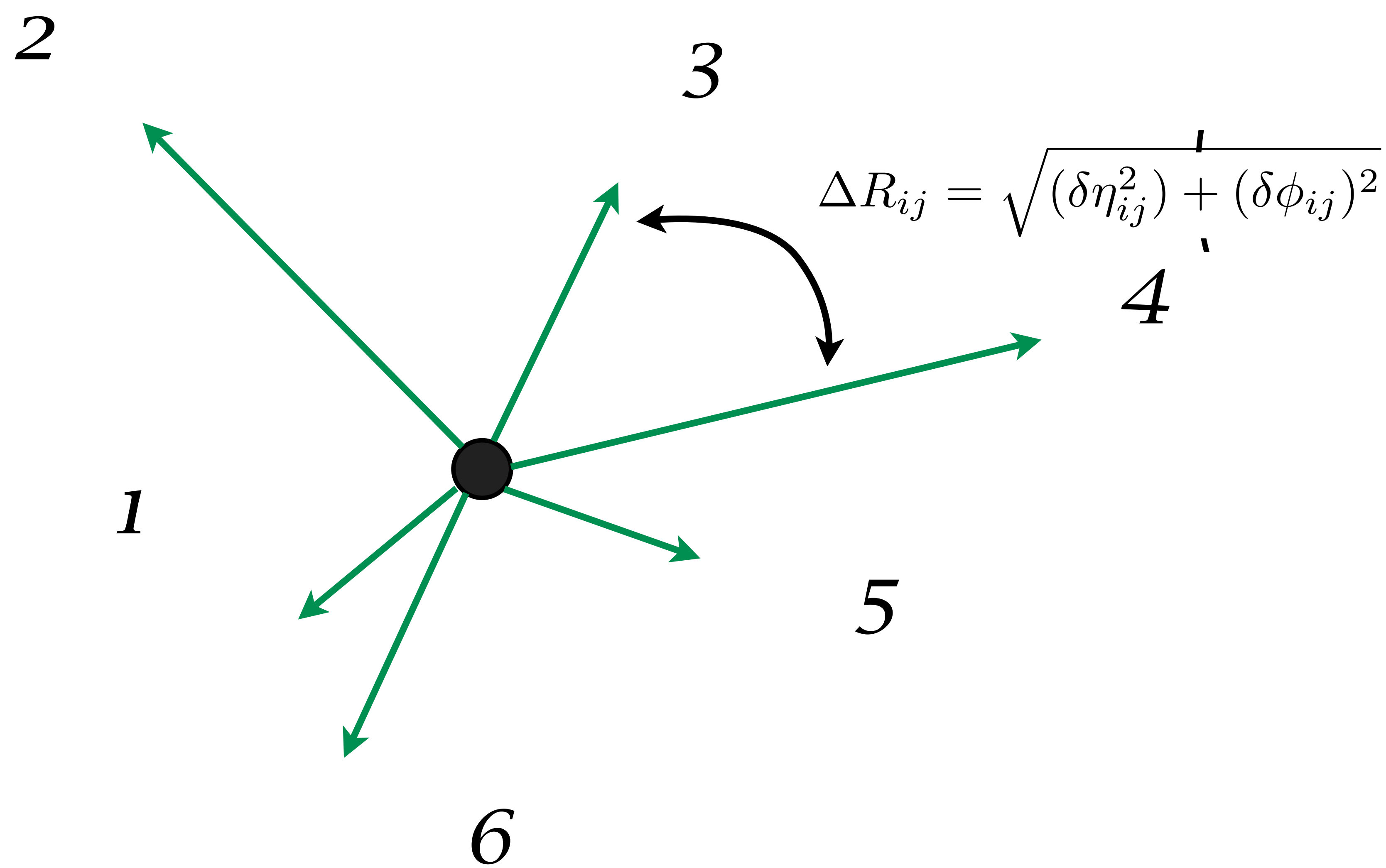
1. Briefly discuss clustering
2. Discuss simple substructure analysis
3. Describe our algorithm

First:

clustering

(I will talk about recombination scheme)

Recombination jet algorithm



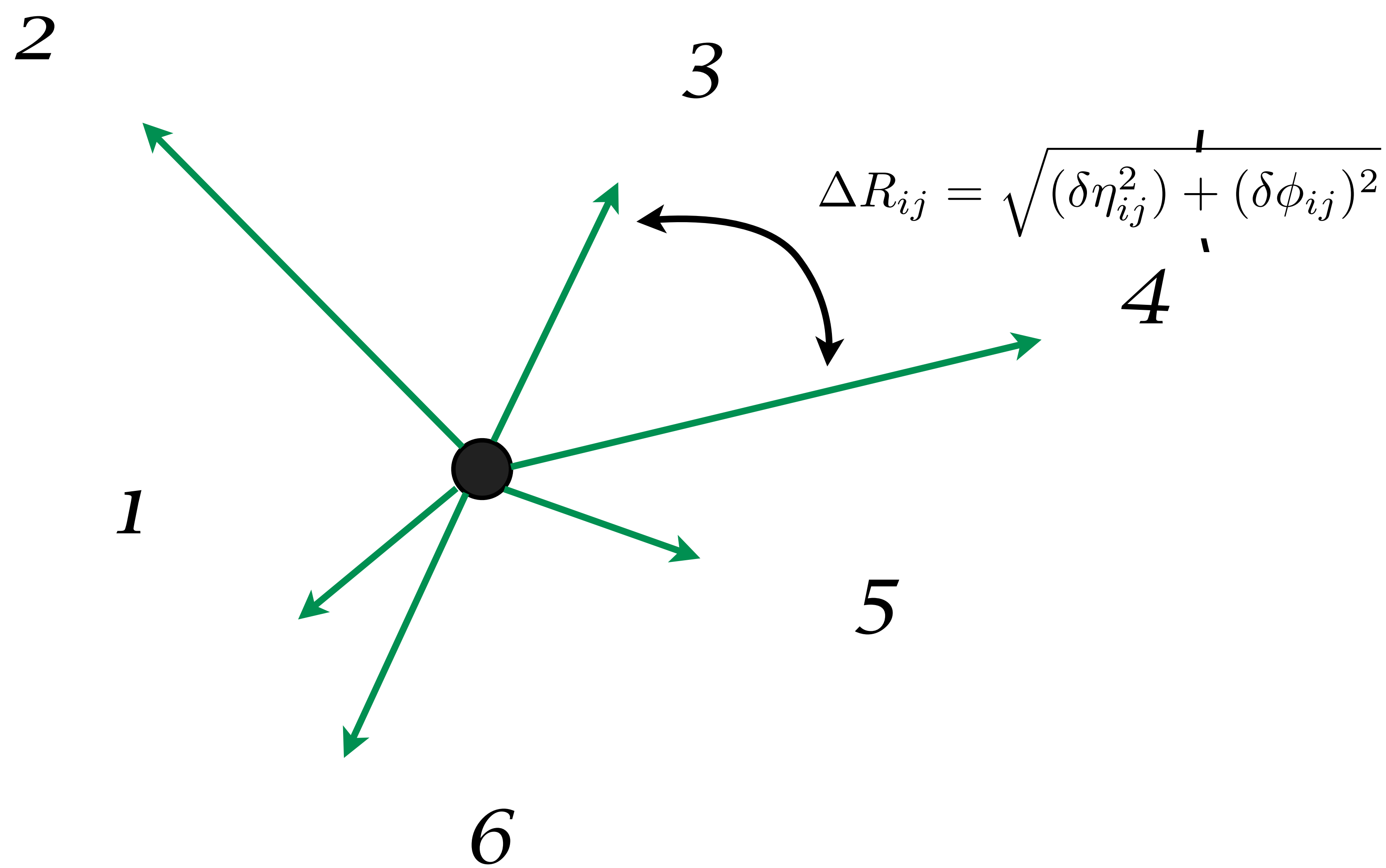
calculate

$$d_{ij} = \min\left(p_{ti}^{2n},\ p_{tj}^{2n}\right) \Delta R_{ij}^2 / R^2$$

$$d_i = p_{ti}^{2n}$$

$$n = \begin{cases} 1 & k_t \\ 0 & C/A \\ -1 & \text{anti } k_t \end{cases}$$

Recombination jet algorithm



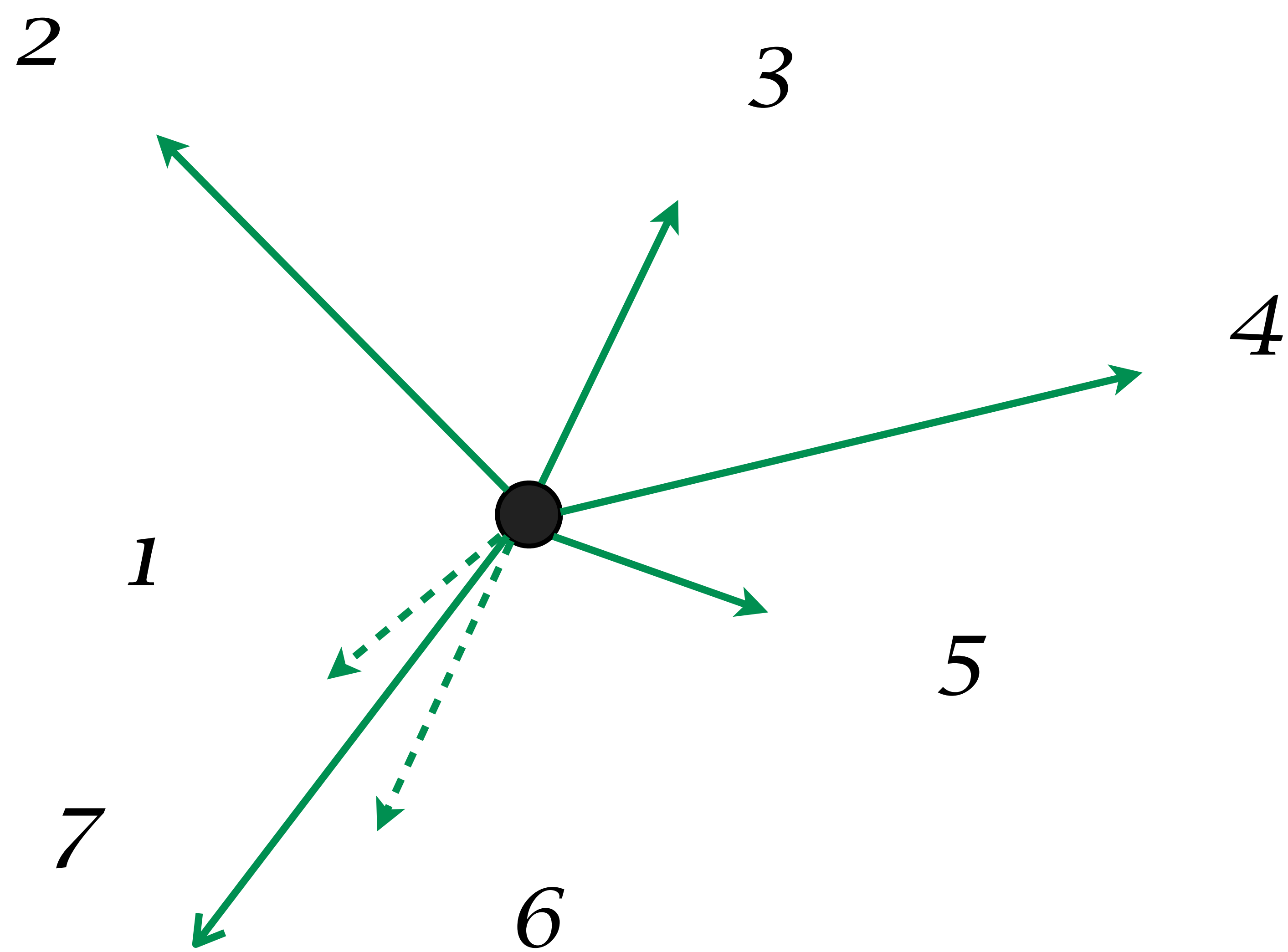
calculate

$$d_{ij} = \min\left(p_{ti}^{2n},\ p_{tj}^{2n}\right) \Delta R_{ij}^2 / R^2$$

$$d_i = p_{ti}^{2n}$$

find $\min\left(d_{ij}, d_i\right)$

Recombination jet algorithm

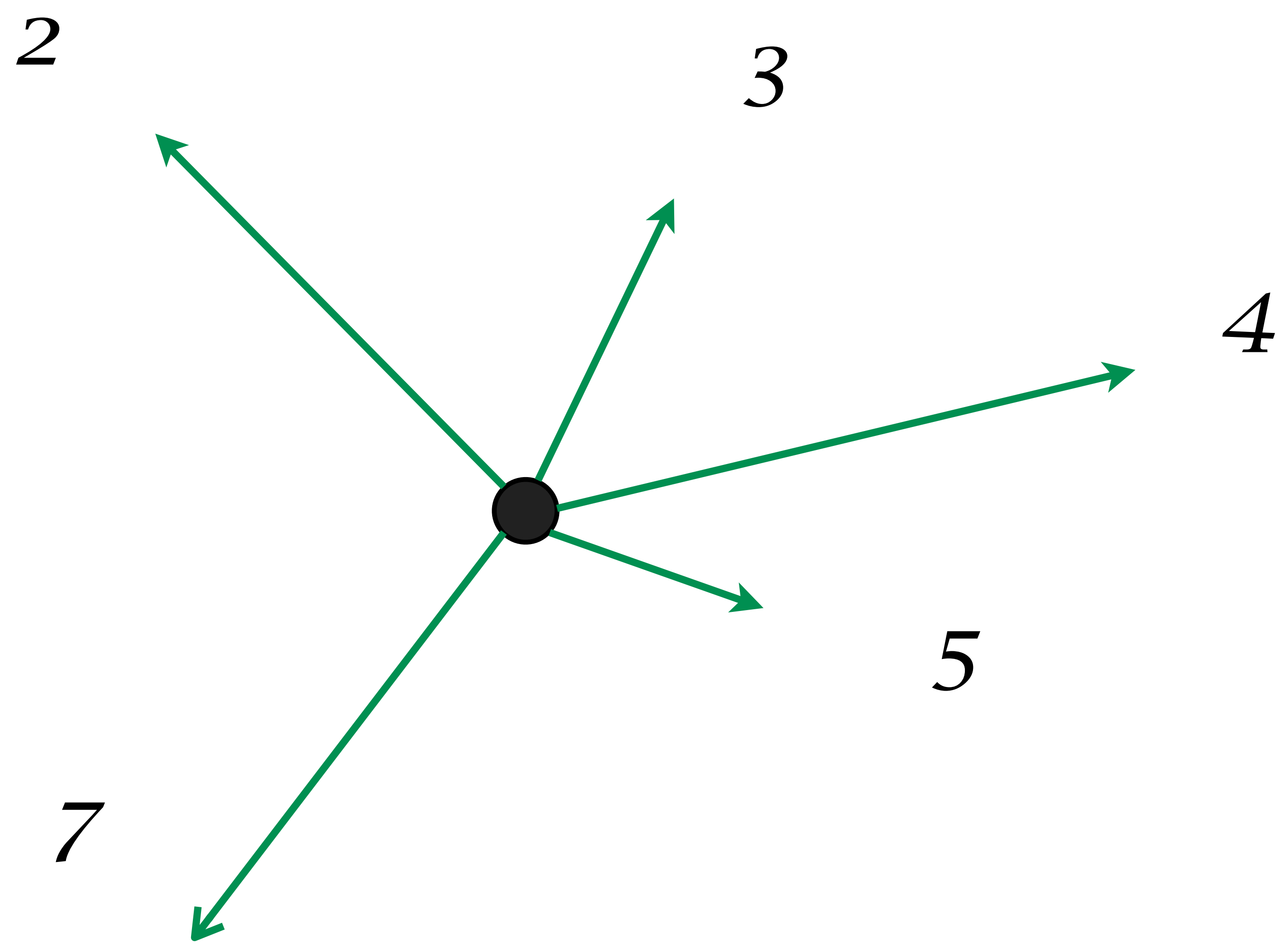


example:

combine 1 and 6 into 7
and remove 1 and 6

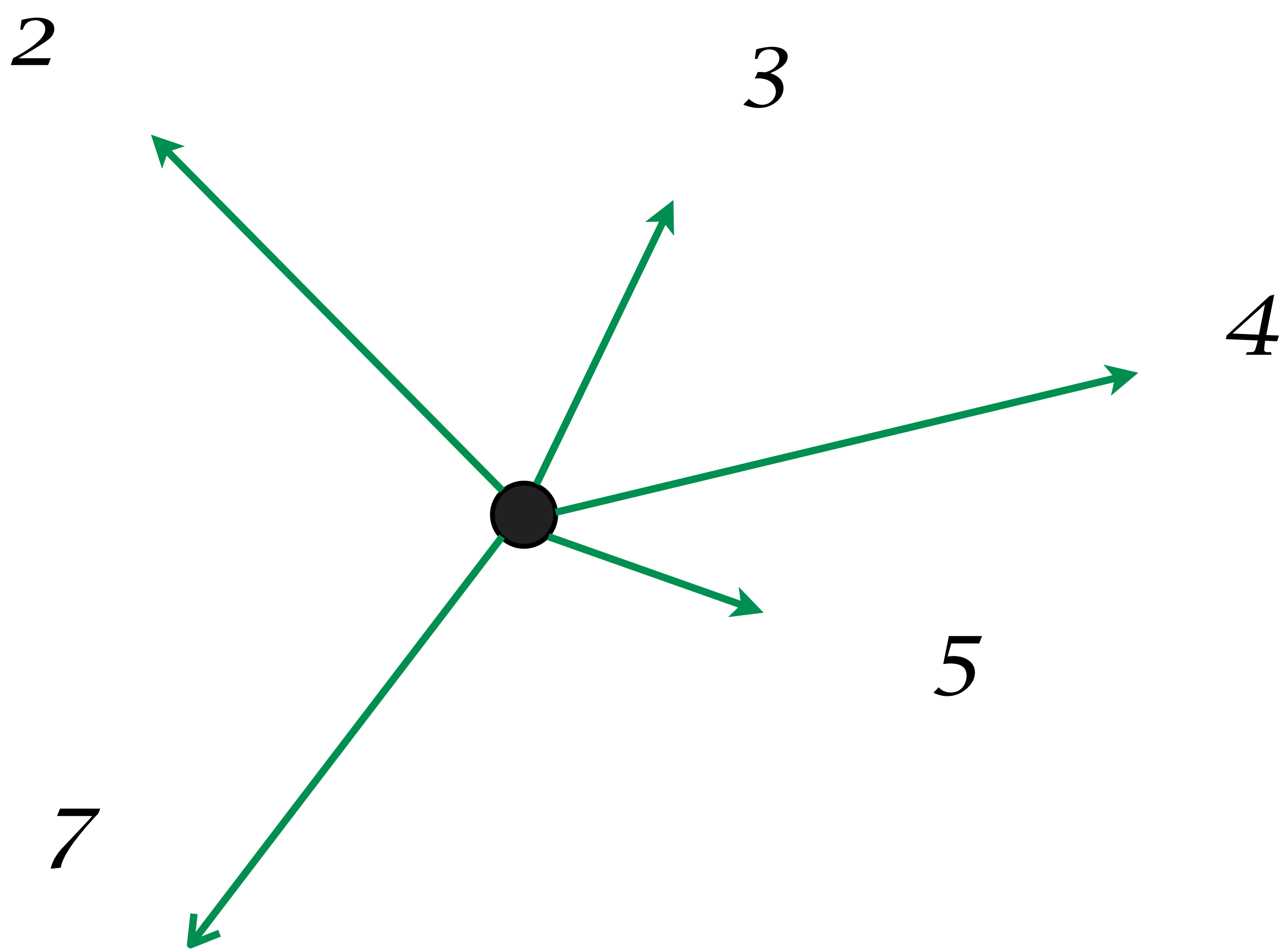
$$\min\left(d_{ij}, d_i\right) \;=\; d_{1\ 6}$$

Recombination jet algorithm



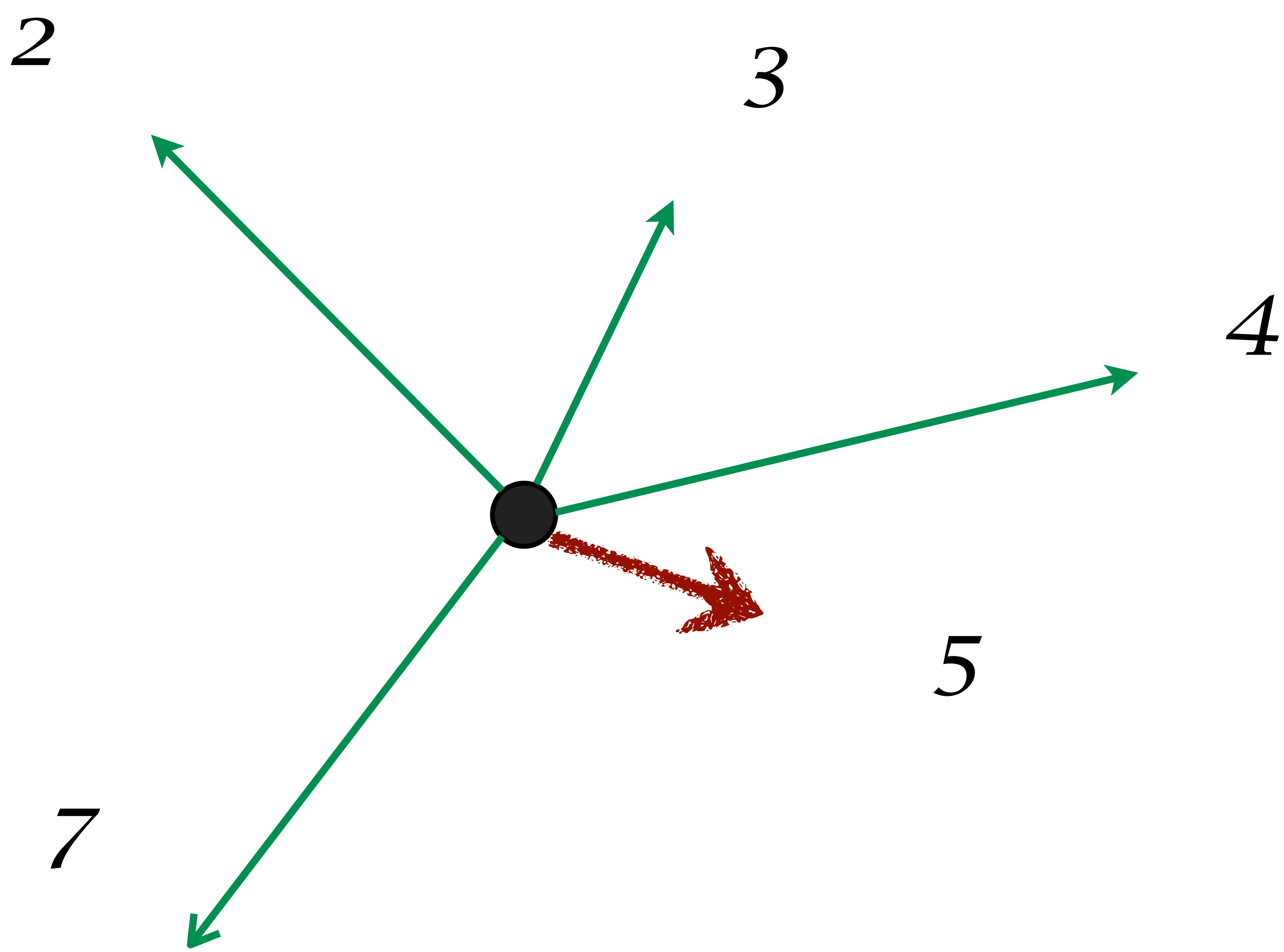
calculate again $\min\left(d_{ij}, d_i\right)$

Recombination jet algorithm



$$\min\left(d_{ij}, d_i\right) \;=\; d_5$$

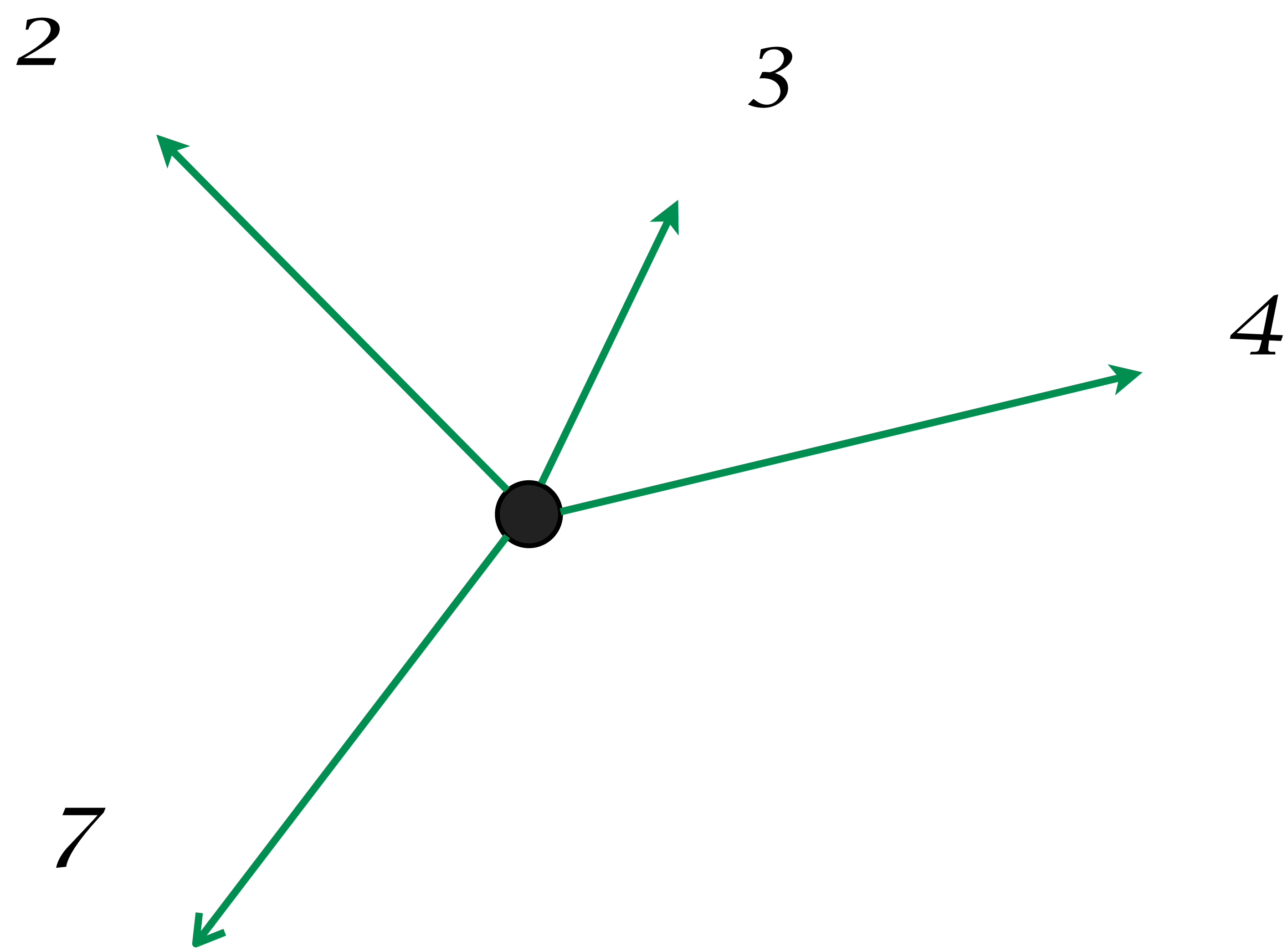
Recombination jet algorithm



$$\min\left(d_{ij}, d_i\right) \;=\; d_5$$

promote 5 to jet and remove

Recombination jet algorithm

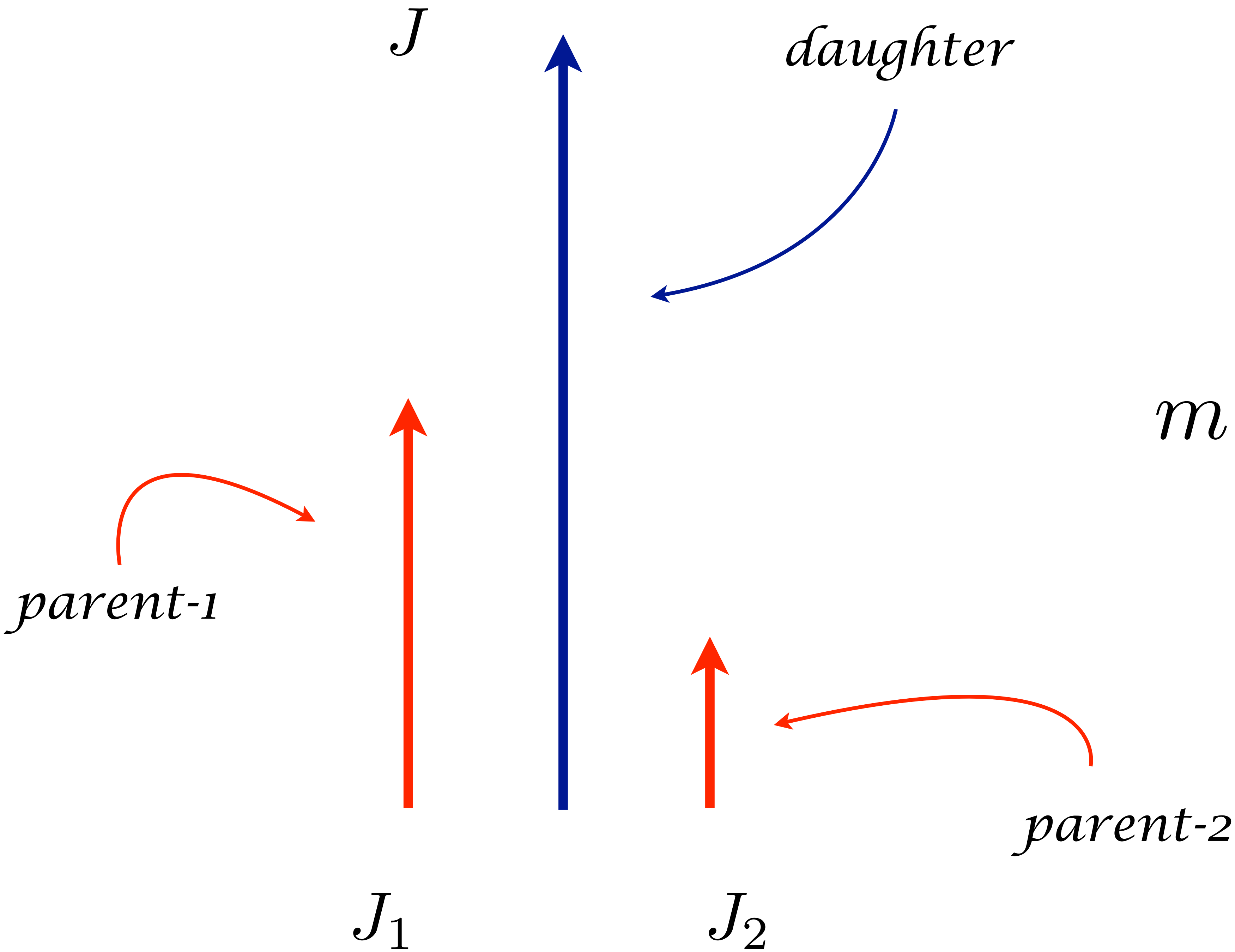


repeat until the list is empty

Next:

de-clustering and finding heavy particle threshold

break a C/A b-jet J into two parents
by undoing its last stage of clustering



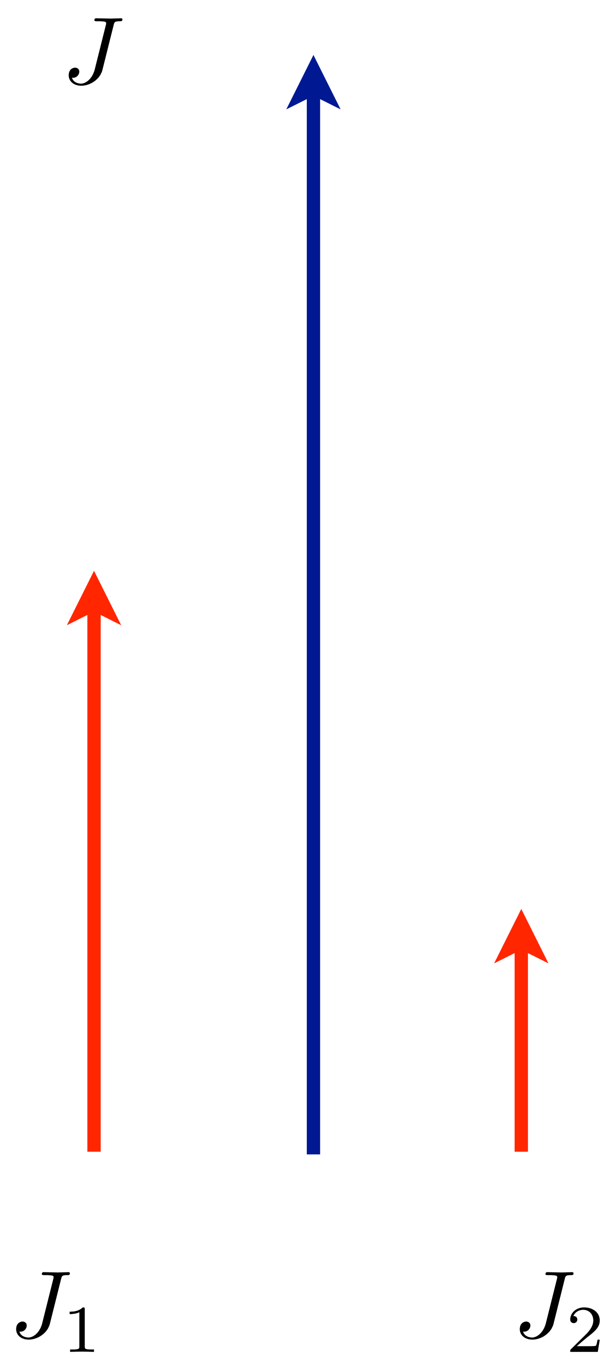
$$m_{J1} > m_{J2}$$

is J a suspect ?

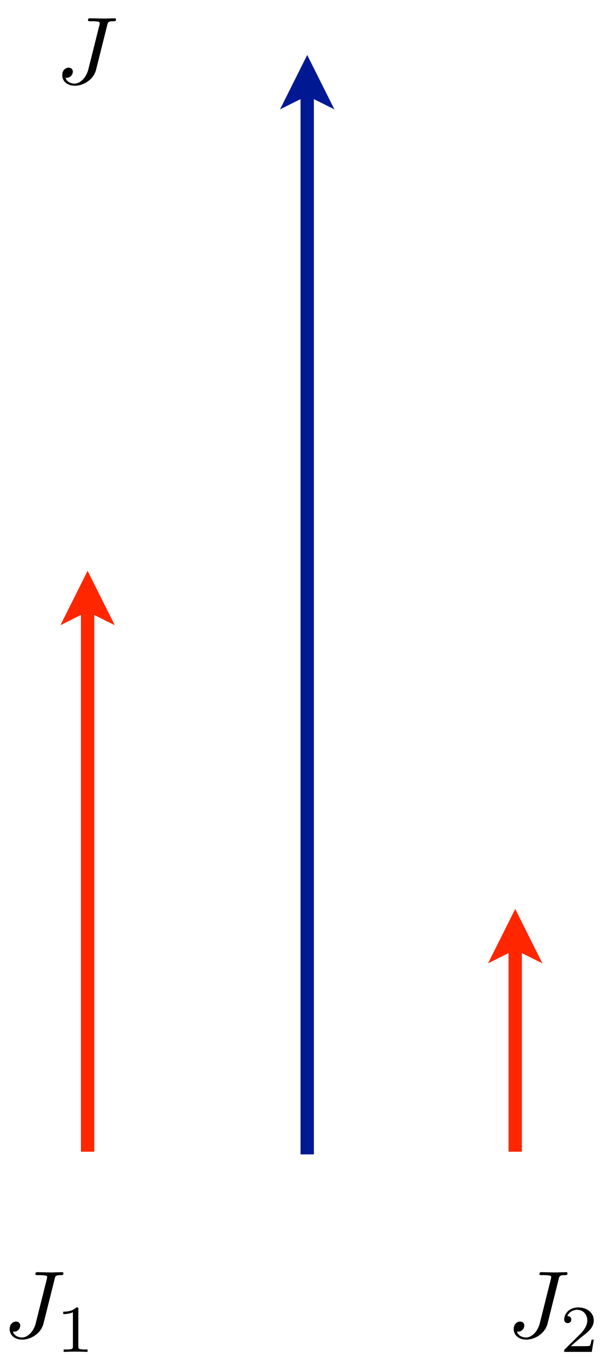
check if

$$m_{J1} < 0.68\, m_J$$

$$\min\left(p_{t1}^2, p_{t2}^2\right)\ \frac{\Delta R_{12}^2}{m_J^2}\ > (0.3)^2$$



is J a suspect ?



check if

$$m_{J1} < 0.68\, m_J$$

$$\min\left(p_{t1}^2, p_{t2}^2\right) \; \frac{\Delta R_{12}^2}{m_J^2} \; > (0.3)^2$$

if yes

J is at heavy particle threshold

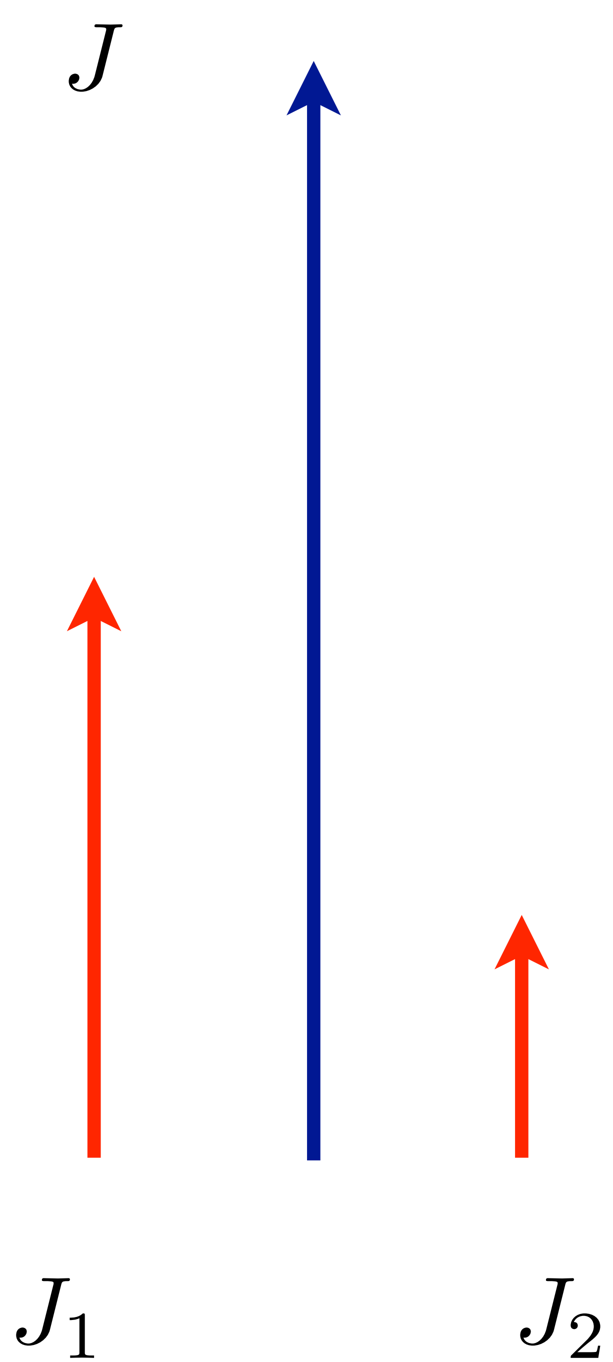
exit

is J a suspect ?

check if

$$m_{J1} < 0.68\, m_J$$

$$\min\left(p_{t1}^2, p_{t2}^2\right)\ \frac{\Delta R_{12}^2}{m_J^2}\ > (0.3)^2$$

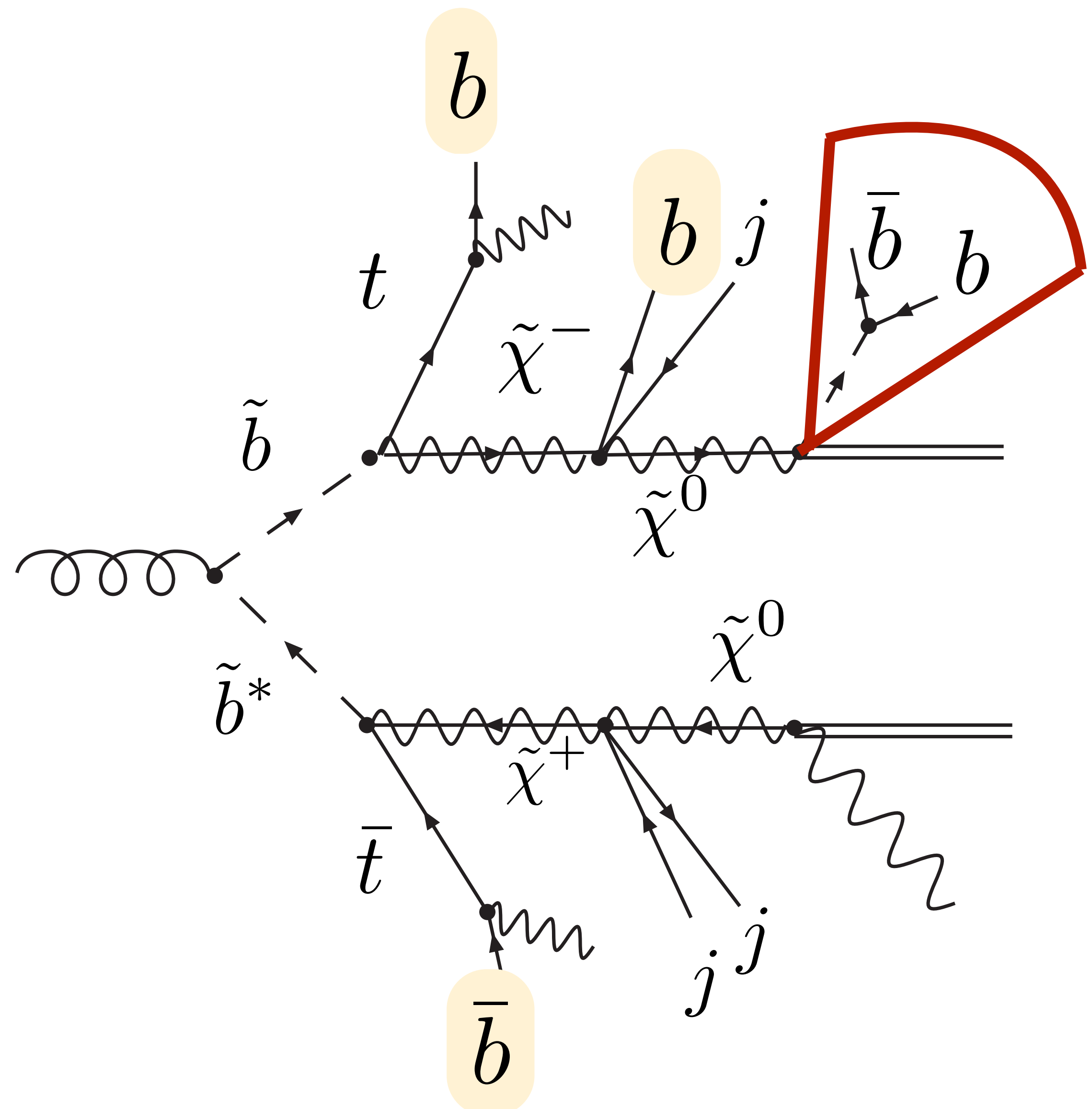


if no

replace J by J1

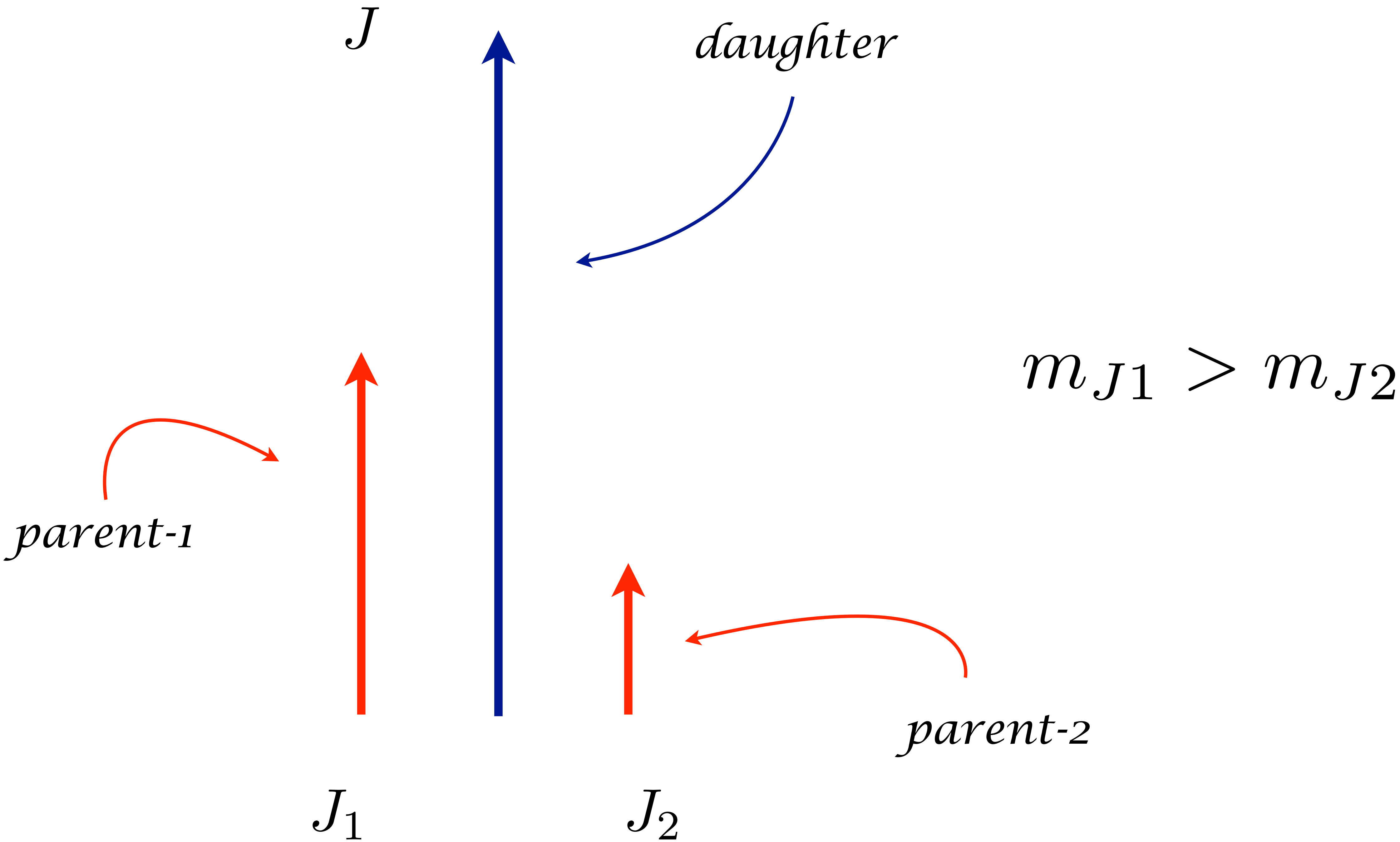
repeat

extra hard jet may enter the Higgs cone



simplest substructure algorithm does not work so well *break a C/A b-jet J into two parents by undoing its last stage of clustering*

Martin, Kribs, TR, Spannowsky



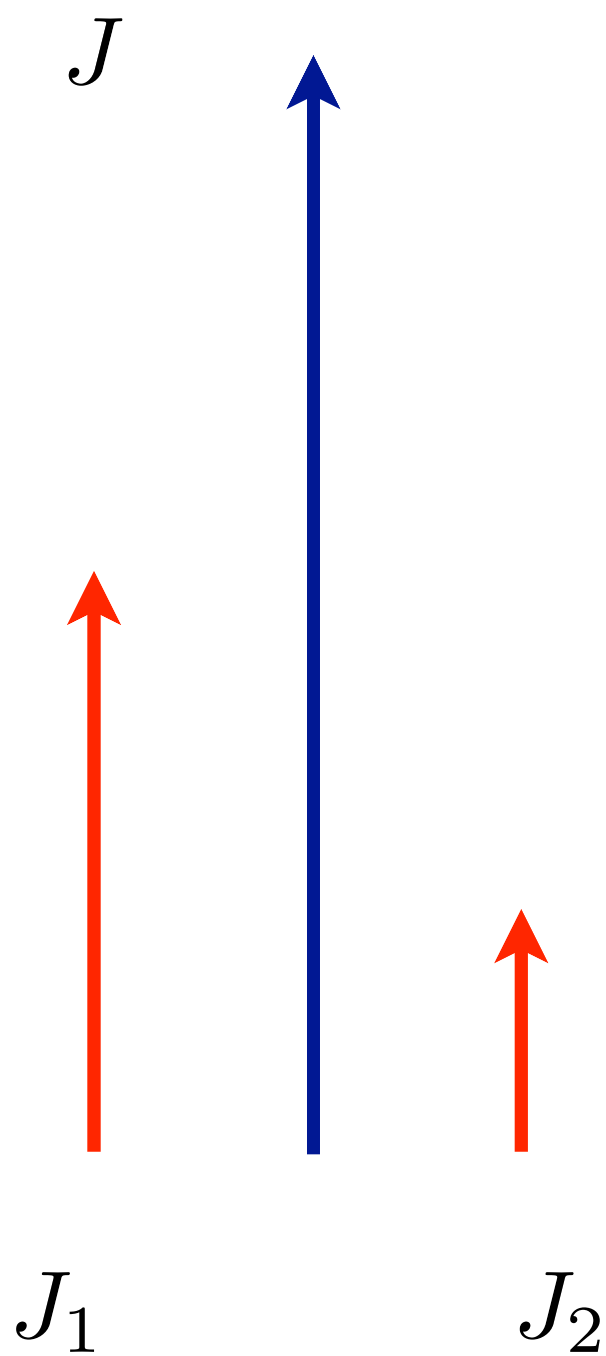
is J a suspect ?

Martin, Kribs,
TR, Spannowsky

check if

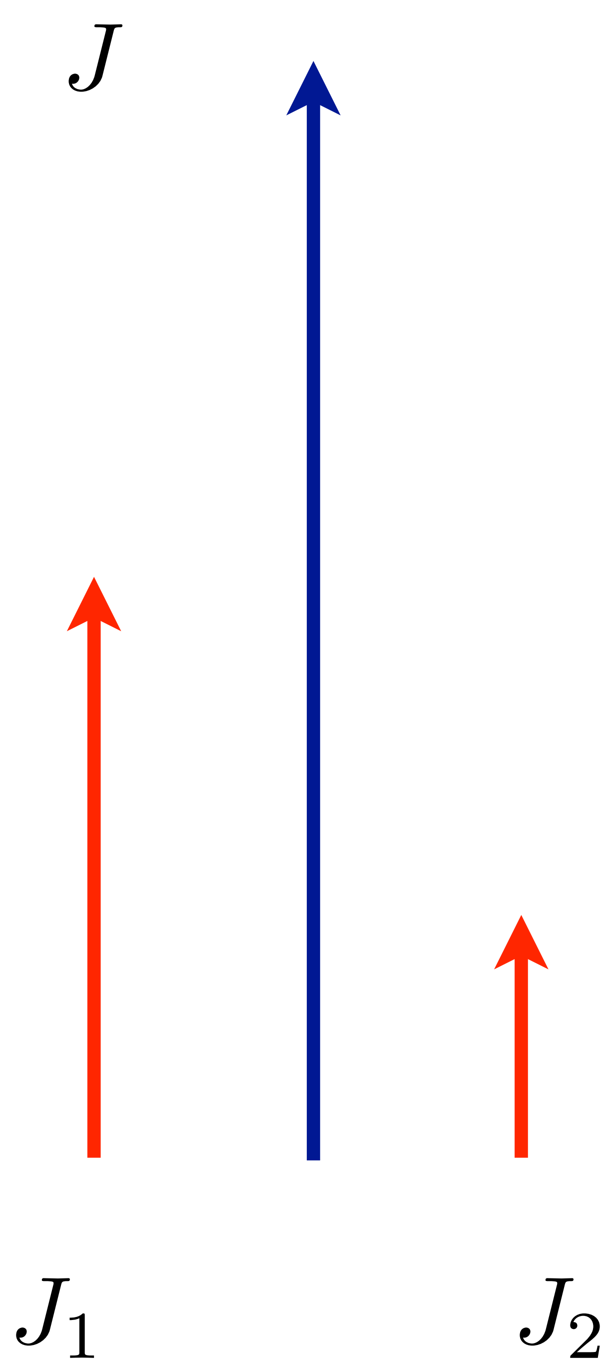
$$m_{J1} < 0.68\, m_J$$

$$\min\left(p_{t1}^2, p_{t2}^2\right)\ \frac{\Delta R_{12}^2}{m_J^2}\ > (0.3)^2$$



is J a suspect ?

Martin, Kribs, TR, Spannowsky



check if

$$m_{J1} < 0.68\, m_J$$

$$\min\left(p_{t1}^2, p_{t2}^2\right)\; \frac{\Delta R_{12}^2}{m_J^2} \;>\; (0.3)^2$$

if yes

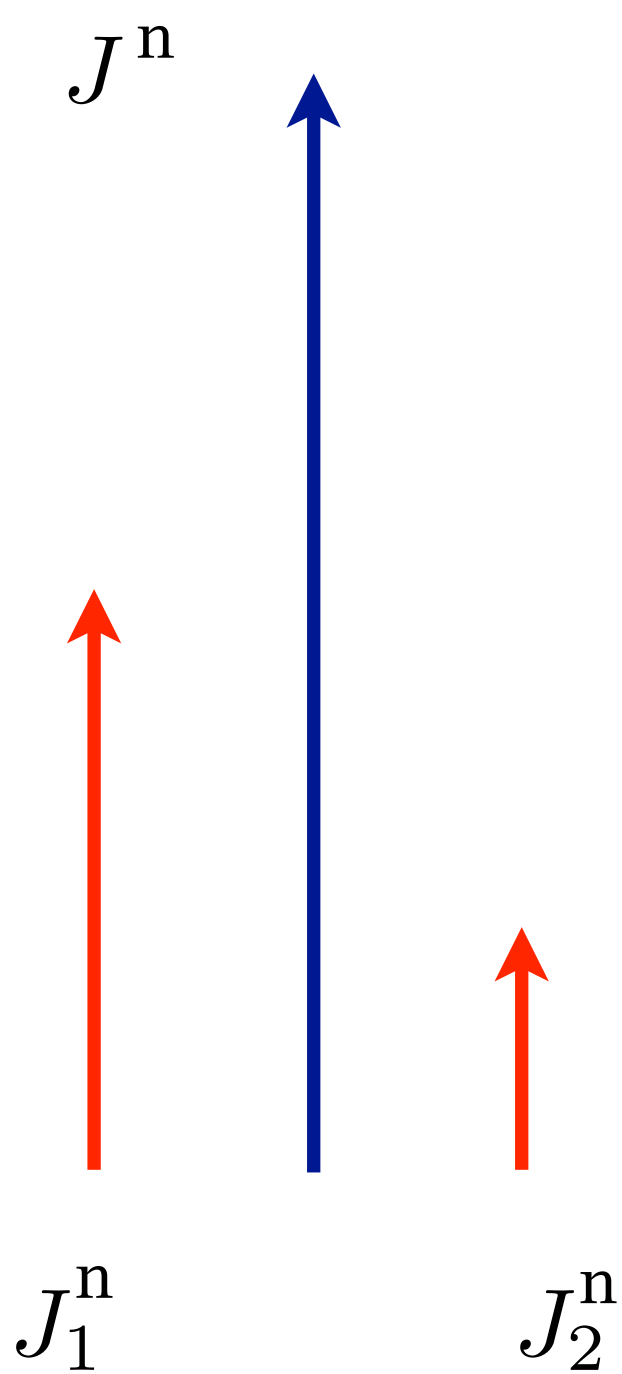
record $Z = \dfrac{\min\left(p_{tJ1}^2,\; p_{tJ2}^2\right)}{p_{tj}^2}\, \Delta R_{J1J2}$

replace J by J1

repeat as long as J has parents

is J a suspect ?

Martin, Kribs,
TR, Spannowsky



J^n is a Higgs candidate

if

z is the largest

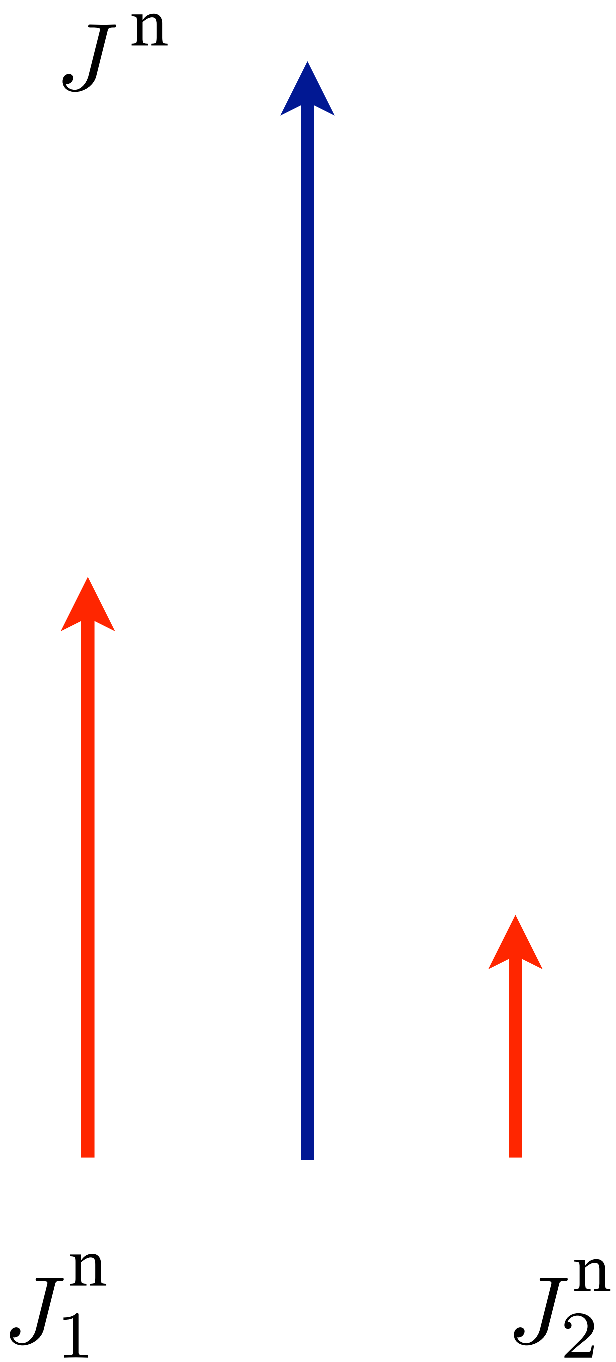
and

both parents are b-tagged

(Butterworth et al 0802.2470)

Filtering

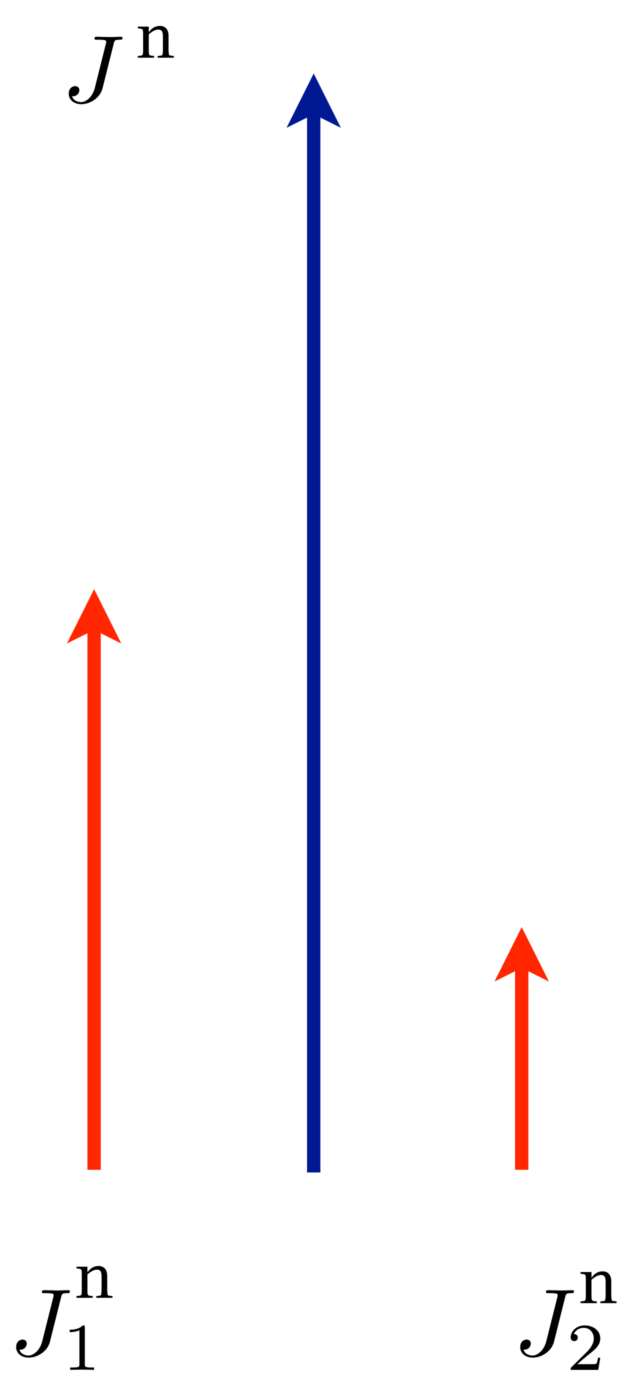
J^{n} *is a Higgs candidate*



(Butterworth et al
0802.2470)

Filtering

J^{n} *is a Higgs candidate*



record $\Delta R_{J_1^n, J_2^n}$

(Butterworth et al
0802.2470)

Filtering

J^{n} *is a Higgs candidate*

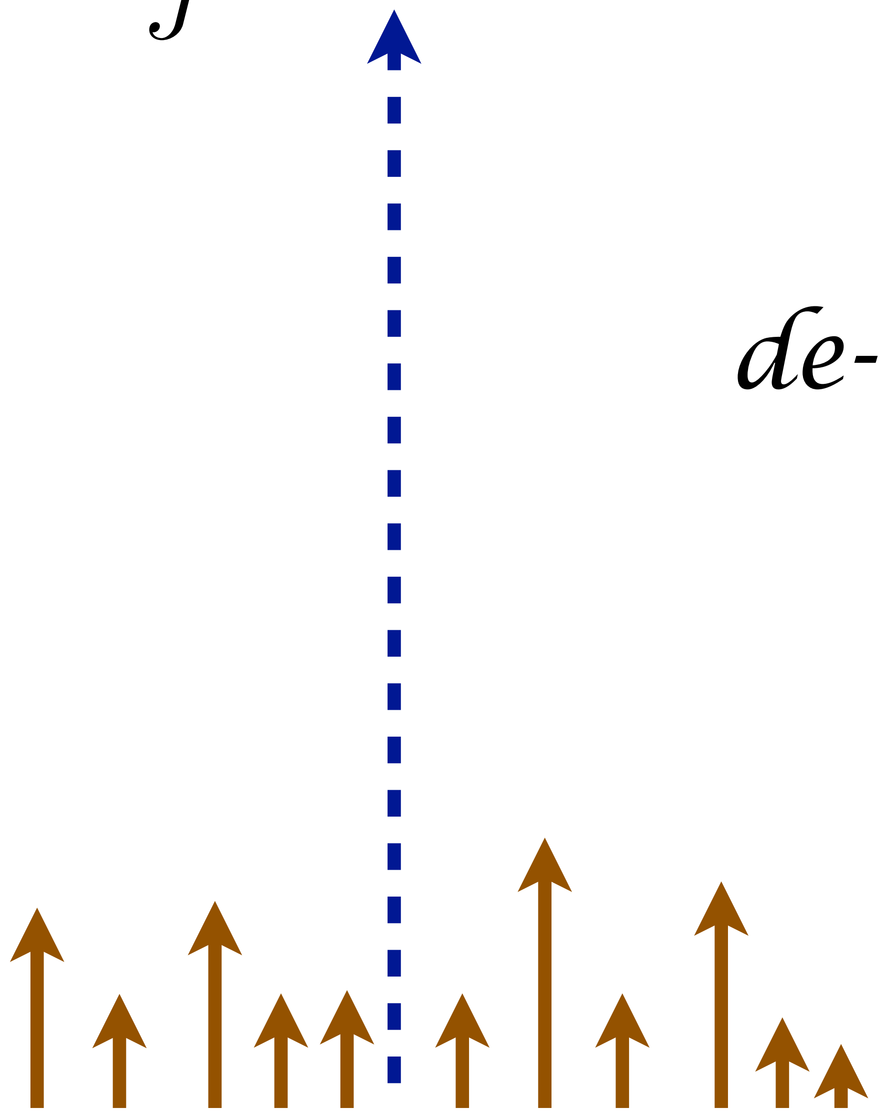
J^{n}

record $\Delta R_{J_1^n, J_2^n}$

(Butterworth et al 0802.2470)

Filtering

J^n is a Higgs candidate



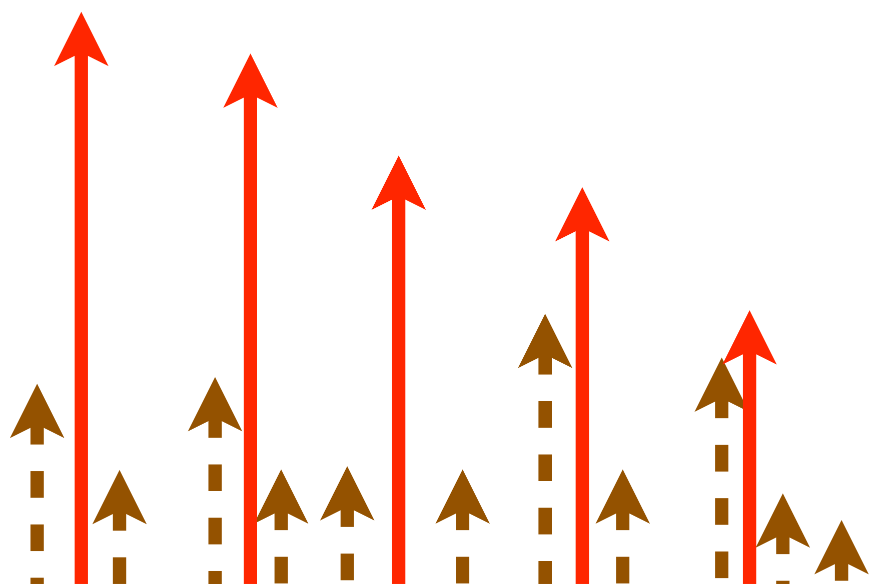
de-cluster J^n completely

(Butterworth et al 0802.2470)

Filtering

re-cluster using

$$R_{\rm filt} = \min\left(\frac{\Delta R_{J_1^n, J_2^n}}{2},\ 0.3\right)$$

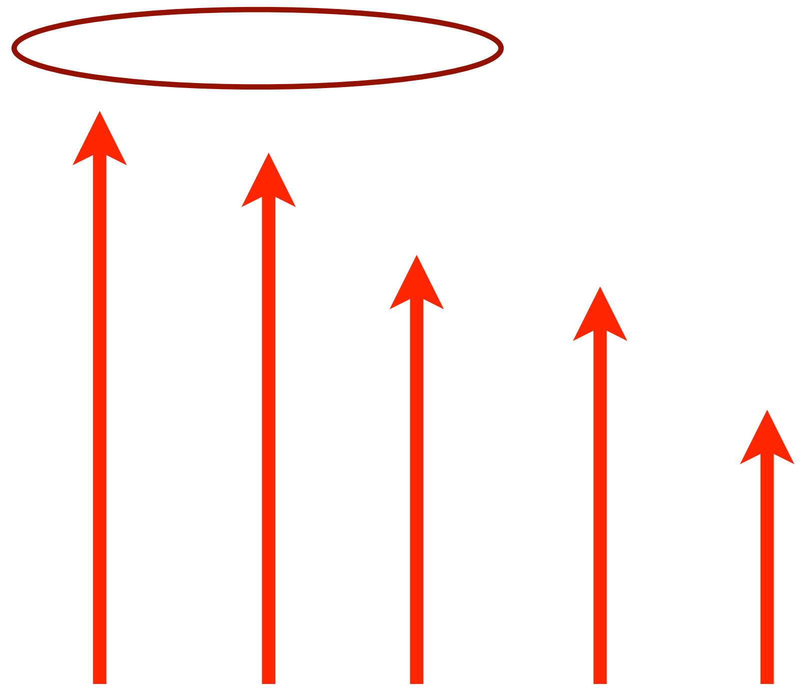


Pt order the jets

(Butterworth et al 0802.2470)

Filtering

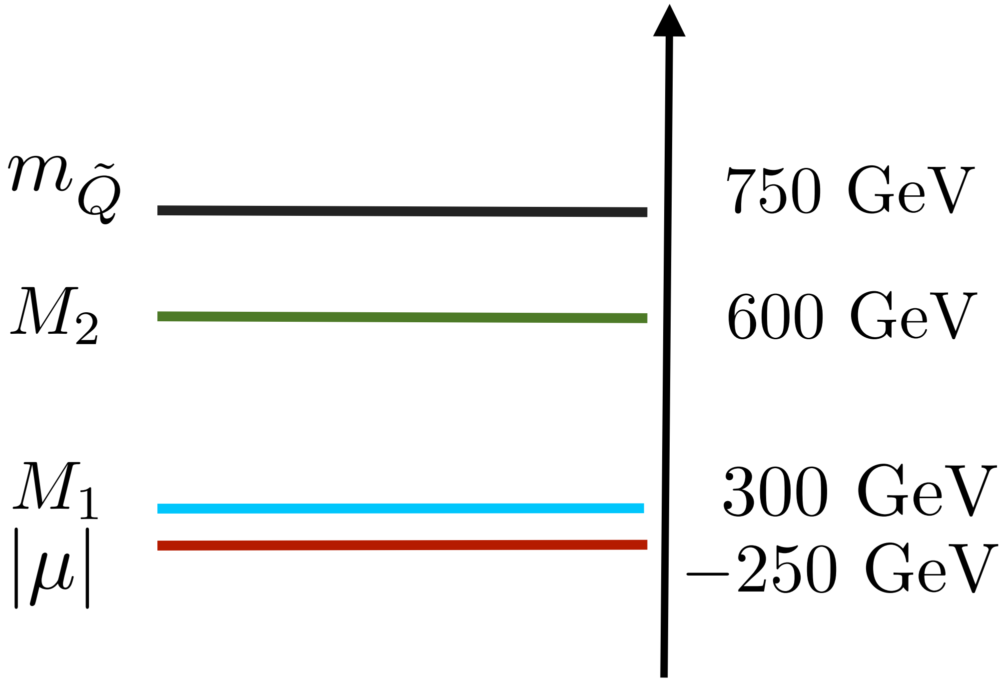
- *retain only three hardest component and combine. call it Higgs Jet*



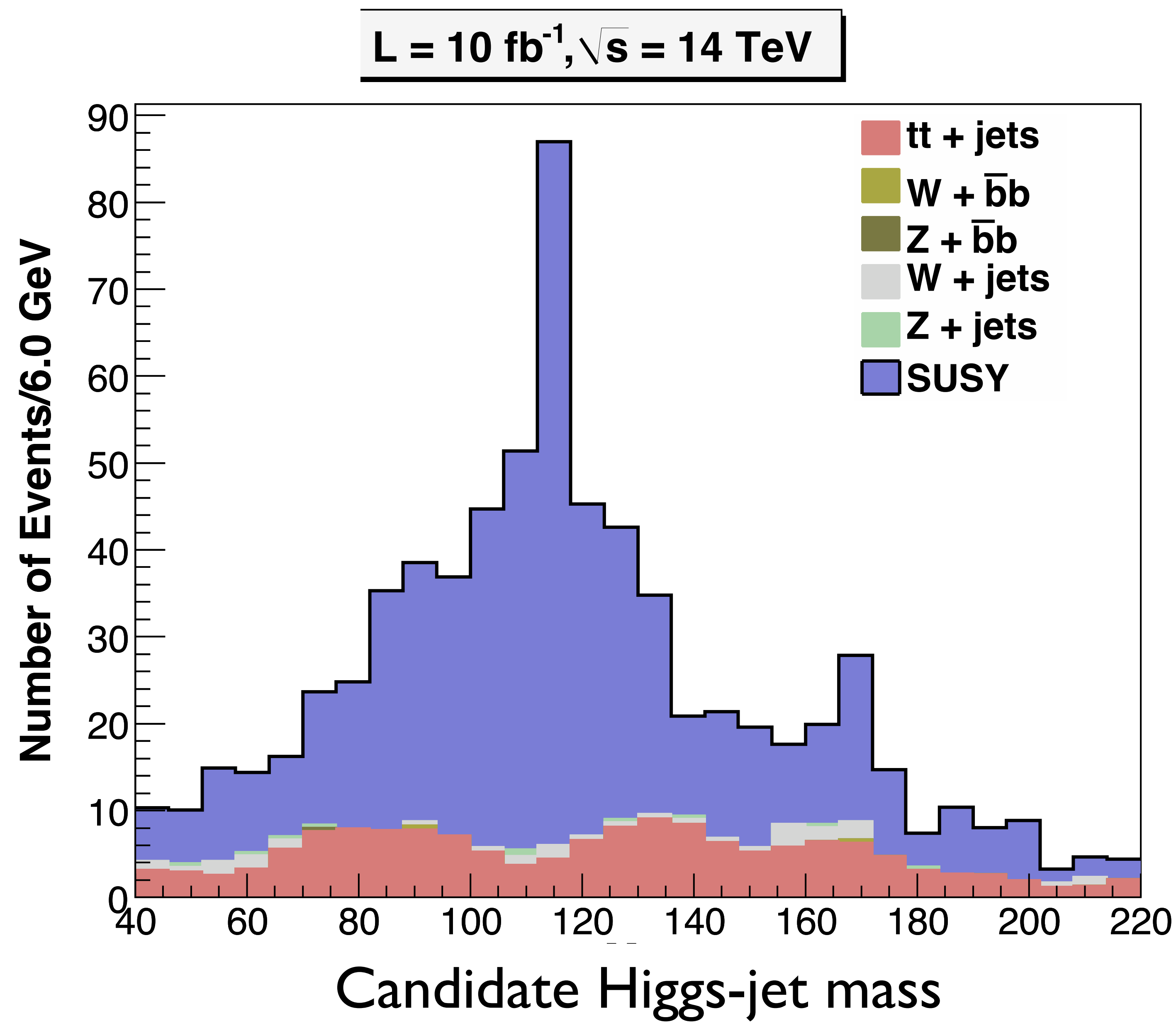
Results

For example: take the spectrum

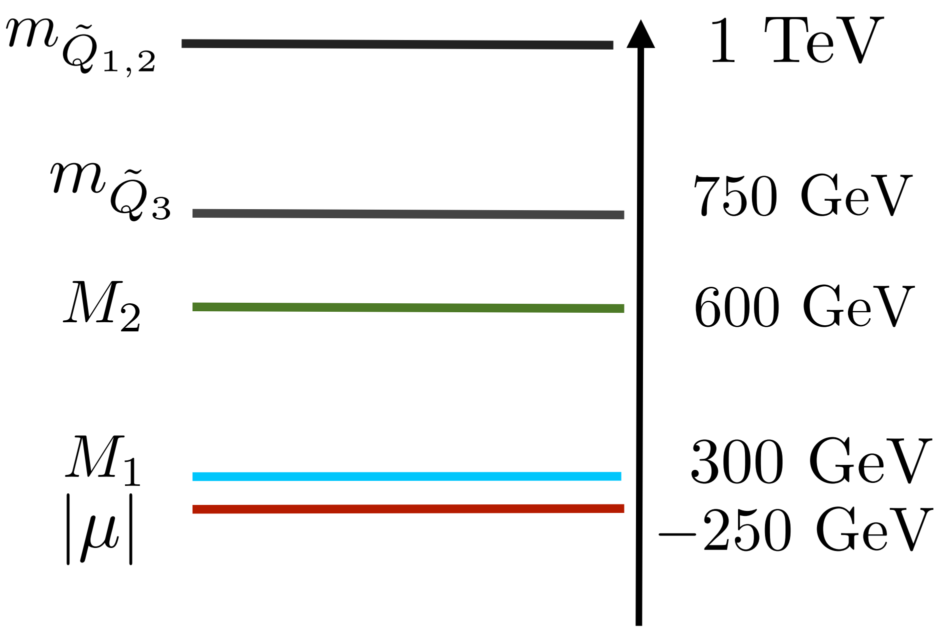
substructure + $\not{E}_T > 100$ GeV, $p_{T\gamma} > 80$ GeV



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

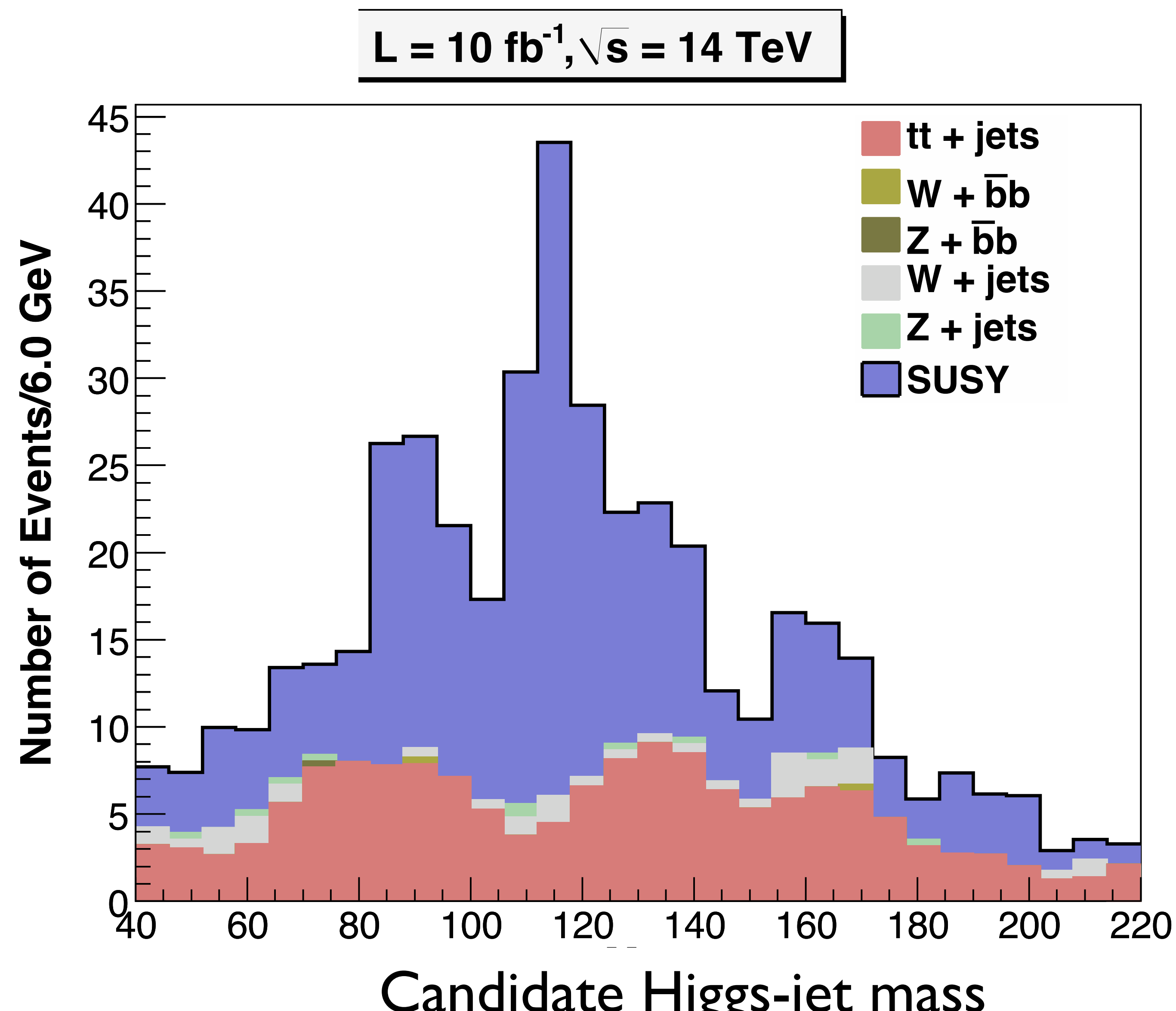


For example: this one is harder

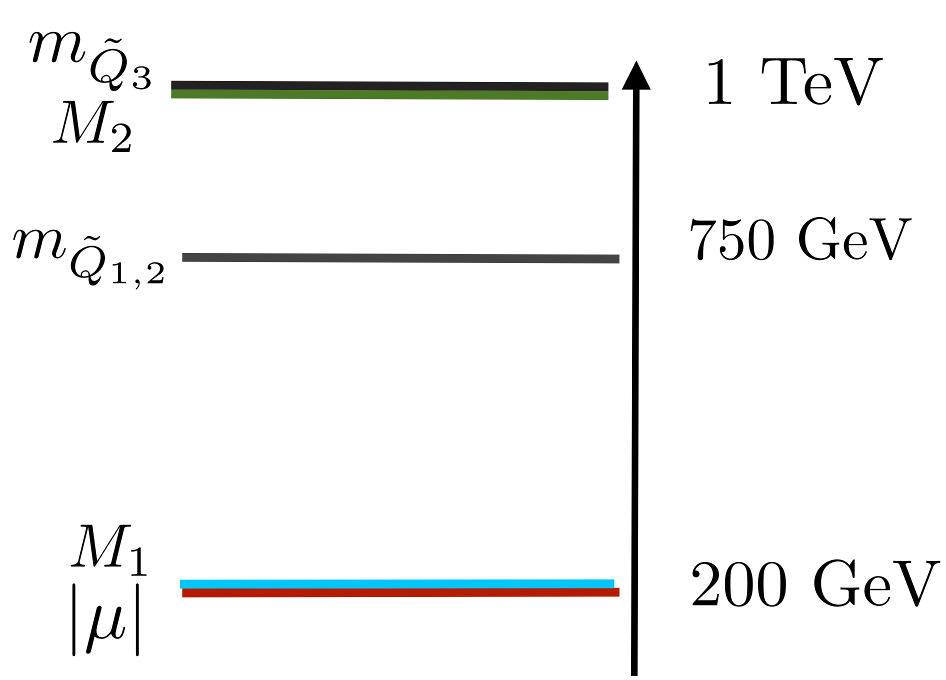


$$BR(\tilde{\chi}^0 \rightarrow \tilde{G} + \gamma) \sim 43\%$$
$$BR(\tilde{\chi}^0 \rightarrow \tilde{G} + Z^0) \sim 29\%$$
$$BR(\tilde{\chi}^0 \rightarrow \tilde{G} + h) \sim 28\%$$

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

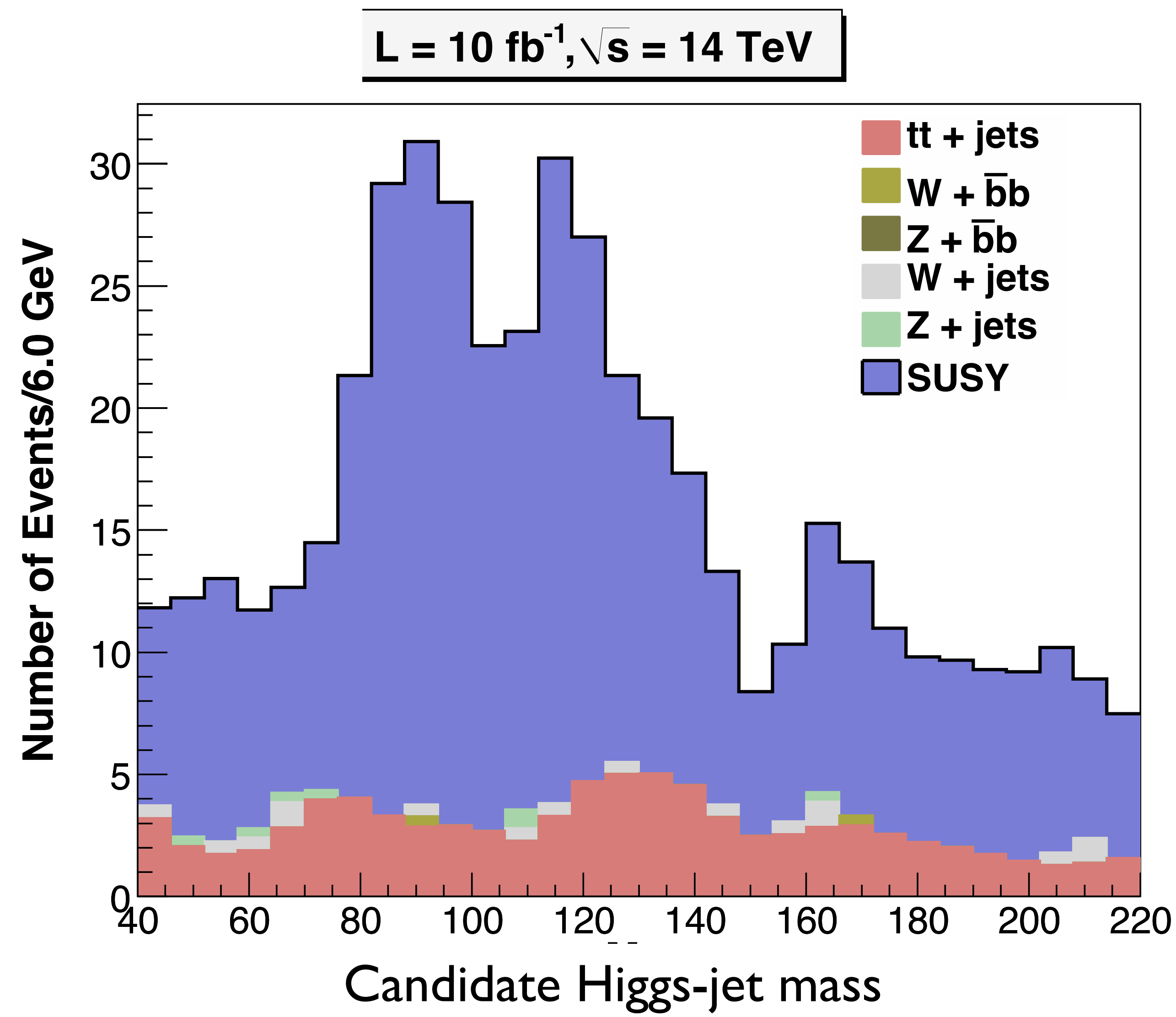


For example: this one is almost impossible

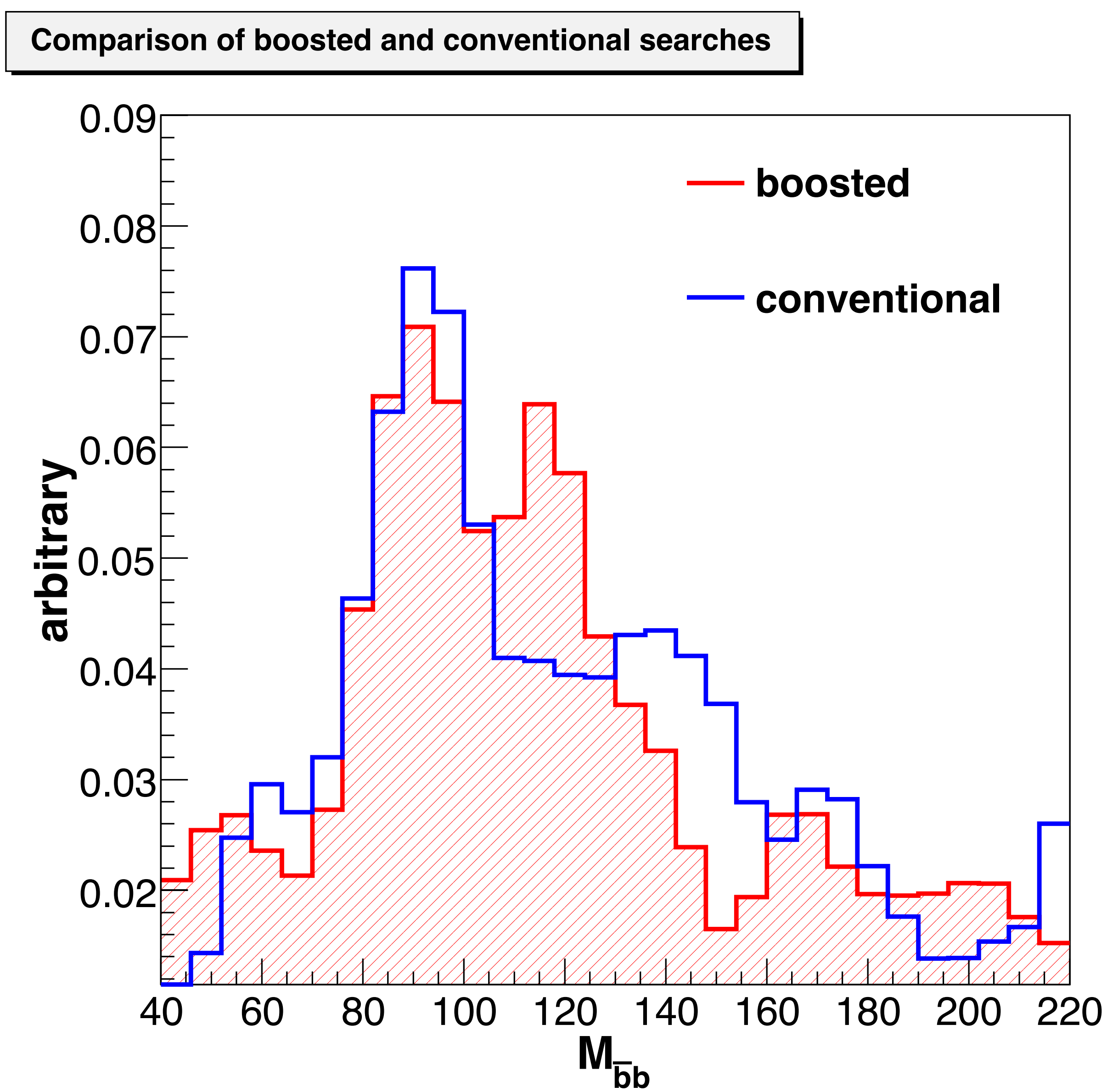


substructure + $\not{E}_T > 100$ GeV, $p_{T\gamma} > 80$ GeV

$$\begin{aligned} \mathrm{BR}(\tilde{\chi}^0 \to \gamma + \tilde{G}) &\sim 82.6\% \\ \mathrm{BR}(\tilde{\chi}^0 \to Z + \tilde{G}) &\sim 16\% \\ \mathrm{BR}(\tilde{\chi}^0 \to h + \tilde{G}) &\sim 1.3\% \end{aligned}$$



boosted analysis finds Higgs peak even when conventional search completely fails



Higgses from other BSM scenarios

work in progress

Higgses from other BSM scenarios

Example: MSSM with neutralino LSP

work in progress

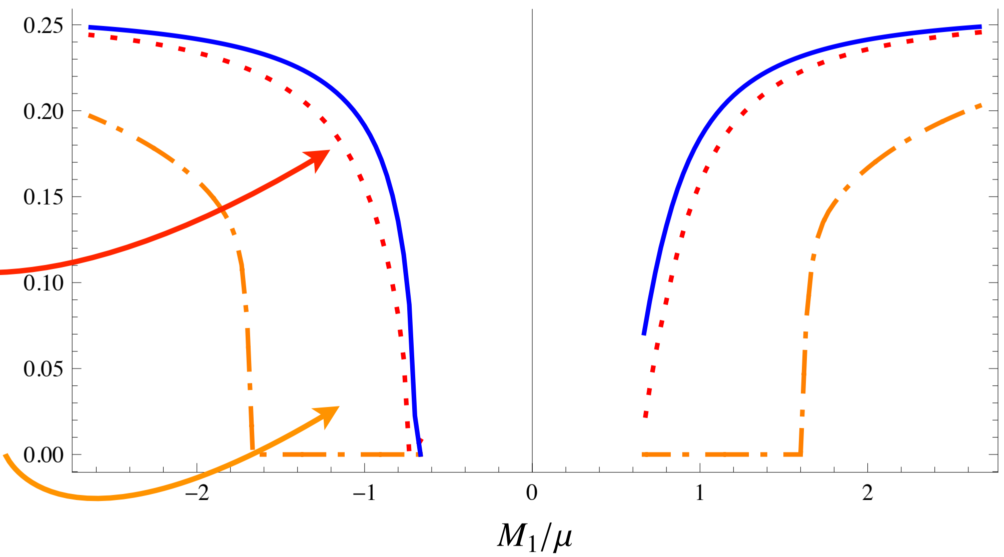
should appear in 1 week

Results: MSSM with neutralino LSP

$\chi_4 \to h + \ldots$

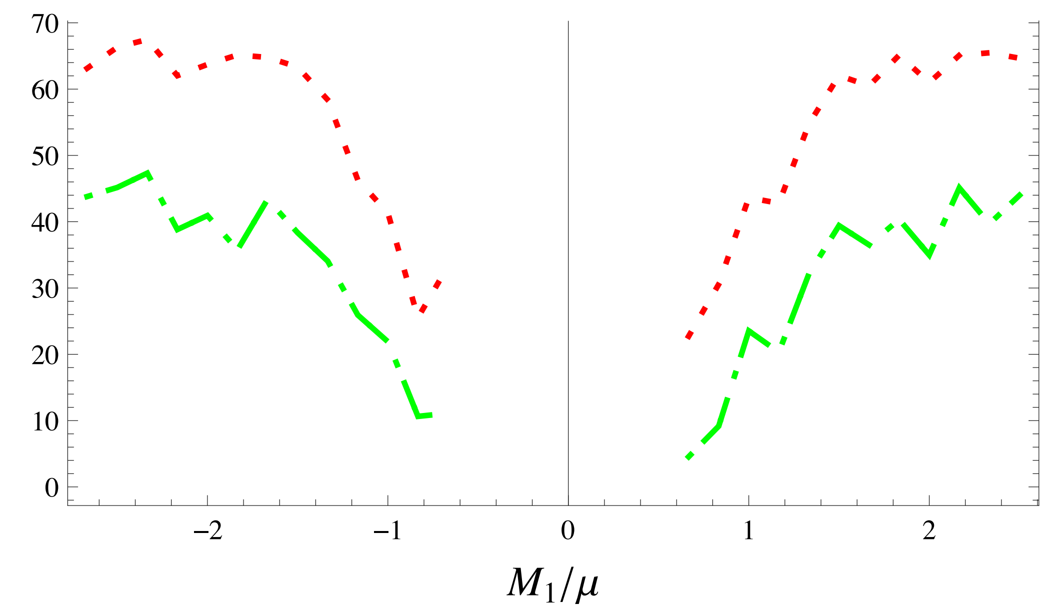
$\chi_2^{\pm} \to h + \ldots$

$\chi_3 \to h + \ldots$



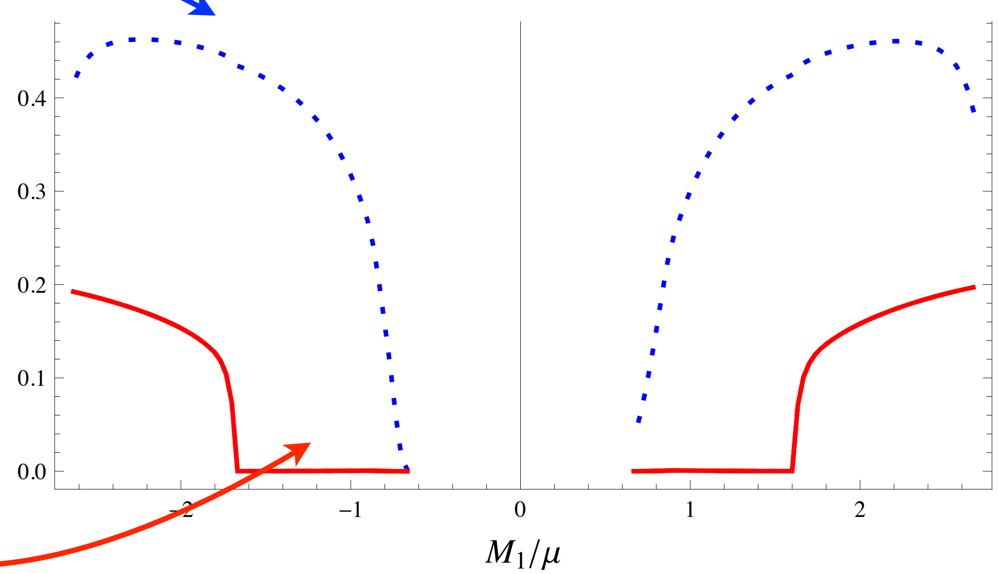
pT(h) > 200 GeV

pT(h) > 300 GeV

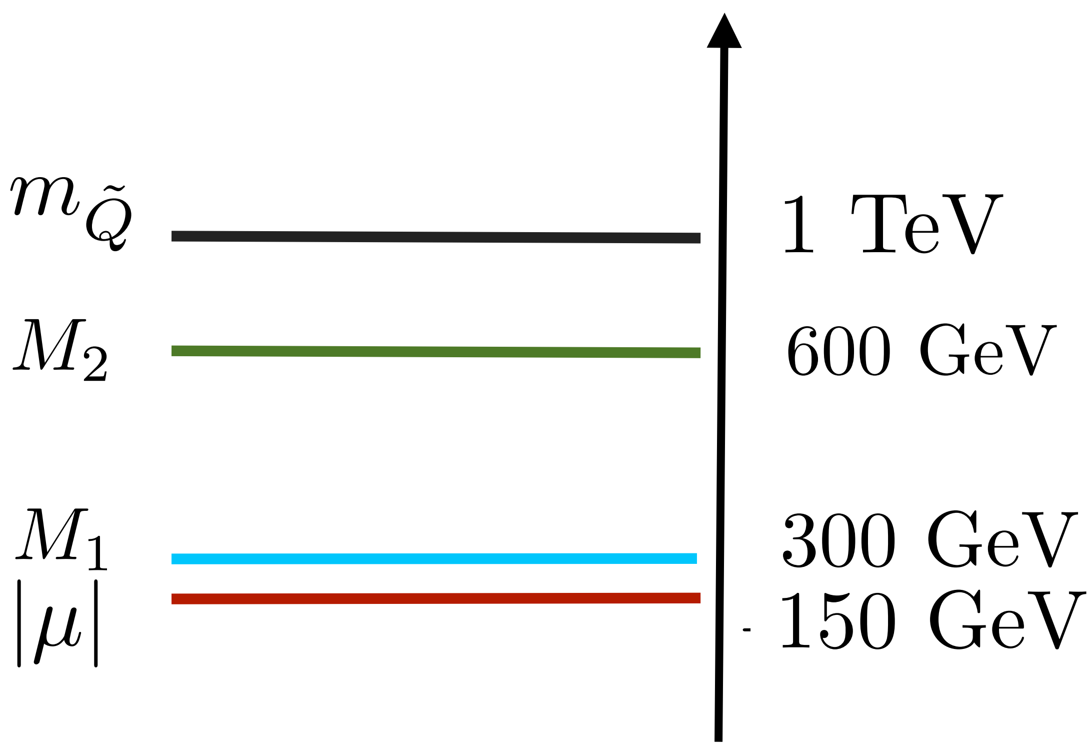


$\tilde{q}_L \to h + \ldots$

$\tilde{q}_R \to h + \ldots$

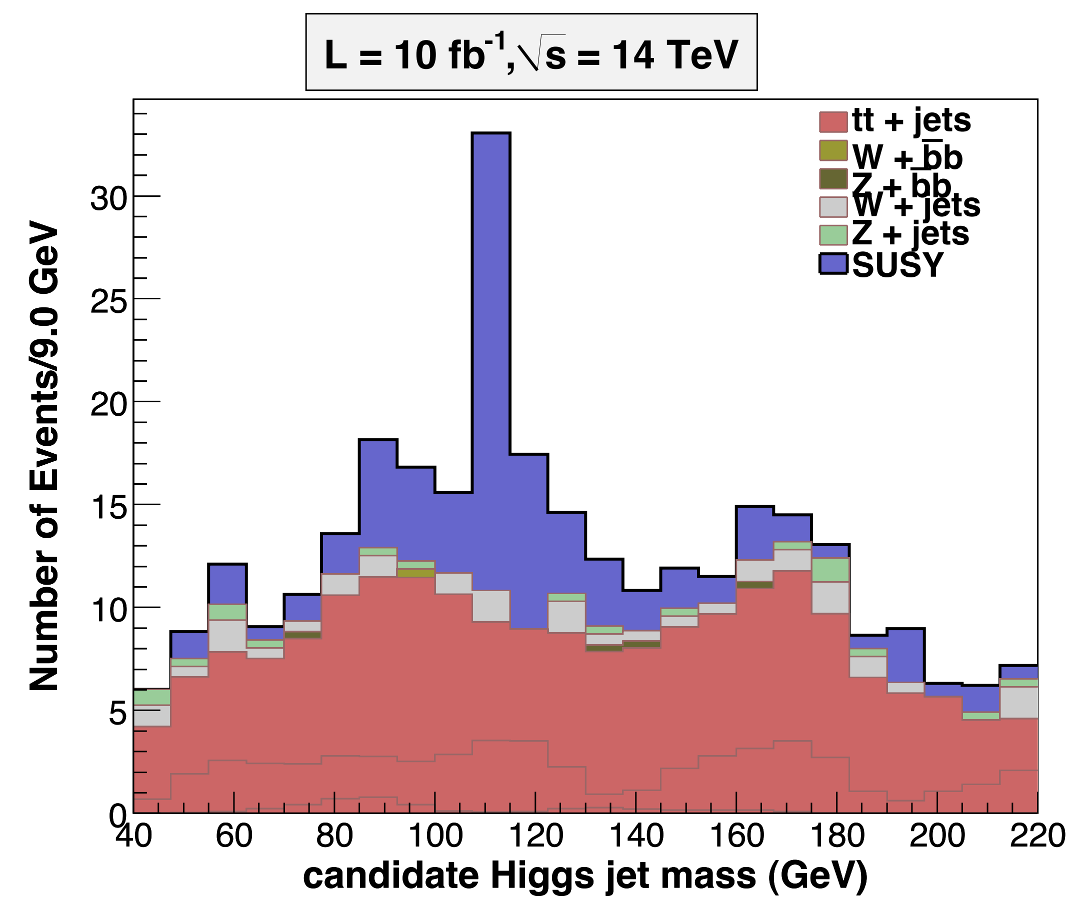


Results: MSSM with neutralino LSP



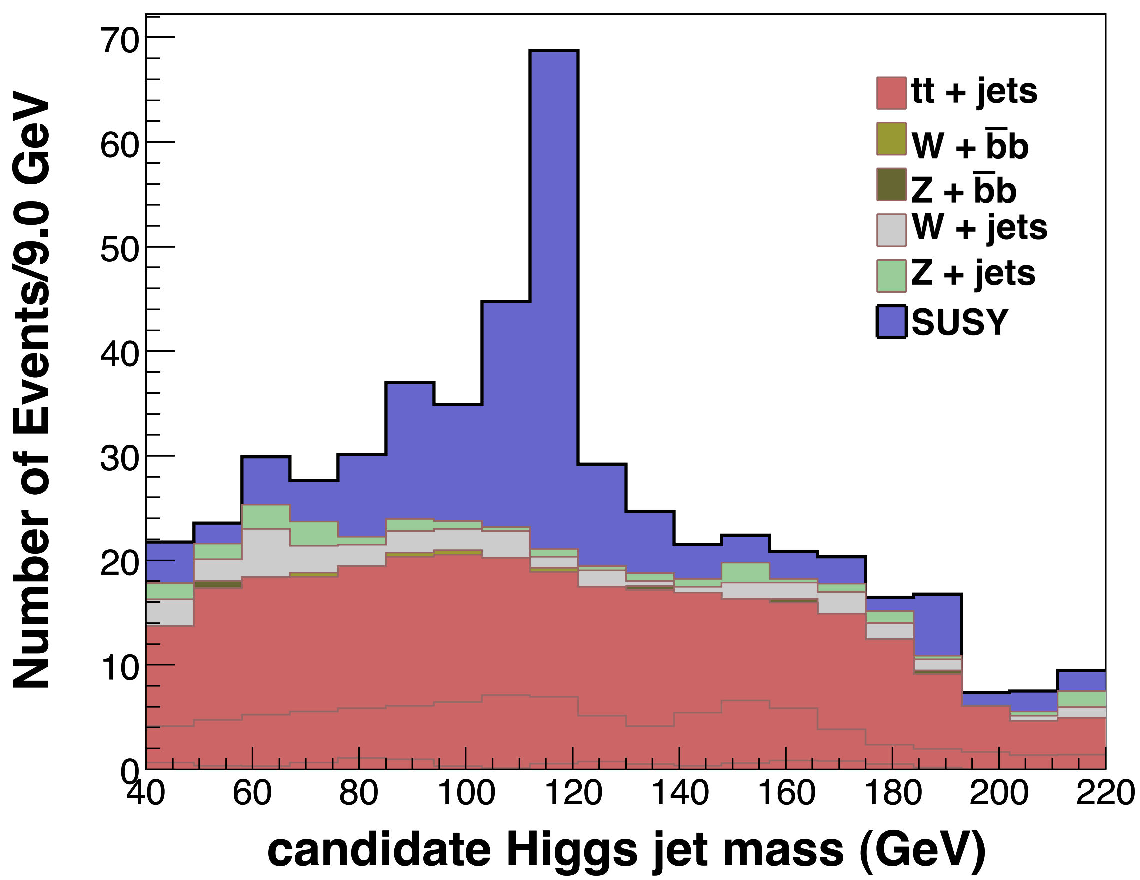
$$H_T > 1.5\,\text{TeV}, \not{E}_T > 150\,\text{GeV}$$
$$2^+ \text{ high-}p_T \text{ jets } + \text{ substructure}$$

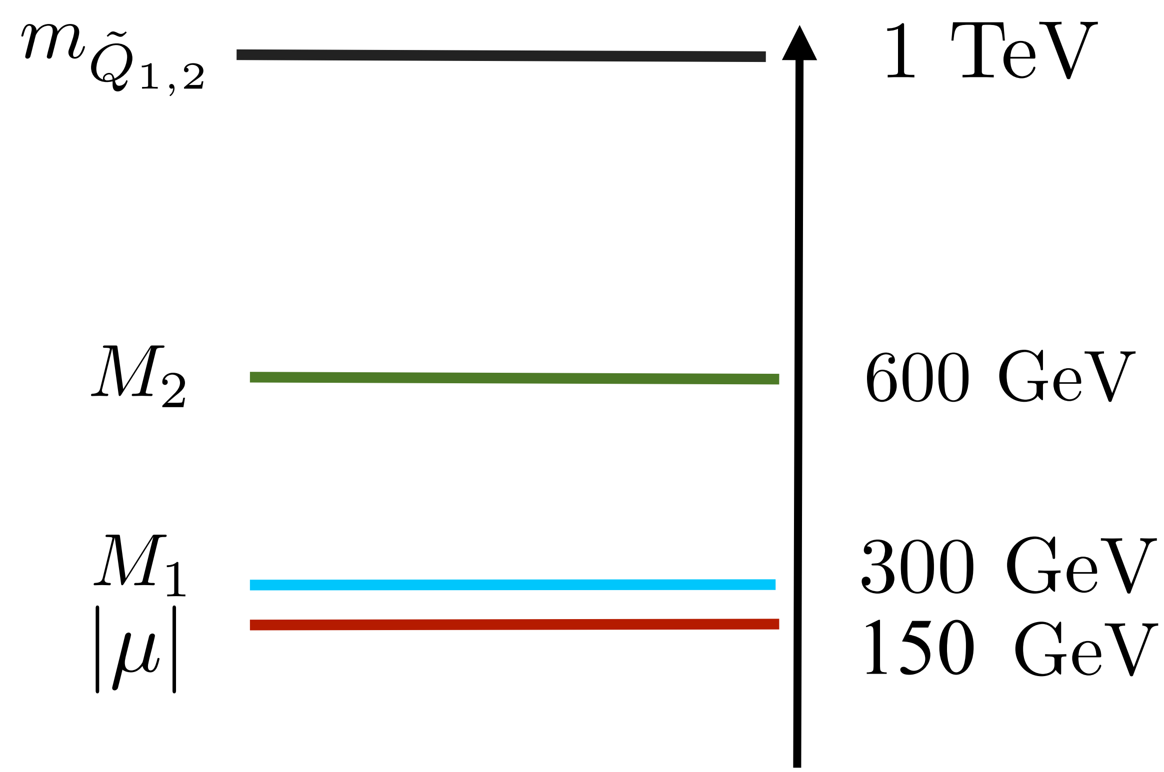
$$\chi_3 \rightarrow h + \chi_1 \quad \sim \quad 16\%$$
$$\chi_4 \rightarrow h + \chi_1 \quad \sim \quad 16\%$$
$$\chi_2^\pm \rightarrow h + \chi_1^\pm \quad \sim \quad 25\%$$



Results: MSSM with neutralino LSP

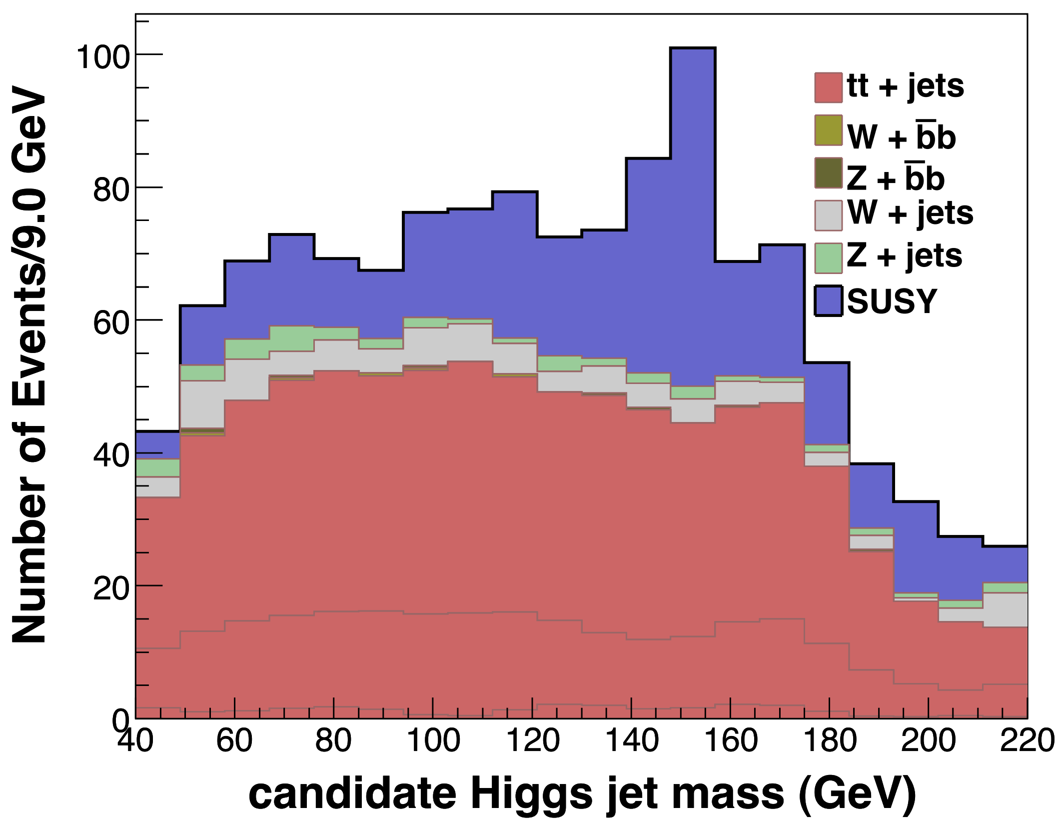
$\not{E}_T > 300 \text{ GeV}, H_T > 1.0 \text{ TeV}$



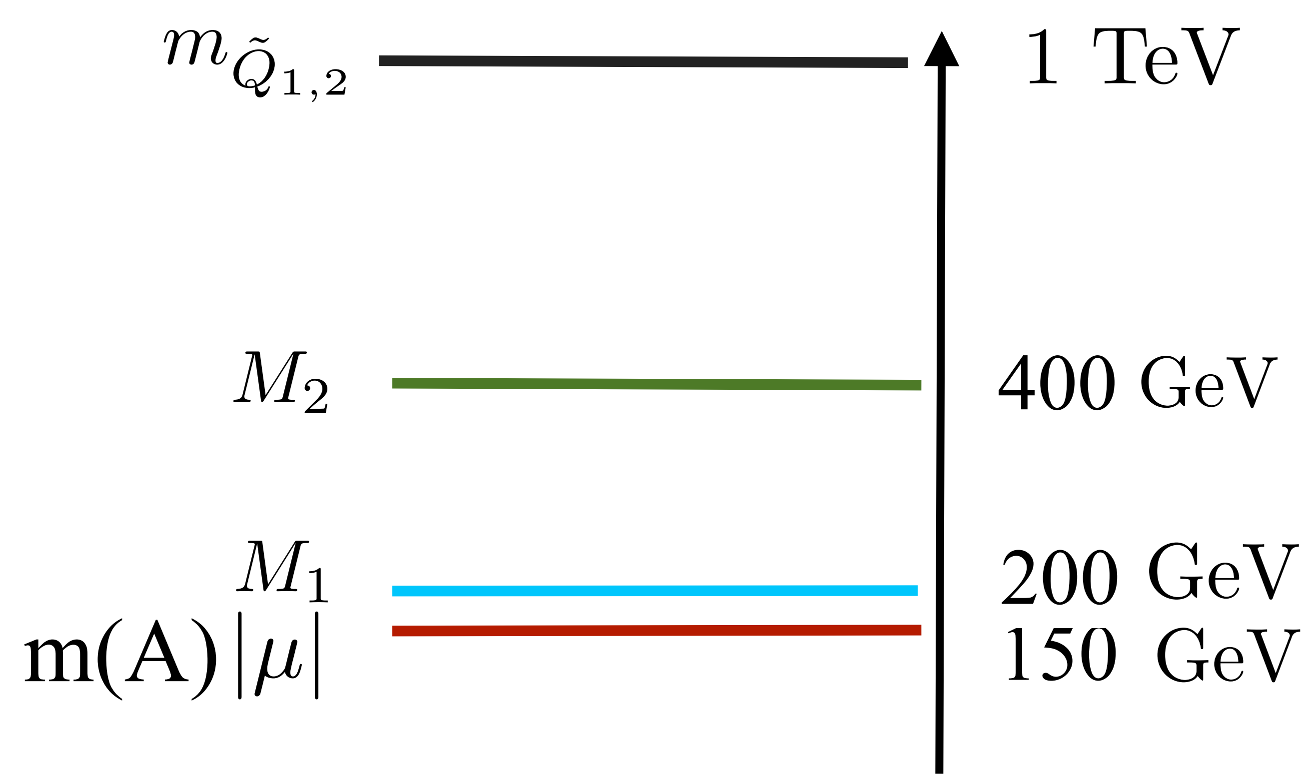


Results: MSSM with neutralino LSP

$$\not{E}_T > 300\ \text{GeV}, H_T > 1.0\ \text{TeV}$$



tan β = 6.5



Can even discover heavier A,H states!

conclusions

light Higgs are hard to find at the LHC

decays of BSM particles provide a new and natural source of boosted Higgs at the LHC

- rate is smaller but BSM provides additional tools to suppress background

Substructure opens up the dominant channel $h \to \bar{b}b$

- our algorithm extends it to busier environment
- complimentary to conventional search
- these new Higgs discovery channels can easily be as significant (or more so !) than conventional $h \to \gamma\gamma$

Offering

seems important enough to have a full detector simulation