Title: Boosting Higgs Discovery

Date: May 07, 2010 11:00 AM

URL: http://pirsa.org/10050024

Abstract: An enormous effort is underway to search for the Higgs boson at the LHC. One new development of the past couple of years is to look into the kinematic region where the Higgs boosted, which has led to the possibility to observe the dominant b-bar decay mode as a single "fat jet" when the Higgs is light. I'll discuss how this technique has great promise not only within the Standard Model, but potentially has even greater promise to find a light Higgs in new physics models such as supersymmetry.

Boosting Higgs Discovery

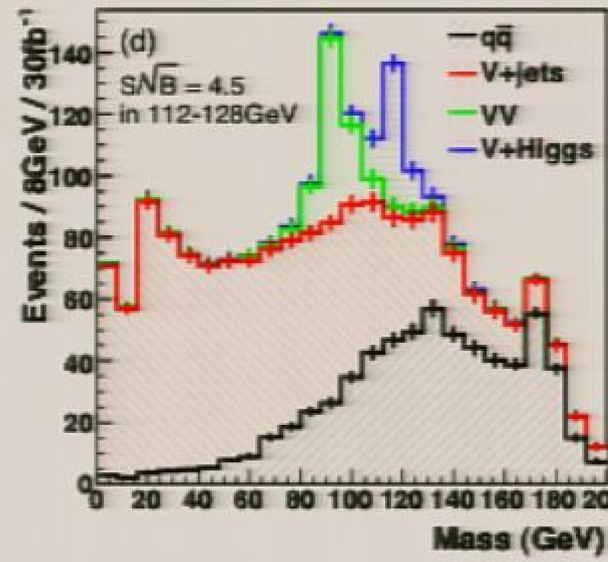
Graham Kribs

University of Oregon

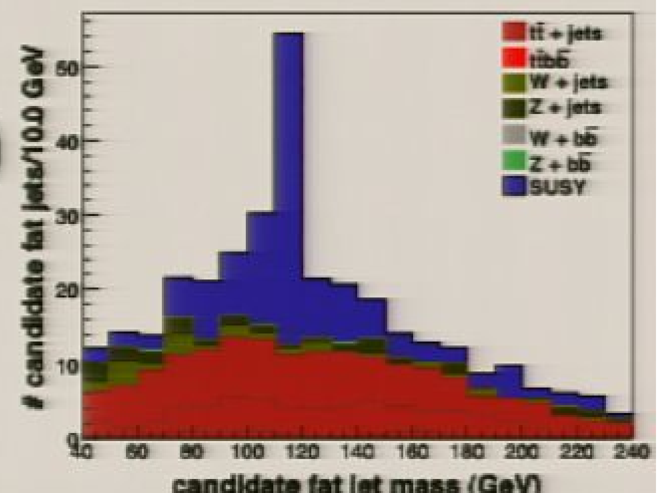
PI 7 May 2010

Punchline

BDRS developed a qualitatively new method, using "jet substructure", to demonstrate discovery of h -> b,bbar at the LHC for light Higgs masses with S ≈ 4 for 30 fb^{-1}



We find that light MSSM Higgses can also be discovered using BDRS technique (but with a few additional tricks of our own) applied to the sparticle production and decay into h (& H,A).



Could be first h discovery mode before h -> γγ, h -> ττ!!

"We"

Adam Martin	Fermilab postdoc
Tuhin Roy	Oregon/UWash postdoc
Michael Spannowsky	Oregon postdoc

"Discovering the Higgs Boson in New Physics Events using Jet Substructure"
0912.4731

"Discovering the Higgs Bosons of the MSSM using Jet Substructure"
[to appear very soon...]

"..."
[work in progress]

Outline

- Higgs in SM
- Boosting & Jet Substructure
- Higgs in SUSY
- Boosted SUSY Higgs
- Summary and Offerings

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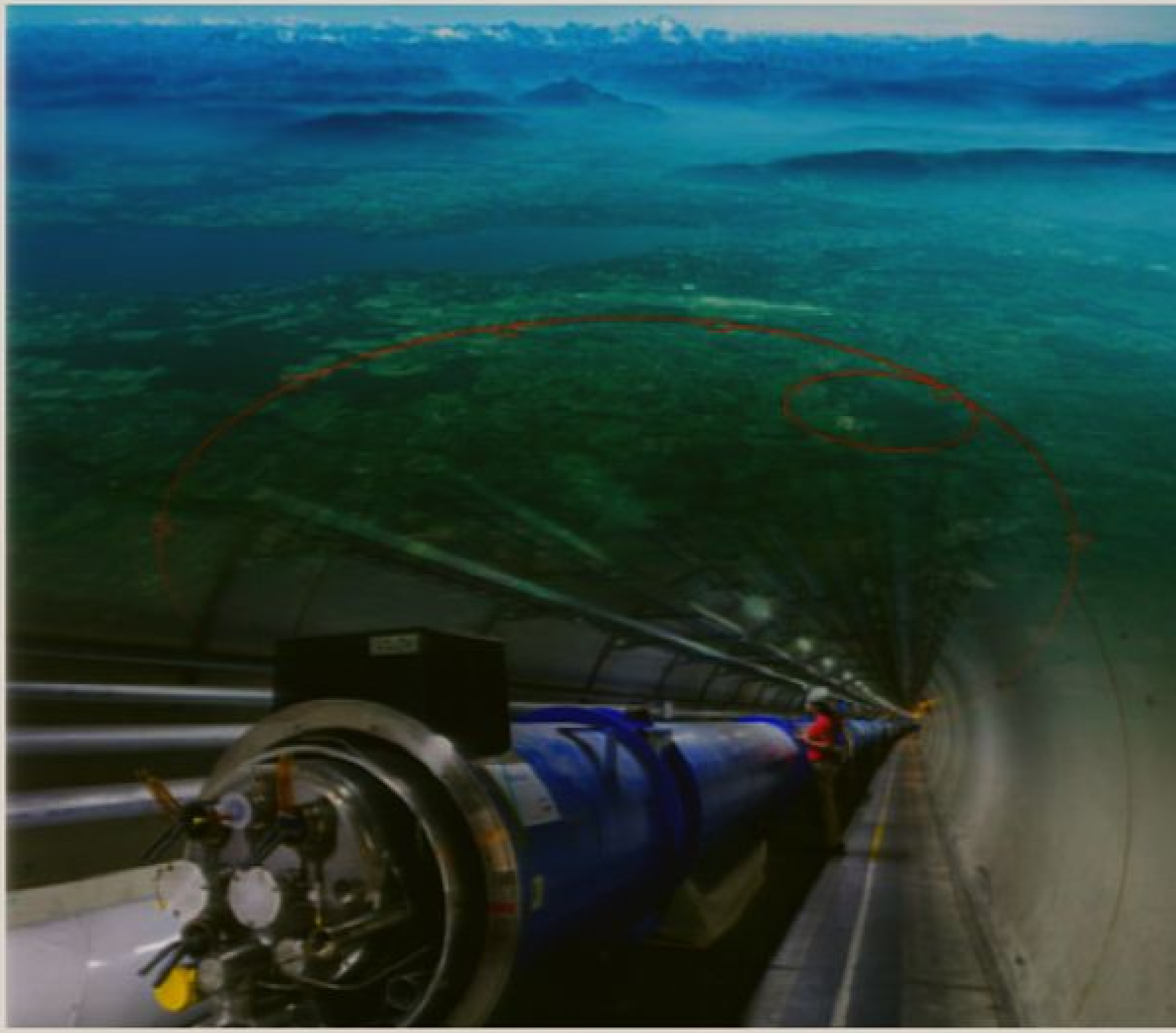
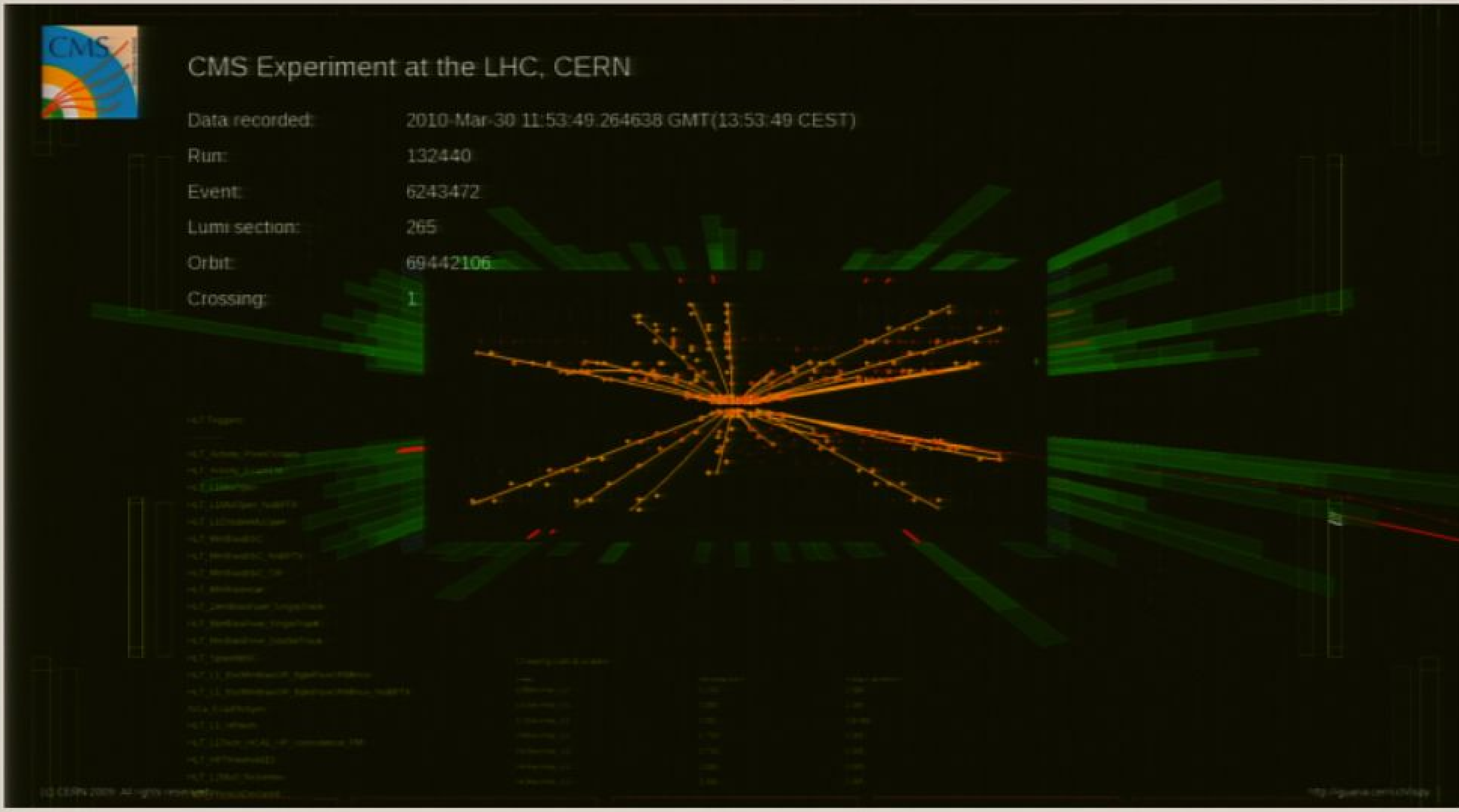
LHC finally colliding!



built to find the Higgs...

7 TeV events...



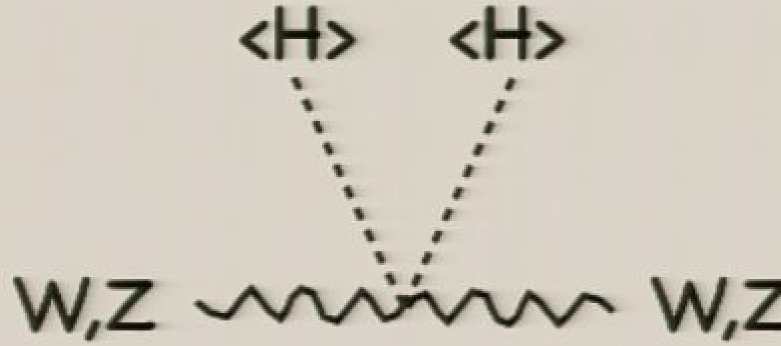
(Higgs?)

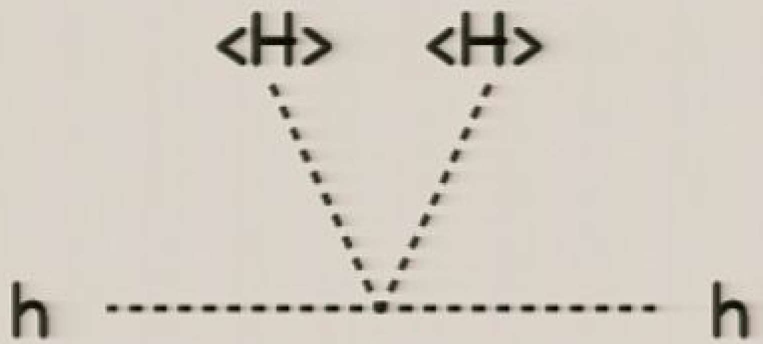
Back to theory.

If Standard Model is right...

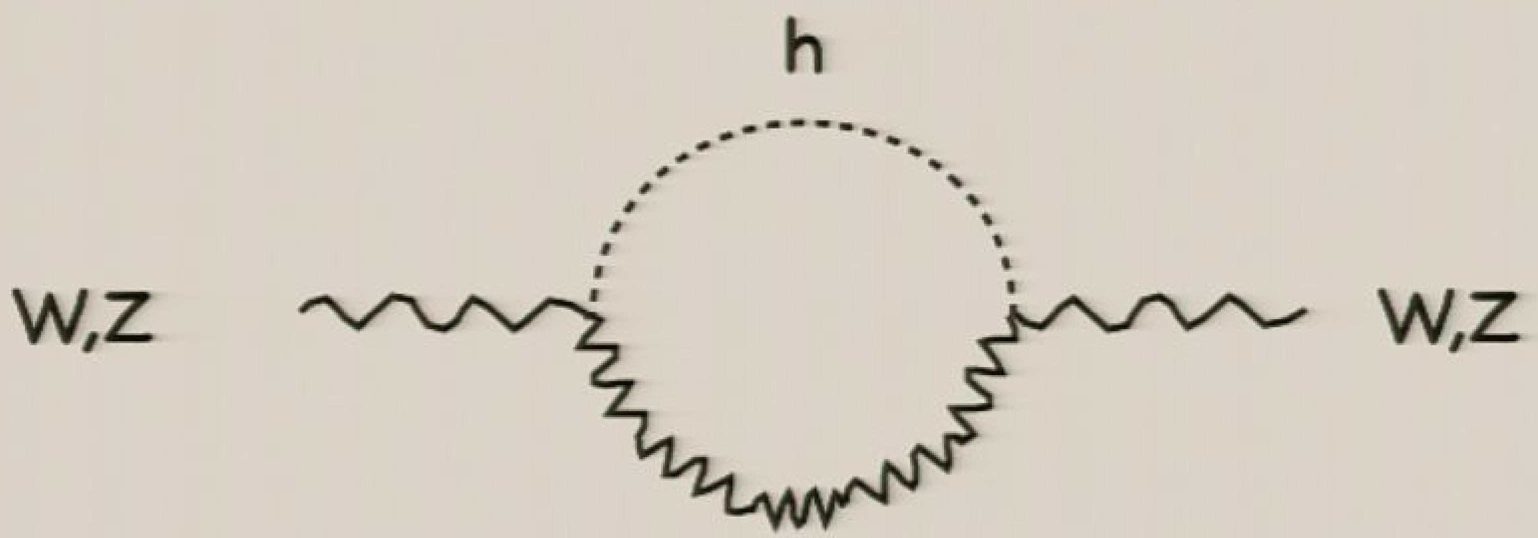
$$H = \begin{pmatrix} \omega^{+} \\ \frac{h + v}{\sqrt{2}} + i z^{0} \end{pmatrix}$$

Higgs VEV gives Mass

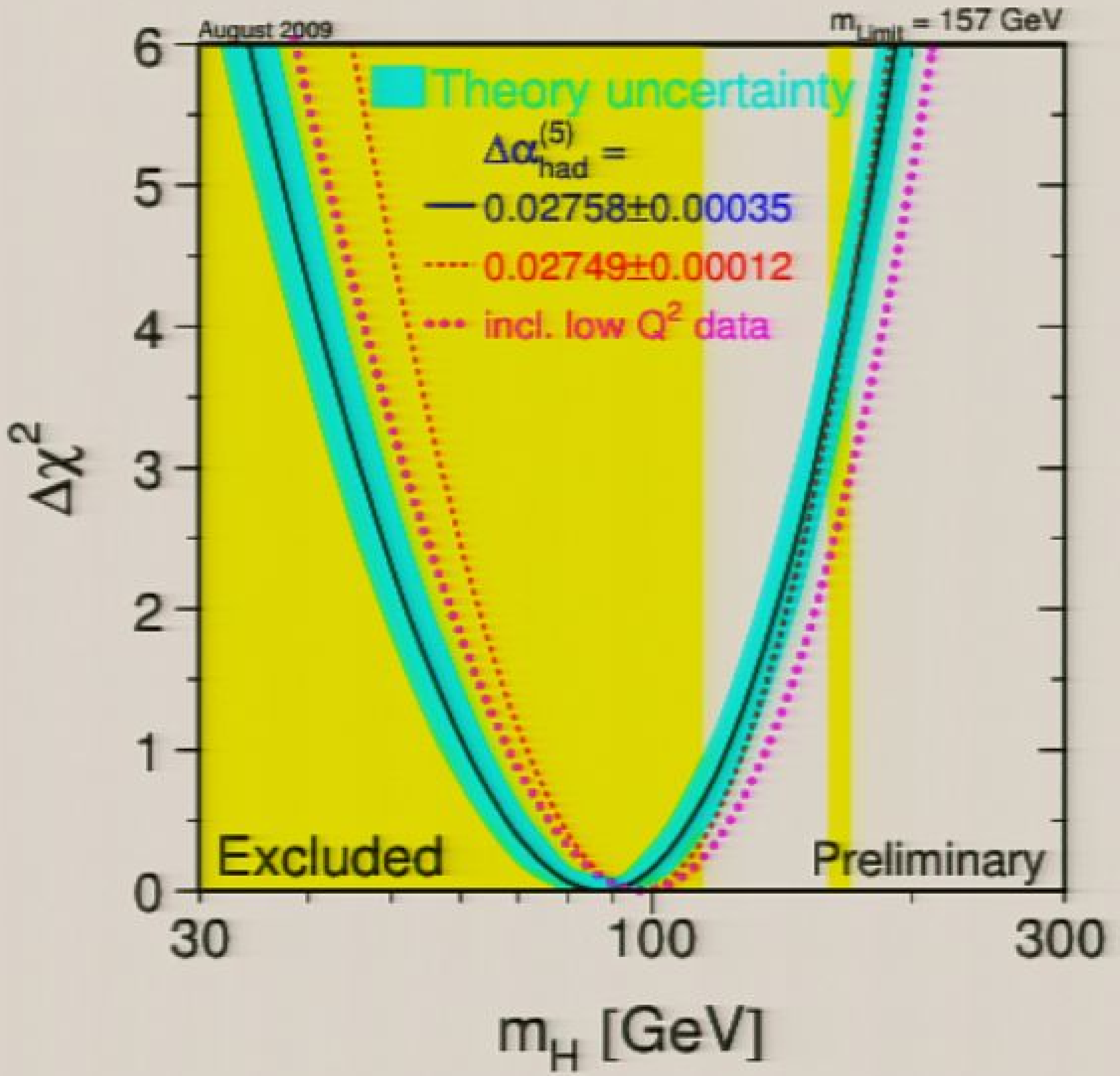




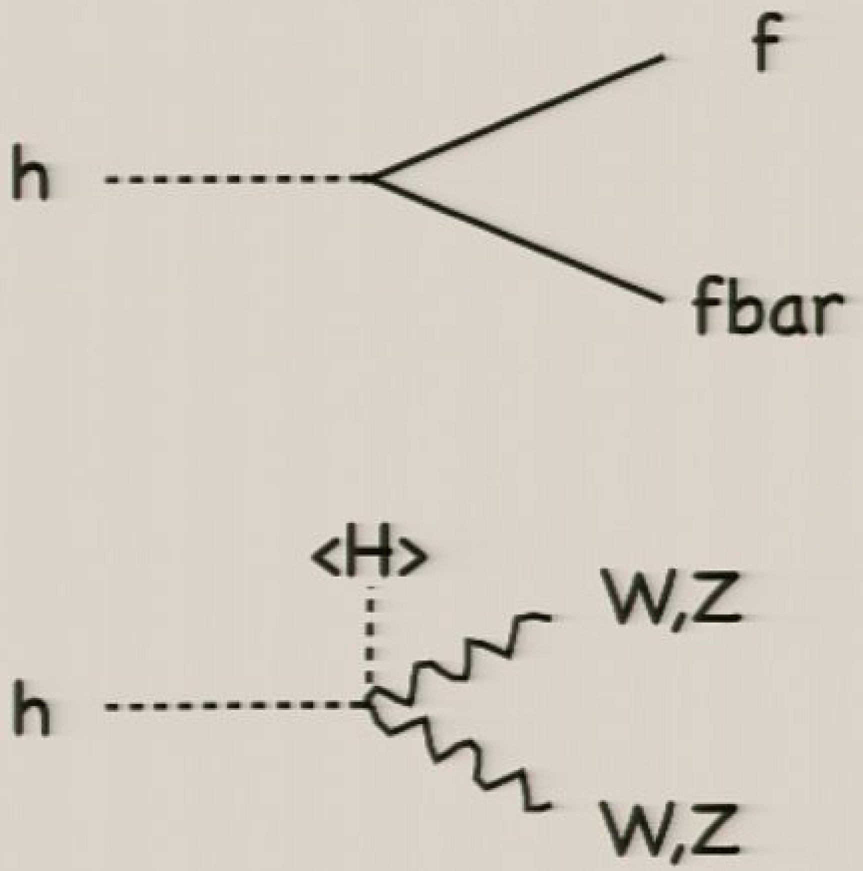
Virtual Electroweak Effects



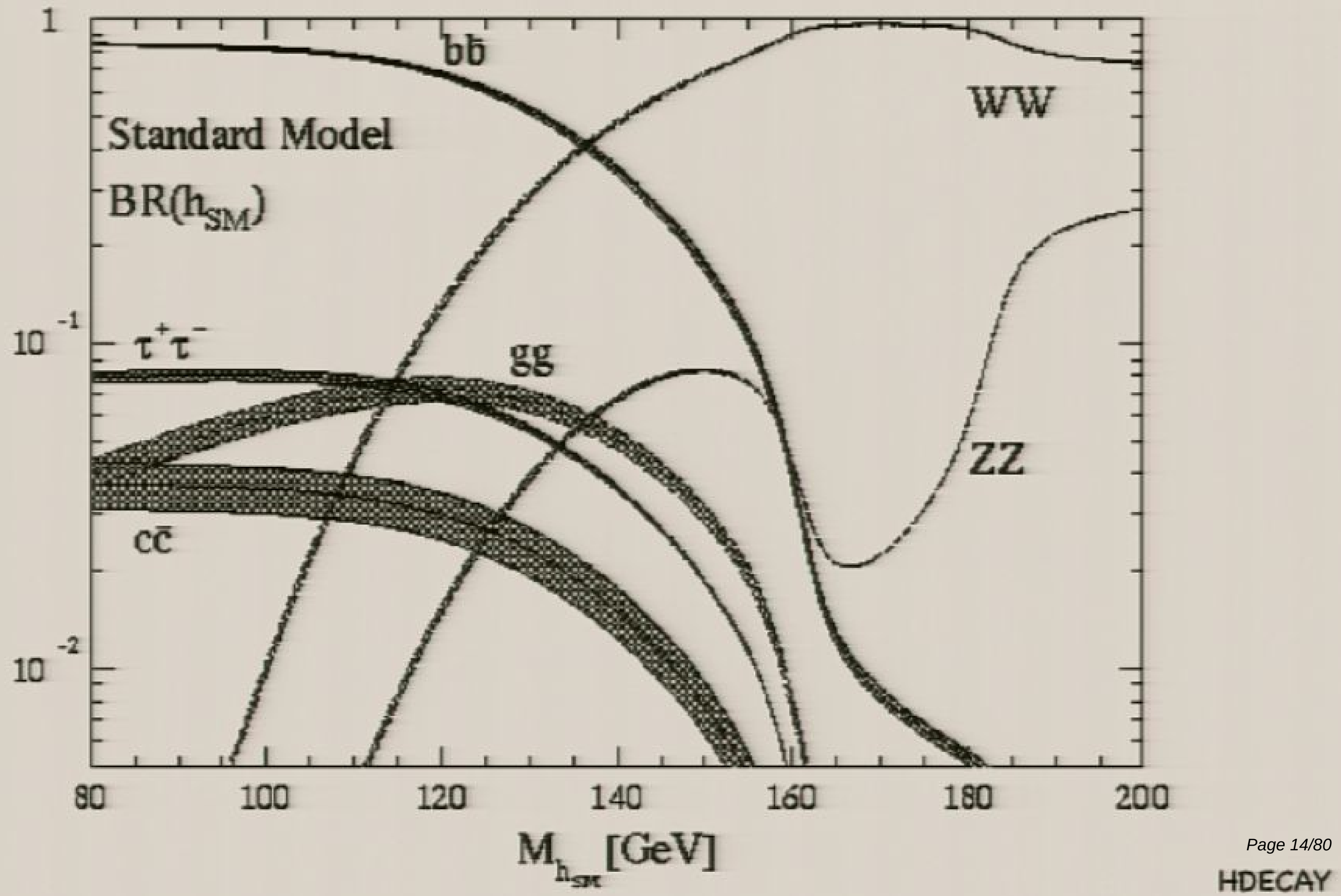
Suggest SM Higgs is Light



h Decay



Branching Ratios of SM Higgs



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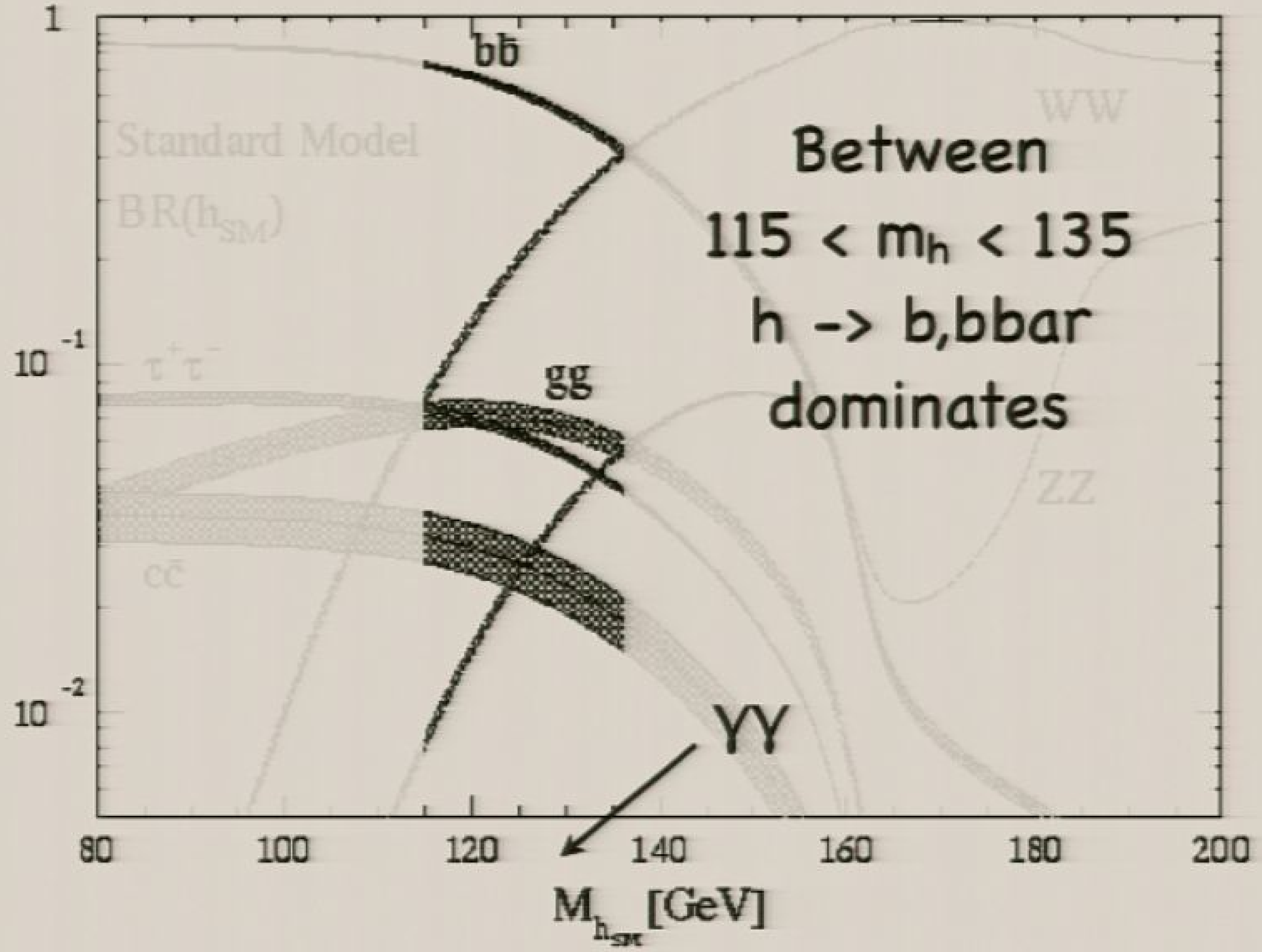
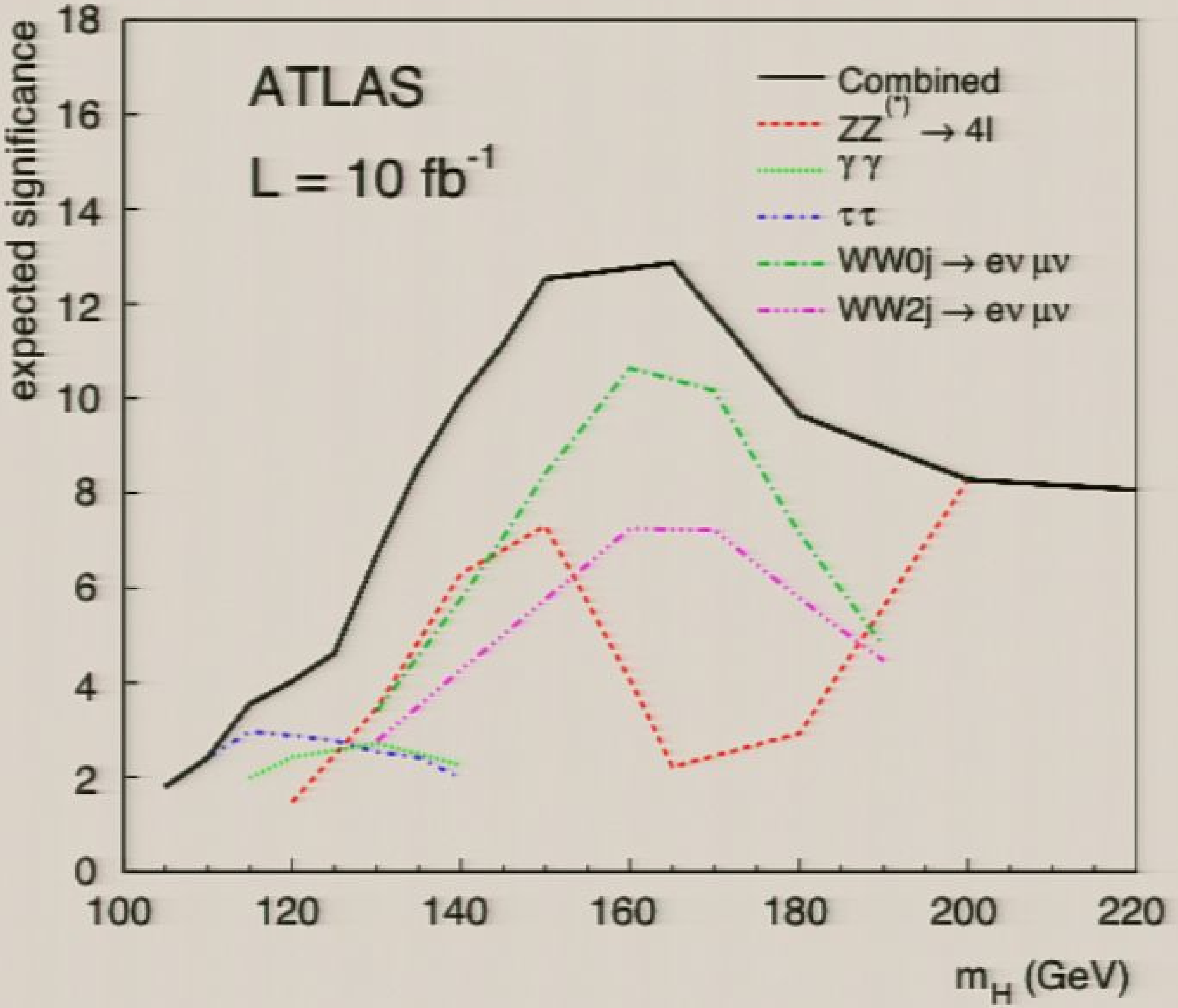


ATLAS TDR 2009



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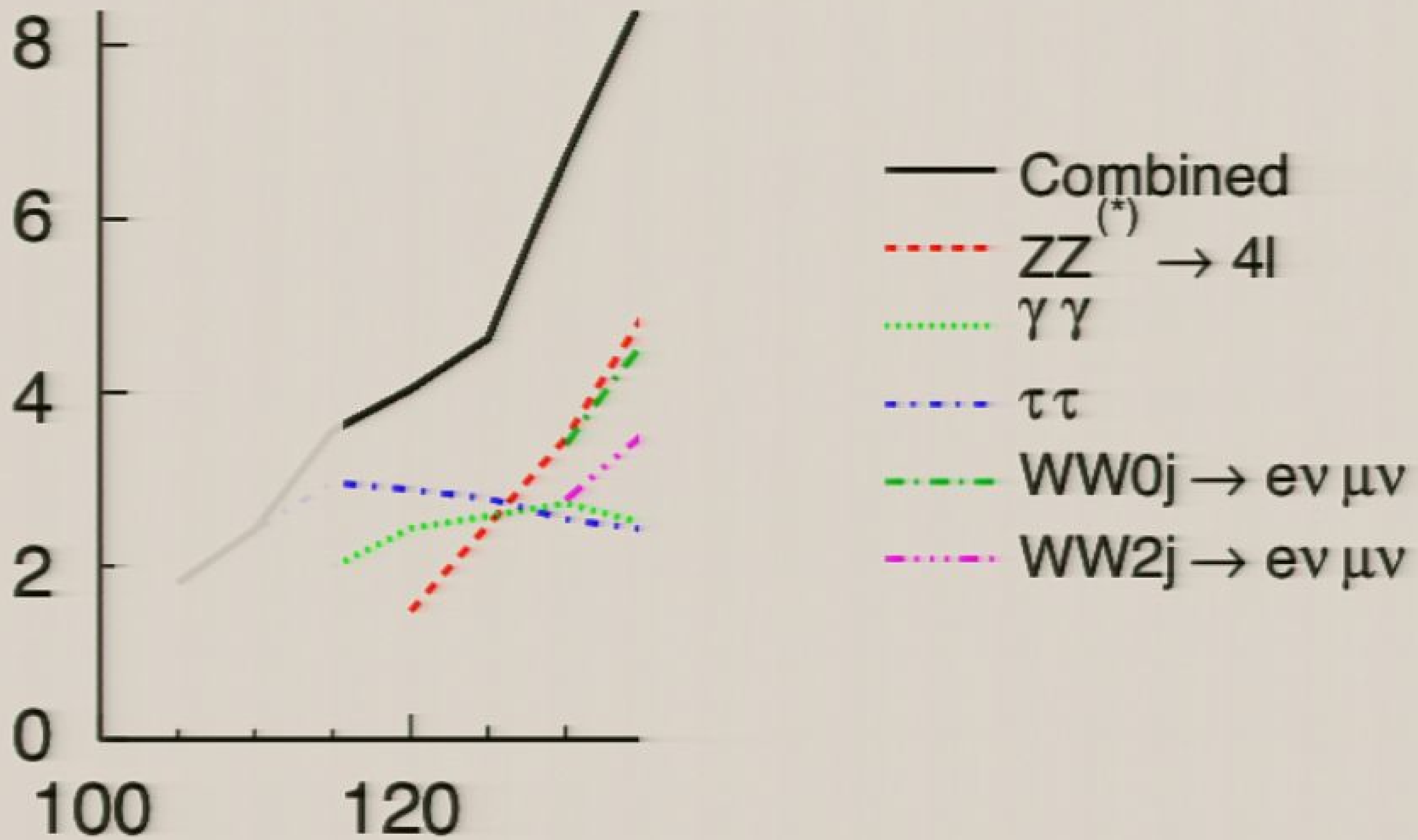
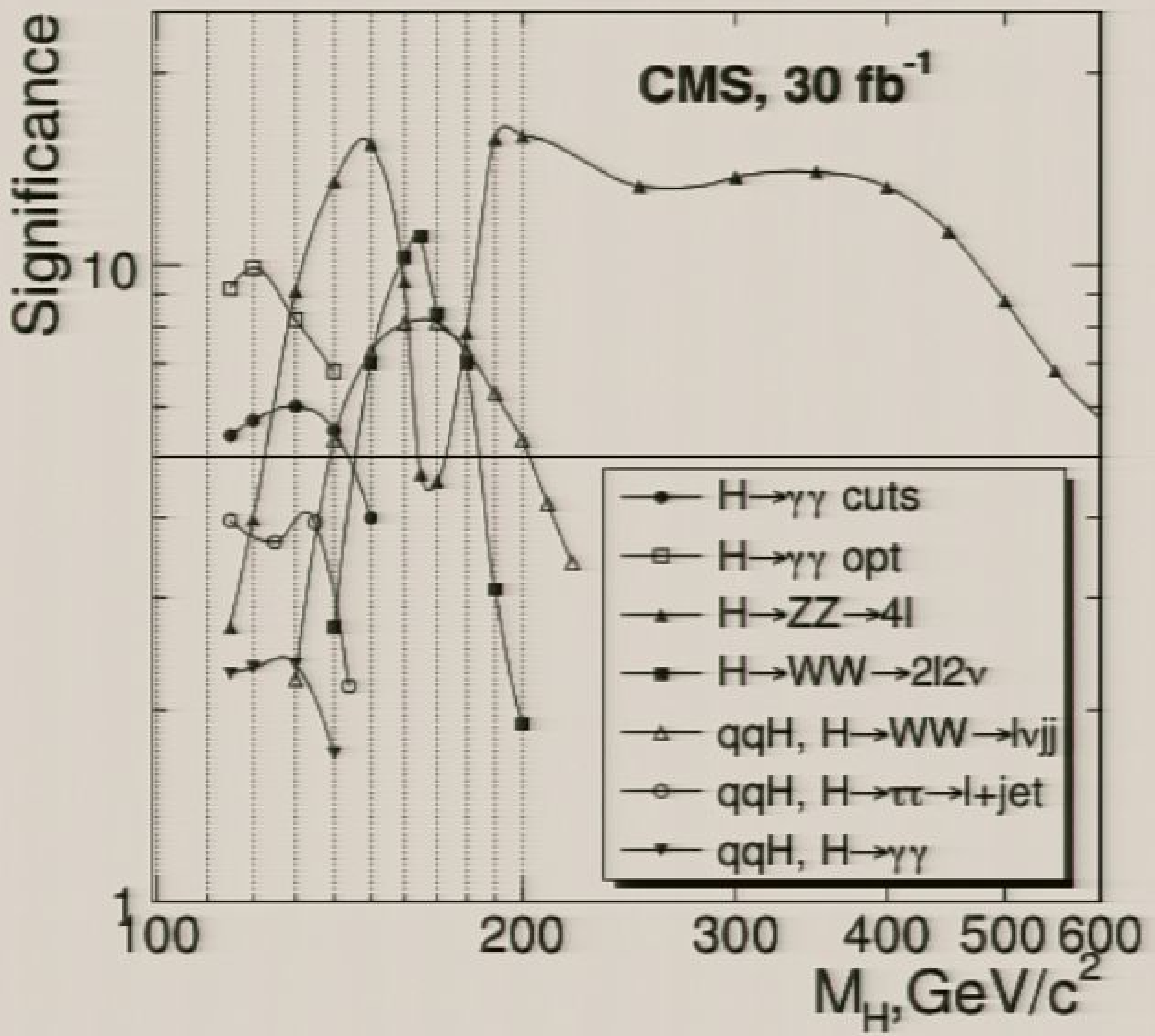
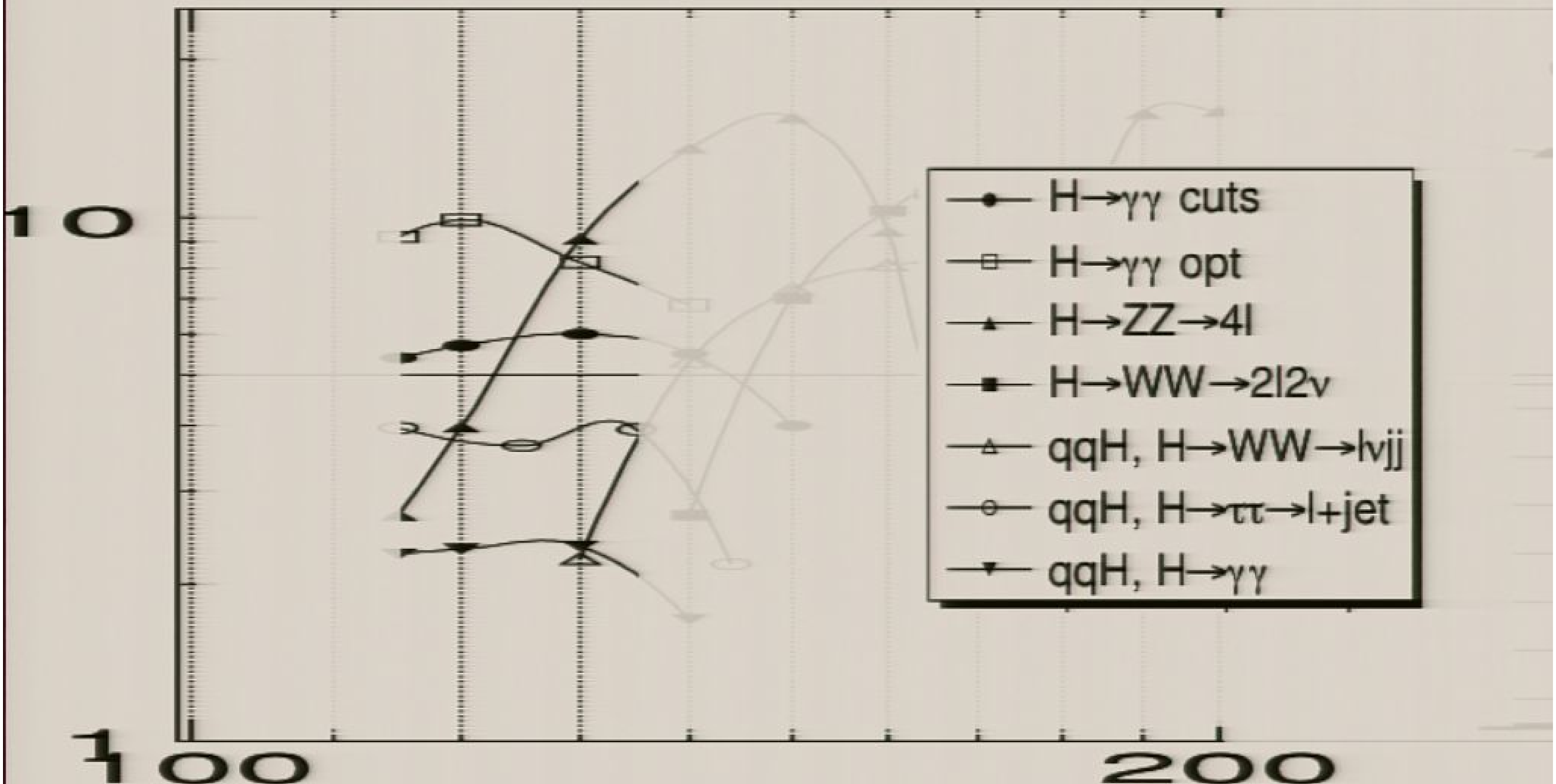


CMS TDR 2006


CMS, 30 fb^{-1}
Significance
10
1
100
200
300
400
500
600
M_H, GeV/c^2
$H\to\gamma\gamma$ cuts
$H\to\gamma\gamma$ opt
$H\to ZZ\to 4l$
$H\to WW\to 2l2\nu$
qqH, $H\to WW\to l\nu jj$
qqH, $H\to\tau\tau\to l$+jet
qqH, $H\to\gamma\gamma$

CMS TDR 2006



10
1
100
200
H→γγ cuts
H→γγ opt
H→ZZ→4l
H→WW→2l2ν
qqH, H→WW→lνjj
qqH, H→ττ→l+jet
qqH, H→γγ

Viable Channels for $115 < m_h < 125$

$h \to \gamma\gamma$ $\quad$ $BR(h \to \gamma\gamma) \approx 1\text{-}2 \times 10^{-3}$

$h \to \tau\tau$ $\quad$ $BR(h \to \tau\tau) \approx 5\text{-}7 \times 10^{-2}$

Until 2008, was thought that the largest one,
$BR(h \to b,\bar{b}) \approx 0.7\text{-}0.9$
was lost in the QCD background.

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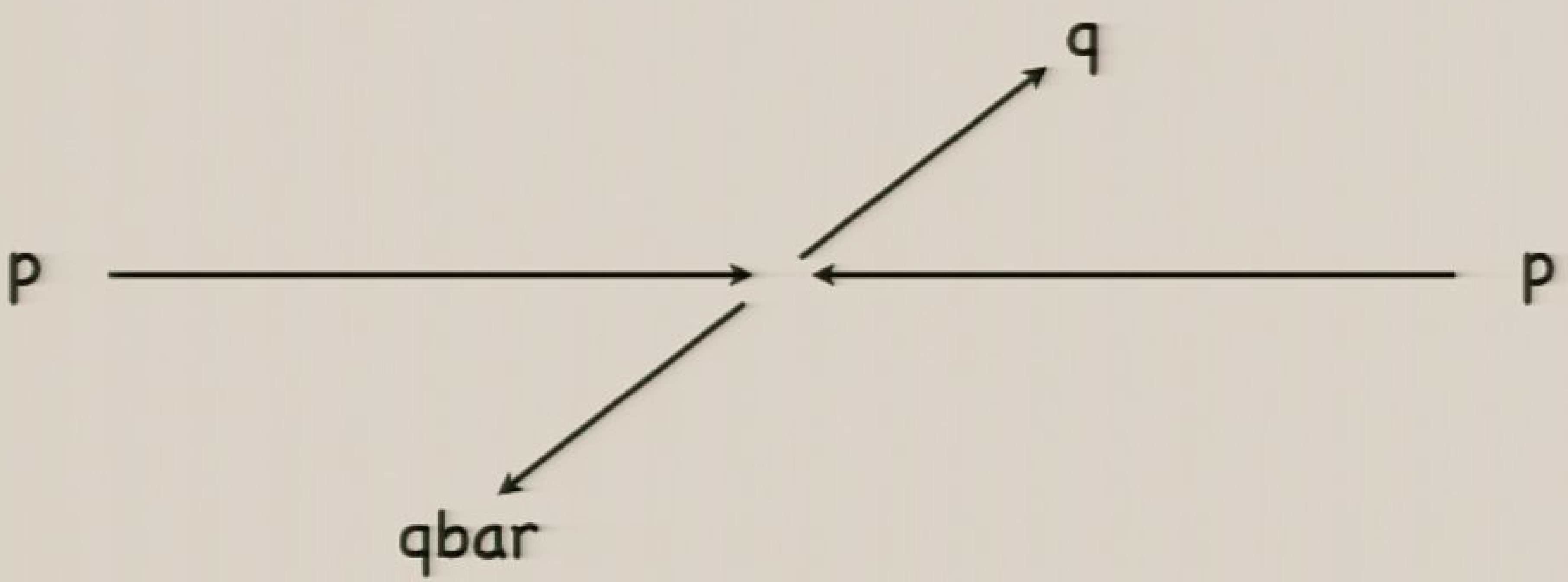
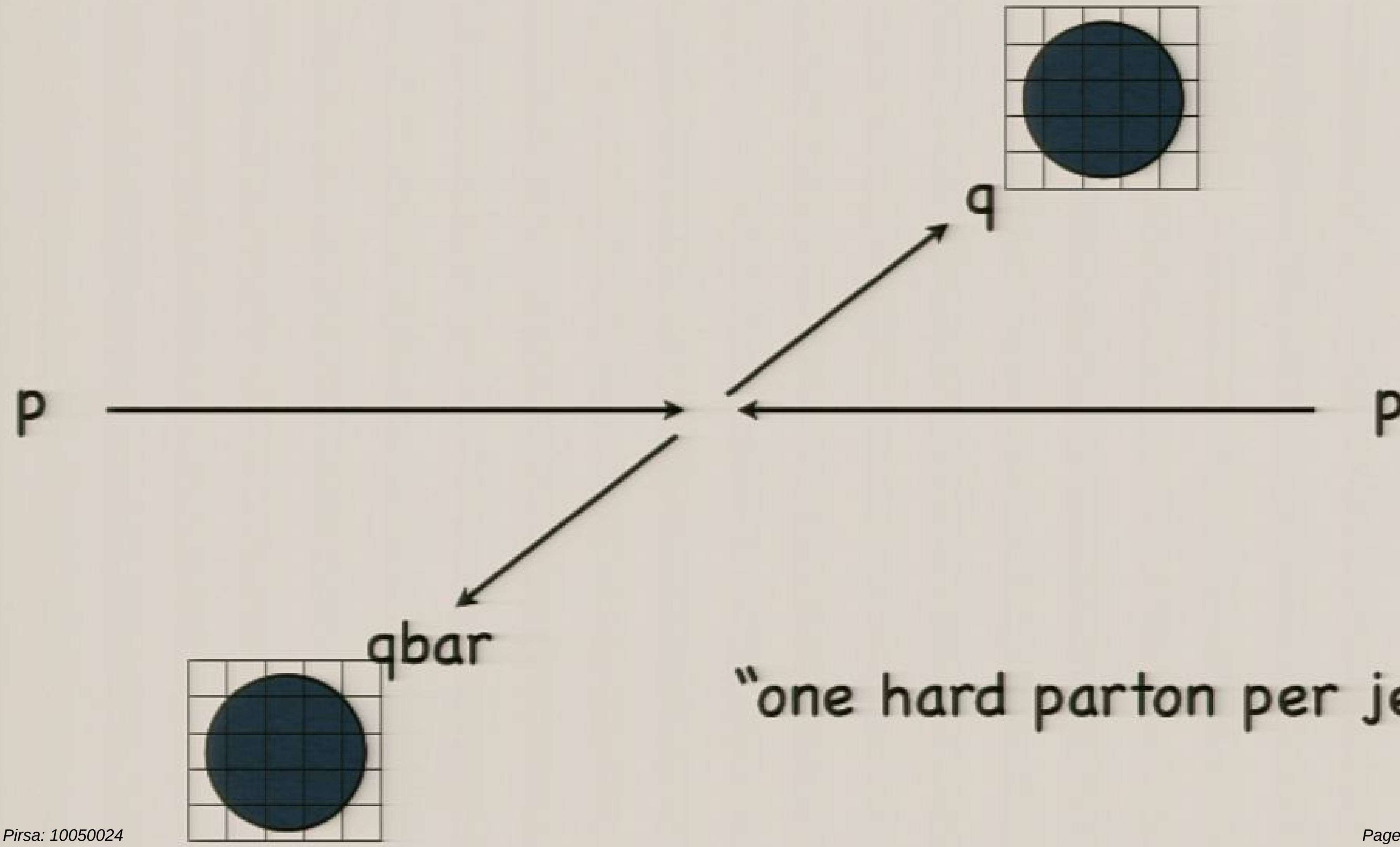
Common Lore
(for this theorist)

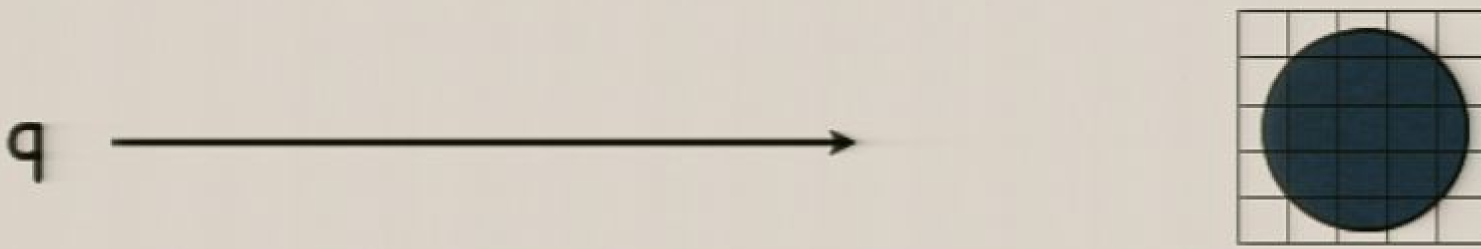


Common Lore

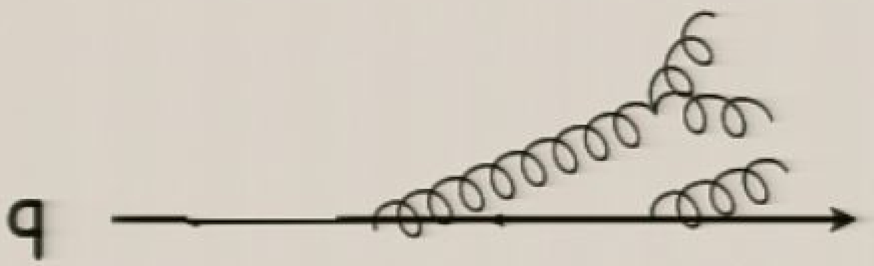


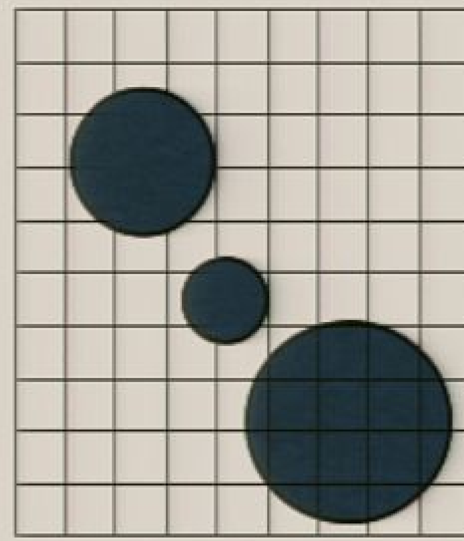
"one hard parton per jet"

Parton to Detector...



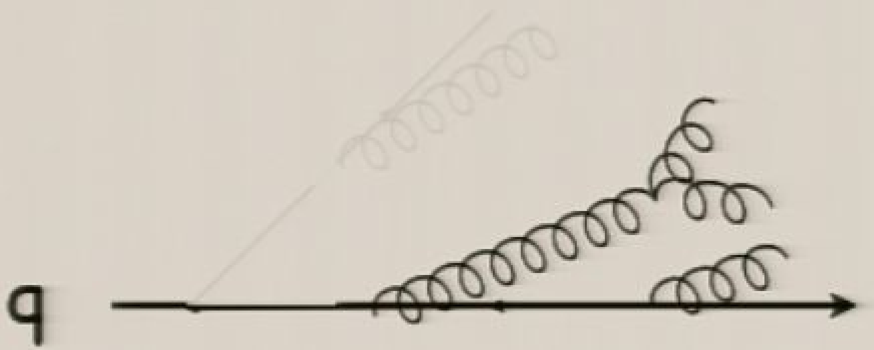
More complicated...

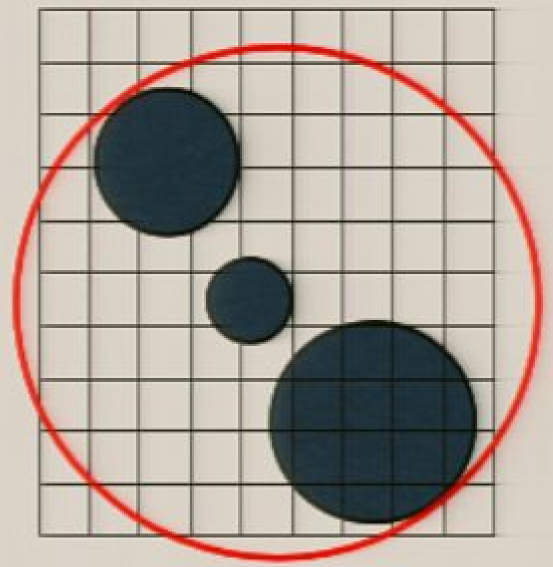




Parton shower; hadronization/decay...

More complicated...

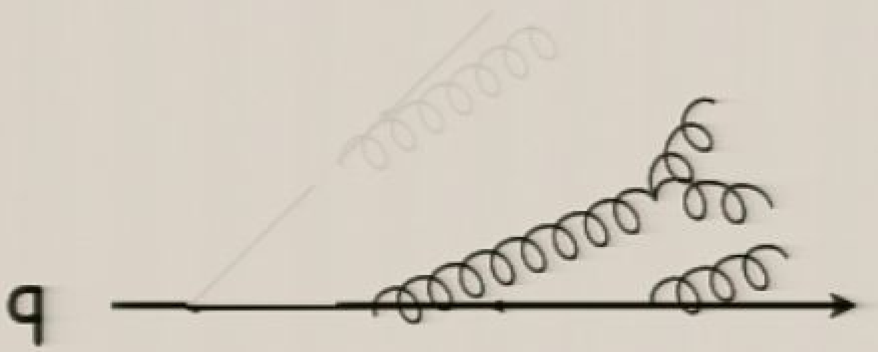


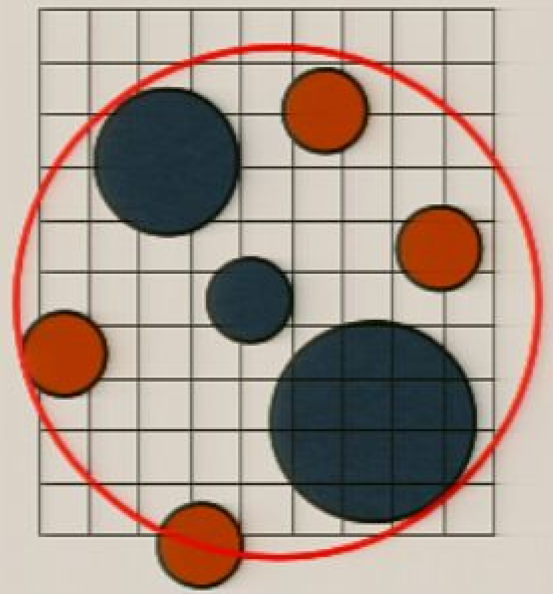


Parton energy -> Jet energy

Need to capture radiation

Even more complicated...

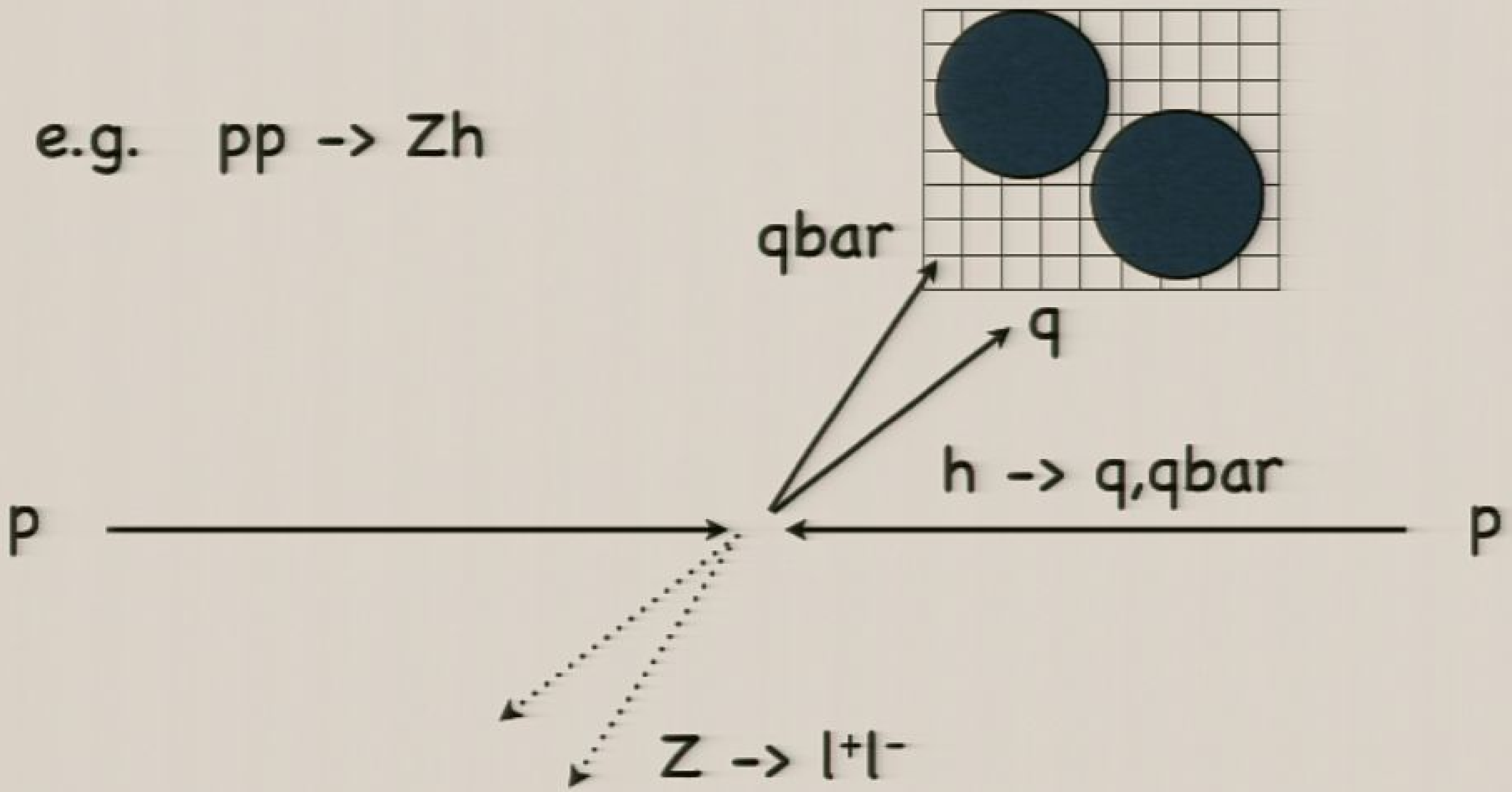




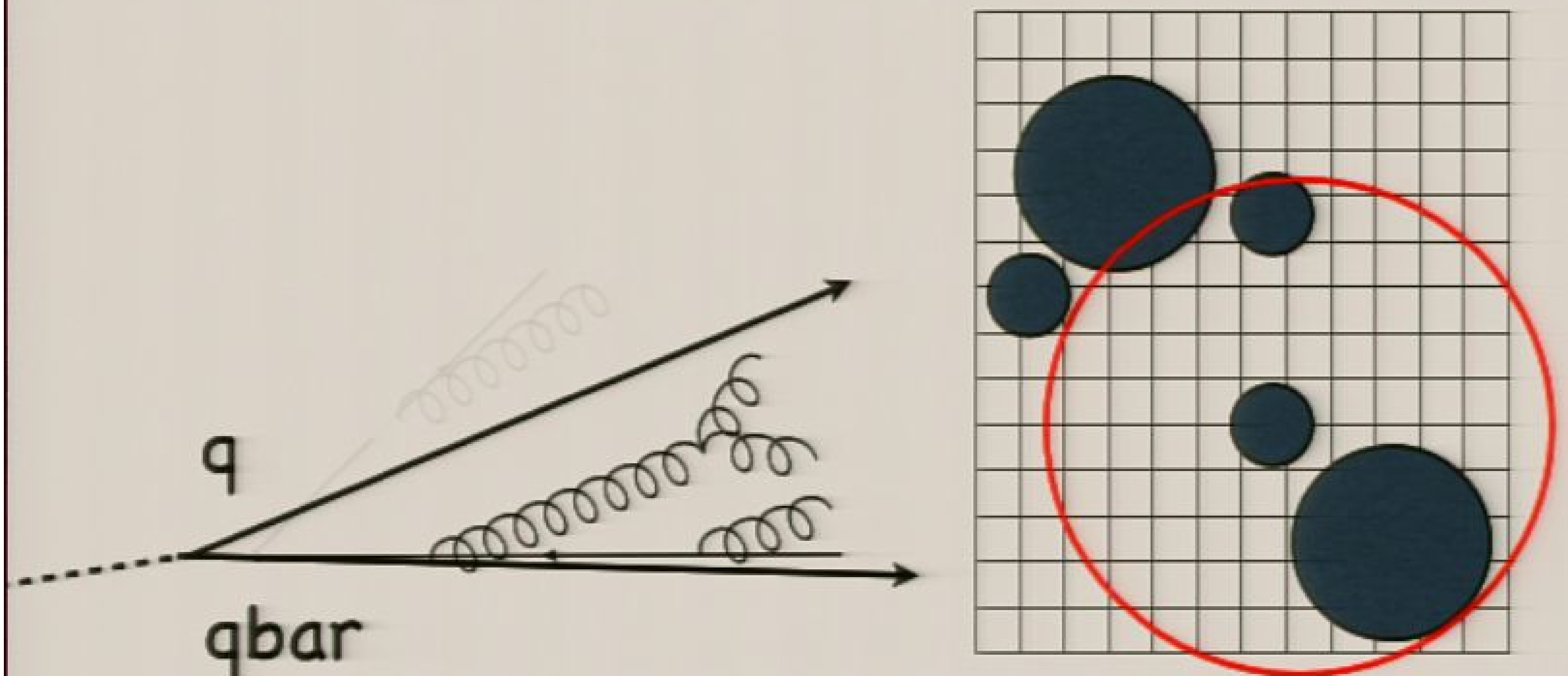
Jet cone contains non-parton energy
(underlying event)

Boosted Jets

e.g. pp -> Zh

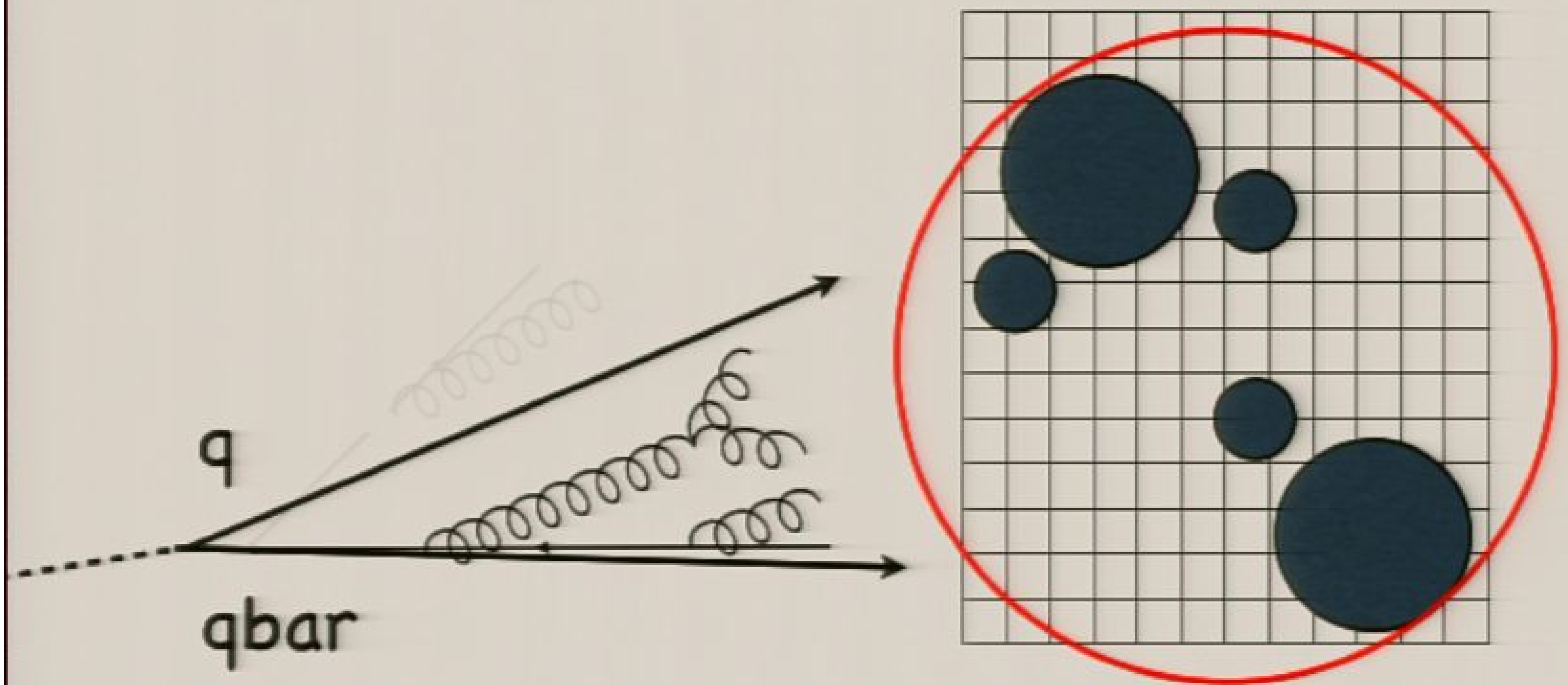


Boosted Jets



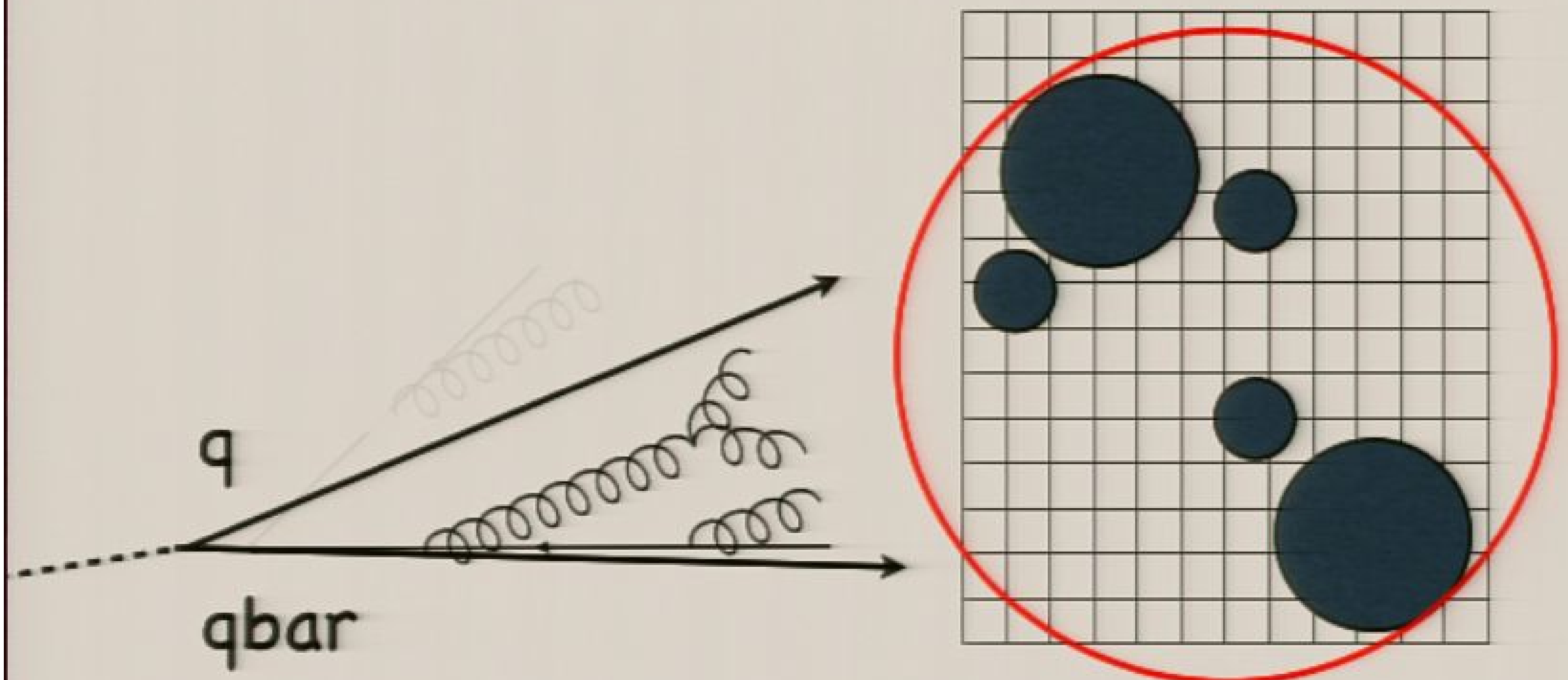
Jet cone has energy from two hard partons and their showers!

Boosted Jets



Enlarge jet cone to capture
hard partons and shower radiation

Boosted Jets

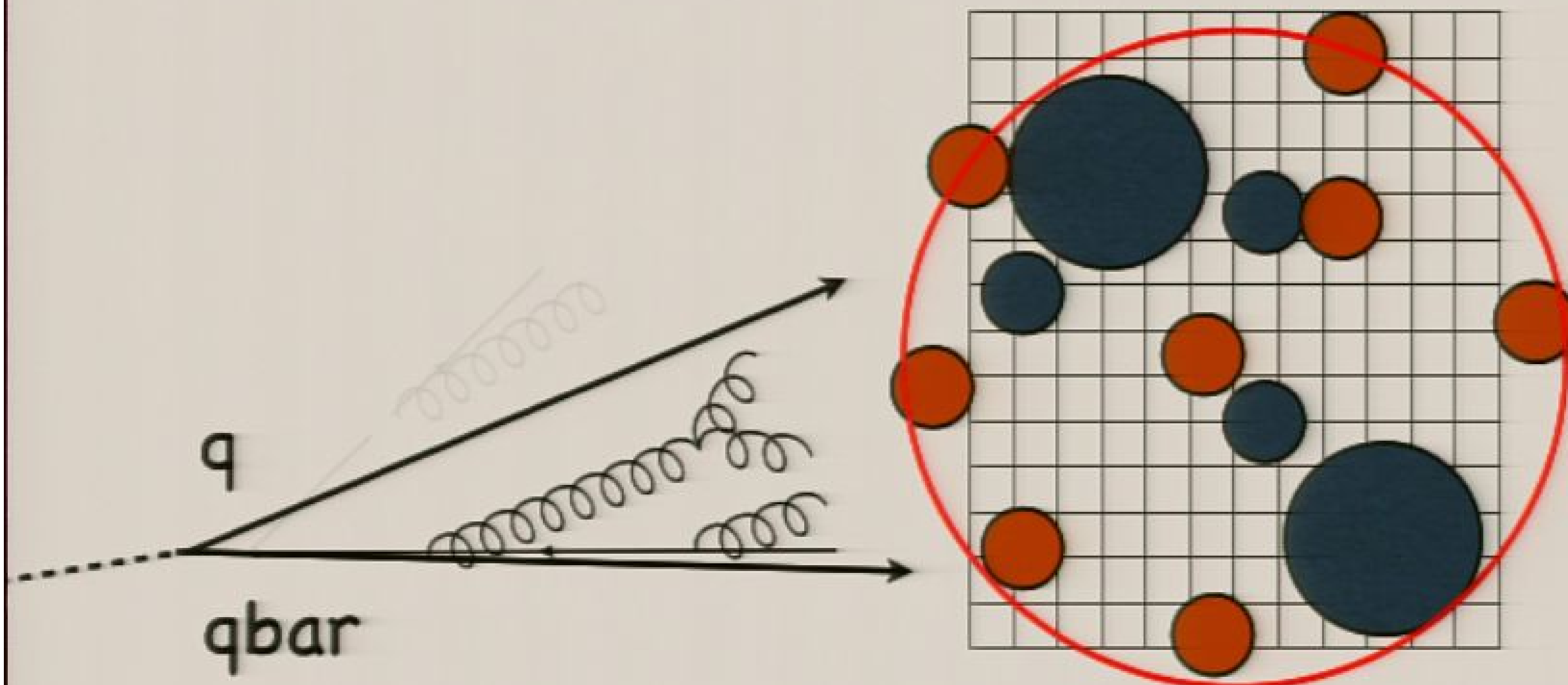


Boosted Advantage: Objects with high pT have excellent jet energy resolution:

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

(ATLAS TDR, cone jets.)

Boosted Jets



Large Cone Disadvantage: Underlying event significantly contaminates "fat jet" energy

BDRS

(Butterworth, Davison, Rubin, Salam; 0802.2470)

Proposed a technique that involved "jet substructure" and "filtering" to discover

h -> b,bbar

for 115 < m_h < 125 GeV range.

BDRS Basic Premise:

Lose cross section by requiring Higgs is boosted
pT(h) > 200 GeV
(only 5% of Zh/Wh production at
14 TeV LHC has this level of boost)

Gain on signal/background through the
relative uniqueness and characteristics
of the "fat jet" over QCD background

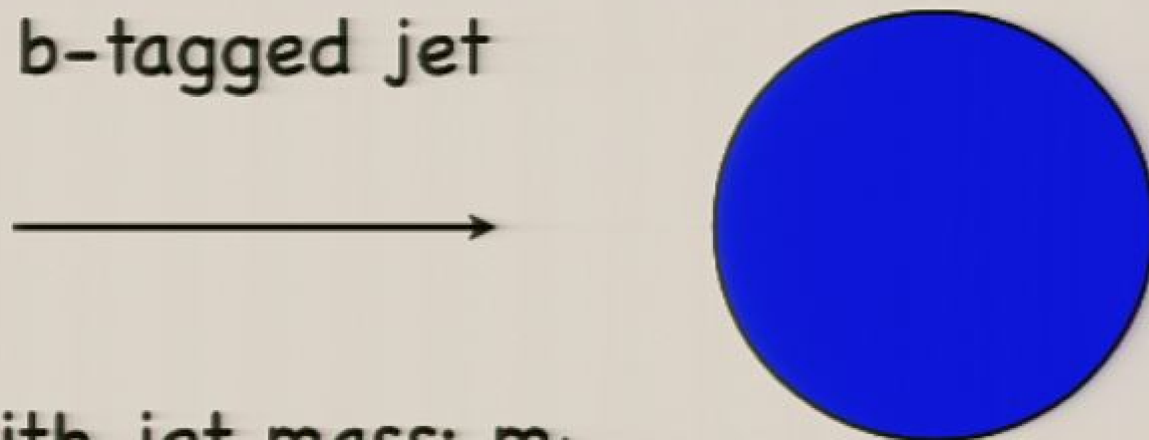
BDRS Requirements

- trigger! Zh or Wh with leptonic Z/W decay
- pT(h) > 200 GeV
- several (standard) cuts to help reduce background

- cluster jets with inclusive Cambridge/Aachen R = 1.2
- "fat jet" is b-tagged
- "mass drop" from jets to subjets
- "symmetric" pT from jets to subjets
- two b-tags of two highest pT subjets
- filter the subjets

Jet Decomposition

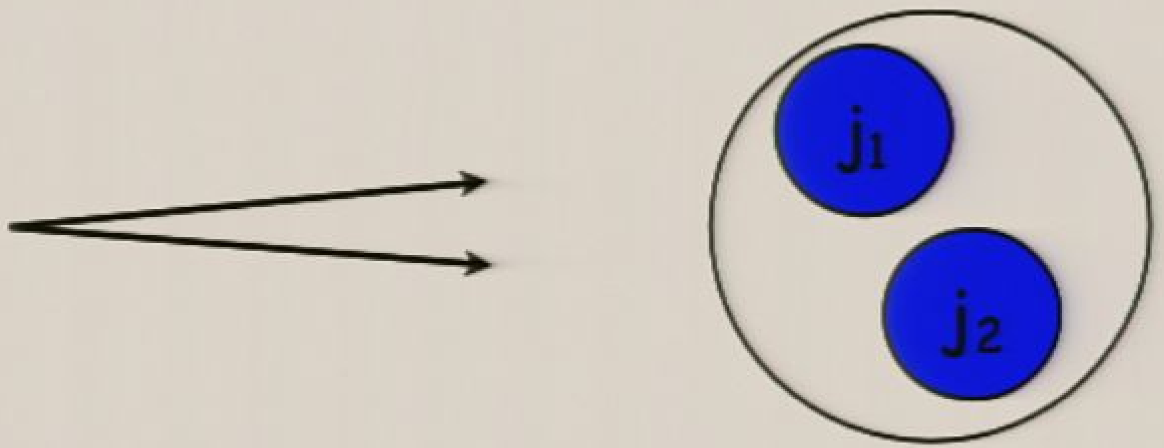
b-tagged jet



with jet mass: m_j

Jet Decomposition

undo clustering

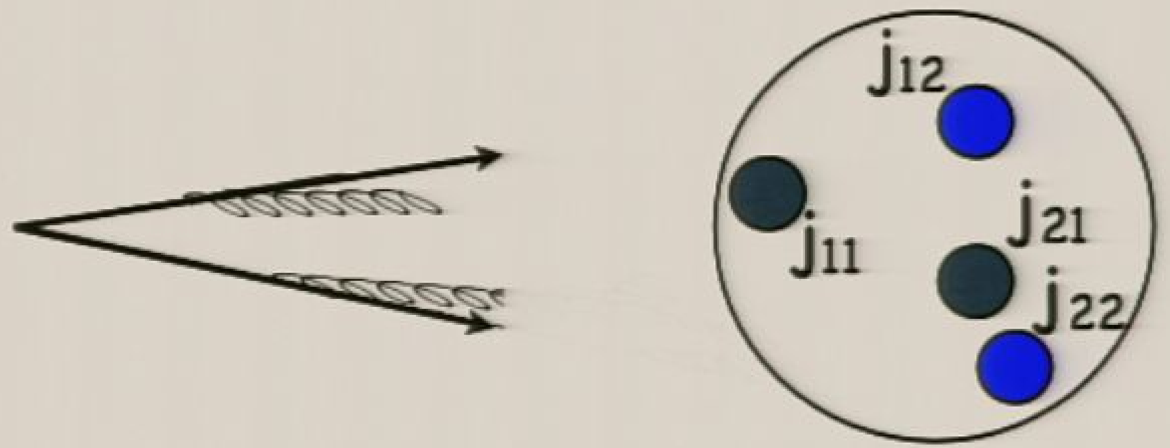


In C/A, this came from two jets with masses

m_{j1} , m_{j2}

Jet Decomposition

repeat unclustering:



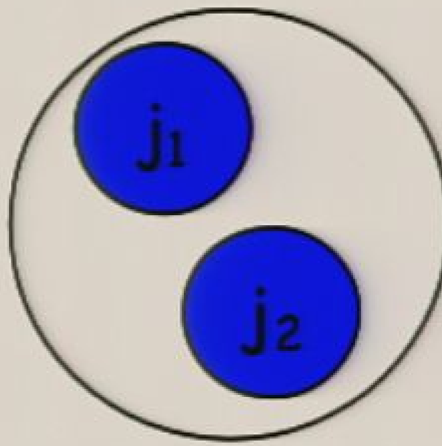
four jets with masses: m_{j11} m_{j12} m_{j21} m_{j22}

Higgs Jet Identification

1) check for mass drop

$m_{j1} < \mu \, m_j$?

$0<\mu<1$ is a parameter



2) check "asymmetry"

$$y = \frac{\min\left(p_{t_{j1}}^2, p_{t_{j2}}^2\right)}{m_j^2} \Delta R_{j1,j2}^2 > y_{\rm cut}$$

y_{cut} is a parameter

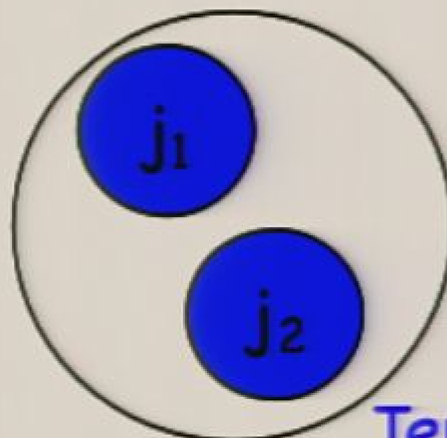
Higgs Jet Identification

1) check for mass drop

$m_{j1} < \mu\, m_j$?

BDRS used $\mu = 0.68$

Expect drop for heavy particle decay



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$$y = \frac{\min\left(p_{t_{j1}}^2, p_{t_{j2}}^2\right)}{m_j^2} \Delta R_{j_1, j_2}^2 > y_{\rm cut}$$

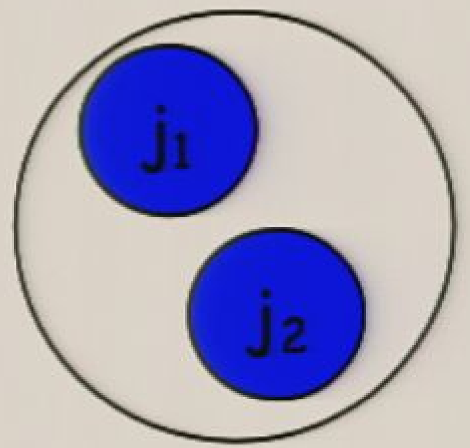
BDRS used $y_{cut} = (0.3)^2$

Tends to reject soft/colinear QCD contamination

Higgs Jet Identification

3) are both subjets b-tagged?

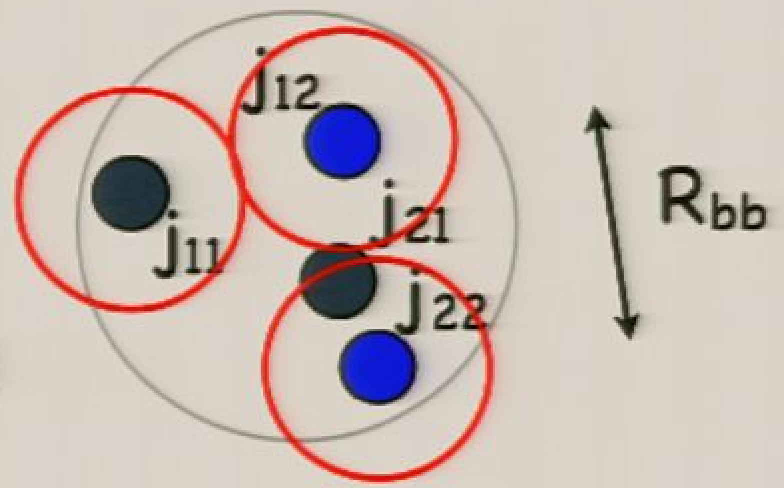
yes - continue
no - scrap this "fat jet"



Higgs Jet Identification

4) Filter the subjets to remove more UE:

- take 3 highest pT subjets ("third" captures leading parton shower gluon)
- subjets $R_{j1,j2,j3} = \min(R_{bb}/2, 0.3)$



Higgs Candidate Mass formed from 3 highest pT subjets

Higgs Jet Identification

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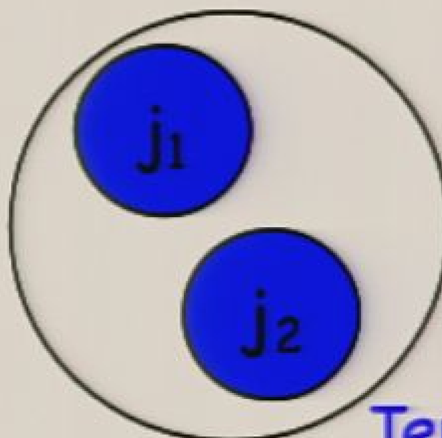
Expect drop for heavy particle decay



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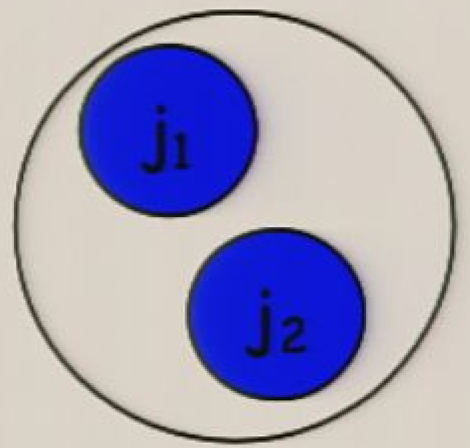

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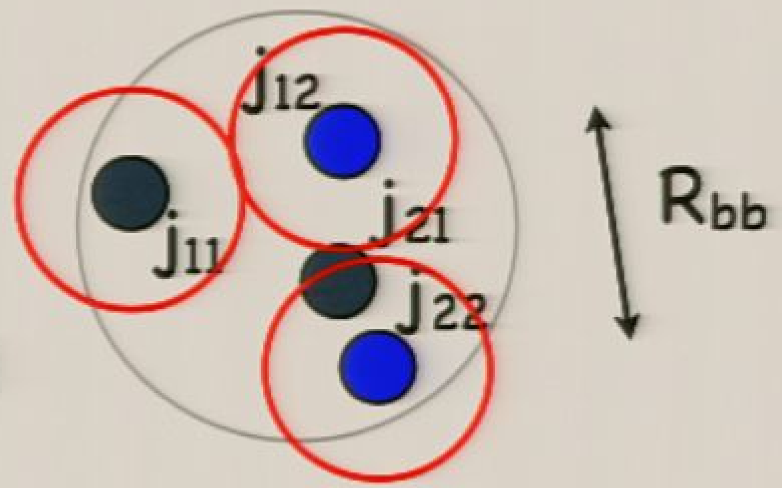
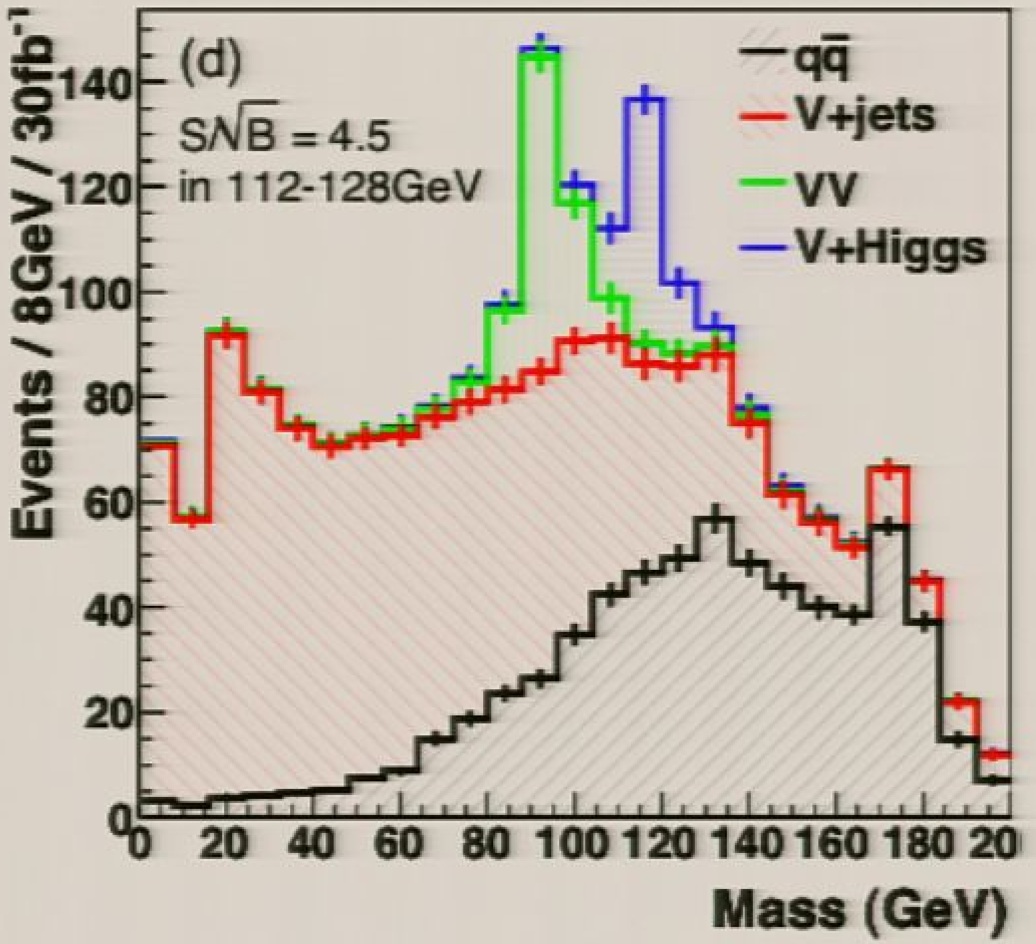


Higgs Candidate Mass formed from 3 highest pT subjets

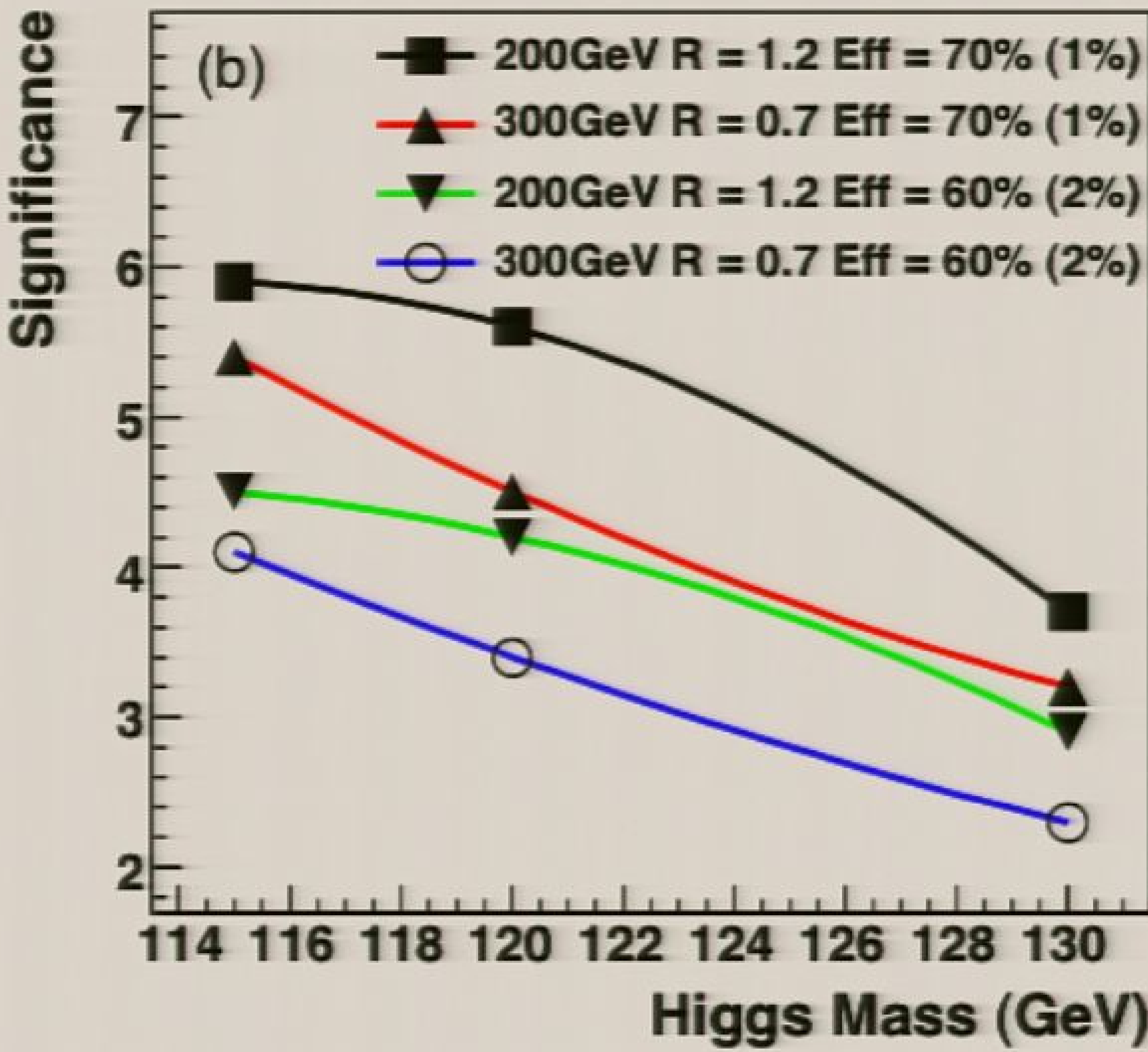
BDRS Result



- LHC 14 TeV; 30 fb^{-1}
- HERWIG/JIMMY cross-checked with PYTHIA with "ATLAS tune"
- 60% b-tag; 2% mistag
- no smearing

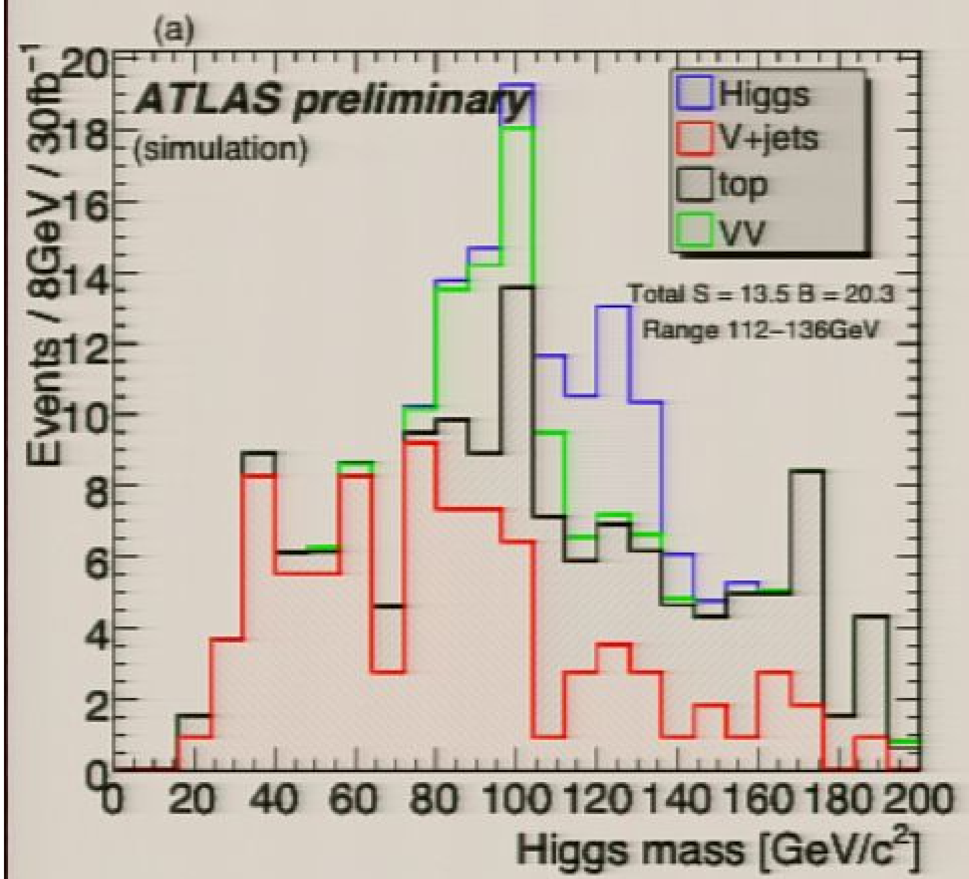
BDRS 0802.2470

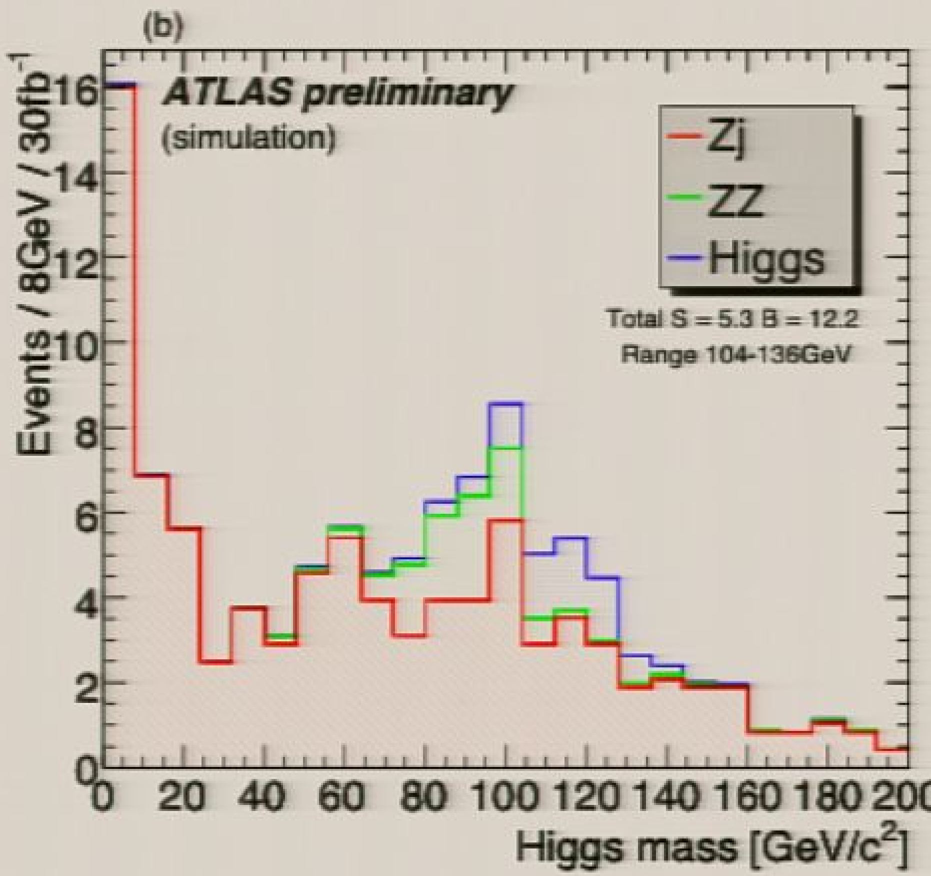
BDRS Result



BDRS 0802.2470

ATLAS Simulation





ATL-PHYS-PUB-2009-088 (Aug 2009)

ATLAS Simulation

For the cut-based analysis presented here, the combined sensitivity of these channels after an integrated luminosity $L = 30\ \text{fb}^{-1}$ of data, considering only statistical errors, is 3.7σ for a Higgs-boson mass of 120 GeV. If the major backgrounds have a systematic uncertainty of around 15%, the significance drops to 3.0σ, and if the systematic uncertainty is as high as 50% this sensitivity drops to around 2.2σ. For $L = 10\ \text{fb}^{-1}$ we might expect sensitivity of up to 2.1σ. This is very close to the ATLAS sensitivity in any other single channel [2] in this region. In addition, this channel would give the most direct information on the $H \to b\bar{b}$ coupling and will therefore be critical for determining the parameters of the Higgs sector [27].

$$S_{BDRS} \approx 4.2 \quad \text{versus} \quad S_{ATLAS} \approx 3.7$$

ATL-PHYS-PUB-2009-088 (Aug 2009)

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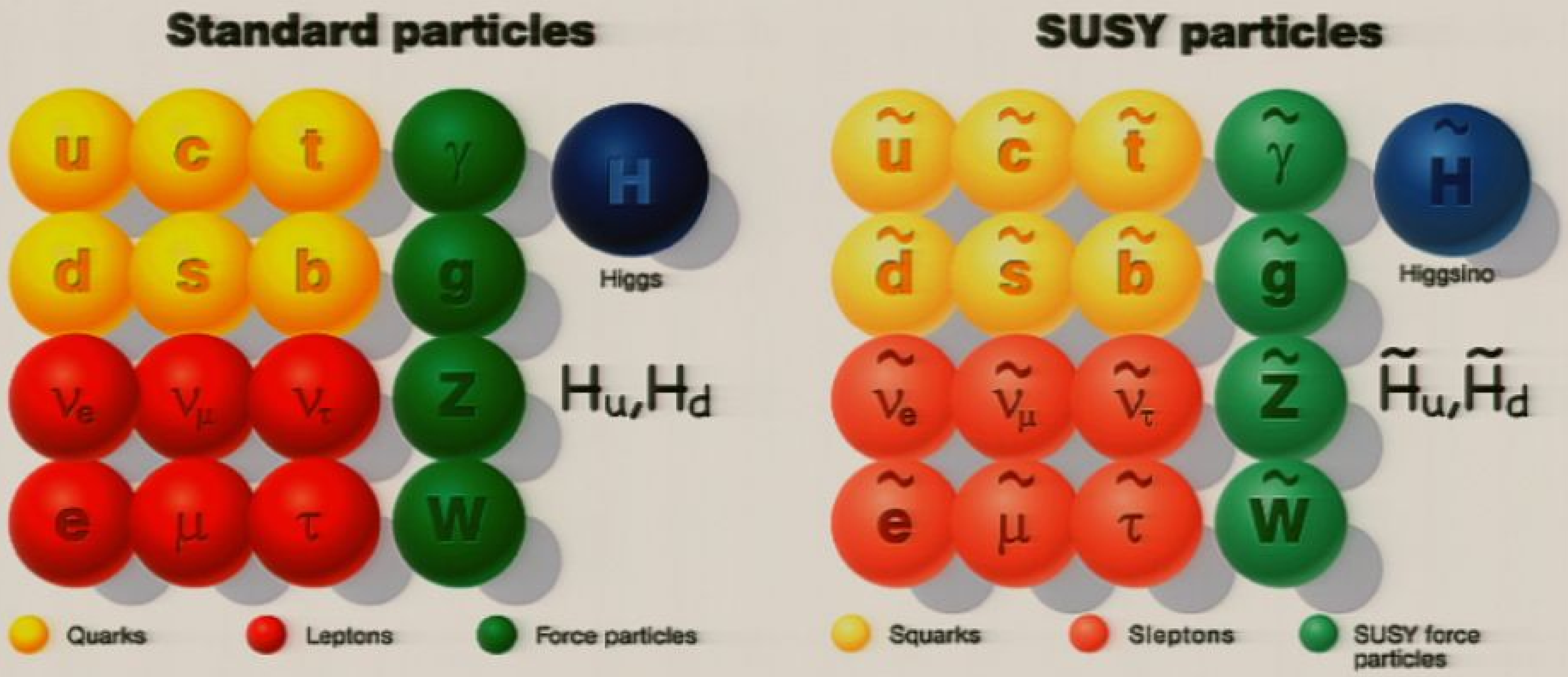
Weak Scale Supersymmetry



"Minimal Supersymmetric Standard Model (MSSM)"

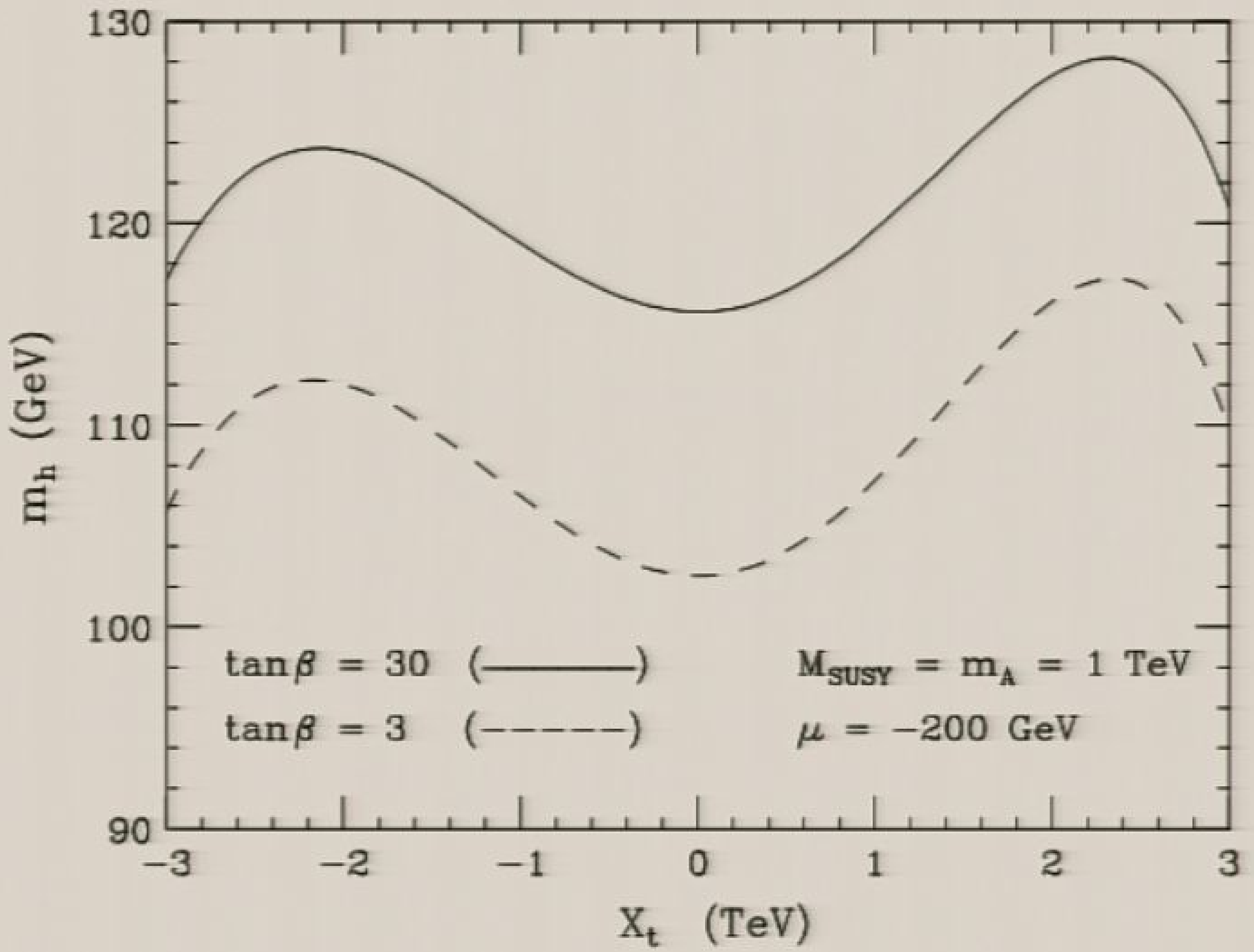
Higgs Sector of MSSM

quartic coupling λ — **determined!** $g^2 + (g')^2$ — up to radiative corrections

$$m_h^2 = M_Z^2 \left(\frac{\tan^2\beta - 1}{\tan^2\beta + 1} \right)^2 \quad + \quad y_t^4 \log m_{st}/m_t$$

(schematic)

h is light



Carena, Haber Higgs report 2002

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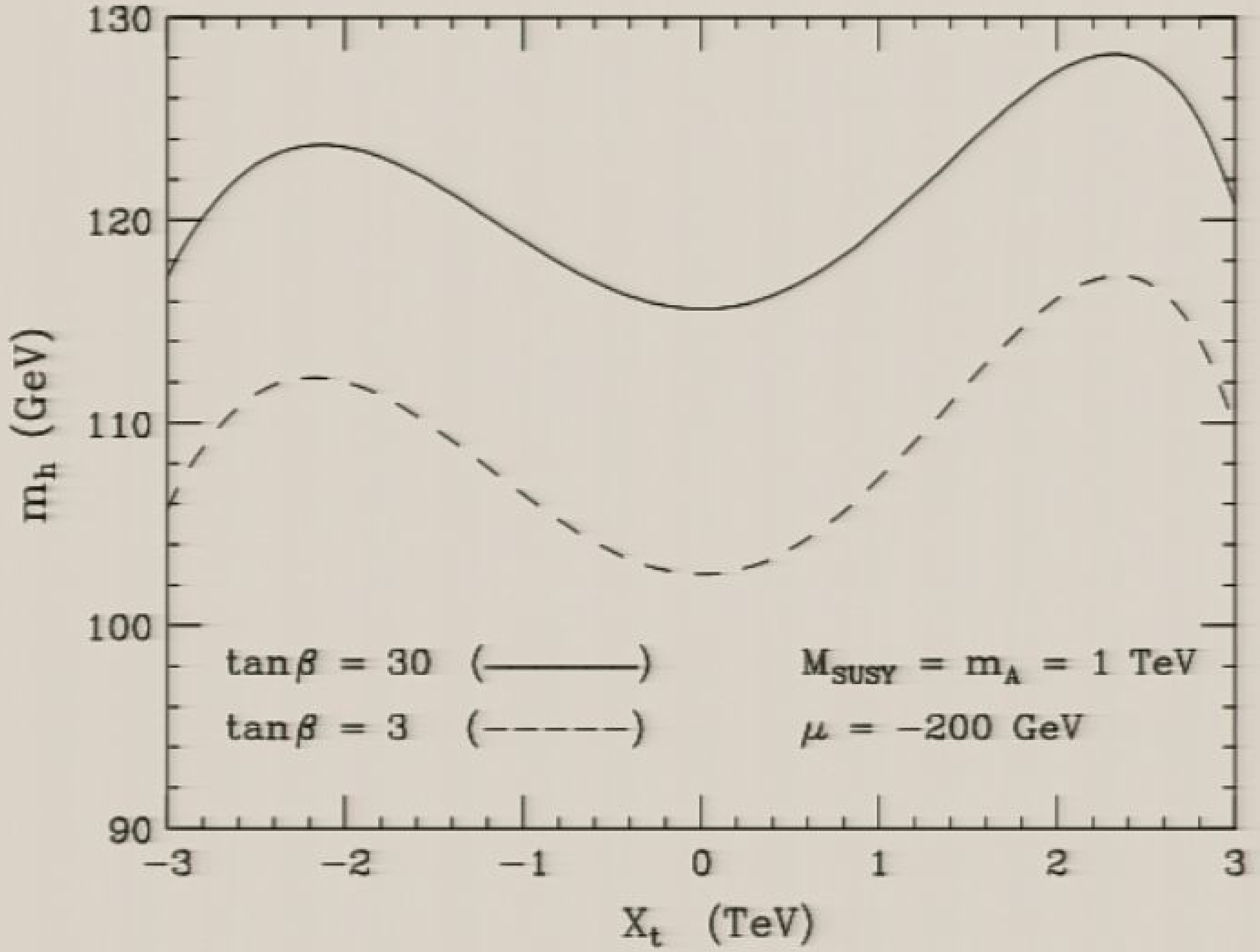

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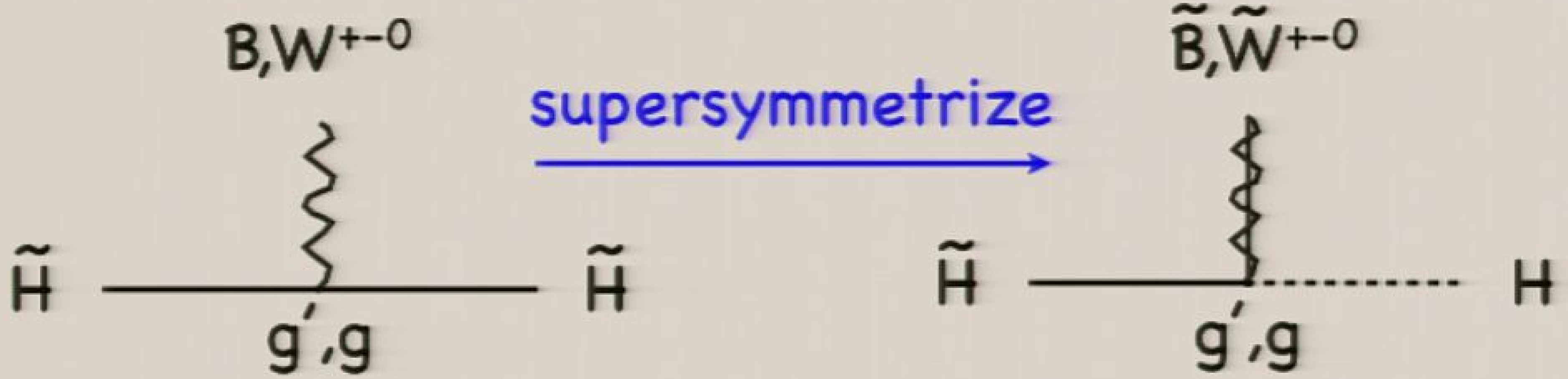
Supersymmetrize Higgs Interactions



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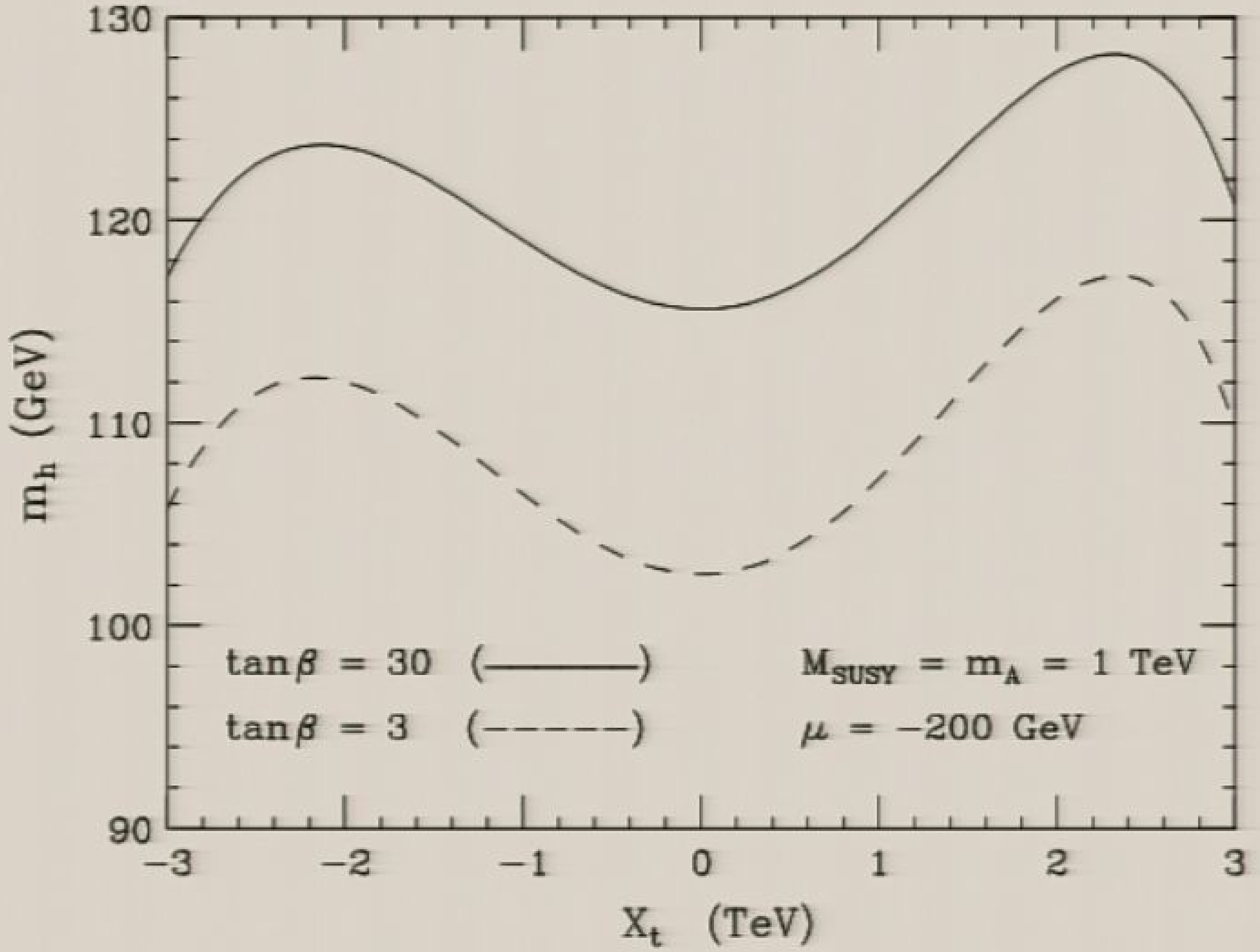
(schematic)

h is light



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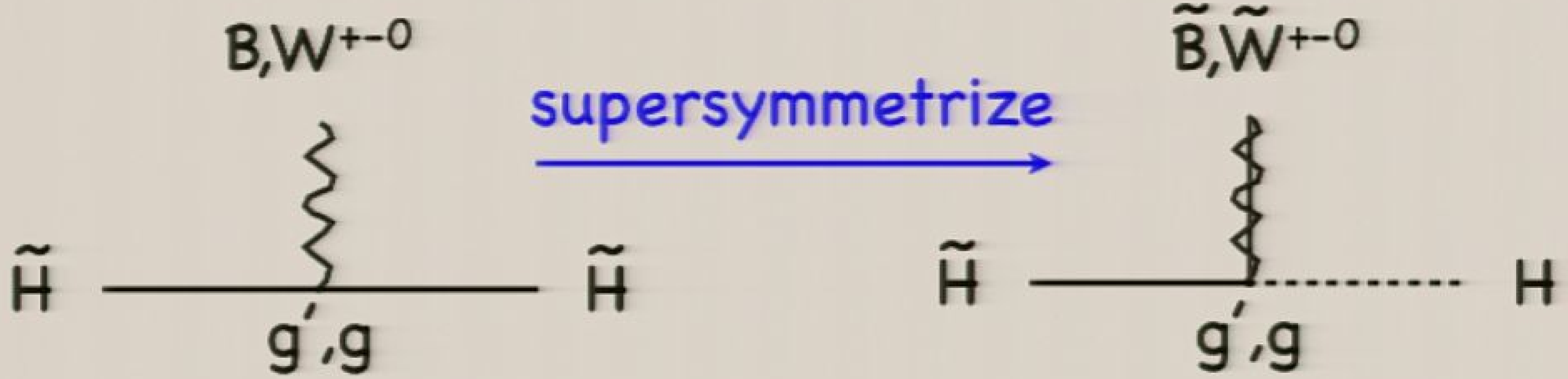
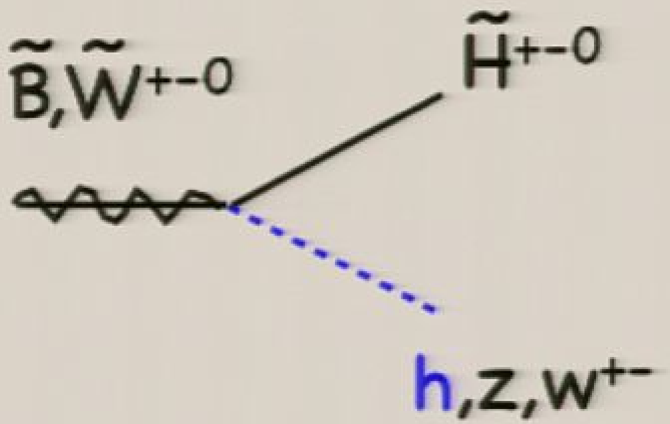
Supersymmetrize Higgs Interactions



Gauginos can decay to Higgs I

(if kinematically open)



"Goldstone region"

When m_A large,

≈ 25% of time

decay to h

≈ 75% of time to

longitudinal W/Z

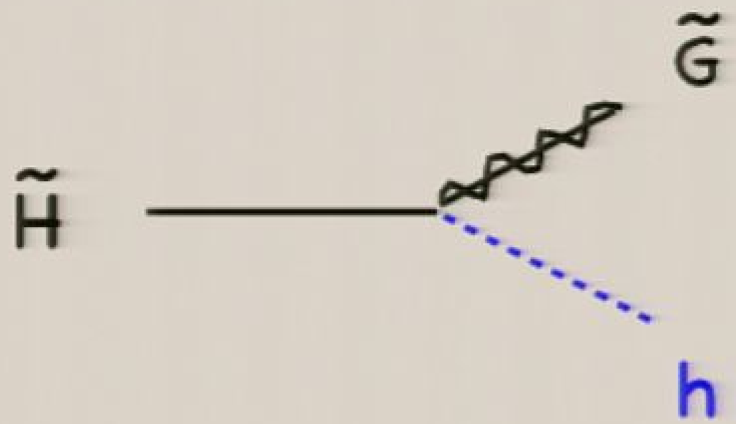
Kinematical requirement

$$m_W > \mu + m_h$$

$$> 100 + 120 = 220 \text{ GeV}$$

Gauginos can decay to Higgs II

(Higgsino NLSP; Gravitino LSP)



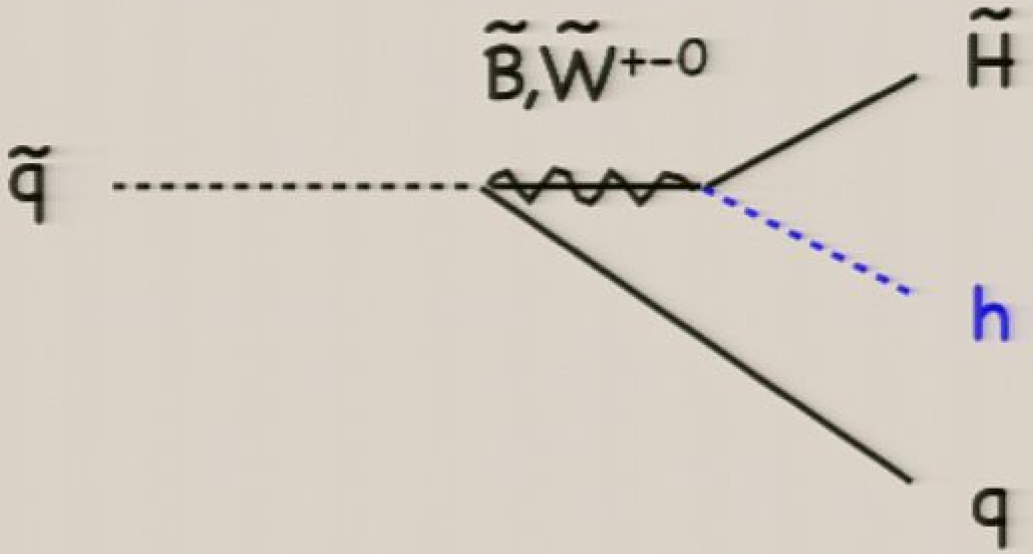
Kinematical requirement

$$\mu > m_{\tilde{G}} + m_h$$

$$> 120 \text{ GeV}$$

Squark Production to Gauginos

(which then decay to Higgs)



typical $\sigma(\text{squarks})_{14\ \text{TeV}} \approx$ several pb!!

Outline

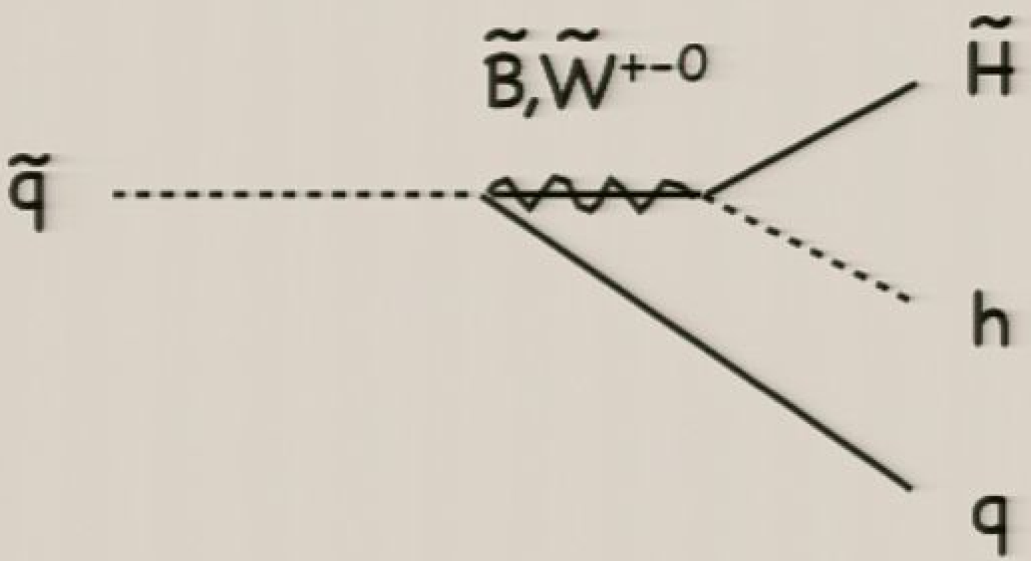
- Higgs in SM
- Boosting & Jet Substructure
- Higgs in SUSY
- **Boosted SUSY Higgs**
- Summary and Offerings

MSSM Higgs

- Higgs is light; h -> b,bbar always present!
- New production sources of Higgs from superpartner cascades can have large cross sections and large decay rates
- Heavy superpartners decaying to light Higgs implies boost is often large (≈ 50%!)

Ideal for Boosted Higgs Analysis!

Problem with SUSY production:



Supersymmetric events tend to be "busy" with a lot of hadronic activity from squarks/gluinos and associated parton showers.

Can have extra hard b subjets in "fat jet" cone!

Similar problem also with t,tbar,h!

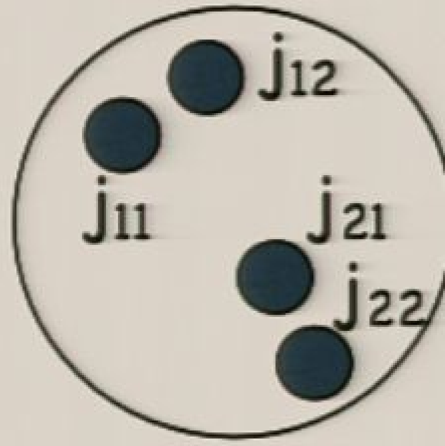
Plehn, Salam, Spannowsky

Our New Step: Maximize "Similarity"

1) Do BDRS procedure.

2) At each stage of unclustering, calculate "S":

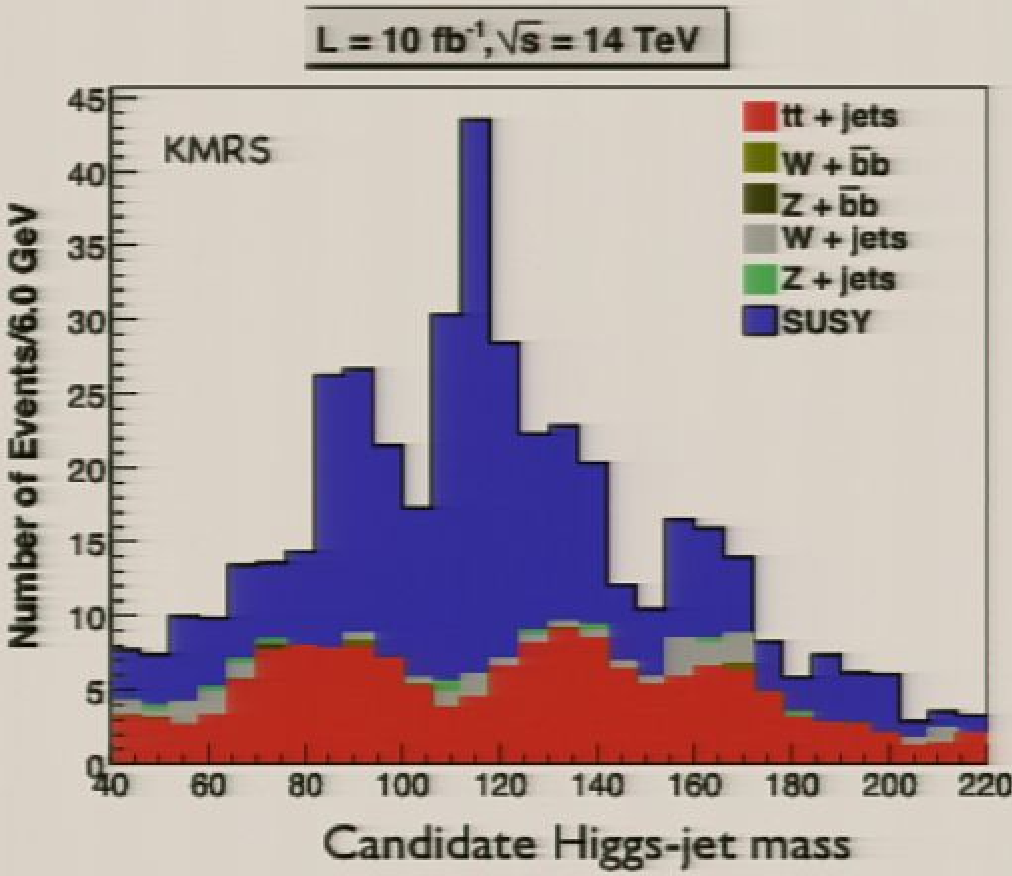
$$S_i = \frac{\min\left(p_{t_{j_1}}^2, p_{t_{j_2}}^2\right)}{\left(p_{t_{j_1}} + p_{t_{j_2}}\right)^2} \Delta R_{j_1 j_2}$$

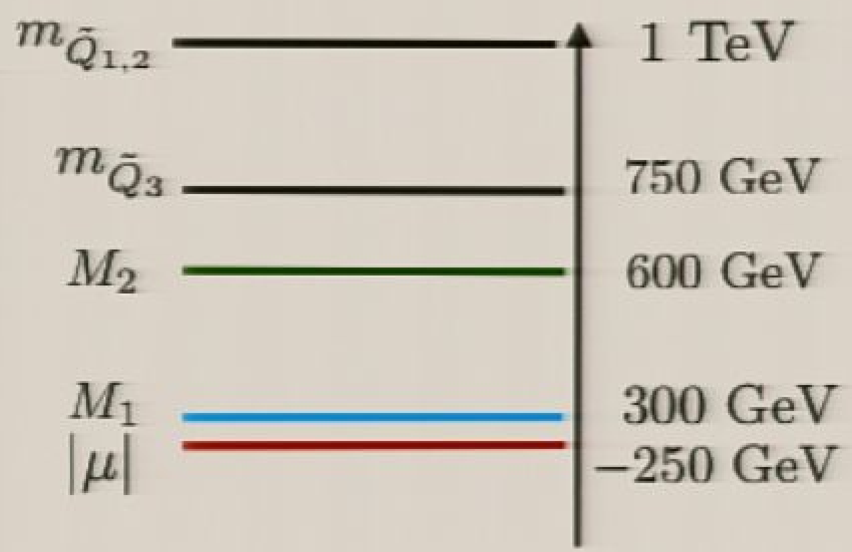


3) Choose 3 highest pT jets (2 highest b-tagged) from stage which maximizes "S"

This helps reject SUSY backgrounds with extra hard b's not from Higgs decay.

Higgsino NLSP -> h Gravitino LSP





cuts:

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

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

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

Simulations details...

Background: ALPGEN $\longrightarrow$ PYTHIA6.4
Signal: SUSPECT2 $\longrightarrow$ 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)

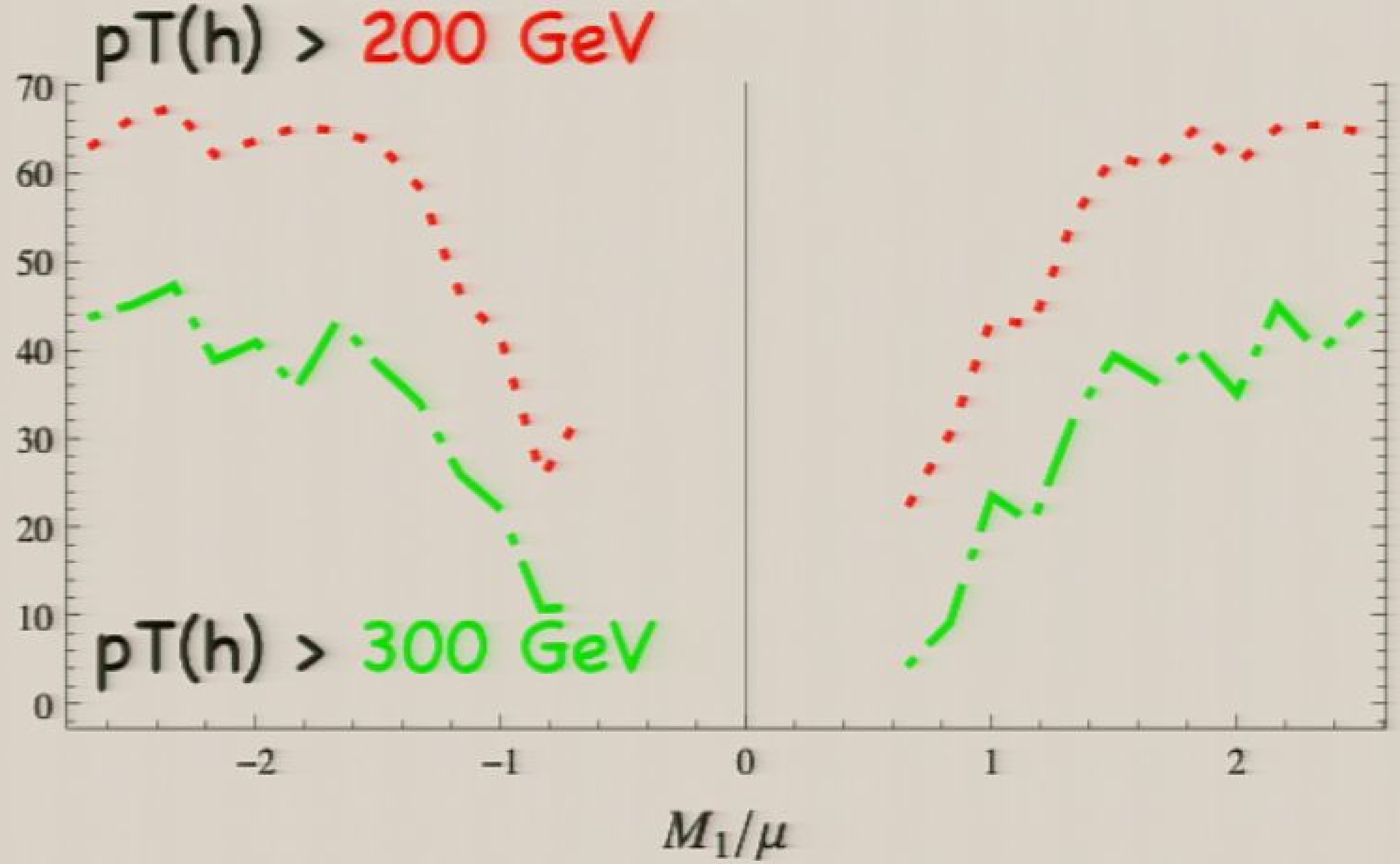
jet gymnastics performed using FastJet (hep-ph/0512210)

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

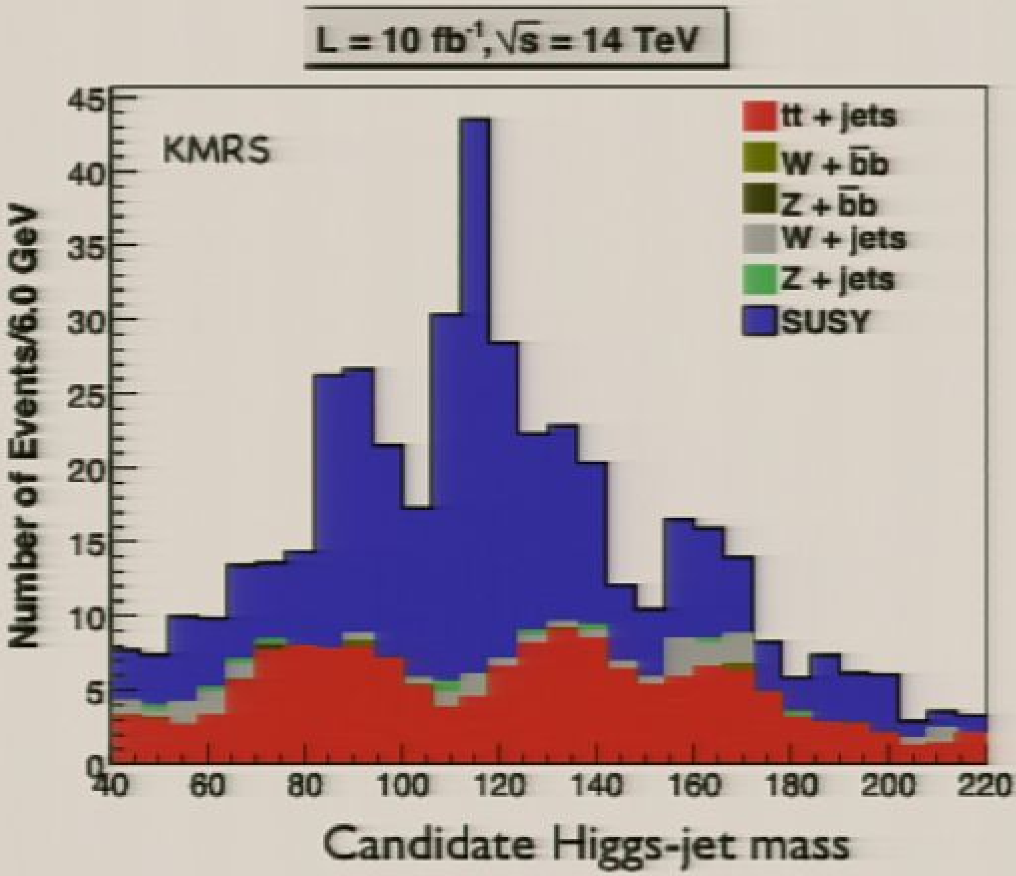
jet-photon fake rate: $.1\%$

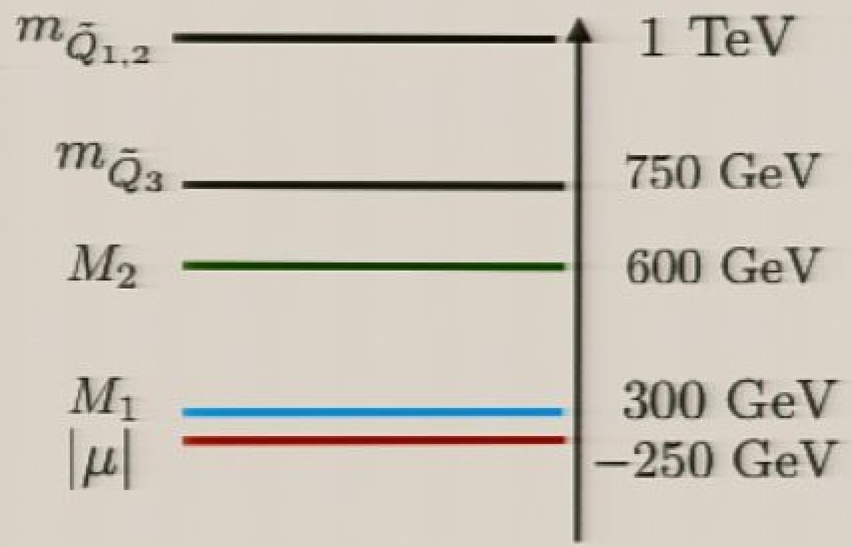
MSSM (Neutralino LSP)

Boosted Fraction



Higgsino NLSP -> h Gravitino LSP





cuts:

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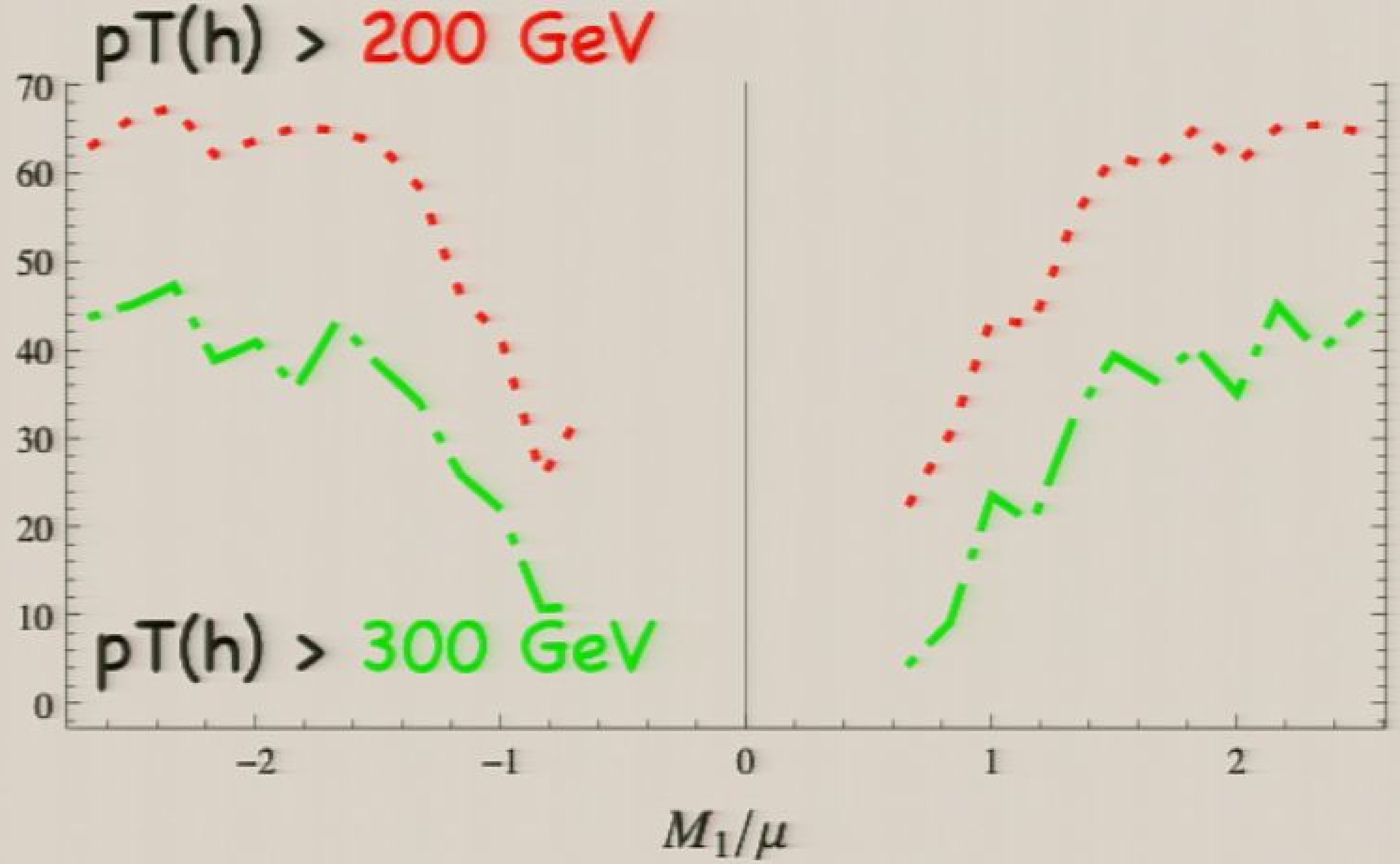
$p_{T\gamma} > 80$ GeV

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

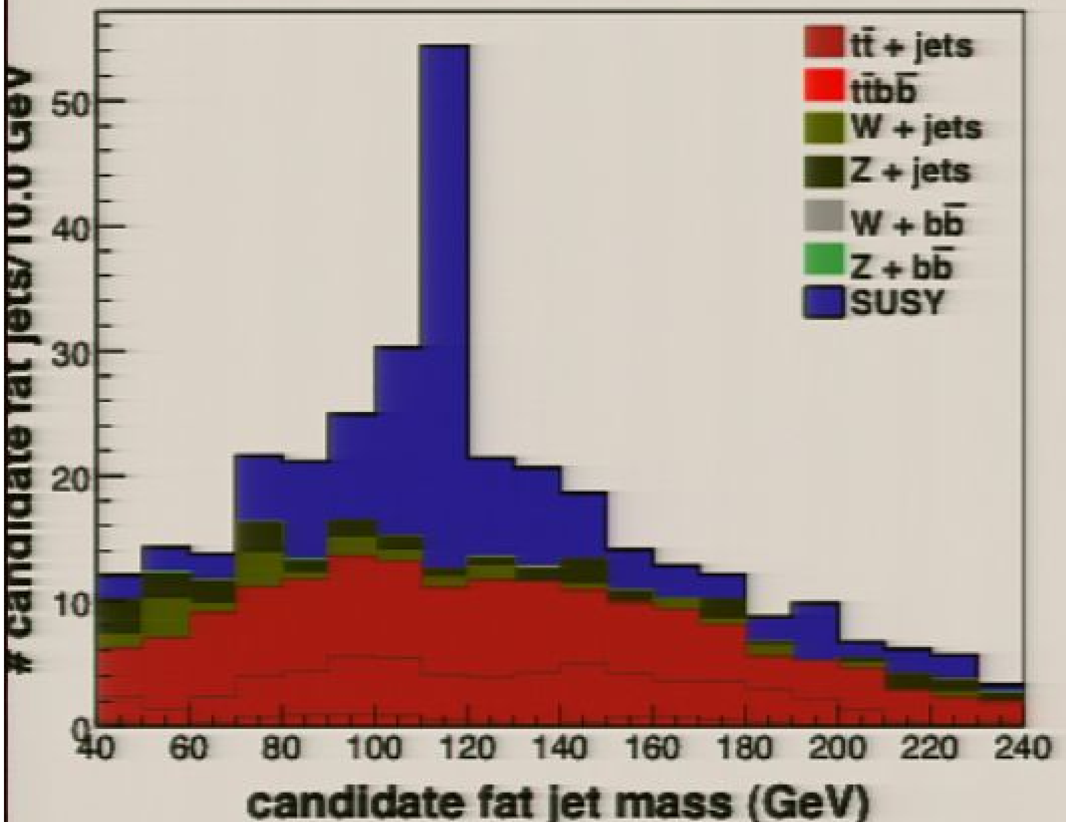
$$
\begin{aligned}
BR(\tilde{\chi}^0 \to \tilde{G} + \gamma) &\sim 43\% \\
BR(\tilde{\chi}^0 \to \tilde{G} + Z^0) &\sim 29\% \\
BR(\tilde{\chi}^0 \to \tilde{G} + h) &\sim 28\%
\end{aligned}
$$

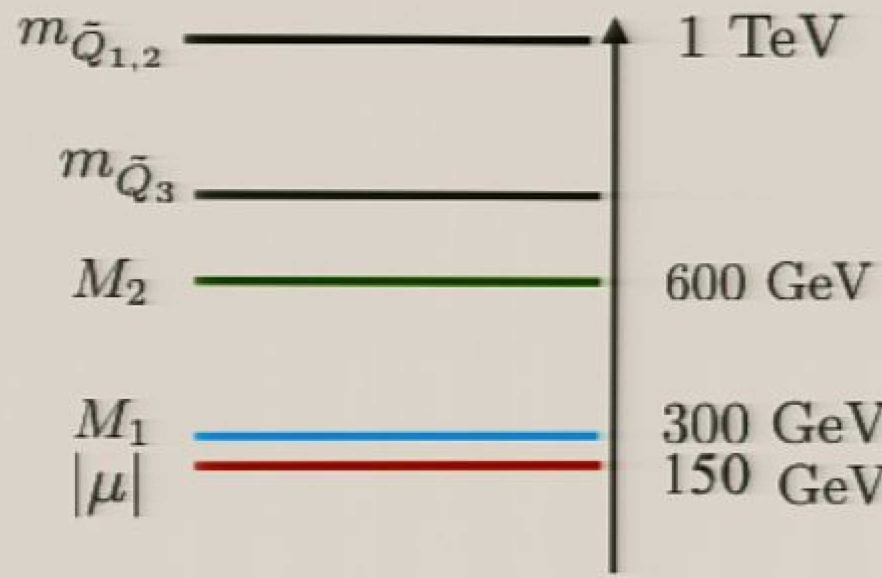
MSSM (Neutralino LSP)

Boosted Fraction



MSSM (Neutralino LSP) Point 1A



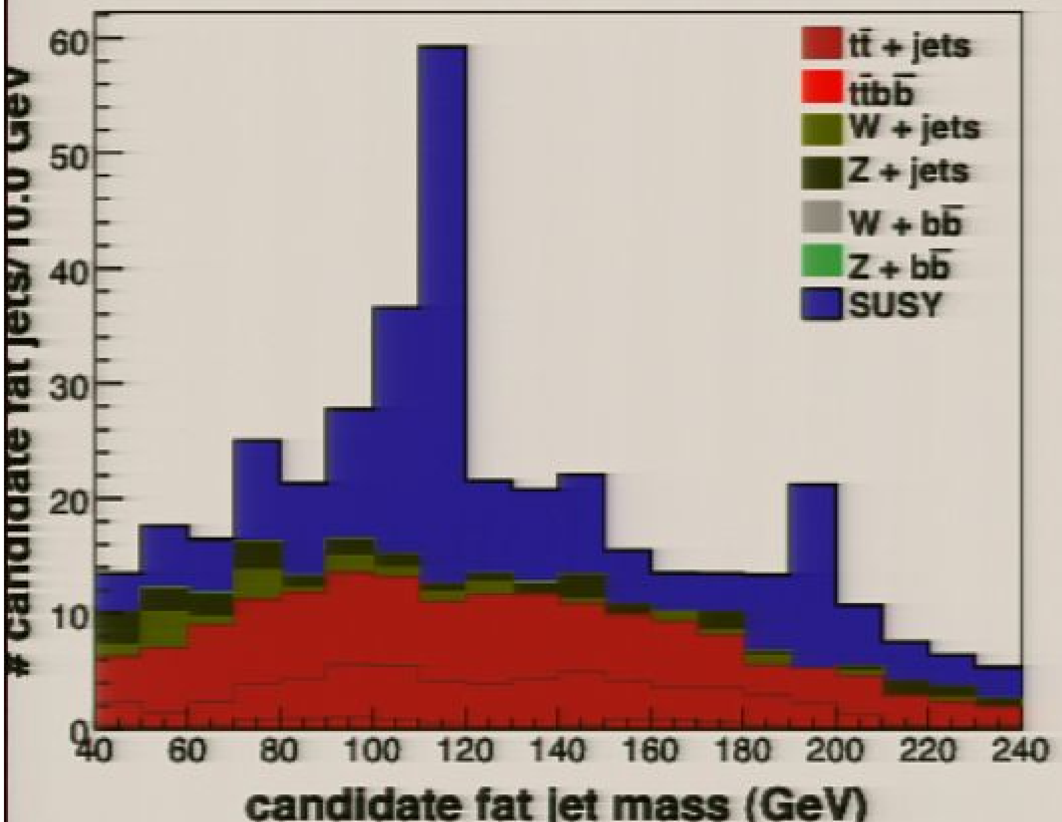


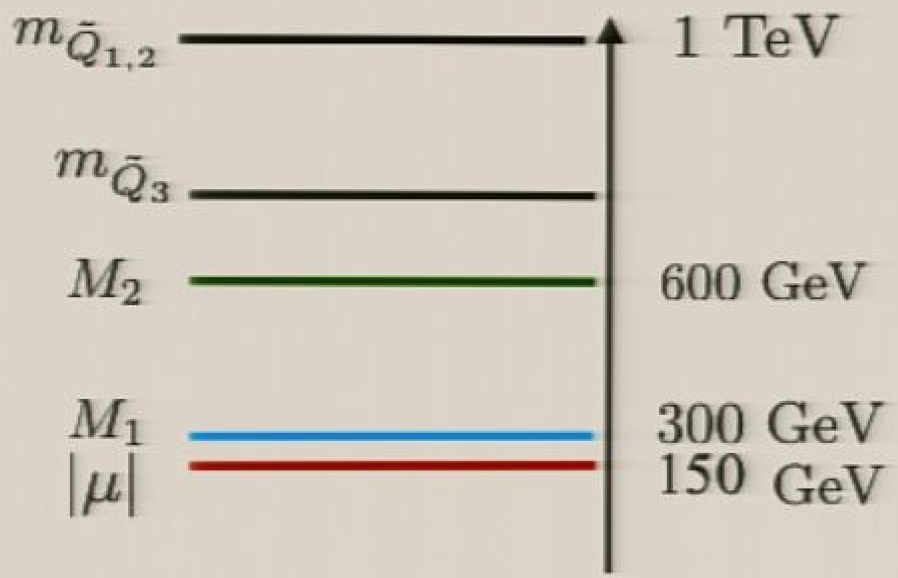
$\not{E}_T > 300\ \mathrm{GeV}, H_T > 1.0\ \mathrm{TeV}$

+ lepton veto

MSSM Point 1C

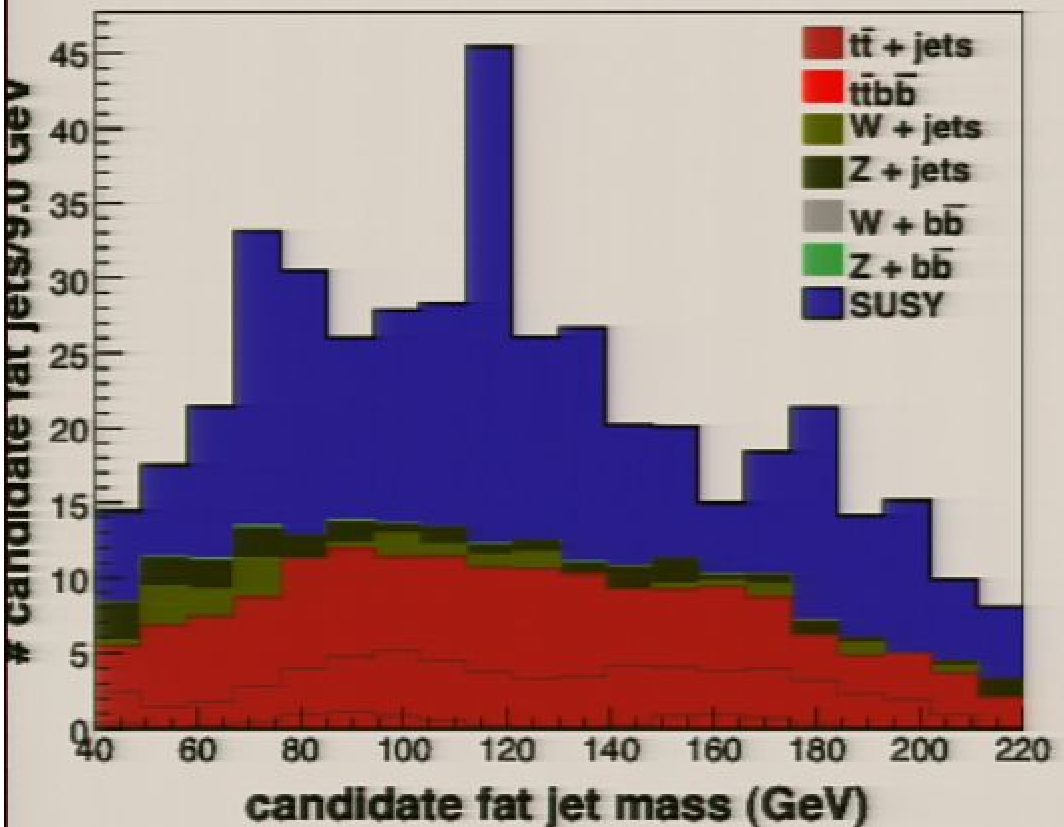
now, m_A = 200 GeV

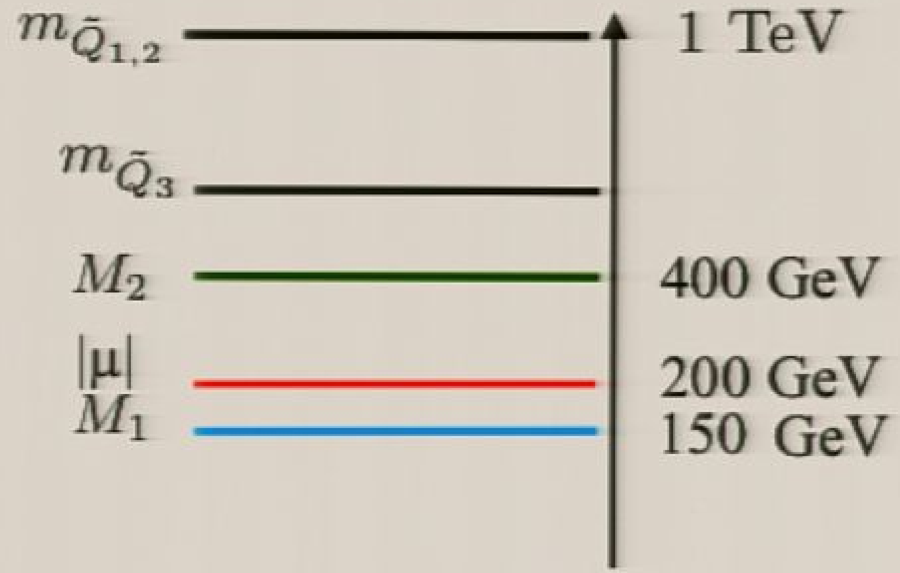




Can even discover heavier A,H states!

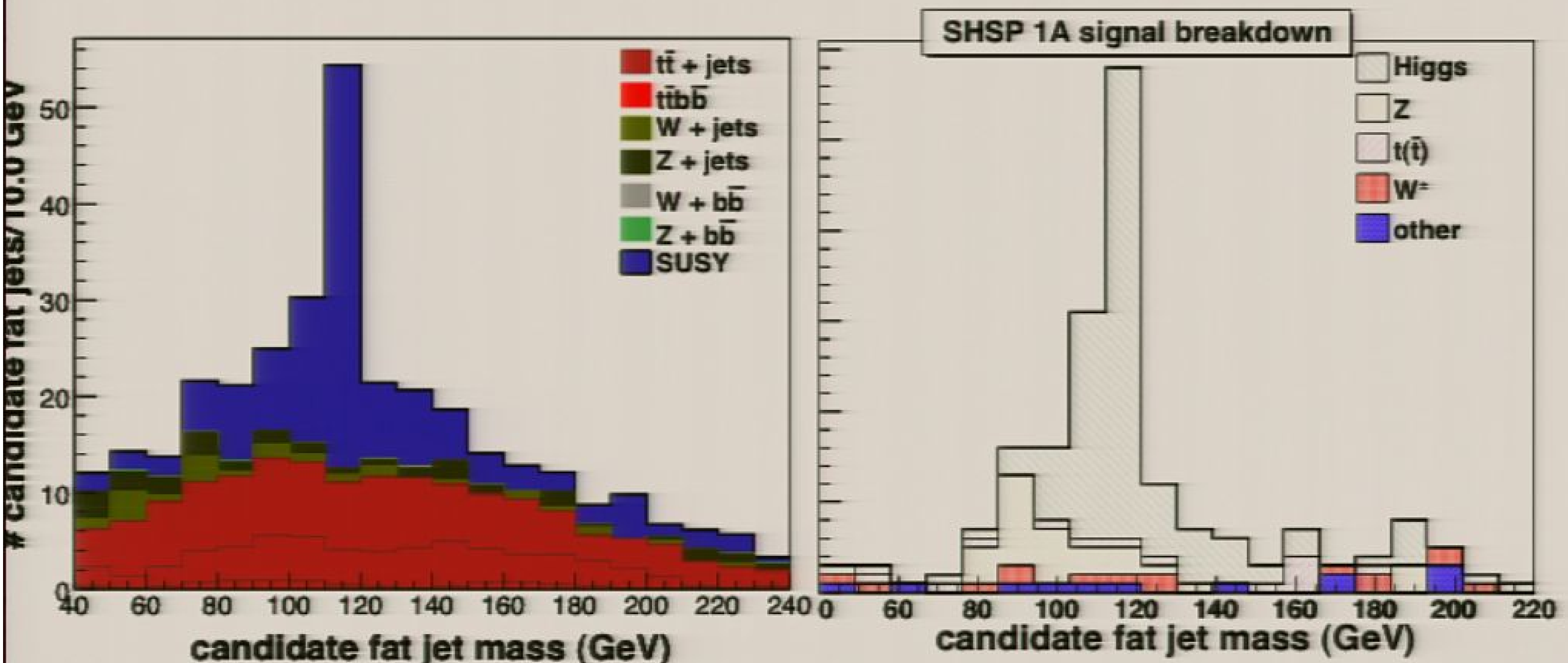
MSSM (light bino) Point 3





(Density of LSP gives right thermal relic abundance)

Monte Carlo Truth...



"Point 1A"

Summary

- Jet substructure techniques can find boosted Higgs h -> b,bbar, even in busy environment

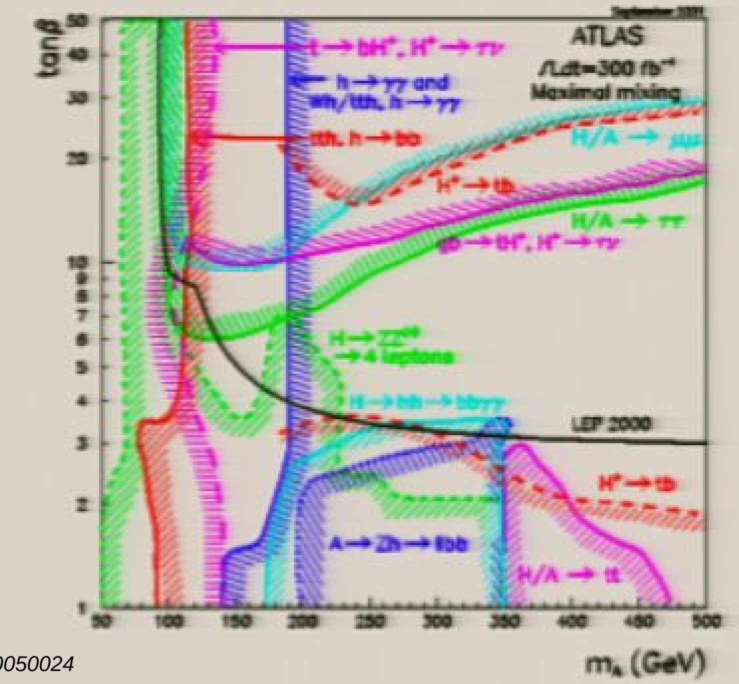
- MSSM h automatically light, could have large rate from squark production and cascade decay

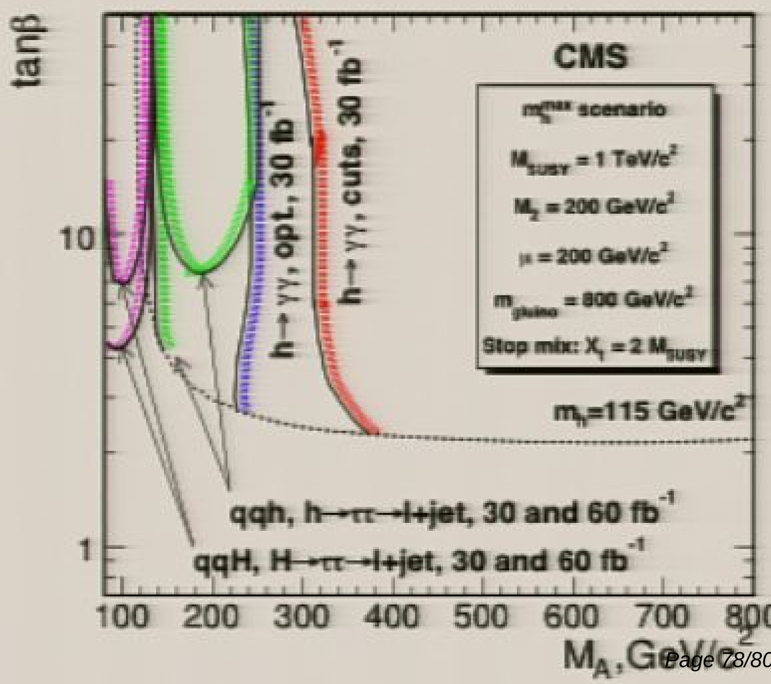
- Cascade decay implies large fraction boosted!

- Could discover h (and/or A,H) well before conventional modes -- less than 10 fb^{-1}!!

Extra

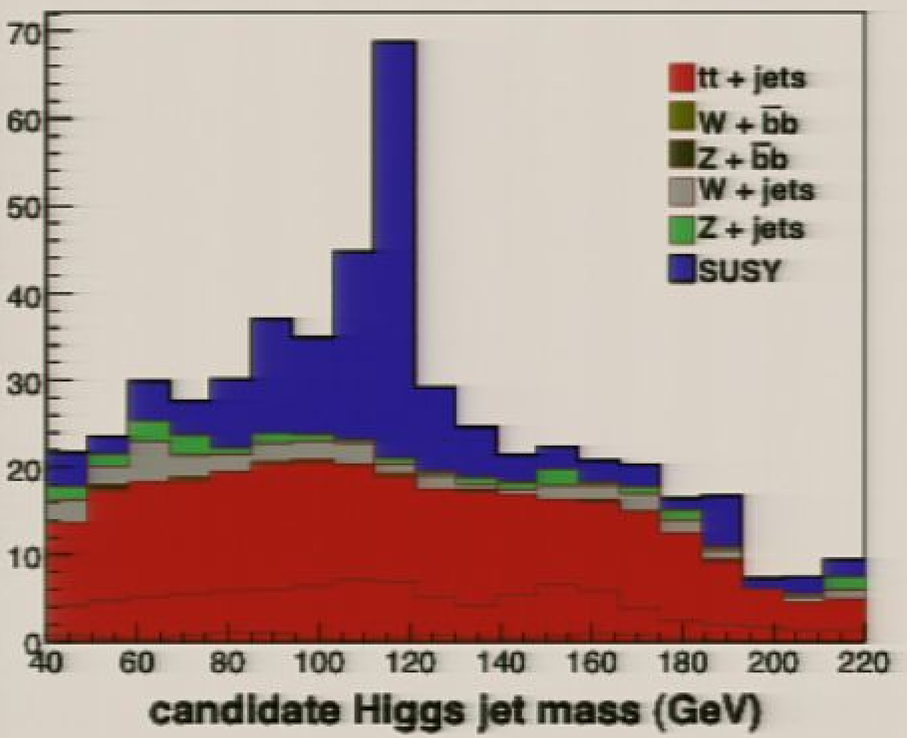
Can we help get a full detector simulation of this?

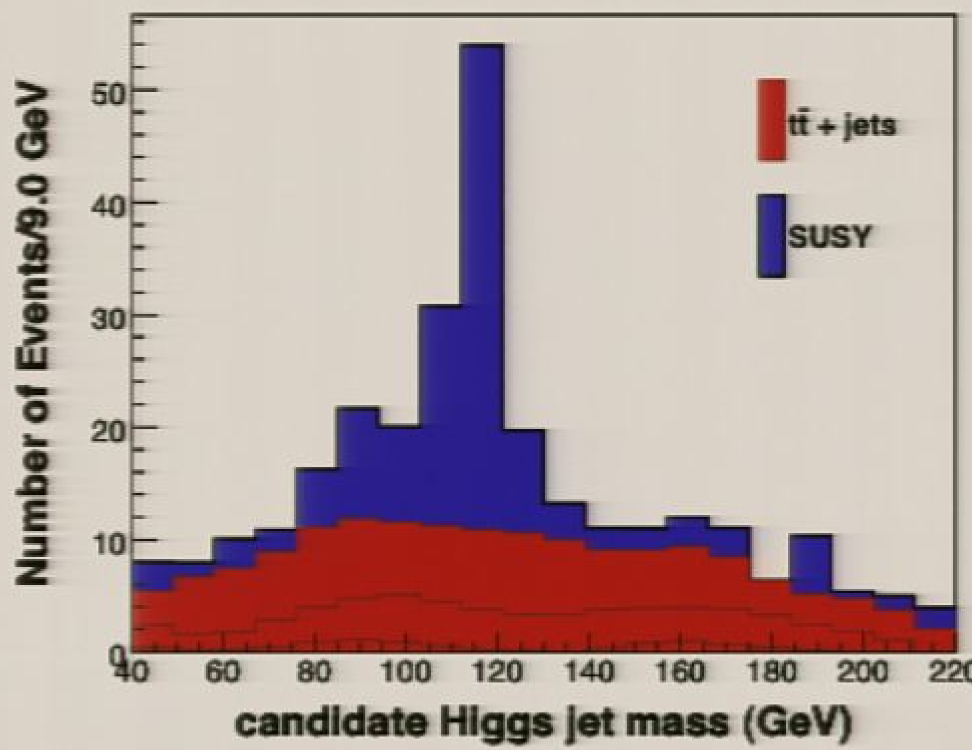




MSSM (Neutralino LSP)

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





additional lepton veto

Summary

- Jet substructure techniques can find boosted Higgs h -> b,bbar, even in busy environment

- MSSM h automatically light, could have large rate from squark production and cascade decay

- Cascade decay implies large fraction boosted!

- Could discover h (and/or A,H) well before conventional modes -- less than 10 fb^{-1}!!