Searching for MSSM Higgs with 3 B-jets

J. Sayre

Homer L. Dodge Department of Physics

University of Oklahoma

Based on work with C. Kao

Supersymmetric Higgs

Higgs content of the Standard Model is minimal: one SU(2) doublet charged under U(1).
More complicated models can be easily constructed.

Natural extension: two doublets (2HDM).
Often constructed with one "up-type" and one "down-type" to avoid FCNCs.

$$\phi_u = (\mathbf{2}, \frac{1}{2}), \quad \phi_d = (\mathbf{2}, -\frac{1}{2})$$

$$\mathscr{L} = Y_u Q \phi_u u^c + Y_d Q \phi_d d^c + Y_e L \phi_d e^c$$

Supersymmetry requires 2 doublets in minimal model (MSSM). $\rightarrow$ Important signal at LHC.

The 2HDM

Both doublets acquire vevs to break $SU(2) \times U(1)$:

$$\langle \phi_u \rangle = \begin{pmatrix} 0 \\ v_2 \end{pmatrix}, \quad \langle \phi_d \rangle = \begin{pmatrix} v_1 \\ 0 \end{pmatrix}.$$

This leaves five fields: $h^o, H^o, A^o, H^{\pm}$.

- h^0, H^0: "standard model" and heavy neutral scalars.
- A^0: neutral pseudoscalar
- H^+, H^-: charged scalar.

Two free parameters:m_A and $\tan\beta \equiv \frac{v_2}{v_1}$.

Phenomenology

For $m_A \gtrsim 125$ GeV, $m_A \simeq m_H \rightarrow A$ and H^0 are indistinguishable at LHC. If $m_A \lesssim 125$ GeV, h^0 and A become indistinguishable.

$$d\bar{d}A^0 \propto \frac{g m_d \tan\beta}{2 m_W}$$ (similar for H^0 at high m_A.)

At high $\tan\beta$, couplings of A, H^0 to b quark and τ become large.

- For $\tan\beta < 5$, $gg \rightarrow \phi$ is leading source of inclusive Higgs production.
- For $\tan\beta > 7$, $b\bar{b} \rightarrow \phi$ becomes dominant.
- At large $\tan\beta$, the branching fraction $B(H^0, A \rightarrow b\bar{b}) \simeq 0.89$.

Higgs in Association with b-Quarks

Generally, ϕ decays to two b-quarks at high p_T. We work in a 5-flavor scheme. Use b-quark distribution functions to sum over large logarithms arising from collinear, low p_T quarks.

- For inclusive Higgs production, LO is $b\bar{b} \to \phi \to b\bar{b}$. Unfortunately swamped by QCD background.
- For two associated high-p_T b's, LO is $gg, q\bar{q} \to b\bar{b}\phi \to bb\bar{b}\bar{b}$. Takes advantage of b-tagging but greatly reduced signal. (Dai, Gunion & Vega, '94 & '96; Richter-Was and Froidevaux, '97; Balazs, Diaz-Cruz, He,Tait & Yuan, 99)
- We choose an intermediate approach: LO is $bg \to b\phi \to bb\bar{b}$. Appropriate for 3 b-tagged jets at high p_T. (Campbell, Ellis, Maltoni & Willenbrock, '03; Huang and Zhu, '99)

Signal

We generate a 3 b-quark signal using the above processes in a Monte Carlo program using amplitudes calculated by MadGraph. We choose $\mu_F = \mu_R = m_H/4$ to minimize NLO corrections. (Maltoni, Sullivan & Willenbrock, 2003)
Program allows for potentially complicated cuts. In general we impose the following:

- Minimum p_T cuts on 1^{st},2^{nd}, 3^{rd} jets ordered by p_T.
- Three jets also required to pass maximum η.
- Three jets required to be well separated, $\Delta R > \Delta R_{min}$.
- At least one pair of jets satisfies $|M_{bb} - M_H| < \Delta M$.
- Veto events with missing E_T above some threshold.
- May impose cuts on $\Delta\phi$ angle between jets.

Backgrounds

We consider backgrounds from the following processes:
Irreducible

- $bg \rightarrow bb\bar{b}$ (QCD)

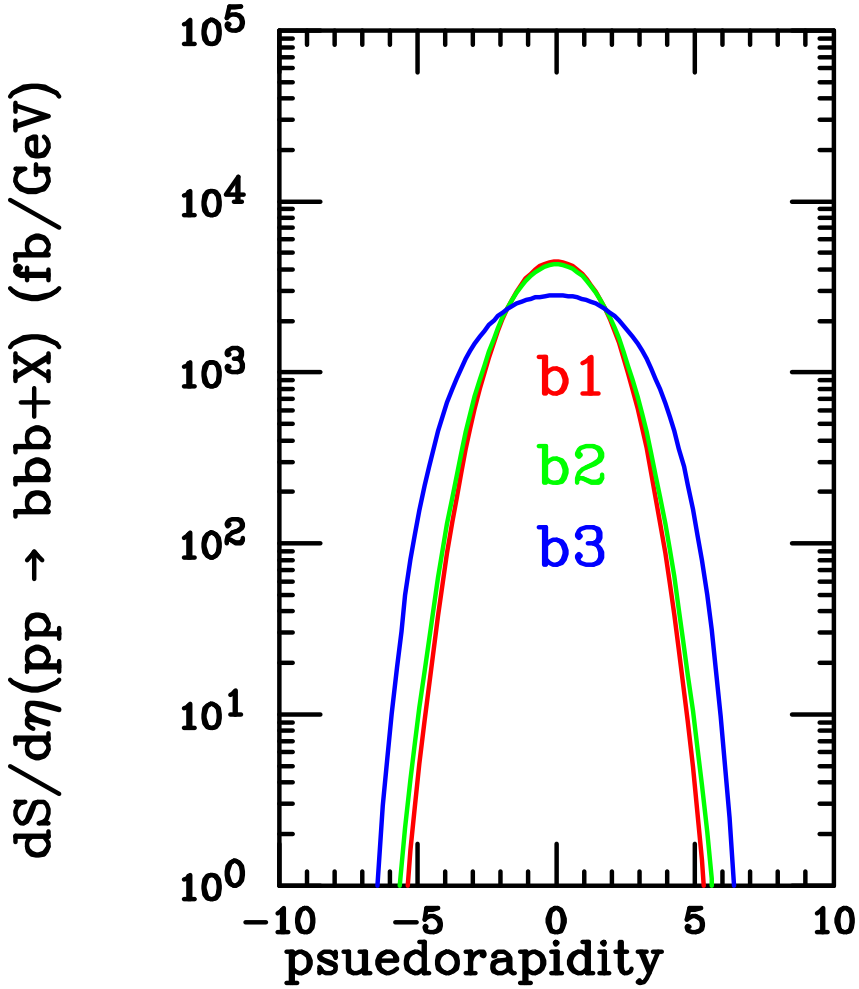
One or more mis-tagged particles

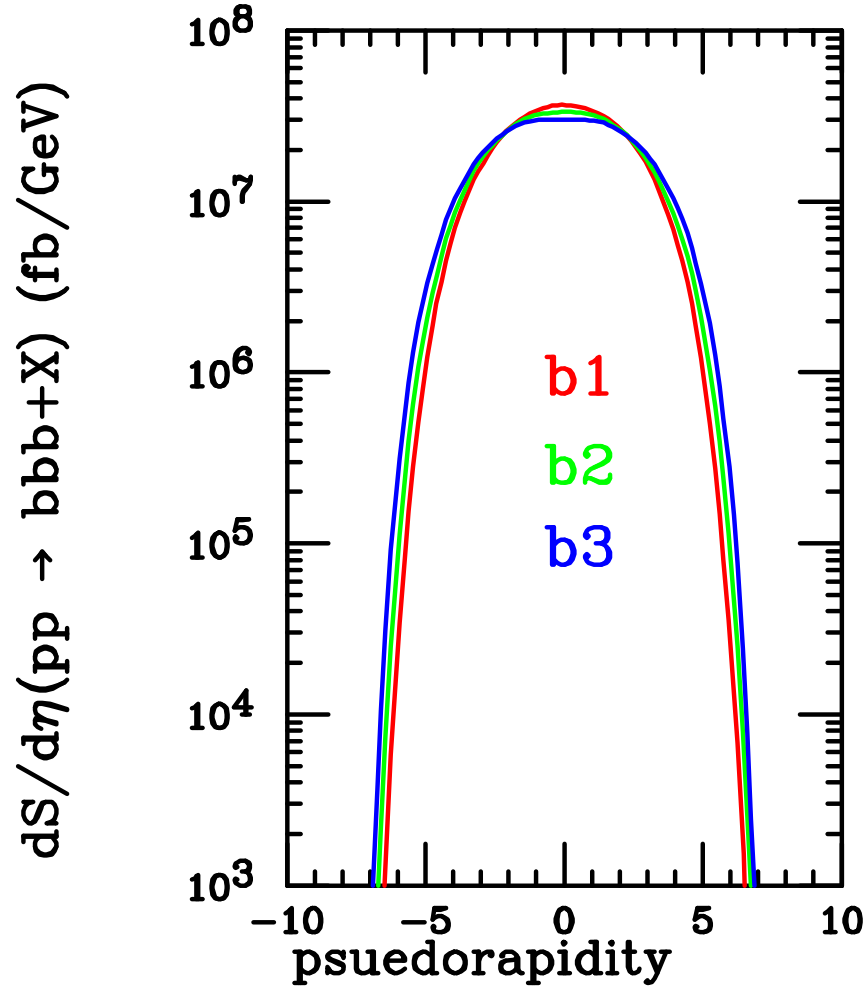
- $cg \rightarrow cb\bar{b}$
- $gg, qq \rightarrow gb\bar{b}$
- $qg \rightarrow qb\bar{b}$
- $pp \rightarrow tt \rightarrow be^{-}\nu\bar{b}d\overline{u}$ (or $c\overline{s}$)
- $pp \rightarrow tt \rightarrow bu\overline{db}d\overline{u}$

The latter are subjected to additional cuts:

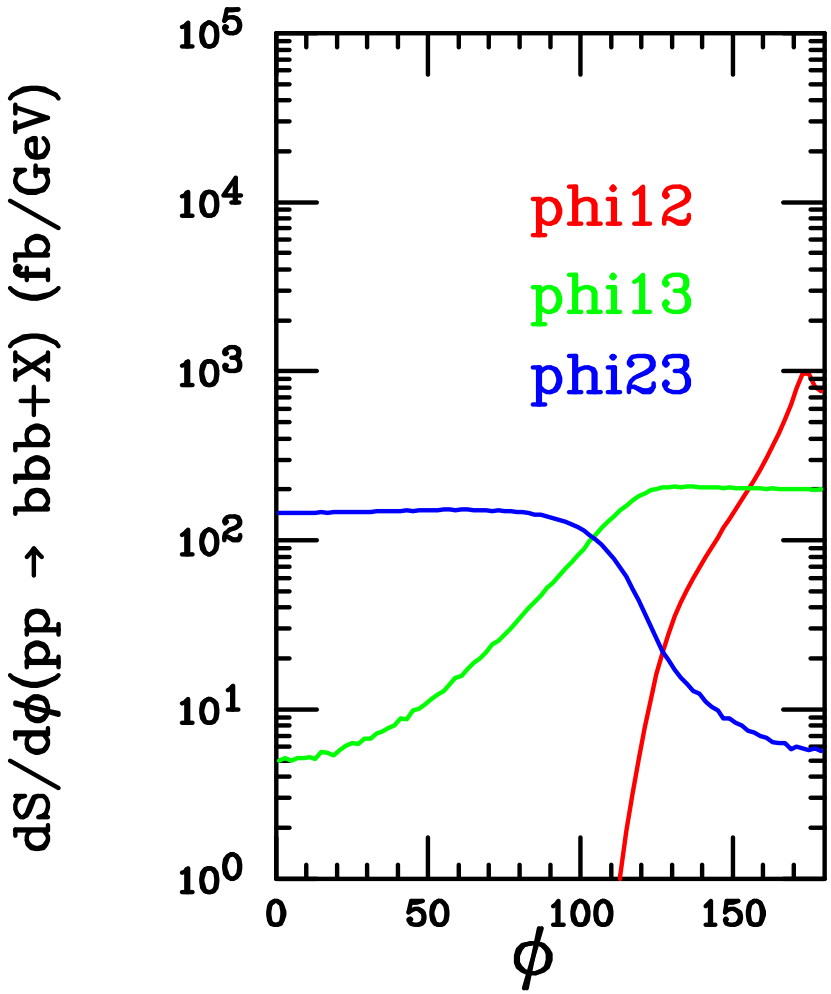
- 4-jet veto for jets above some p_{Tmin} and within $|\eta_{max}|$.
- Veto events with charged leptons above p_T threshold.

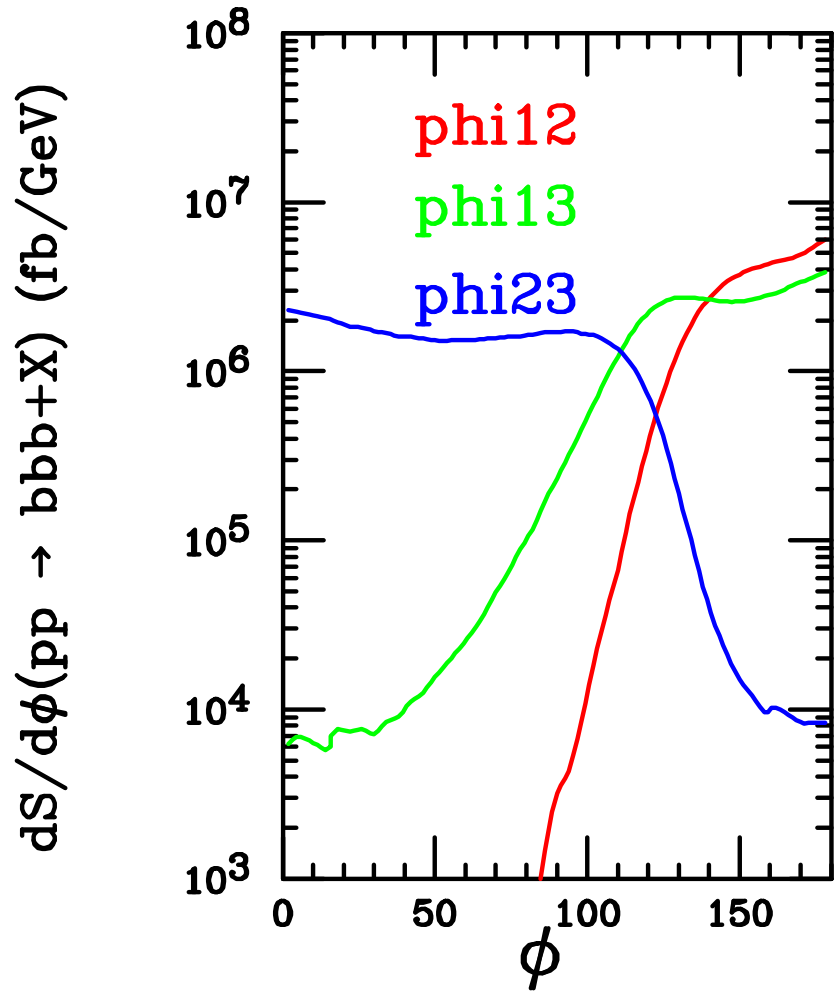
Eta Distributions



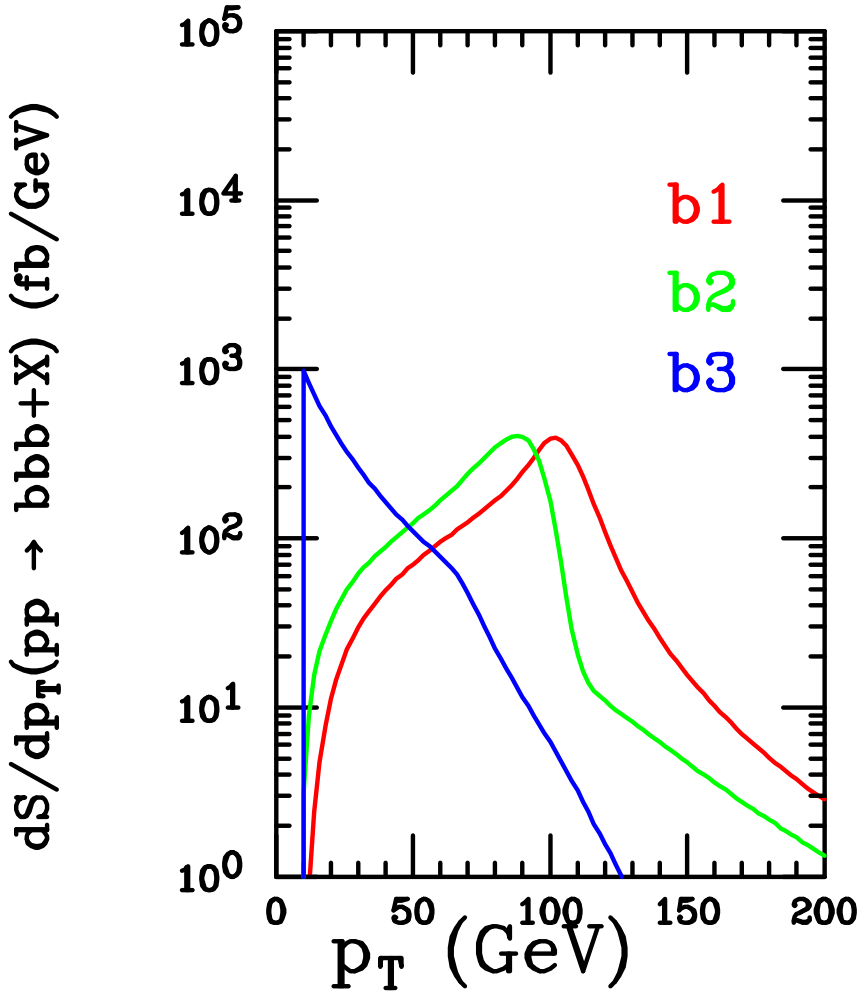


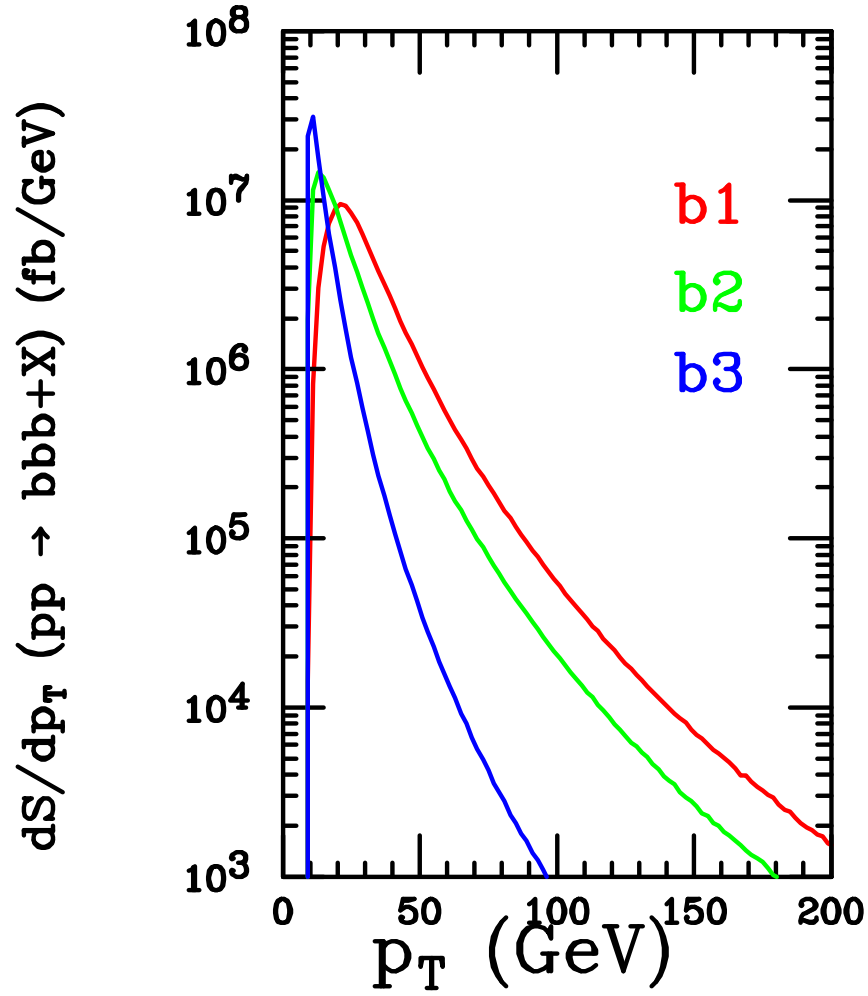
Angular Distributions



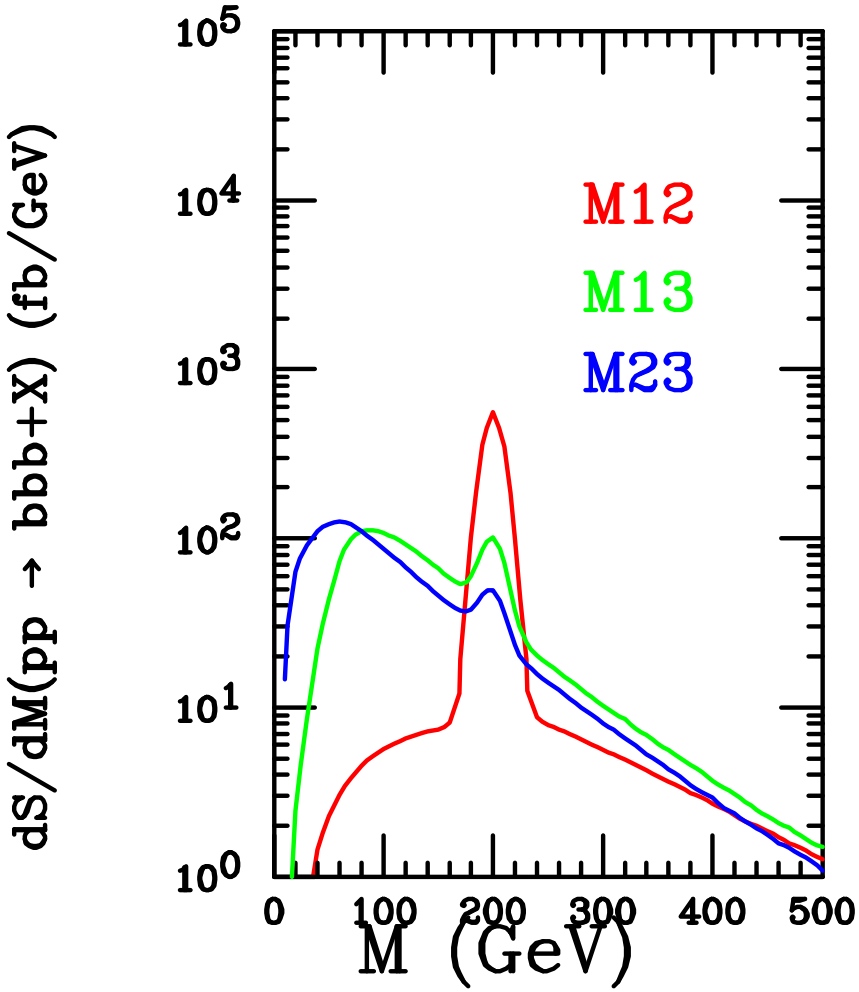


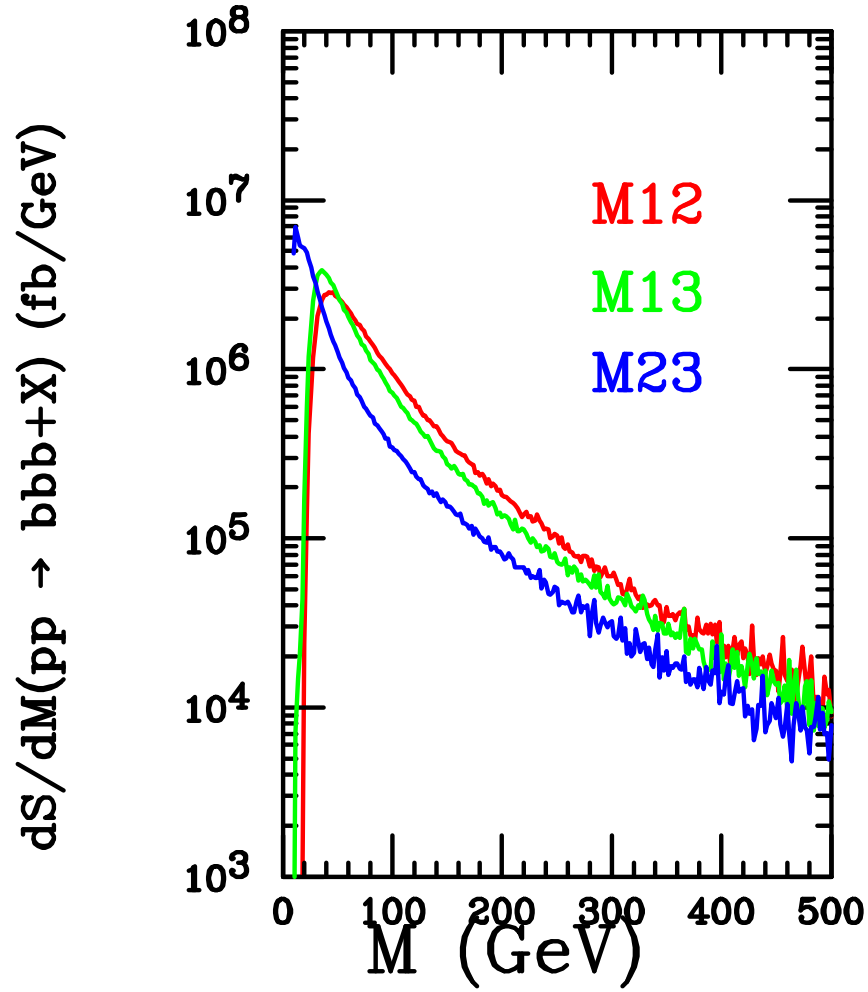
P_T Distributions



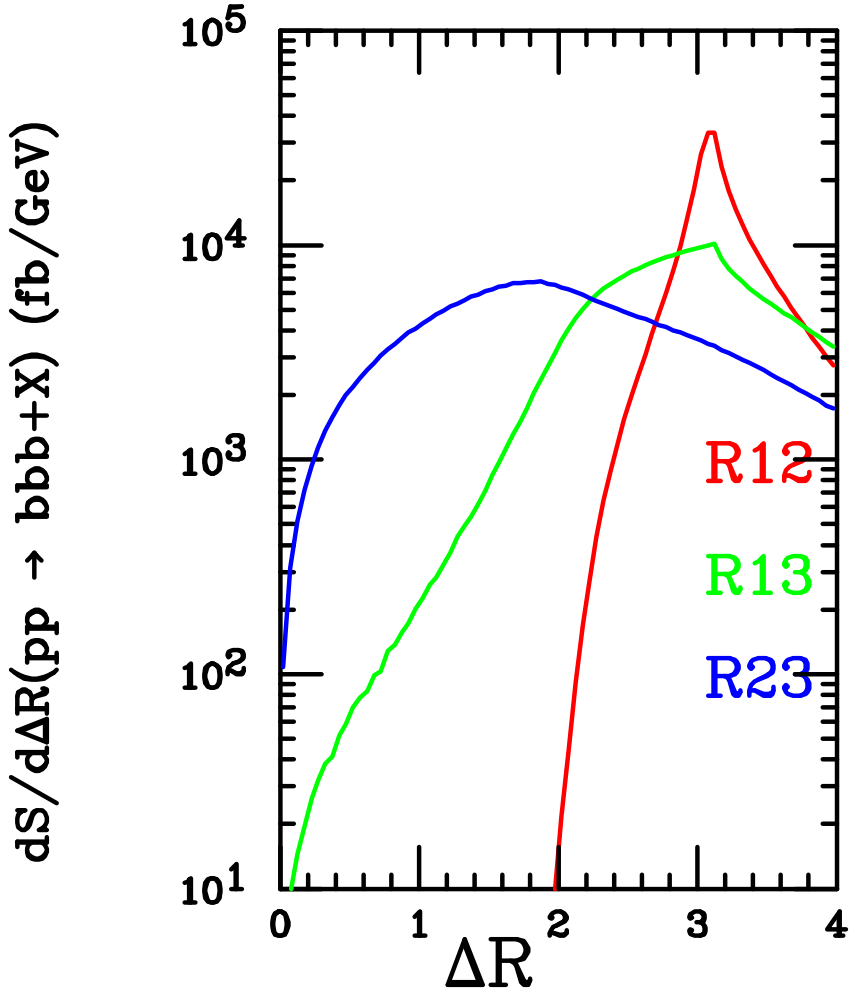


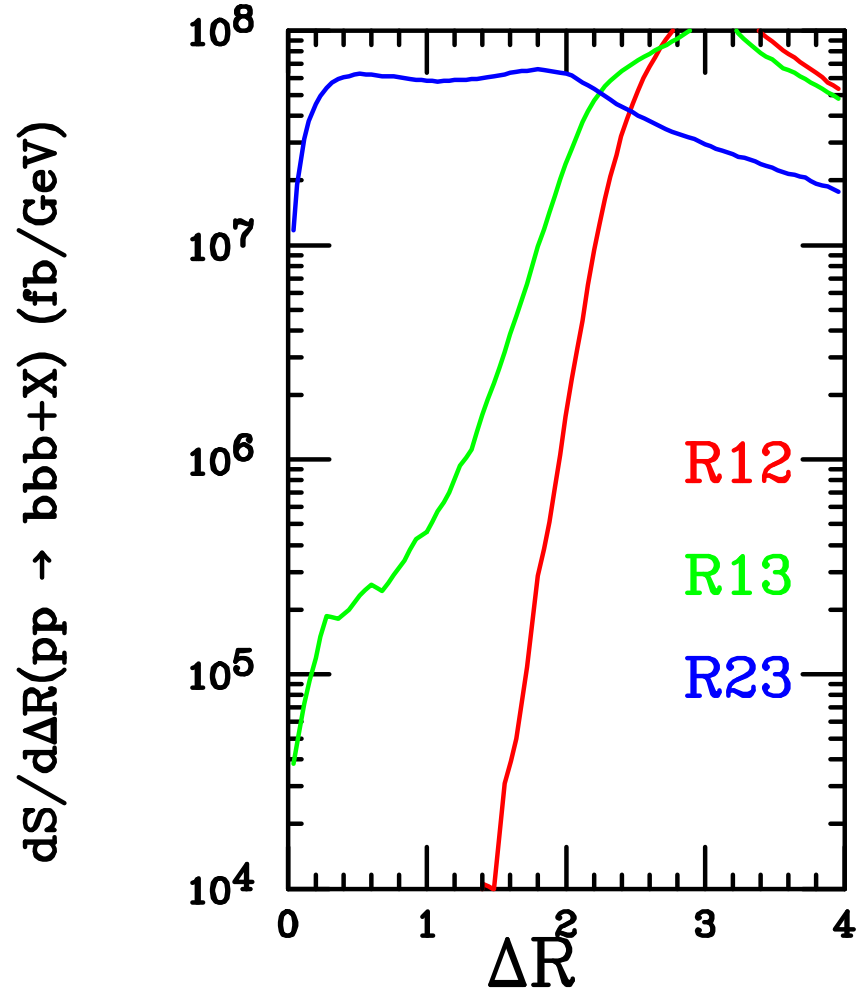
Mass Distributions





Jet Separation





Cuts

We assume the b-tag efficiency $b_{eff} = 0.6, 0.5$ for low and high luminosity running respectively at the LHC. We take the mistag rates as $c_{mis} = 0.15; u, d, s, g_{mis} = 0.01$.
We impose the following cuts:

- $\eta < 2.5$
- Leading jets pass p_T cuts: minimally 20,30,50. Higher to simulate triggers. (CMS TDR 2007; ATLAS TDR 1999,2003)
- $\Delta R > 0.7$ for 3 accepted jets.
- At least one $b\bar{b}$ pair has invariant mass $|M_{bb} - M_A| < \Delta M$. $\Delta M = 0.1, 0.15, 0.2$.
- $E^T_{miss} < 40GeV$
- Veto more than 3 jets with $\eta < 2.5$ and $p_T > 15, 30$ GeV.
- No cuts on ϕ or E_{lepton}.

Comparison of Cross Sections

Signal	bbb	cbb	bbg	qbb
3.11×10^4	2.05×10^8	5.18×10^8	2.48×10^{10}	5.5×10^9
6.72×10^3	4.43×10^7	2.79×10^7	8.95×10^7	1.99×10^7
2.41×10^3	1.503×10^5	6.53×10^4	1.59×10^5	3.44×10^4
2.44×10^2	4.48×10^3	1.86×10^3	4.04×10^3	1.301×10^3

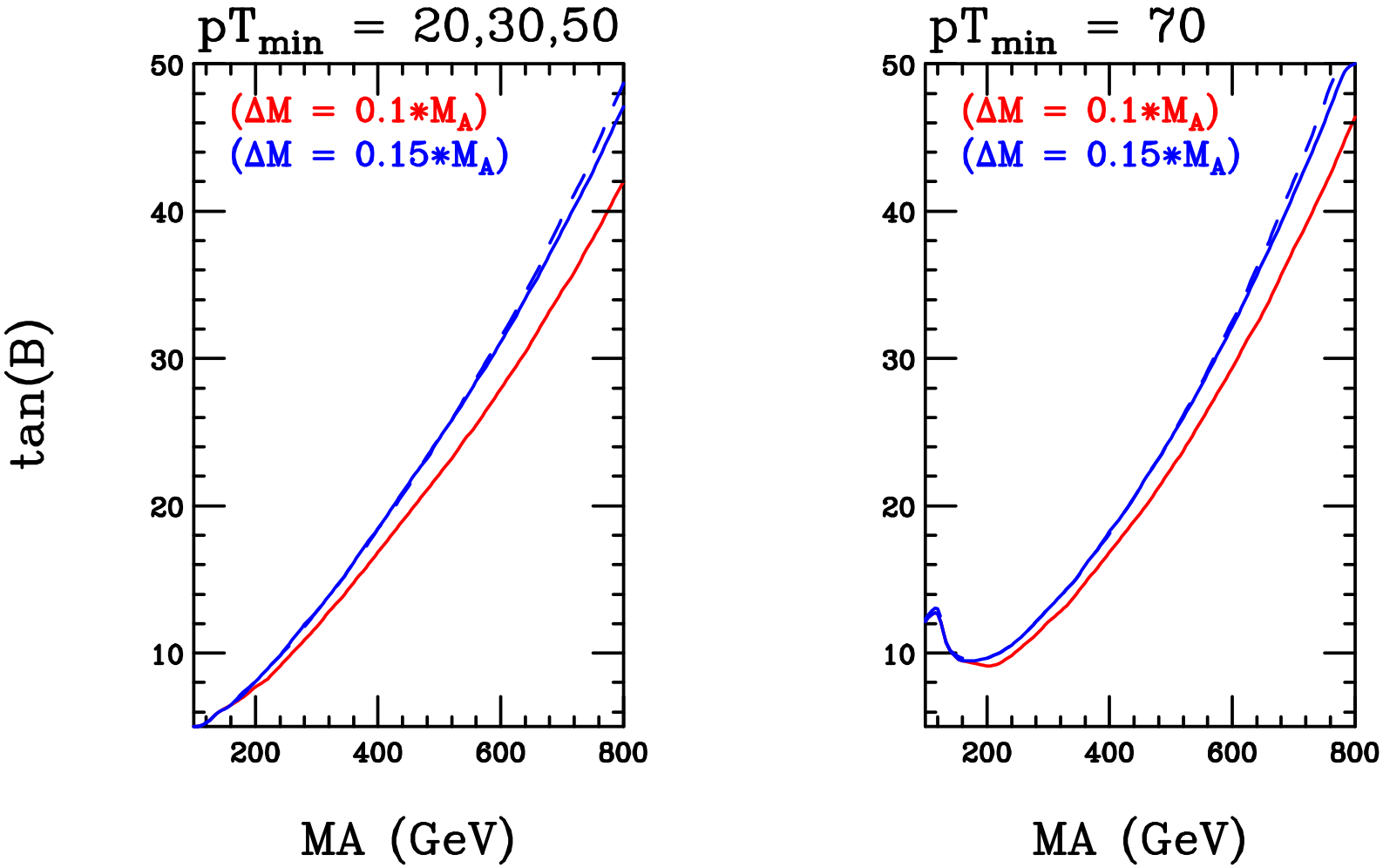
Minimal cuts, no tagging.

With tagging efficiencies.

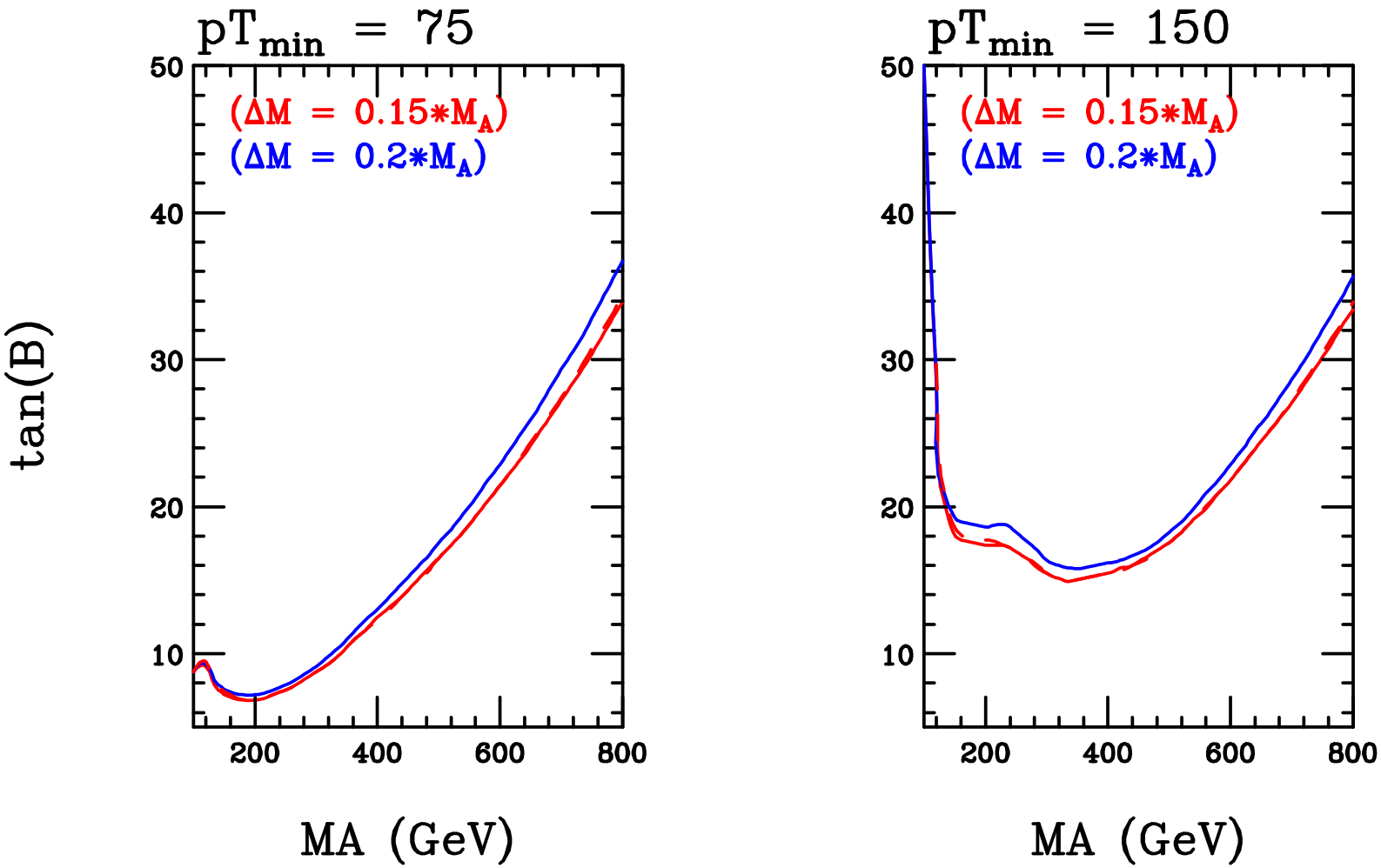
Applying low cuts: $p_T > 20, 30, 50$ GeV.

Applying Level-1 (CMS) Trigger threshold: $p_T > 70$ GeV.

Low Luminosity ($30 fb^{-1}$)



High Luminosity ($300\,fb^{-1}$)



Conclusions

- The 3-b channel is a promising window for discovering neutral MSSM Higgs bosons in the case of high $\tan\beta$.
- QCD backgrounds are large but can be overcome with selective cuts and tight b-tagging.
- In conjunction with $b\tau^+\tau^-$ and $b\mu^+\mu^-$, we can explore the Yukawa couplings of the extended Higgs sector.
  (Kao, Dicus, Malhotra & Wang, '08)