LHC study of Z′ resonance decaying to Zh via Jet Substructure

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How do we reconstruct a full story of Z' ?

Dilepton Channel : probably discovery channel or maybe not

$$Z' \rightarrow \mu^+\mu^-, \ e^+e^-, \ \tau^+\tau^-$$

ttbar (top pair) : with boosted top-tagging
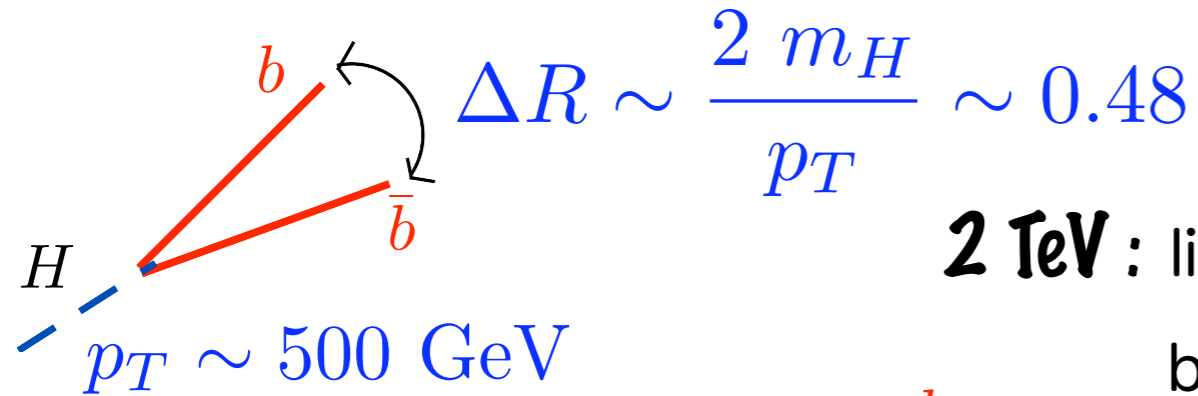
What is missing (or not well understood) ?

Zh/W+W-

: unique in that it measures the **coupling** of Higgs to Z'
DIRECTLY (... crucial to understand the nature of Z')

Note that In this talk we will focus on **Zh-llbb**

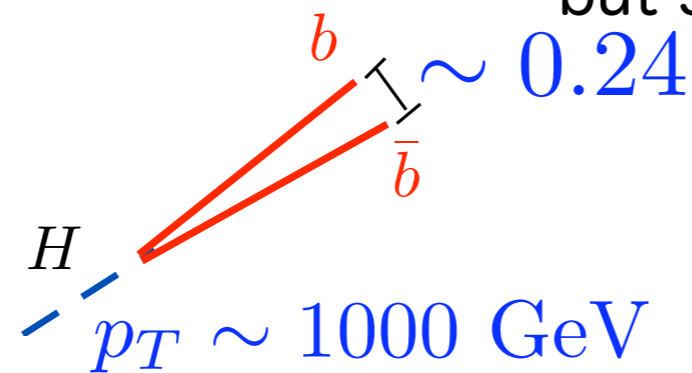# Difficulty in tagging Boosted Higgs

1 TeV Z′ : well separated (bigger than Rjet=0.4)

b

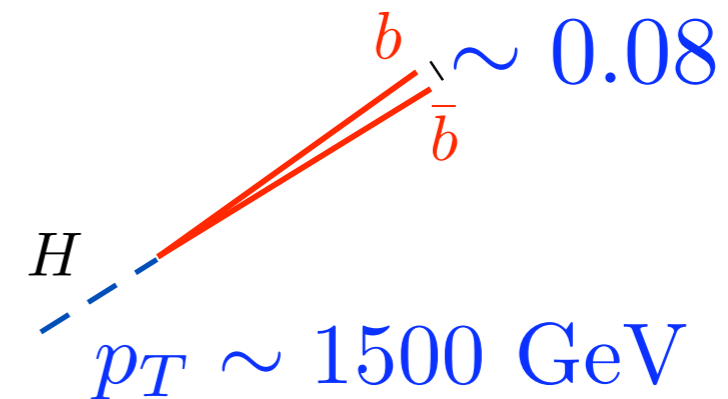$$\Delta R \sim \frac{2\, m_H}{p_T} \sim 0.48$$

$\bar{b}$

H

$p_T \sim 500 \text{ GeV}$

2 TeV : likely merges into single jet

but still better than HCAL resol.(~ 0.1)

b

~ 0.24

$\bar{b}$

3 TeV : smaller than HCAL resol.

H

$p_T \sim 1000 \text{ GeV}$

b

~ 0.08

$\bar{b}$

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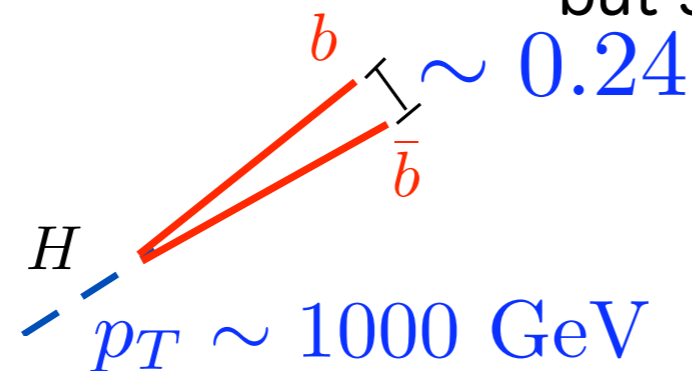
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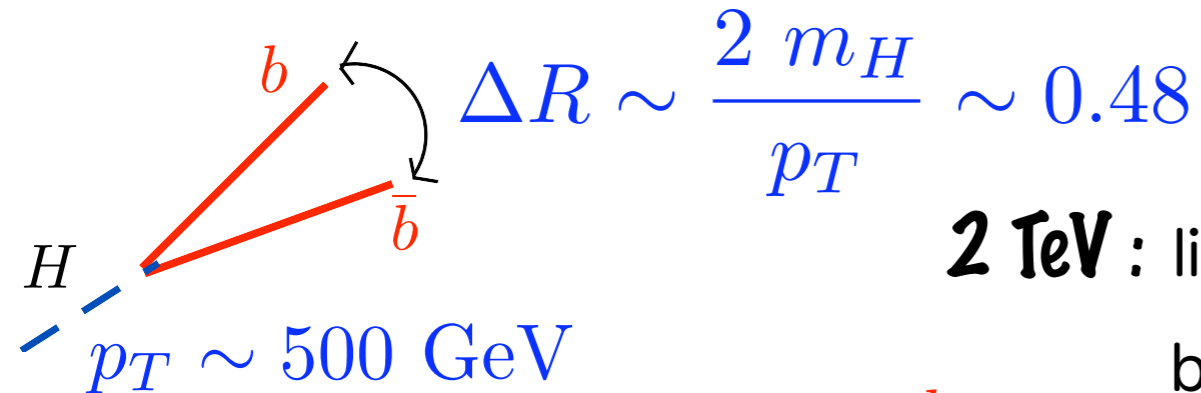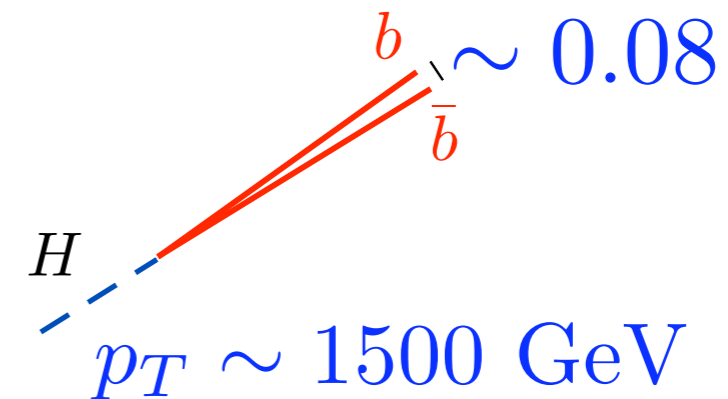
Complication:
   how do we match low-mass dijet search onto high-mass monojet search ?

Worry:

1. artificial shapes might be introduced into joint Z'/Higgs mass distribution.

2. might lose Higgs mass resol. at high boost. are we swamped by Z + jet bkgs. ?

3. b-tagging gets worse at high pT.

Some prelim work

LHC Signals for Warped Electroweak Neutral Gauge Bosons

K. Agashe et. al [arXiv : 0709.0007]

Search for the decays $Z_H \to Zh$ **and** $W_H \to Wh$
in the Little Higgs model assuming $m(h) = 120$ GeV

J. E. Garcia et. al [ATL − PHYS − 2004 − 001]

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: Parton Level Study

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J. E. Garcia et. al [ATL − PHYS − 2004 − 001]

**: Traditional jet-clustering
w/ Rjet = 0.4 with merging jet
for 1 and 2 TeV Z'**

Jet Substructure

In situations with merged jets, substructure can help

Various techniques have been developed which look promising for the application to the current problems

WW scattering at the CERN LHC   substructure of **W** jet

J. M. Butterworth et al [ph/0201098]

Jet substructure **as a new Higgs search channel at the LHC**

Butterworth, Davison, Rubin and Salam [PRL 100 (2008)]

substructure of **H** jet

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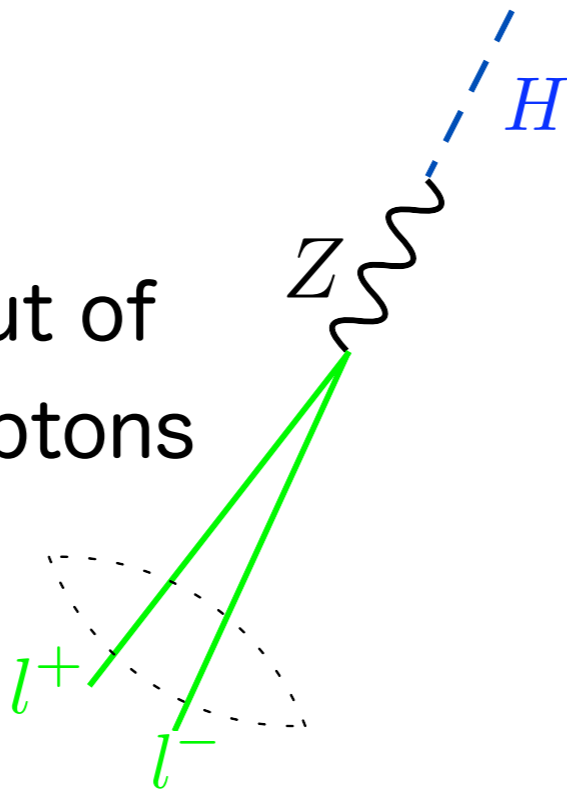substructure of H jet

then why do not we take advantage of it ?

we will focus on Butterworth-Salam style (C/A filtering)

good background rejection and mass resolution

1. reconstruct Z out of two isoloated leptons

H

Z

l^+

l^-

Sequential Procedure with jet Substructure

2. jet clustering with Rjet

R_{jet}

b

$\bar{b}$

g

Fat Higgs jet

H

Z

1. reconstruct Z out of two isoloated leptons

l^+

l^-
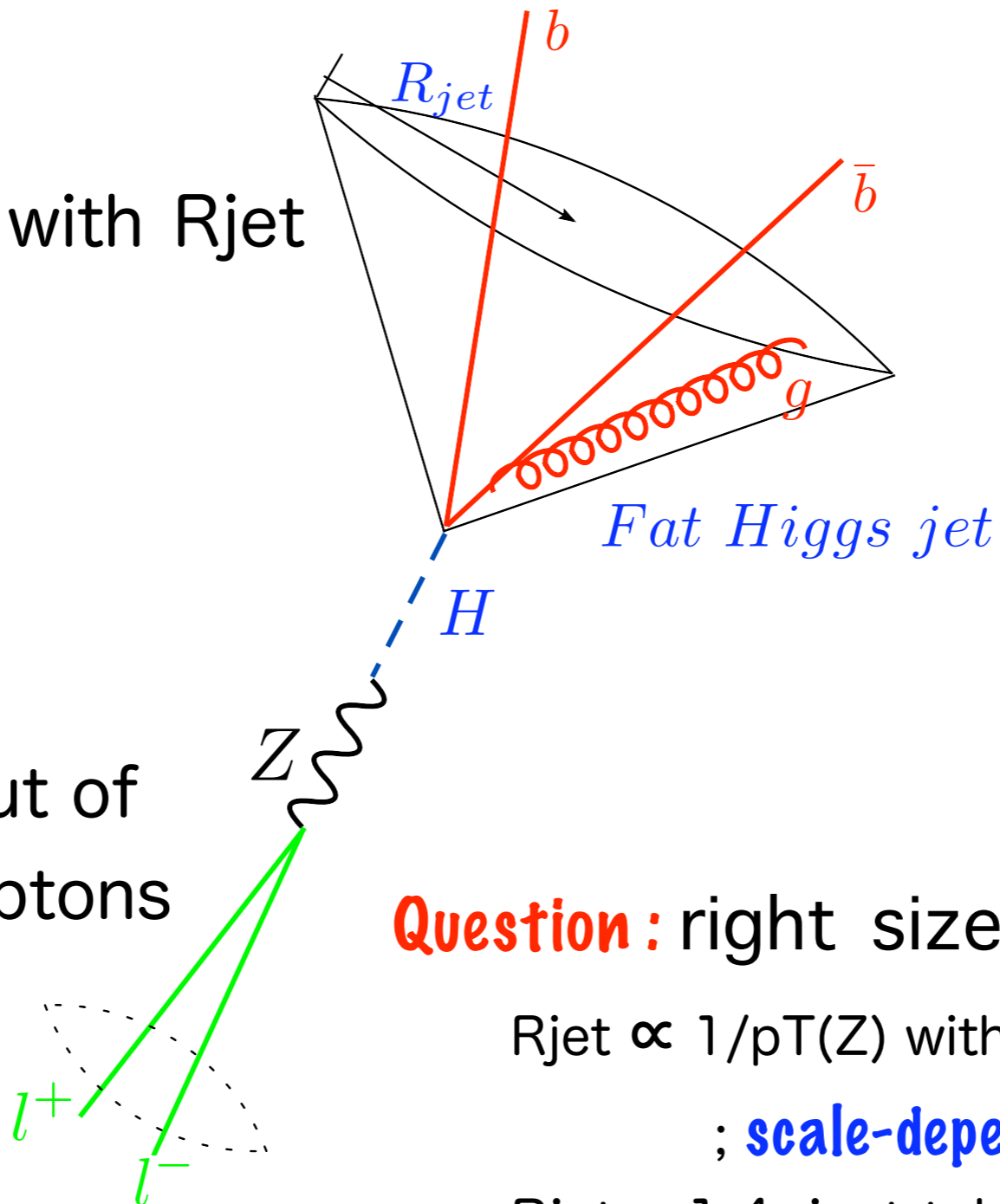
Question : right size of Rjet ?

Rjet ∝ 1/pT(Z) with pT from recon. Z-boson
; **scale-dependent Jet size**

Rjet = 1.4 just take a max. size
; **scale-Independent Jet size**

Sequential Procedure with jet Substructure
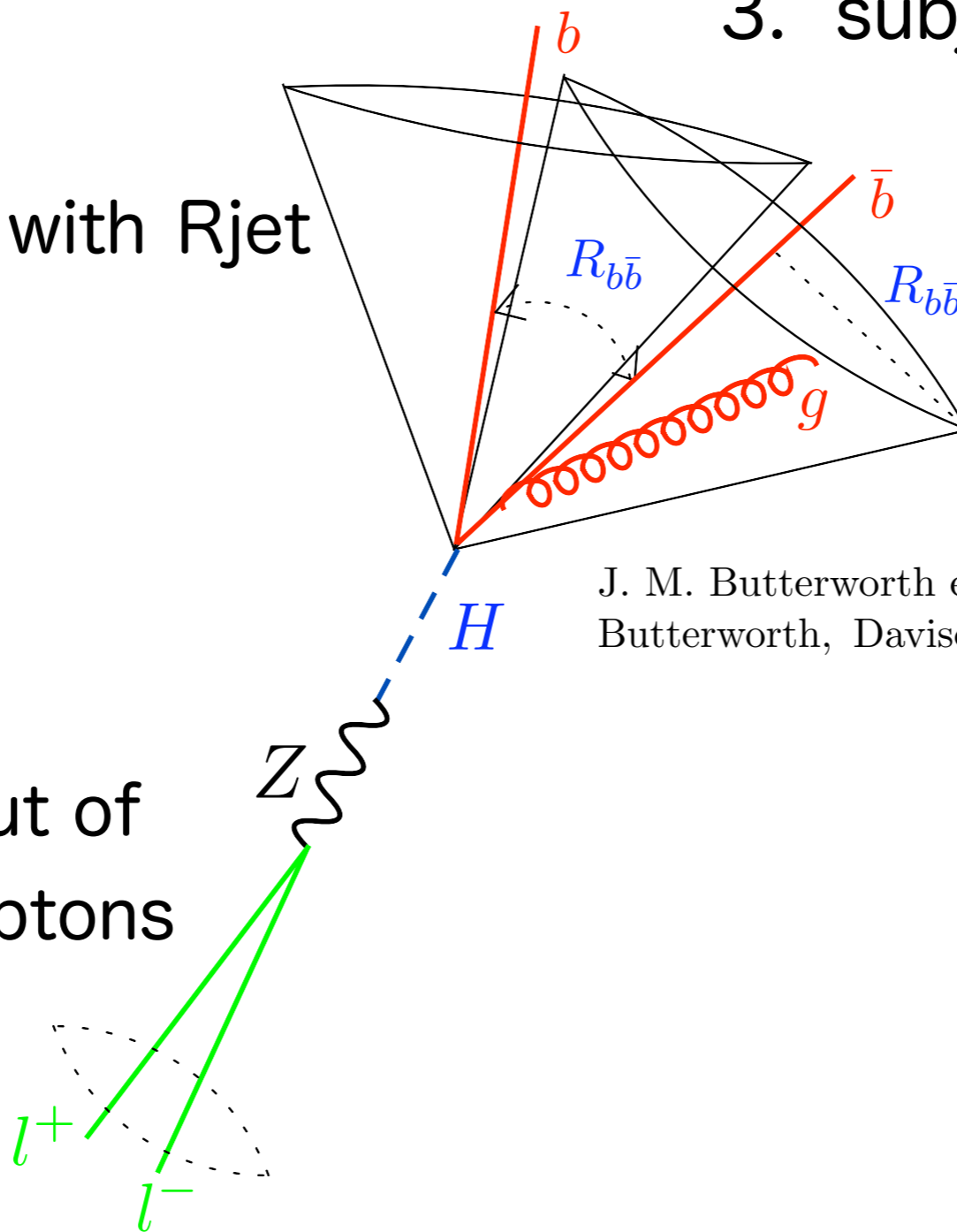
3. subjet-decomposition

2. jet clustering with Rjet

mass drop/asym.

$$m_{sj}/m_j < 67\ \%$$

$$p_{t\,sj<}/p_{t\,sj>} > 9\ \%$$

b

$\bar{b}$

$R_{b\bar{b}}$

$R_{b\bar{b}}$

g

H

J. M. Butterworth et al [ph/0201098]

Butterworth, Davison, Rubin and Salam [PRL 100 (2008)]

Z

1. reconstruct Z out of
   two isoloated leptons

l^+

l^-

Sequential Procedure with jet Substructure

3. subjet-decomposition

b

$\bar{b}$

2. jet clustering with Rjet

mass drop/asym.

R_{filt}

g

filter

$$R_{filt} = \min(0.3,\ R_{b\bar{b}}/2)$$

H

Butterworth, Davison, Rubin and Salam [PRL 100 (2008)]

Z

1. reconstruct Z out of
   two isoloated leptons

l^+

l^-

Question : need Filter at high pT ?

Try with/withOUT filtering/reclustering

Sequential Procedure with jet Substructure

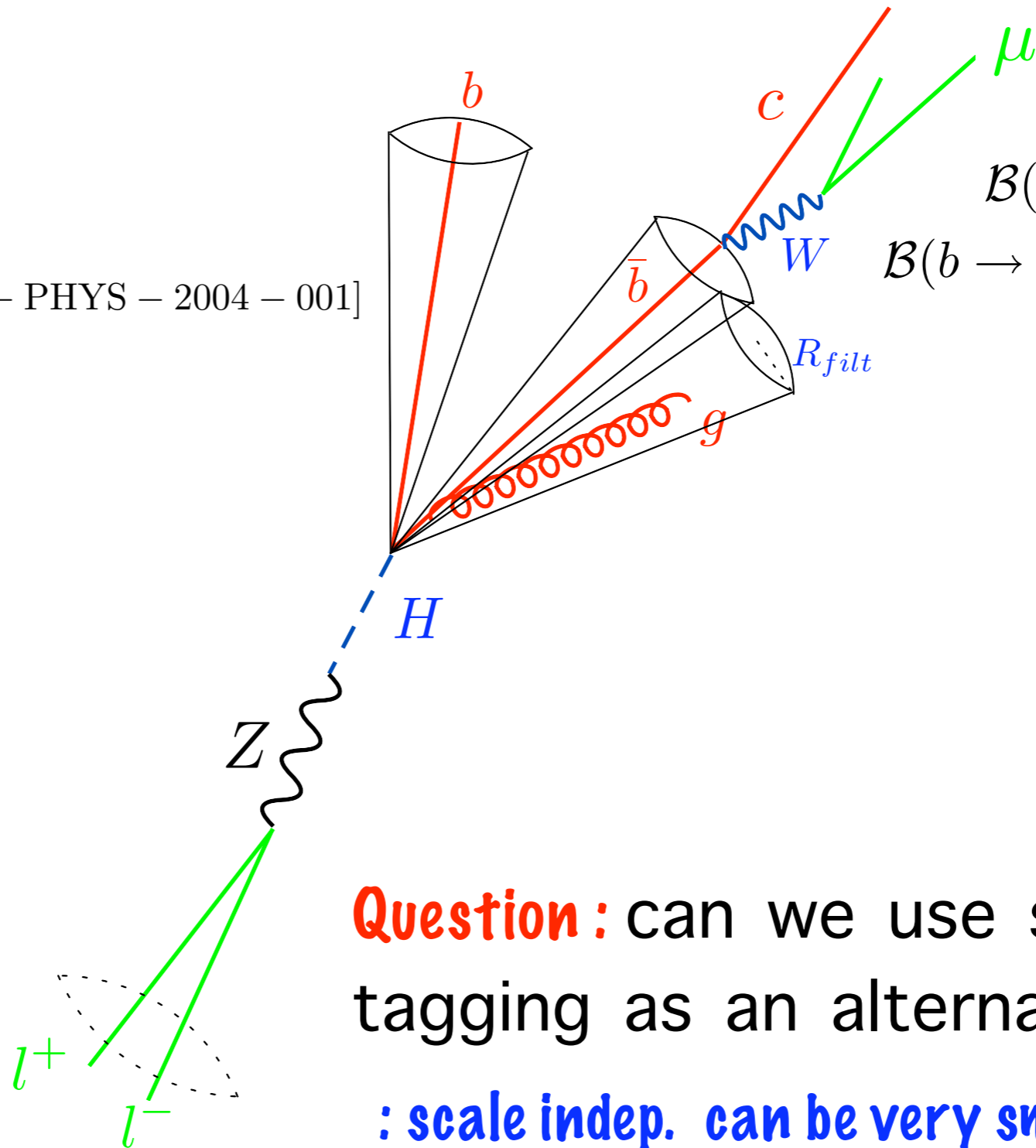

4. reconstruct inv mass of H out of three hardest subjets
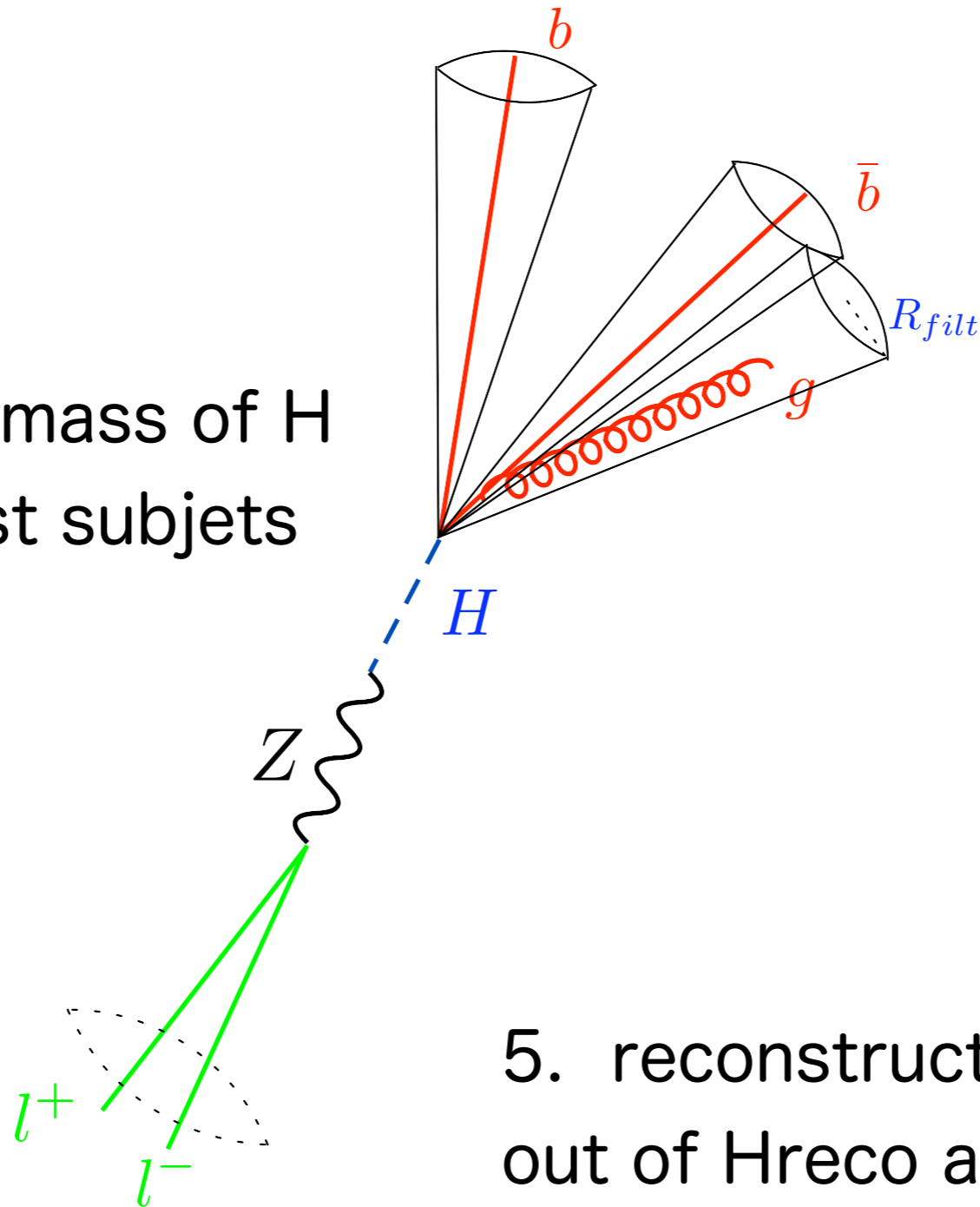
5. reconstruct inv mass of Z' out of Hreco and Zreco

6. b-tagging

ref. ATLAS/CMS TDR

J. E. Garcia et. al [ATL − PHYS − 2004 − 001]

b

c

μ

$\bar{b}$

W

R_{filt}

g

H

Z

l^+

l^-

$\mathcal{B}(b \to \mu \nu X) = 11 \%$

$\mathcal{B}(b \to c \to \mu \nu X) = 10 \%$

Question : can we use soft-muon tagging as an alternative ?

: scale indep. can be very smoothly applied to high-mass search w/o being destroyed

Question :

jet Substructure technique do better than a traditional style ?

perform jet clustering w/ Rjet = 0.4

⟶ If two hardest jets are not too asym. (i.e. pT asym. < 9 %),
take dijet to reconstruct Higgs inv. mass (* also without asymmetry cut)

repeat above, but
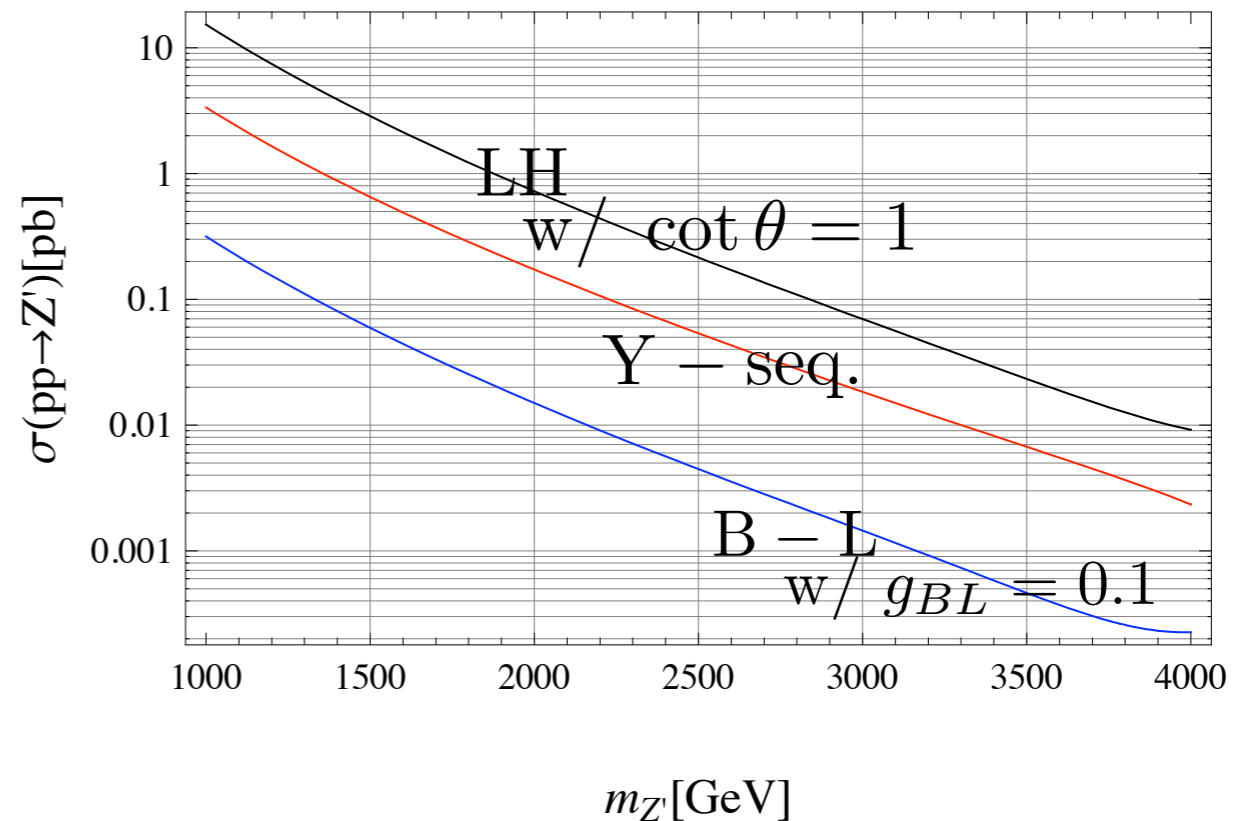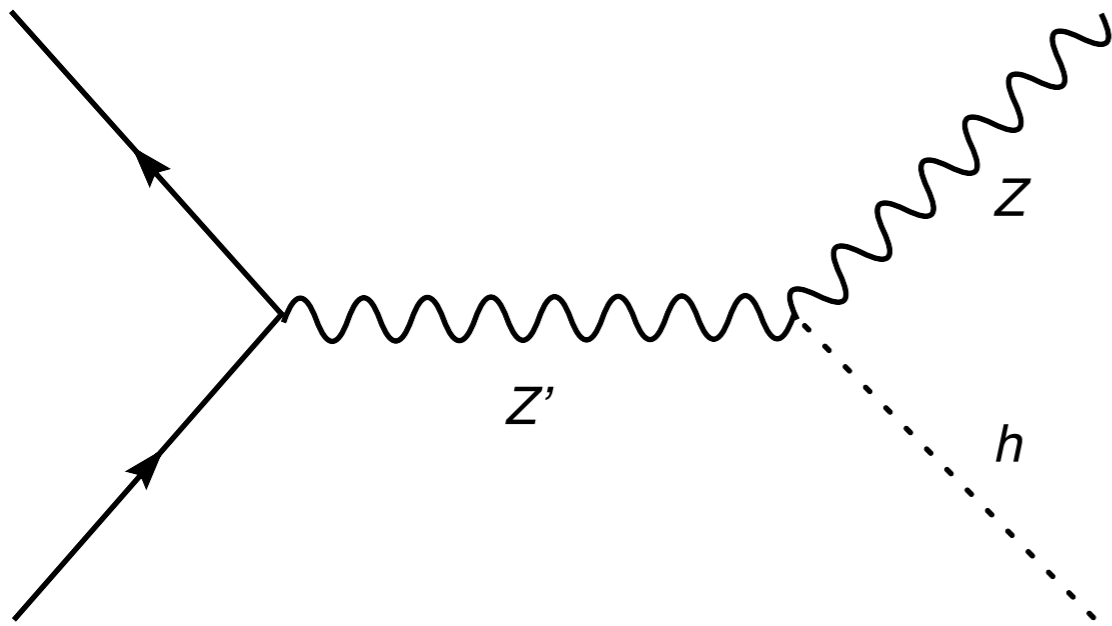⟶ If two hardest jets are too asym., take only hardest jet (monojet) to
reconstruct Higgs inv. mass   ⟶ **merged jet**

Production rate and Branching ratio

Recall we focus on Zh-llbb for a light Higgs with mH = 120 GeV

$$\mathcal{B}(H \to b\bar{b}) \times \mathcal{B}(Z \to ll) \sim 0.7 \times 2/30 = 4.7\ \%$$

Signal Events (Z' - Zh - llbb): Madgraph/Event 4.4.32

Bkgs Events (Z + jet): PYTHIA 6.4.11

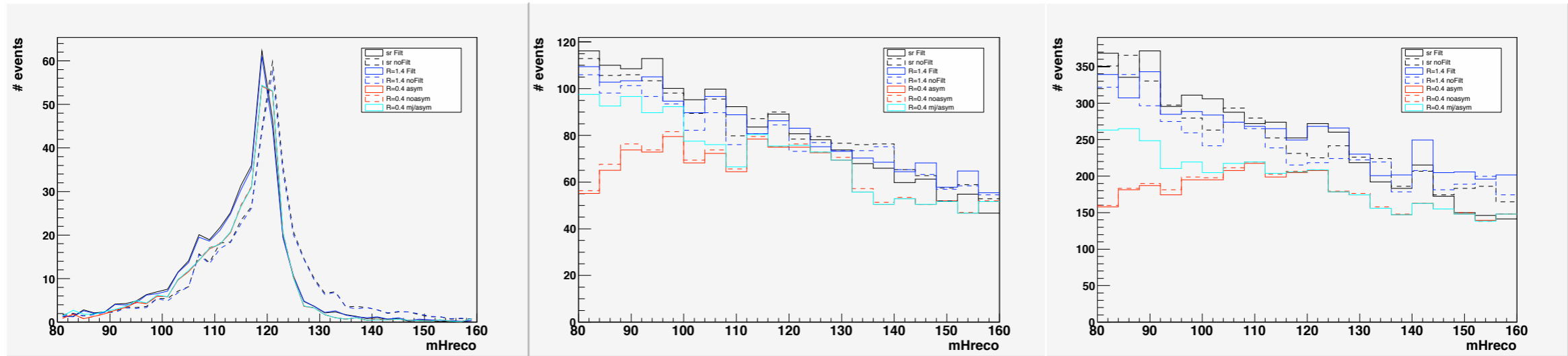**** jet clustering :** fastjet-2.4.1

Reconstruced inv Higgs mass by many variants

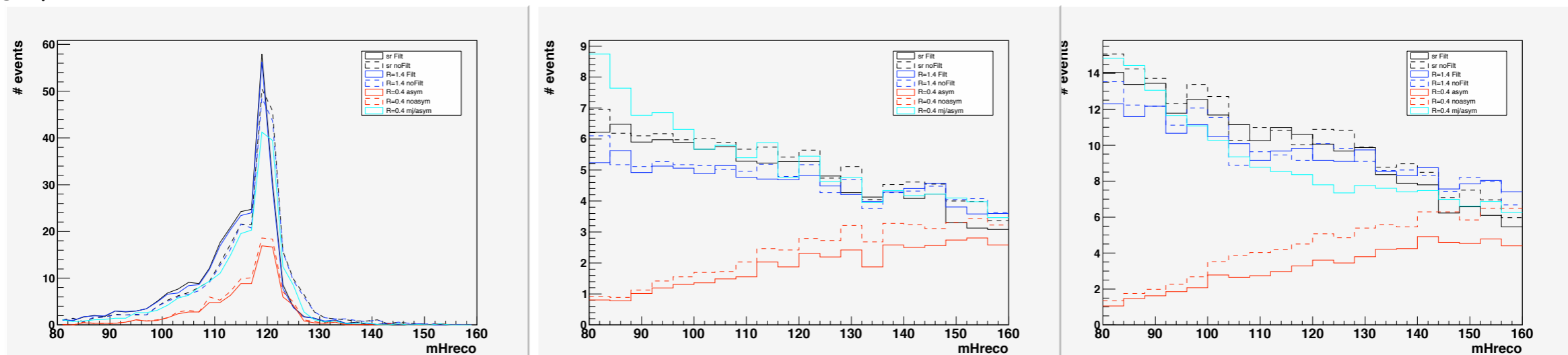**1 TeV** $q\bar{q} - Zh - b\bar{b}l^+l^-$ $q\bar{q} - gZ$ $qg - qZ$

Observation: 1. filtering effect is very slight
2. all procedures perform equally good
   (slight diff. can be improved by tuning pars.)

2 TeV

Observation: 1. filtering effect is gone
2. roughly half of dijets merge into monojet
3. trad. jet technique with merged jets persists to work
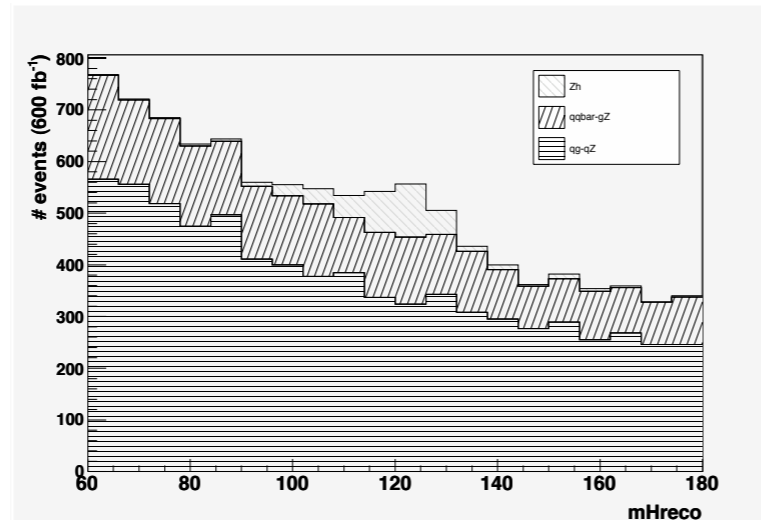
Reconstructed Higgs invariant mass

showing you only the cases with perfect tagging Eff.

$m_{Z'} = 1 \text{ TeV}$
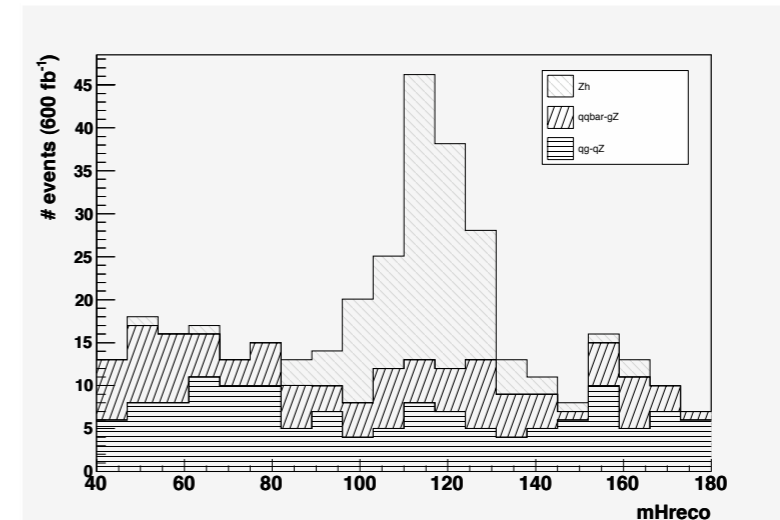
$900 < m_{Z'} < 1100 \text{ GeV}$
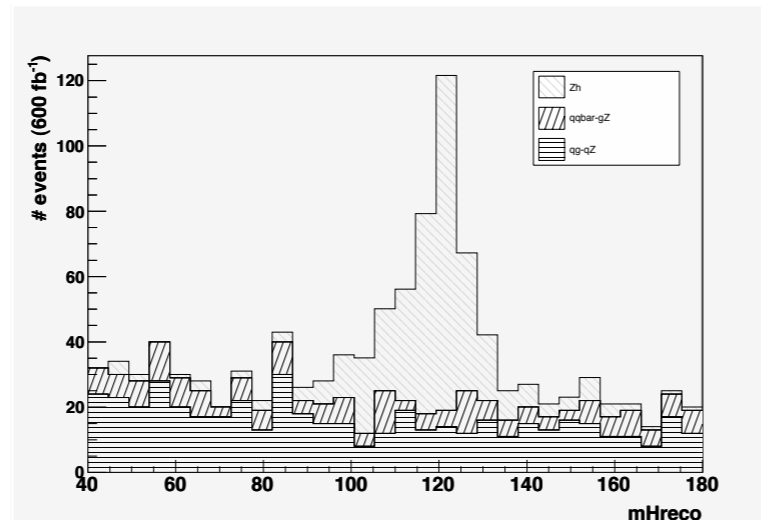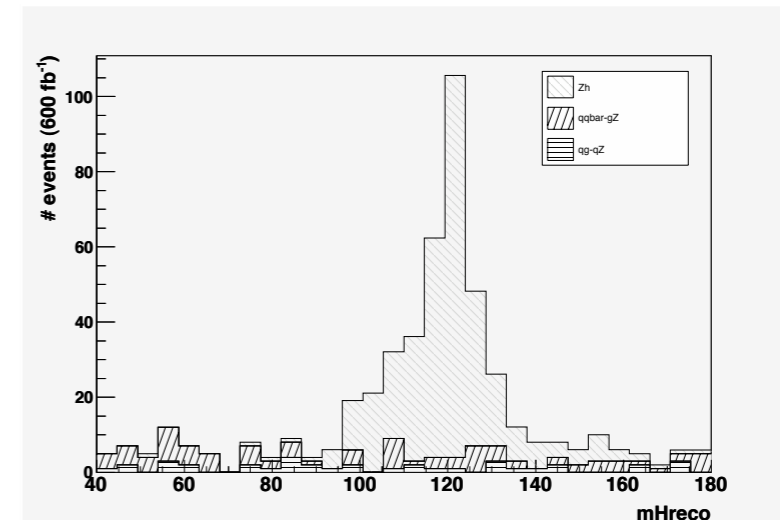
no tagging

perfect one soft muon-tagging

perfect one b-tagging

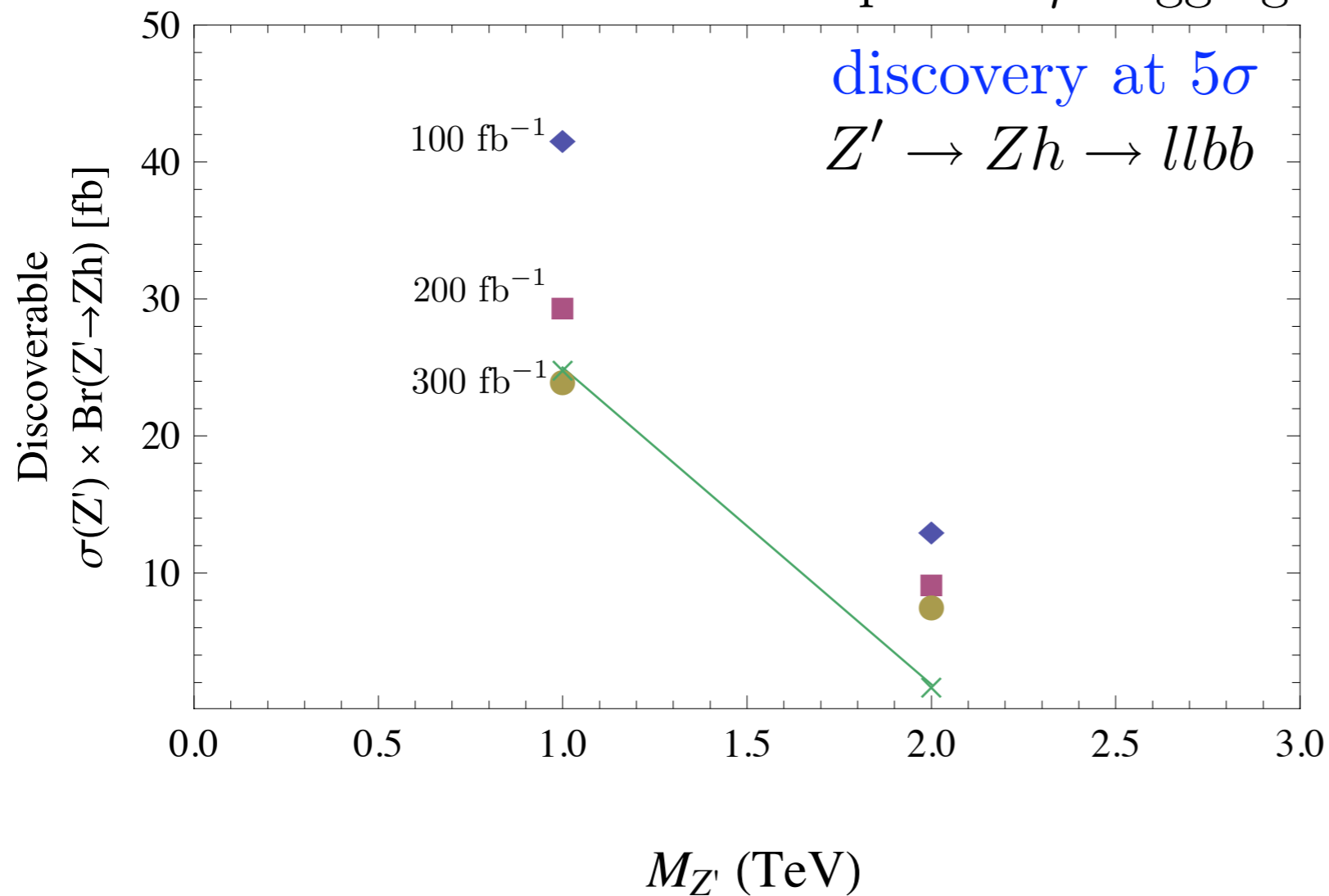### perfect two b-tagging

The reality will be an admixture of the above cases

experimentalists need to figure it out !

"Preliminary" LHC Reach Plot

with perfect μ tagging

discovery at 5σ

$Z' \to Zh \to llbb$

100 fb^{-1}

200 fb^{-1}

300 fb^{-1}

Discoverable $\sigma(Z') \times \text{Br}(Z' \to Zh)$ [fb]

$M_{Z'}$ (TeV)

$\times : \ \sigma(Z') \cdot \mathcal{B}(Zh)|_{S/B=1}$

$$1 = \frac{N_s}{N_b} = \frac{(\sigma \cdot \mathcal{B})_s \, \epsilon_s}{\sigma_b \, \epsilon_b}$$

$\sigma(Z') \cdot \mathcal{B}(Zh)$	Randall-Sundrum	Little Higgs	Y-sequential
1 TeV		214 fb	40 fb
2 TeV	~ 25 fb	10 fb	2 fb
		$\cot \theta = 0.5$	$g_{Z'} = e / \cot \theta_W$

In progress

1. **Investigating possible impact of detector effect for 3 TeV Z' analysis**

2. **Covering additional multi-decay channels of Zh/WW**

3. **etc. including many details**