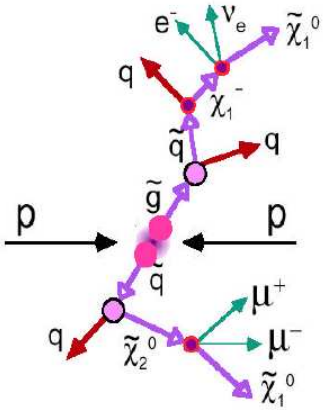
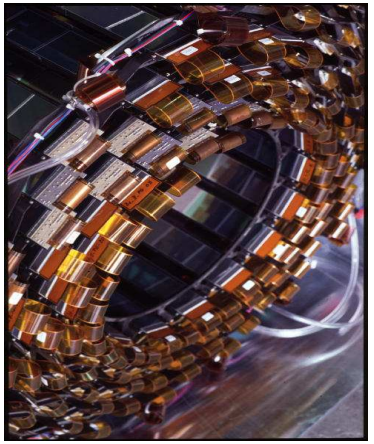
LHC Praha 2003

Detection of MSSM Higgs bosons using supersymmetric decay modes at CMS





Topics

- Introduction

  - neutral Higgs to SUSY (*hep-ph/0112046*)
  - charged Higgs to SUSY (*hep-ph/0304093*)
  - SUSY to Higgs (*hep-ph/0304095*)

- Conclusion & outlook

MSSM Higgs sector

• MSSM contains 2 Higgs doublets, therefore 5 physical Higgs states: h^0, H^0, A^0, $H^\pm$

~ degenerate in mass for high m_A

looks like H_{SM} (but $m_h < 130$ GeV)

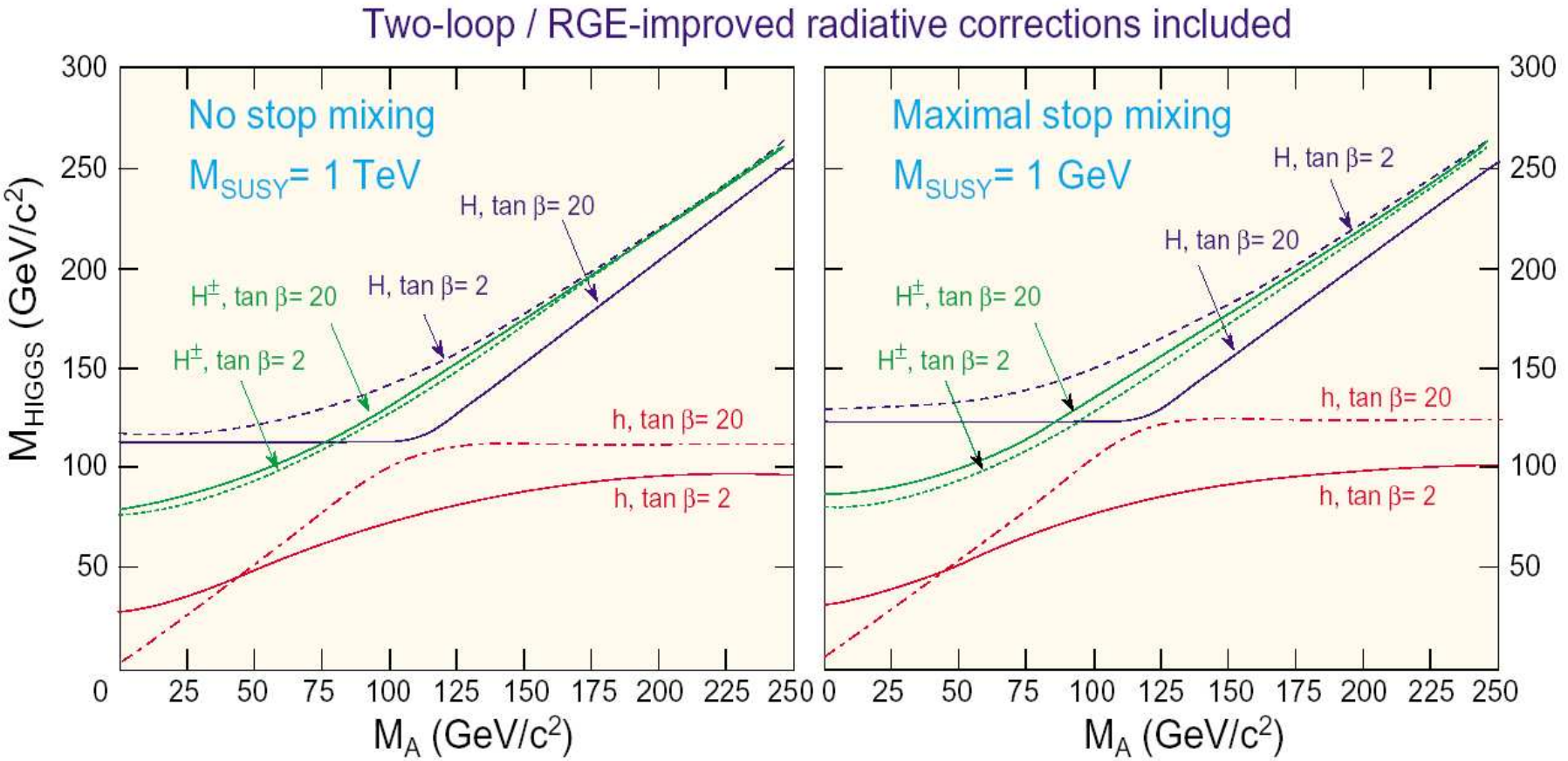
• masses & couplings depend at tree level only on 2 parameters, say m_A & tanβ: (1< tanβ <60)

$$m^2_{H^\pm} = m^2_{A^0} + m^2_{W^\pm}$$

$$m^2_{h^0,H^0} = \tfrac{1}{2}\left(m^2_{A^0} + m^2_{Z^0} \mp \sqrt{(m^2_{A^0} + m^2_{Z^0})^2 - 4m^2_{Z^0} m^2_{A^0} \cos^2 2\beta}\right)$$

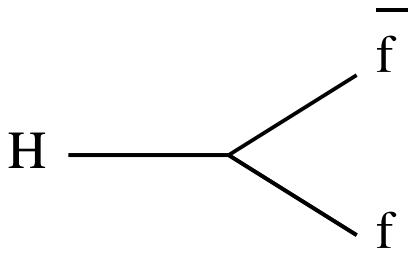
• radiative corrections can be important (e.g. for h^0 !!)

MSSM Higgs masses



Couplings

Higgs couplings to fermions:



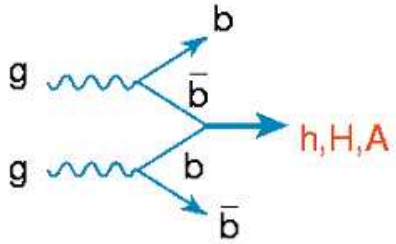
- $g_{h^0 t\bar{t}} \propto m_t \dfrac{\cos\alpha}{\sin\beta}$
- $g_{H^0 t\bar{t}} \propto m_t \dfrac{\sin\alpha}{\sin\beta}$
- $g_{A^0 t\bar{t}} \propto m_t \cot\beta$
- $g_{h^0 b\bar{b}} \propto m_b \dfrac{-\sin\alpha}{\cos\beta}$
- $g_{H^0 b\bar{b}} \propto m_b \dfrac{\cos\alpha}{\cos\beta}$
- $g_{A^0 b\bar{b}} \propto m_b \tan\beta$

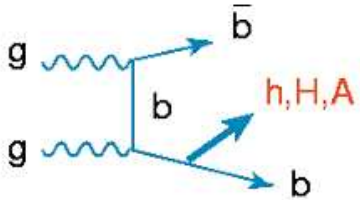
- proportional to mass → 3rd generation favoured
- tan β enhances couplings to down-type fermions

SM channels

… so main production mechanism for A^0 and H^0:

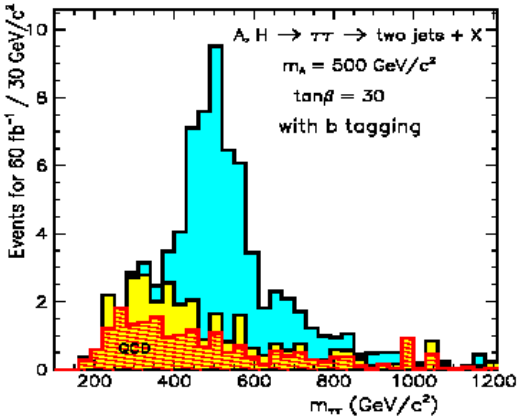
$$gg \to A^0, H^0 b\bar{b}$$

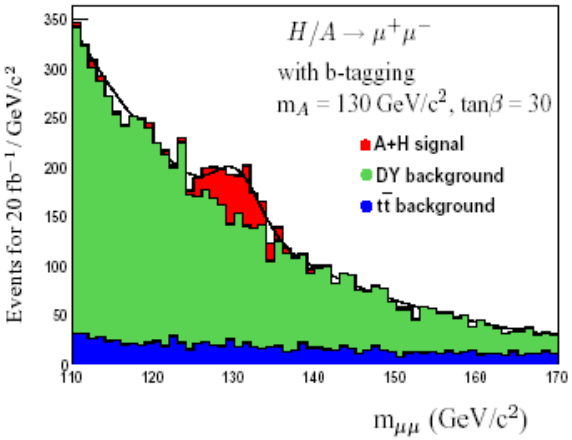




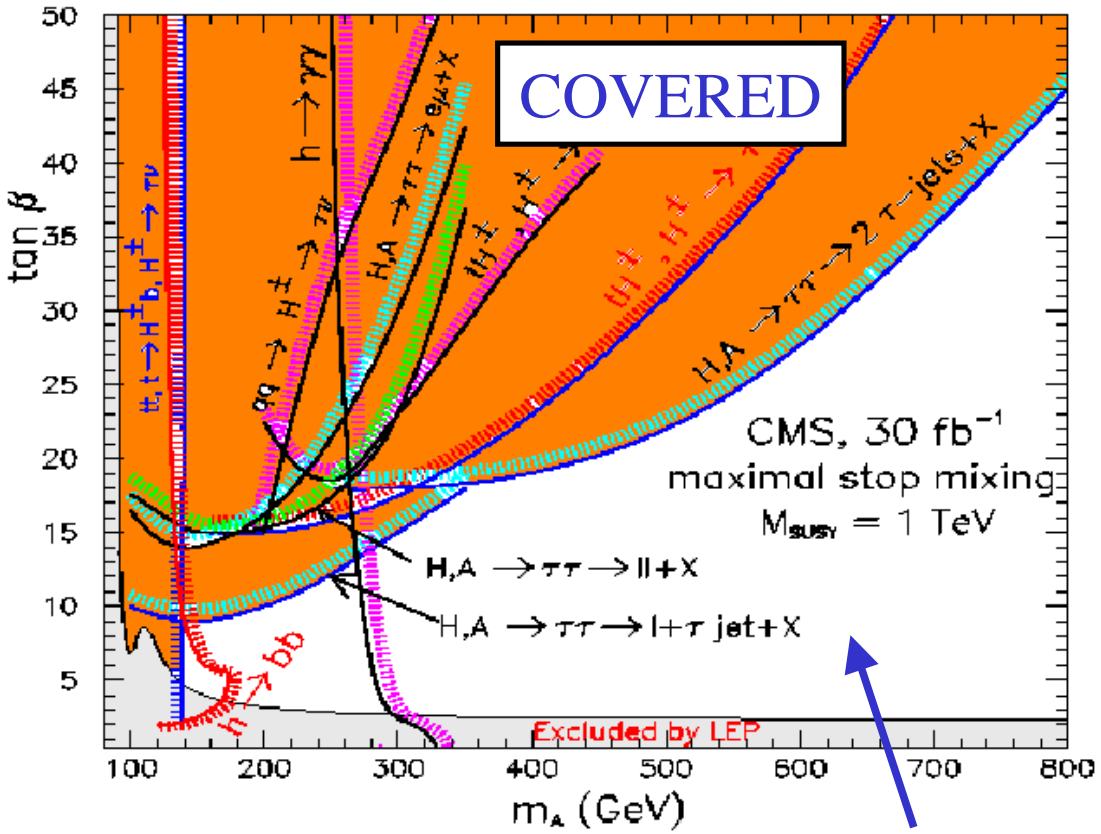
and use decay mode:

$$A^0, H^0 \to \tau\bar{\tau} \qquad A^0, H^0 \to \mu\bar{\mu} \qquad (A^0, H^0 \to b\bar{b})$$





Discovery search



- discovery of the heavy MSSM Higgses limited to upper triangle in m_A – tan β plot
- note: the h^0 can always be found
- problem is that production mechanism (e.g. bbA^0,H^0) needs tan β enhancement

Need new ideas to cover low tanβ - high m_A region …

New channels?

Split problem up in two pieces: production and decay

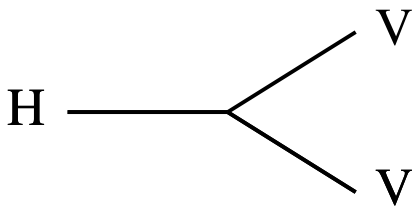
Let's first assume 'classical' production mechanism:

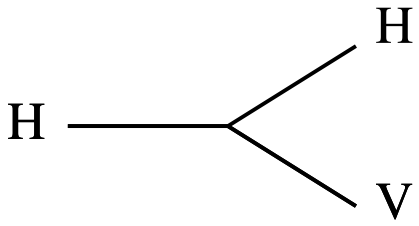
$$gg \to A^0, H^0 b\bar{b}$$

and lets look at the decays …

Couplings revisited

Higgs couplings to bosons??





- $g_{h^0VV} = g_{\phi^0VV}\sin(\beta-\alpha)$
- $g_{H^0VV} = g_{\phi^0VV}\cos(\beta-\alpha)$
- $g_{A^0VV} = 0$

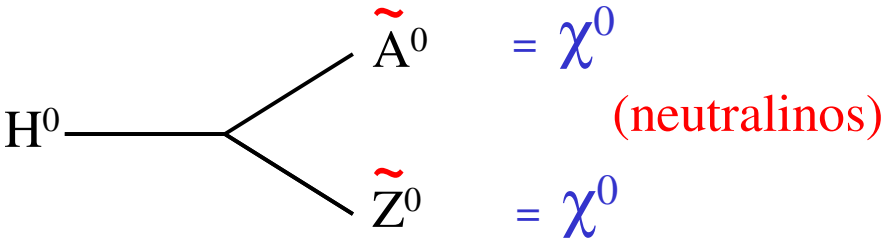
$(V = Z^0, W^{\pm})$

- $g_{h^0h^0V} = 0, g_{H^0H^0V} = 0, g_{A^0A^0V} = 0$
- $g_{h^0A^0Z} = \frac{g}{2\cos\theta_W}\cos(\beta-\alpha)$
- $g_{H^0A^0Z} = \frac{g}{2\cos\theta_W}\sin(\beta-\alpha)$

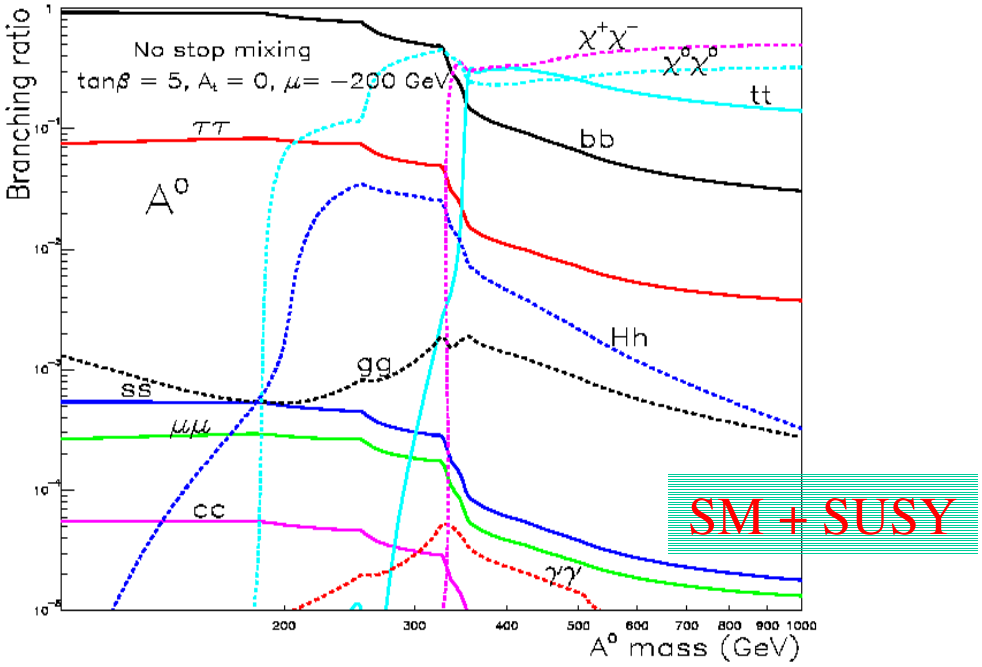
for $m_A > 200$ GeV, $\cos(\beta-\alpha) \approx 0.01$

Light sparticles

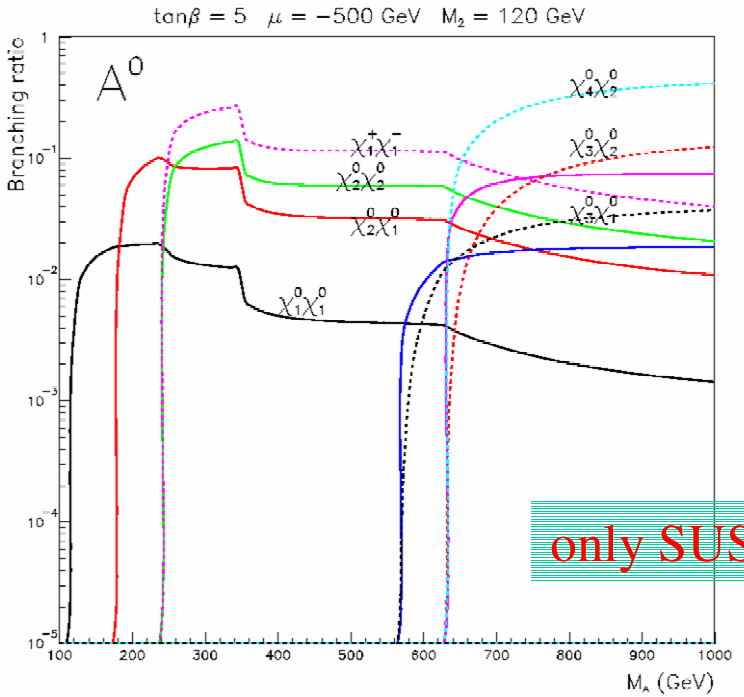
… interesting coupling:



doesn't work for SM, but remember SUSY …



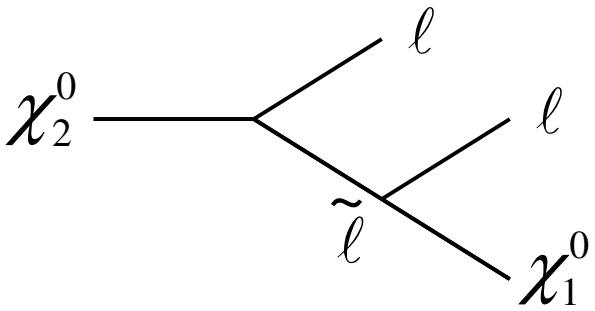
SM + SUSY



only SUSY

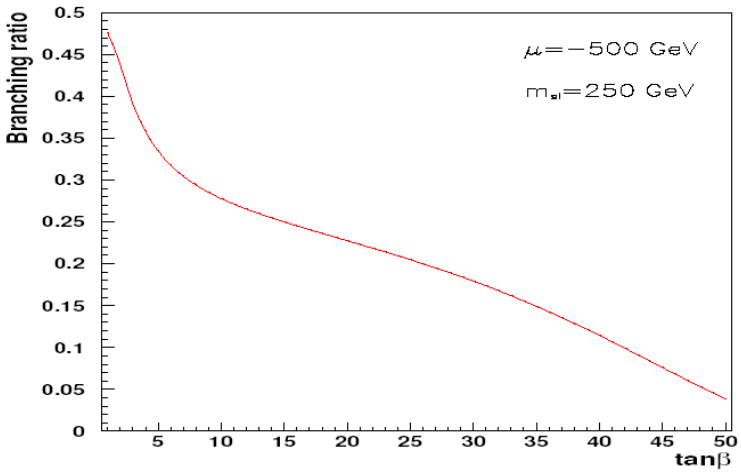
Neutralino decays

Leptonic decays would be preferred experimentally …

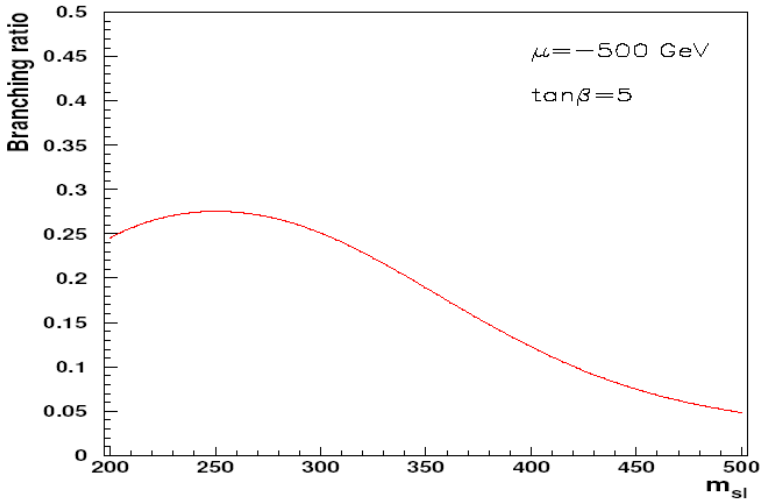


$(\ell = e, \mu)$

BR goes down with tan β

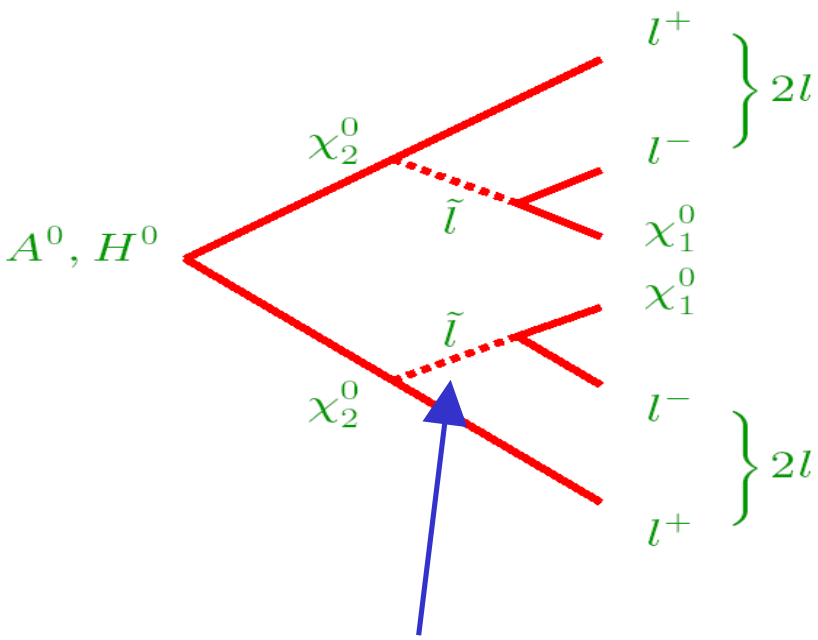


BR goes down with slepton mass



Sparticle modes

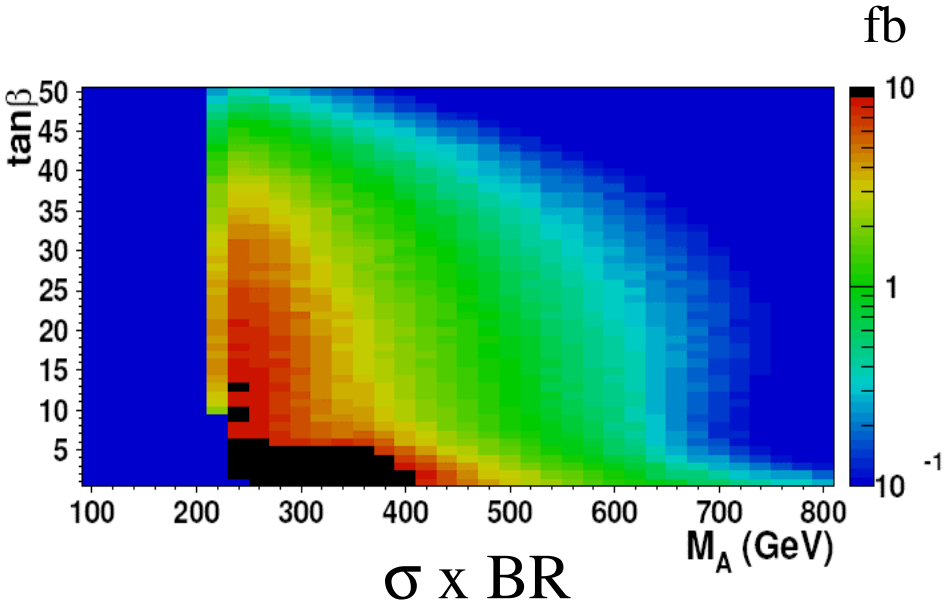
The signature looks like:



intermediate sleptons

4 isolated leptons (e,μ) + E_T^{miss}

powerful signature against the SM + SUSY backrounds @ LHC



σ x BR

Selection criteria

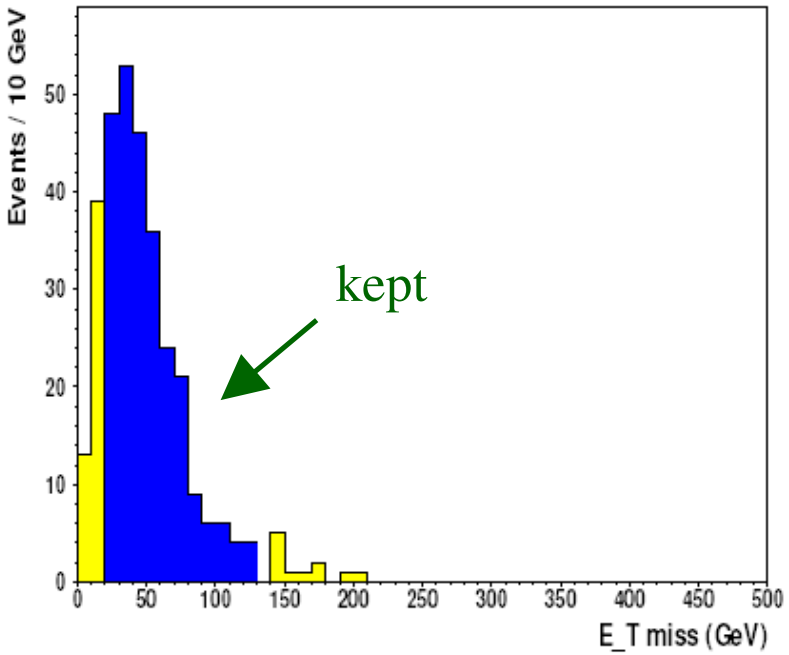
Basic requirements:

- there are four isolated leptons (e/μ) in the final state (no charged particle with $P_T > 1.5$ GeV in the cone of 0.3 rad around each lepton track)
- Z-veto (dilepton effective mass out of $m_Z \pm$ 10 GeV)

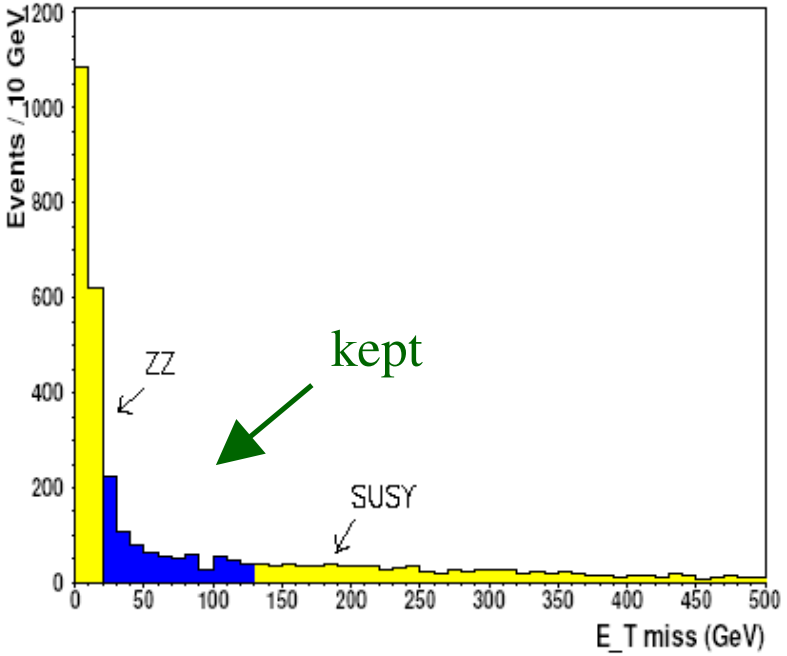
For signal to background optimization:

- P_T hardest lepton $<$ 80 GeV
- 20 Gev $< E_T^{miss} <$ 130 GeV
- E_T hardest jet $<$ 100 GeV
- if necessary (light squark/gluino): only 0,1,2 jets

Some distributions



Missing E_T in the signal (case 1, 100 fb^{-1})



Missing E_T in the background (SM+SUSY)

A case study

Case 1: $m_{\tilde{l}} > m_{\chi_2^0}$

MSSM parameters: $M_2 = 120$ GeV, $M_1 = 60$ GeV,
$\mu = -500$ GeV, $M_{\tilde{l}} = 250$ GeV, $M_{\tilde{q},\tilde{g}} = 1000$ GeV

Low $\tan\beta$:

$M_A = 350$ GeV

$\tan\beta = 5$

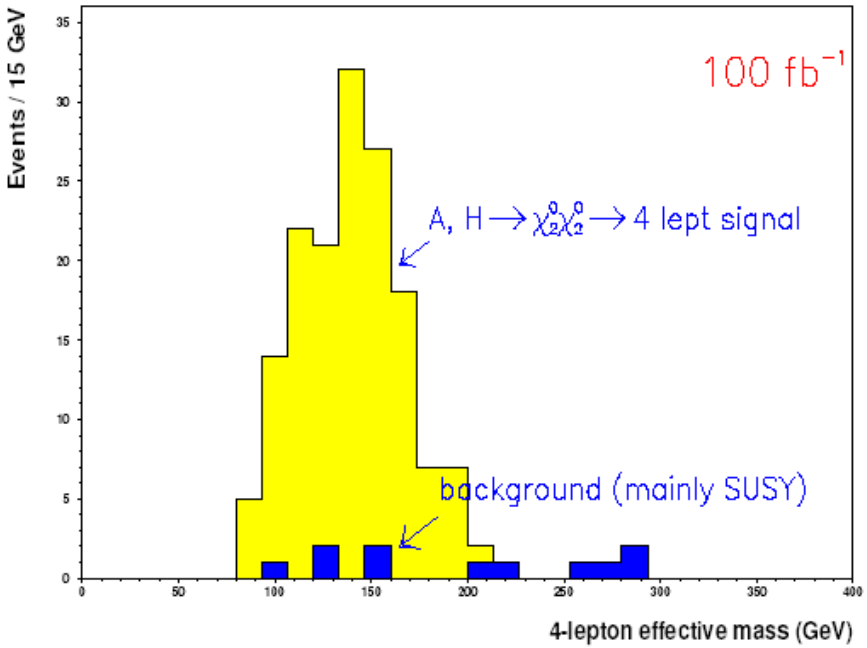


Table for case 1

Process	4 isol. lept.	Z-veto	P_T lept. cut	$\not{E}_T$ cut
$\tilde{q}$, $\tilde{g}$	421	206	60	8
$\tilde{\nu}$ $\tilde{\nu}$	191	92	20	15
$\tilde{q}\tilde{\chi}$	41	23	7	0
$\tilde{\chi}\tilde{\chi}$	40	20	13	5
tot. SUSY	703	345	102	28
ZZ	2106	80	79	10
total bkg.	2809	425	181	38
H, A signal	320	276	263	212

Number of events after successive cuts (100 fb^{-1})

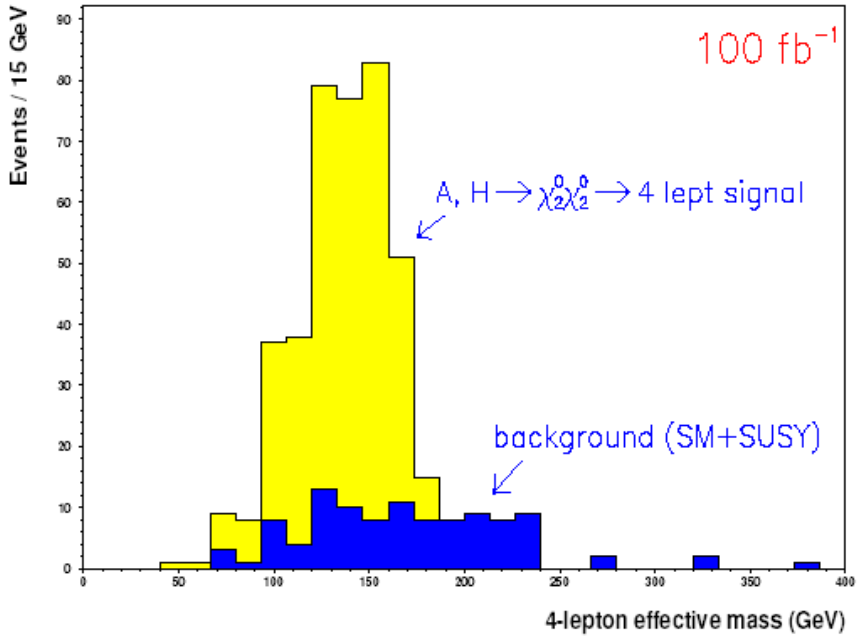
Case 2

Case 2: $m_{\tilde{l}} < m_{\chi_2^0}$

MSSM parameters: $M_2 = 200$ GeV, $M_1 = 100$ GeV, $\mu = +350$ GeV, $M_{\tilde{l}_L} = 200$ GeV, $M_{\tilde{l}_R} = 150$ GeV, $M_{\tilde{q},\tilde{g}} = 550$ GeV

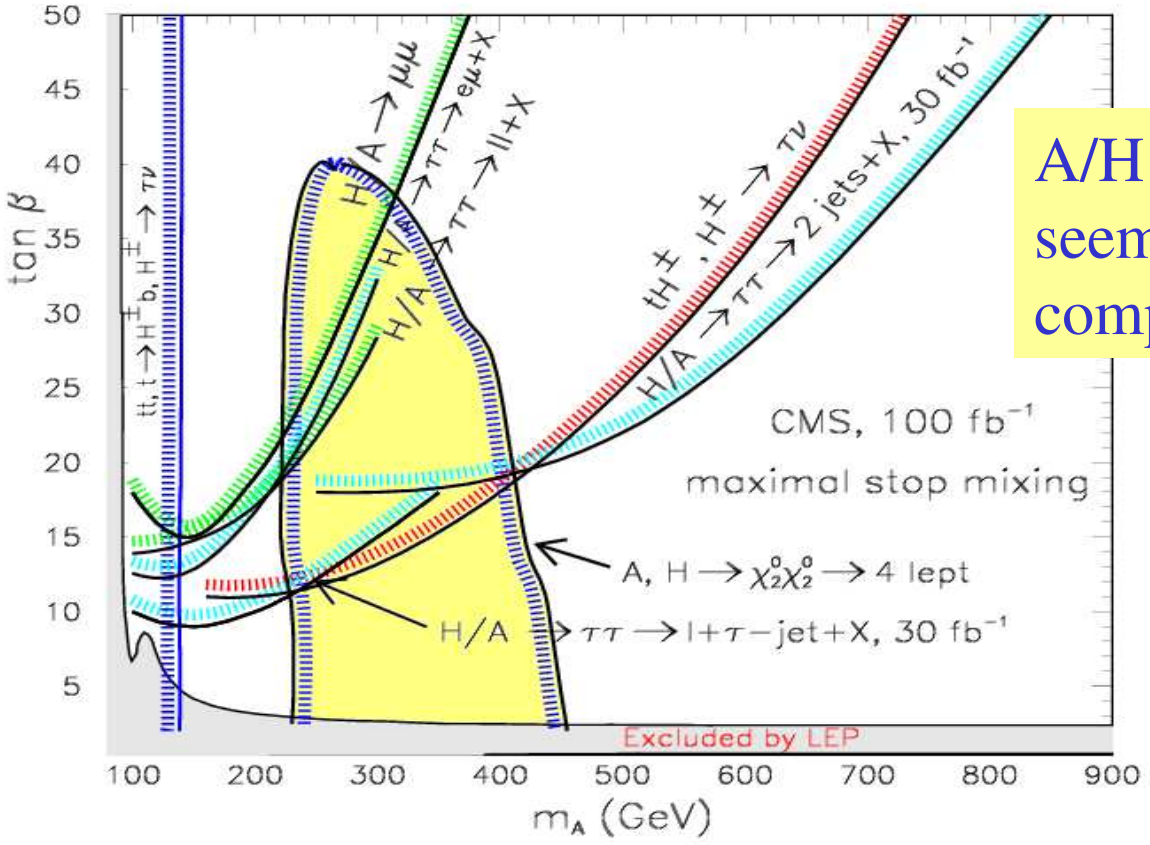
$M_A = 380$ GeV

$\tan\beta = 10$

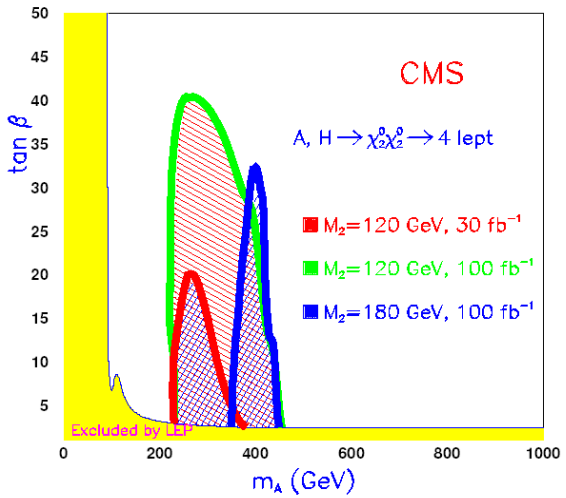


Discovery reach

Typical discovery reach:

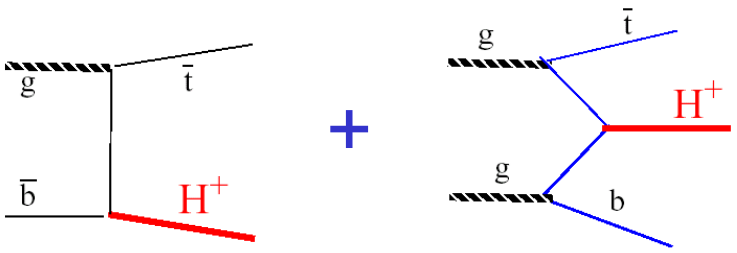


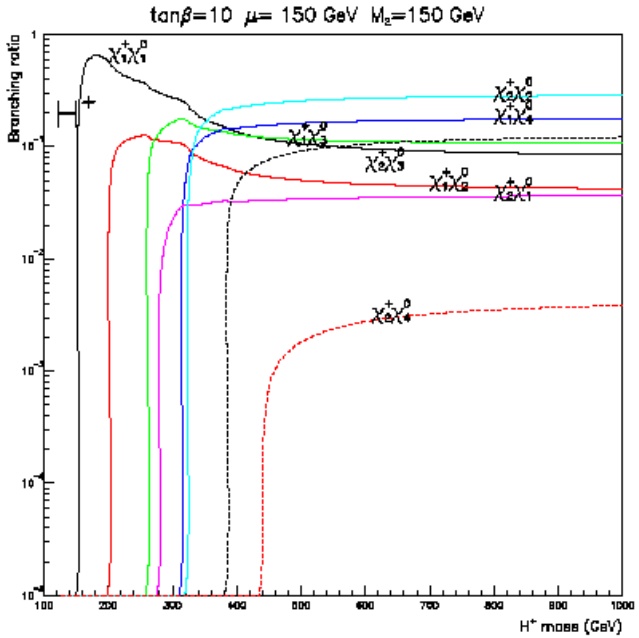
A/H → χχ → 4 leptons
seems to prefer low tan β,
complementary to A/H → ττ !!



Charged Higgs to sparticles

Analogue production mechanism for $H^{\pm}$:





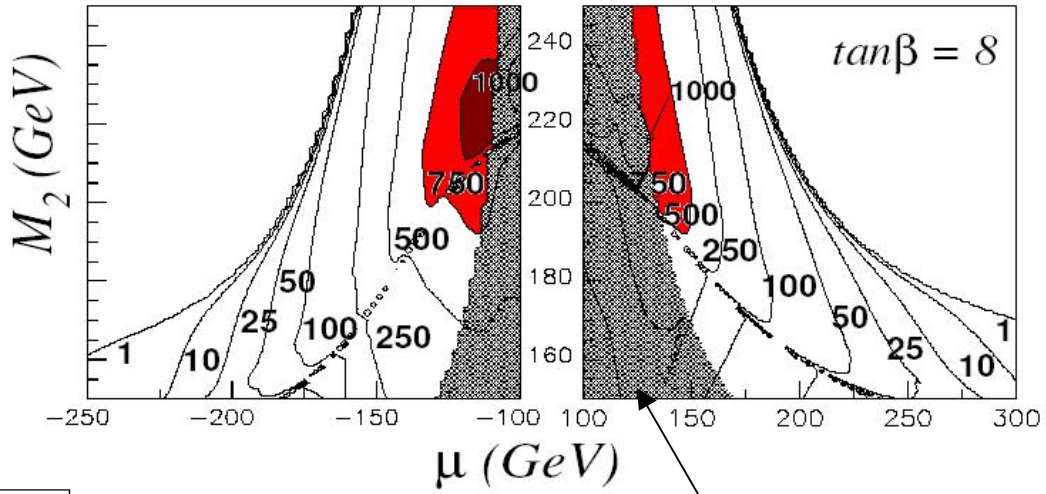
Analogue decay mode:

$$H^{\pm} \rightarrow \chi_{2,3}^{0}\, \chi_{1,2}^{\pm} \rightarrow 3l + E_T^{miss}$$

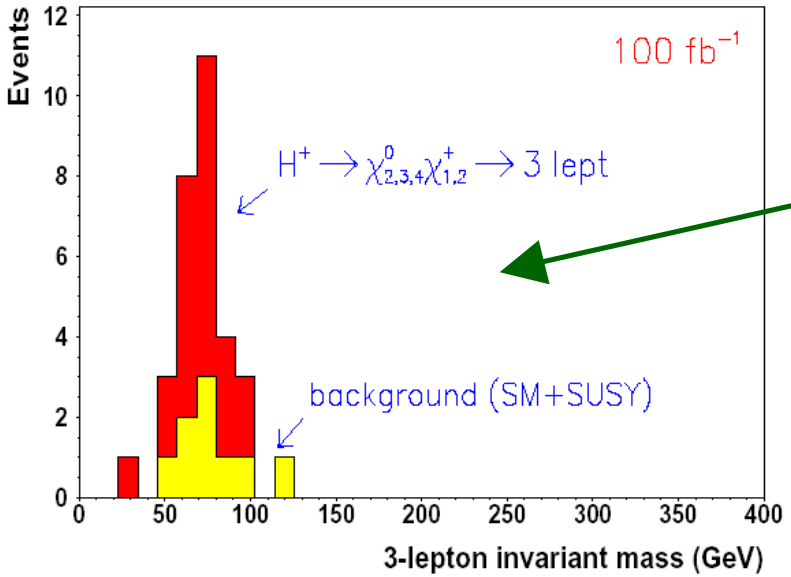
→ only 3 leptons, need to reconstruct additional top (t→bjj)

More tricky this time

works only for small region in MSSM parameter space …



LEP excluded



in red area we can do it!!

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F. Moortgat (Uni. Antwerpen),
S. Moretti (Uni. Southampton)

Charged Higgs selection

We require:

- 3 isolated leptons (e, μ) with P_T leptons $>$ 20, 7, 7 GeV for electrons or 20, 5, 5 GeV for muons.
- Z-veto (dilepton invariant mass out of $m_Z \pm$ 10 GeV)
- minimum three jets with $E_T > 20$ GeV in $|\eta| < 4.5$. find the best top candidates by minimizing $m_{jjj} - m_{top}$
- 2 of those with m_{jj} in the range $m_W \pm 15GeV$
- 3rd jet must give m_{jjj} in the range $m_{top} \pm 35GeV$
- 3rd jet must be b-tagged with $\sigma(ip) = \frac{ip_{xy}}{\Delta ip_{xy}} > 1.5$
- extra jet veto for jets with $E_T > 50$ GeV.
- P_T hardest lepton < 110 GeV, P_T softest lepton < 25 GeV
- $M_{inv}^{3l} < 200$ GeV
- $M_{eff} < 150$ GeV, with $M_{eff} = \sqrt{2p_T^{3l} p_T^{miss}(1 - \cos\Delta\phi)}$ ($\Delta\phi$ is the azimuthal angle between p_T^{3l} and p_T^{miss})

Event selection

Many backgrounds considered:

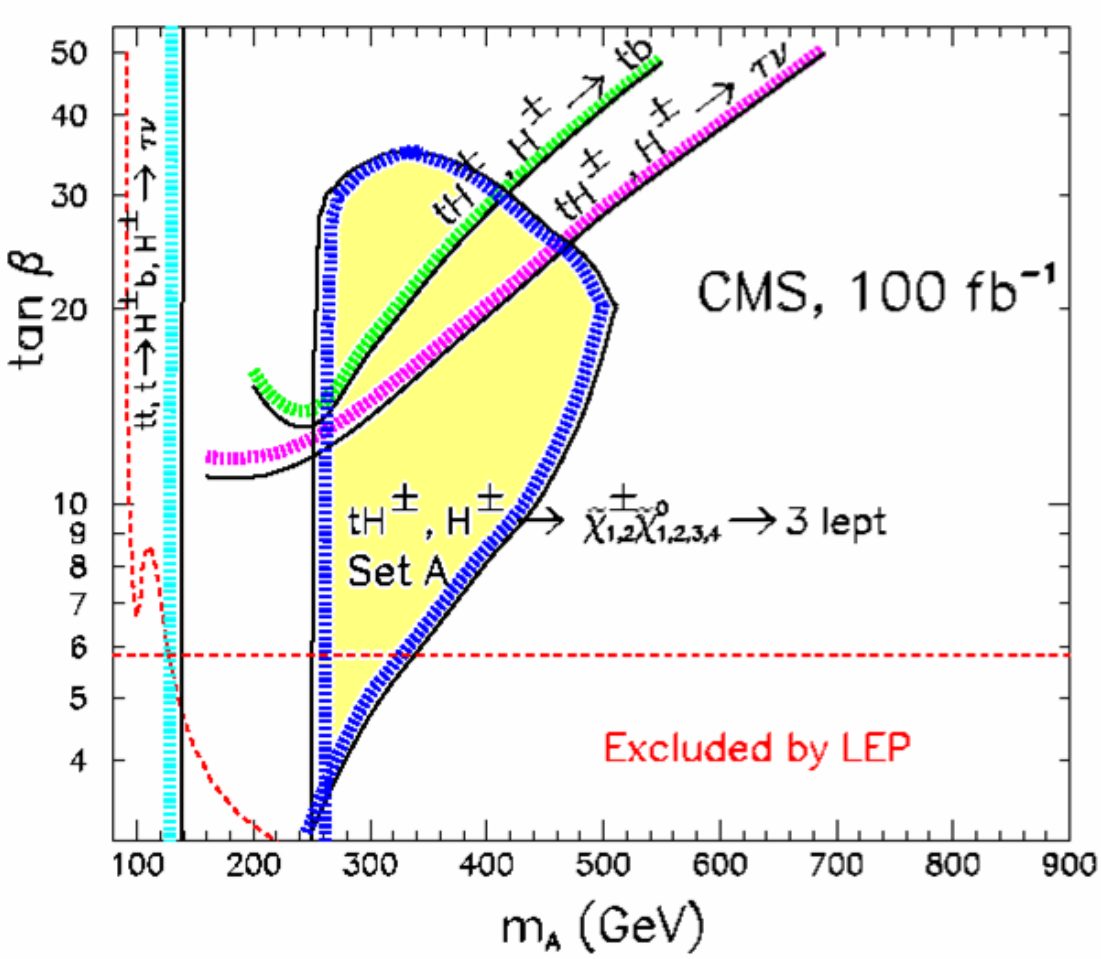
Process	3ℓ events	Z-veto	hadr. top†	b-tag	jet veto††	others†††
$t\bar{t}$	2781	2465	91	15.5	11.1	5.8
$t\bar{t}Z$	492	82	19	8	2.4	0.8
$t\bar{t}\gamma^*$	22	21	7	2	0.4	0.2
$t\bar{t}h$	59	52	17	4	1.6	0.2
$\tilde{\chi}\tilde{\chi}$	19993	18880	237	31	9	3
$\tilde{q}$, $\tilde{g}$	12712	11269	3984	861	6	1
tH^- & $\bar{t}H^+$	508	485	126	36	29	25

† : the top reconstruction requires > 3 jets with $E_T > 20$ GeV, $M_{jj} \sim M_W$ and $M_{jjj} \sim M_t$.

†† : veto additional jets with $E_T > 60$ GeV.

††† : $M_{eff} = \sqrt{2p_T^{3l}p_T^{miss}(1-\cos\Delta\phi)} < 200$ GeV and $m_{inv}^{3l} < 150$ GeV.

Discovery Reach



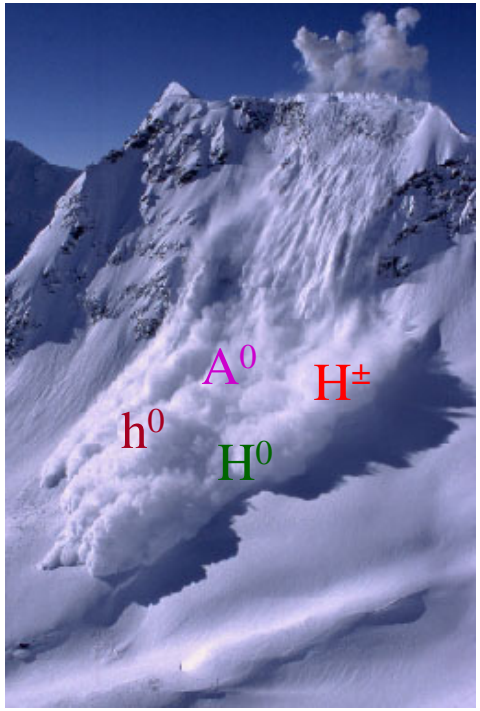
MSSM parameters:

$M_2 = 210$ GeV,
$\mu = 135$ GeV,
$M_{\text{sleptons}} = 110$ GeV,
$M_{\text{squark, gluino}} = 1$TeV

Second branch

So we tried new decay modes …

what about new production mechanisms?



→

try to exploit MSSM Higgs bosons production in SUSY particle cascades

$$\tilde{g} \to q q^{(\prime)} \; \chi_3^0, \chi_4^0, \chi_2^\pm \to \chi_1^0, \chi_2^0, \chi_1^\pm \; A, H$$

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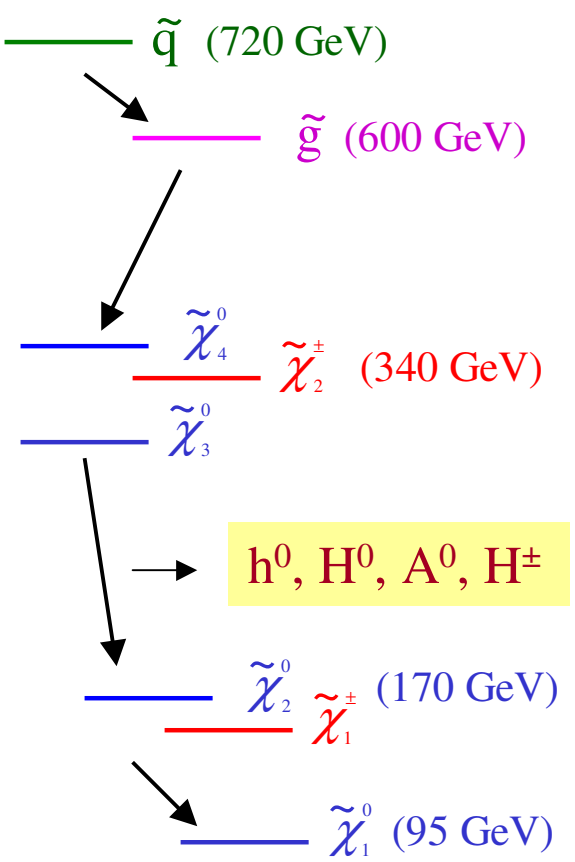
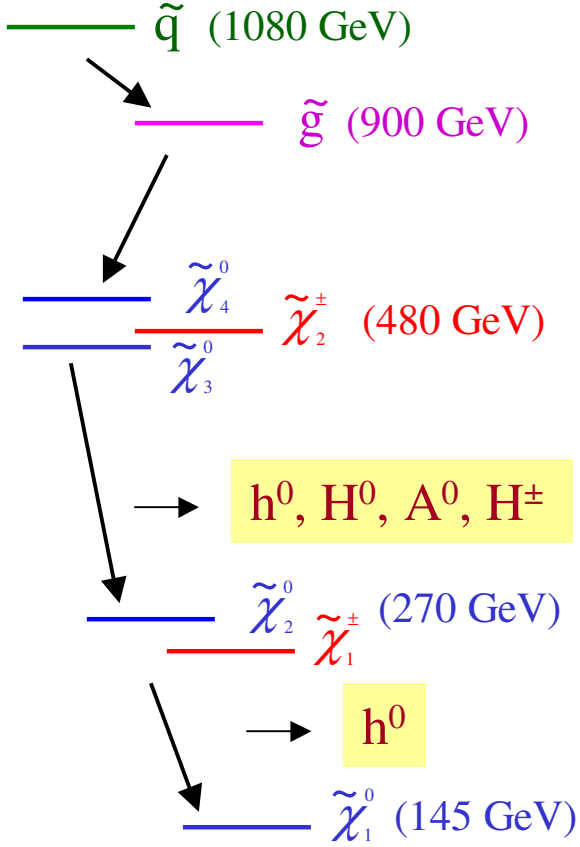
M. Guchait (TIFR Mumbay), F. Moortgat (Uni. Antwerpen),

Scenarios

Scenario 1 (big cascades)

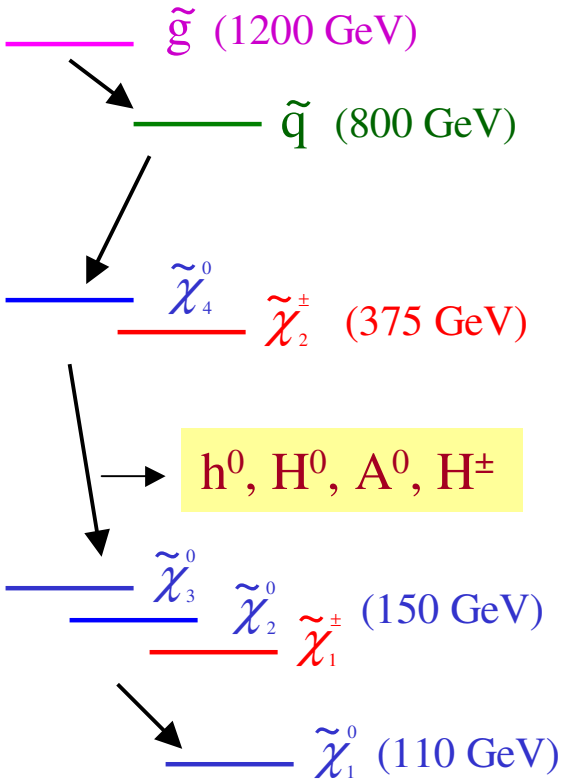


Scenario 2 (little + big cascades)

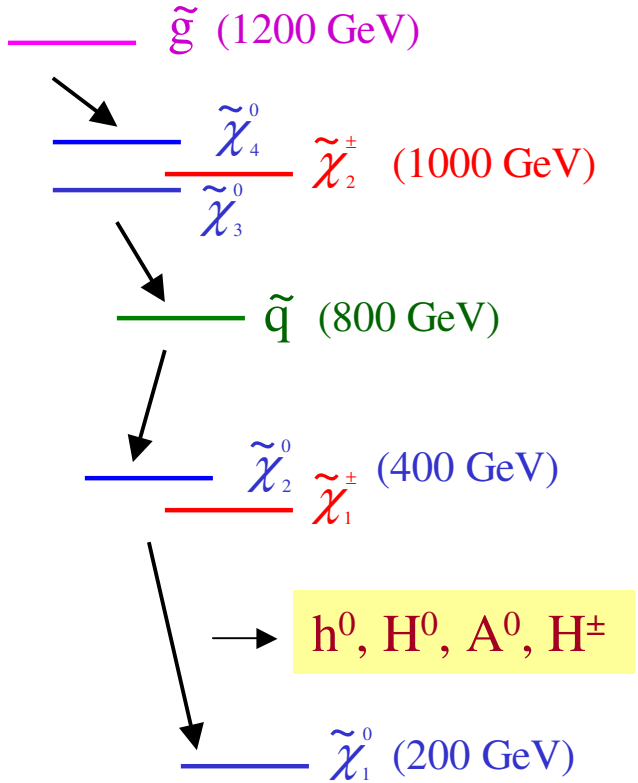


Scenarios (cont'd)

Scenario 3 (big cascades)

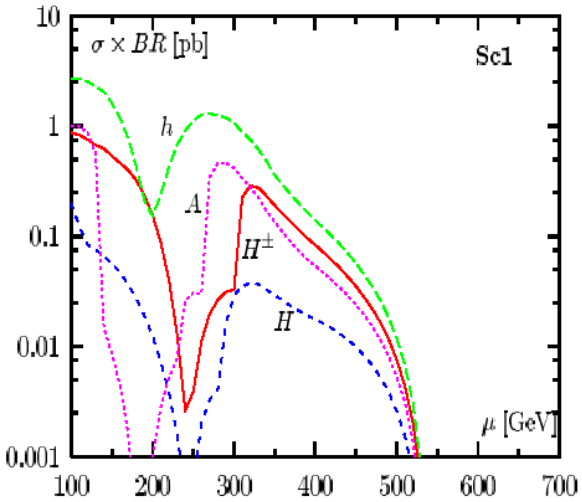


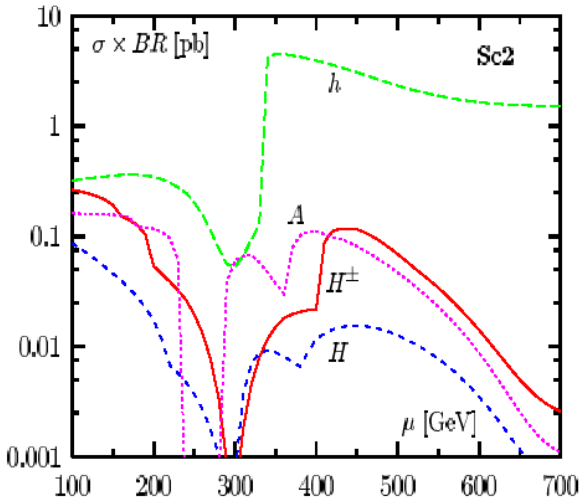
Scenario 4 (little cascades)



Cross section x BR's

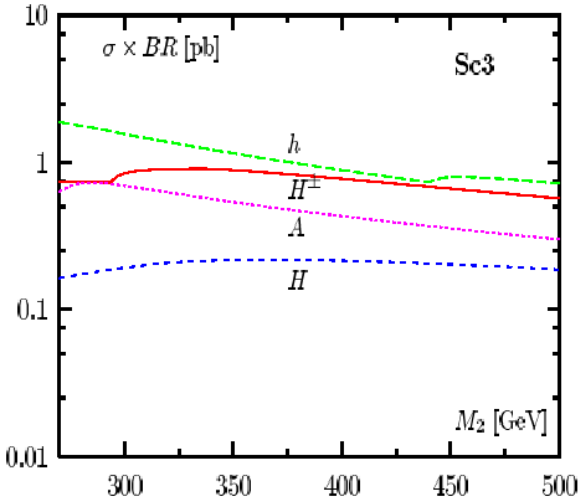
Scenario 1

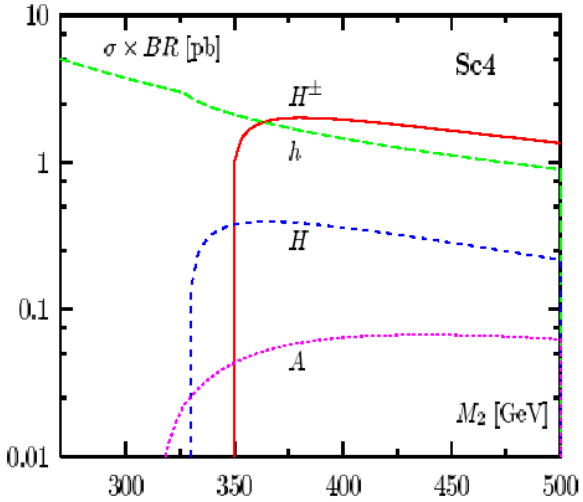




Scenario 2

Scenario 3





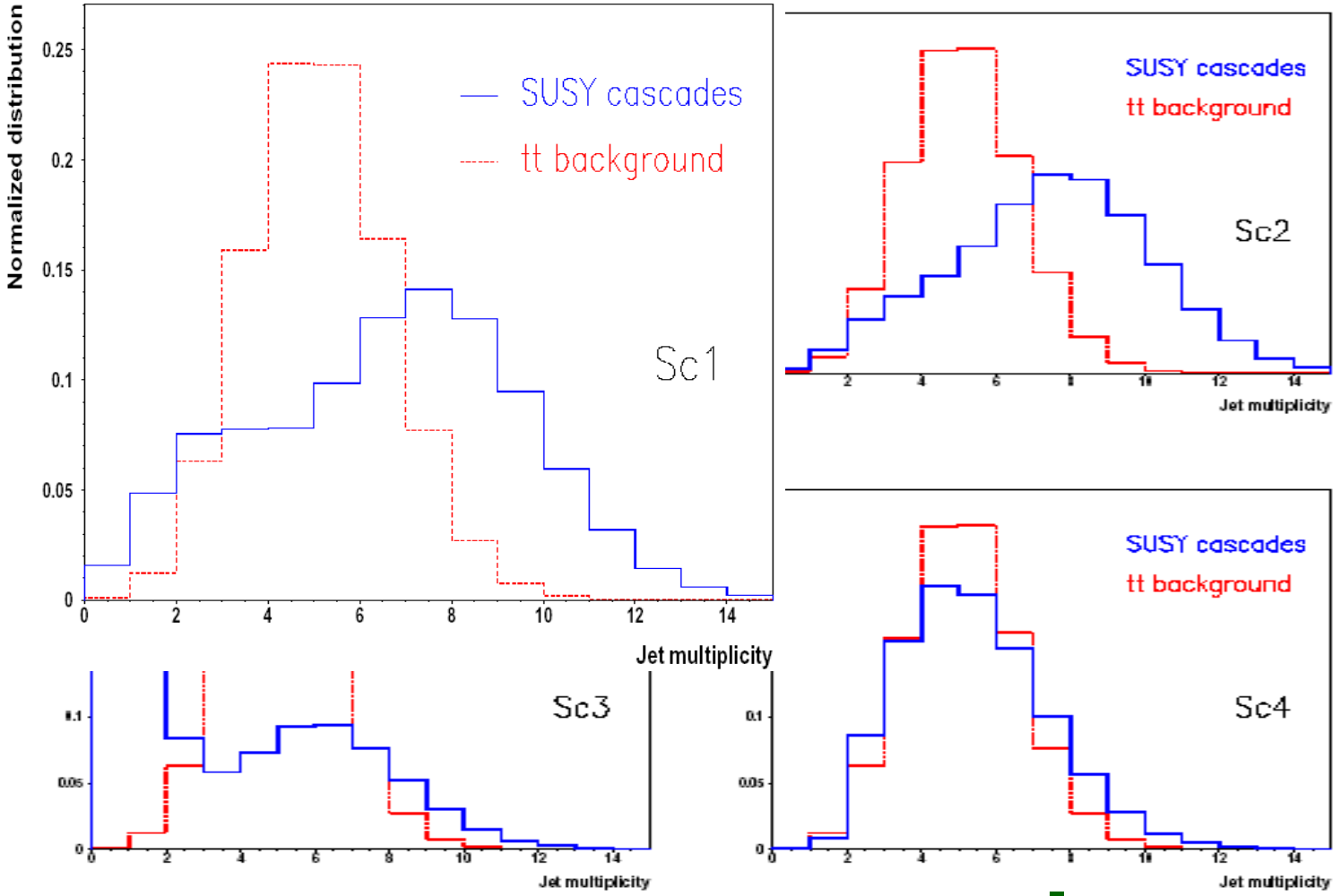
Scenario 4

m_A =150 GeV
tan β = 5

Selection strategy

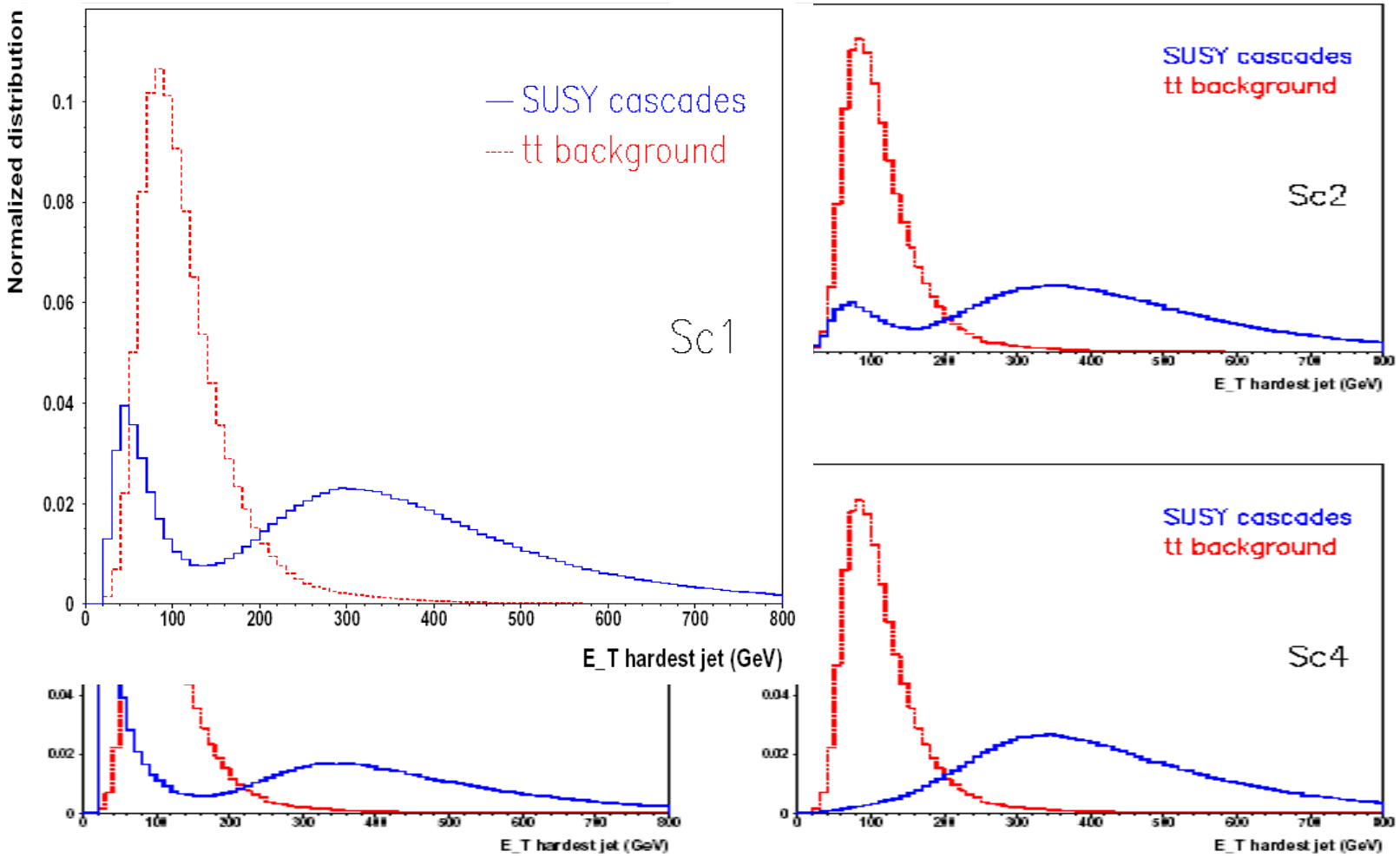
- look for main decay modes of neutral and charged Higgses:
  - $h^0, A^0, H^0 \rightarrow bb$
  - $H^{\pm} \rightarrow \tau\nu$ (cause $m_{H^{\pm}} = 170$ GeV)
- first thing to do: make sure triggering is guaranteed, then separate SUSY cascades from SM background
- let's look at some kinematical distributions …
- using ISASUSY 7.58 + HERWIG 6.4 + CMSJET 4.801 + HDECAY + TAUOLA + ISAWIG

Kinematics



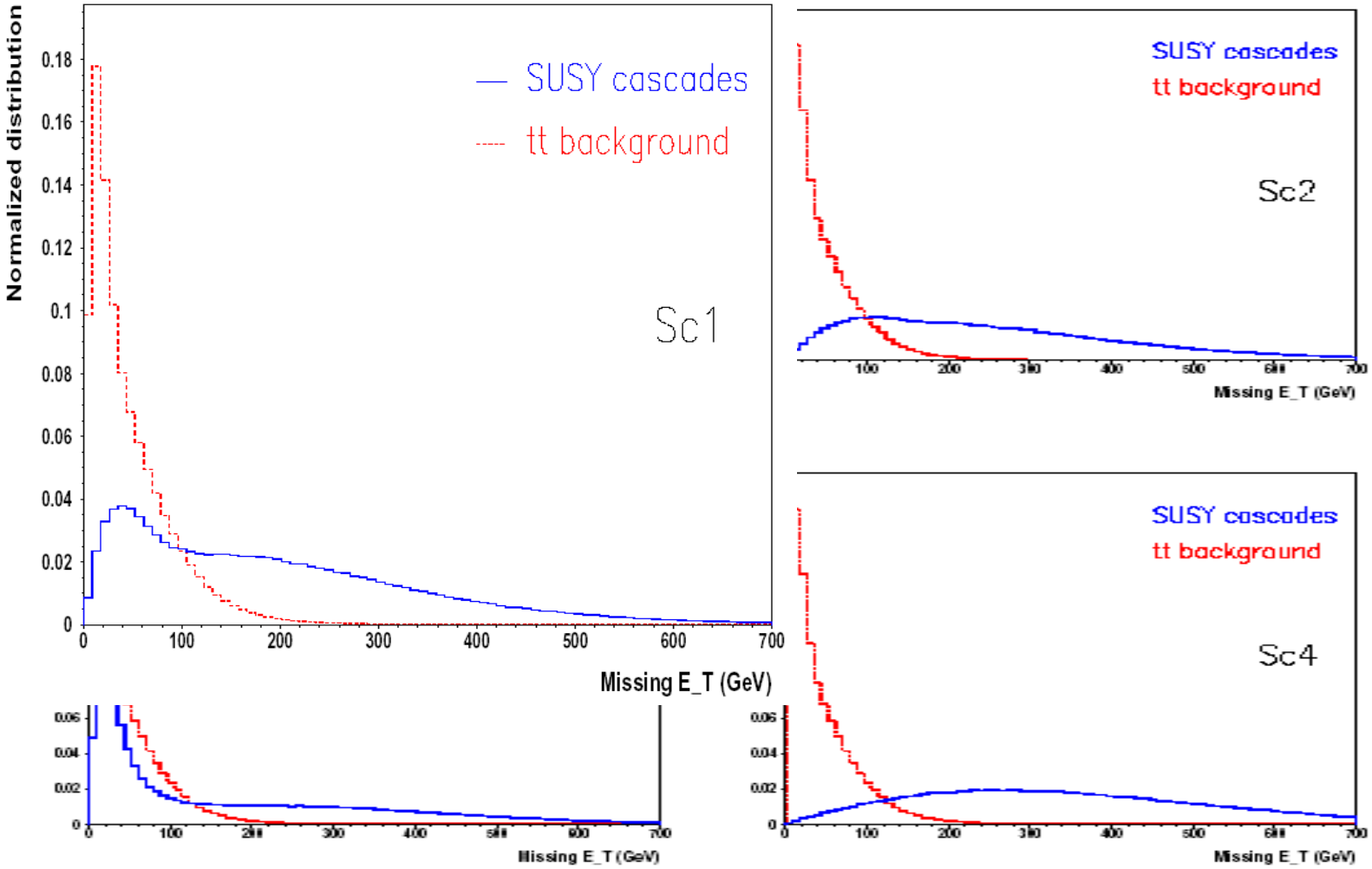
Jet multiplicity in SUSY cascade signal vs. SM $t\bar{t}$ background

Kinematics (2)



E_T (hardest jet) in SUSY cascade signal vs. SM tt background

Kinematics (3)

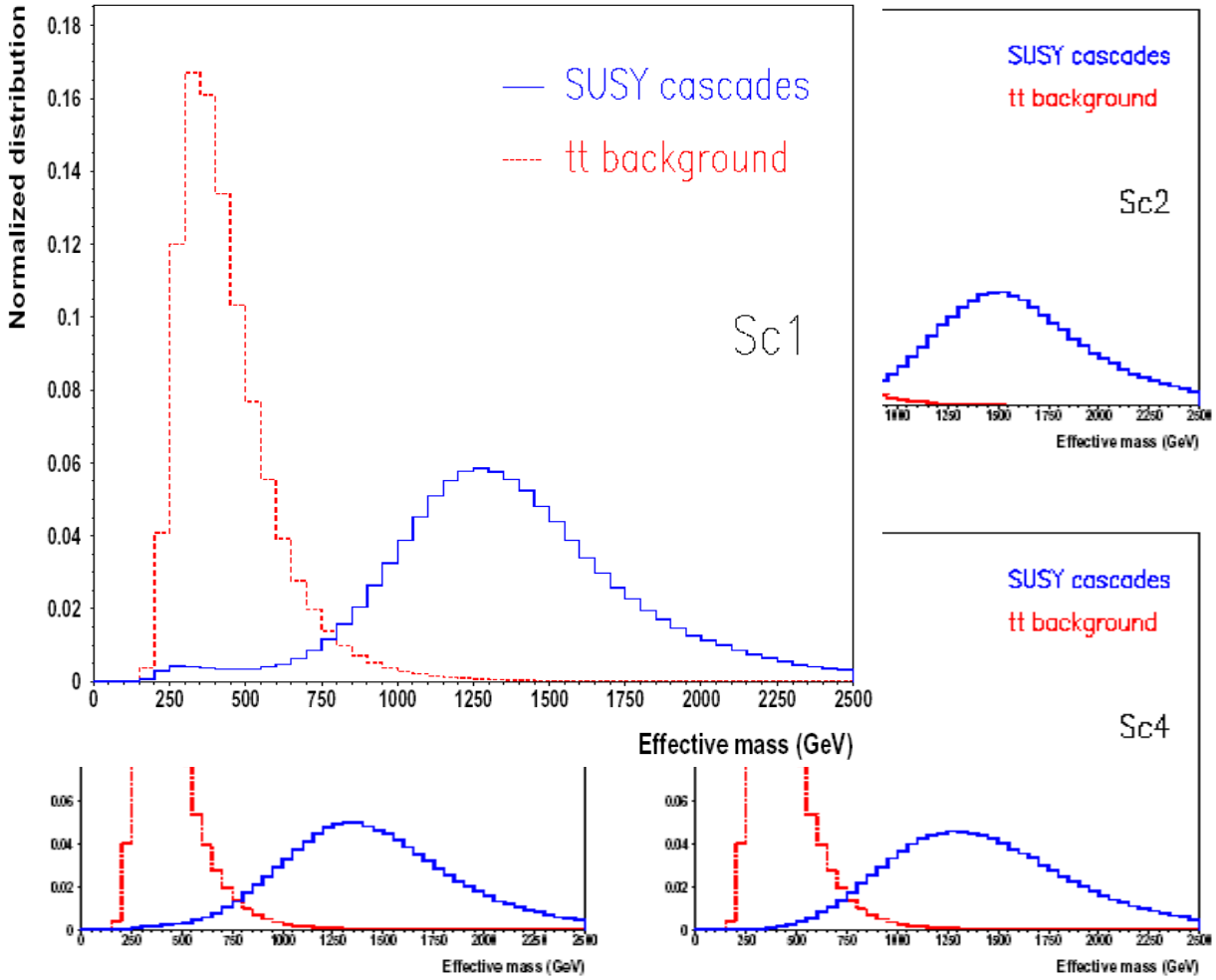


Missing E_T in SUSY cascade signal vs. SM $t\bar{t}$ background

Kinematics (4)

Total transverse energy in SUSY cascade signal vs. SM tt background:

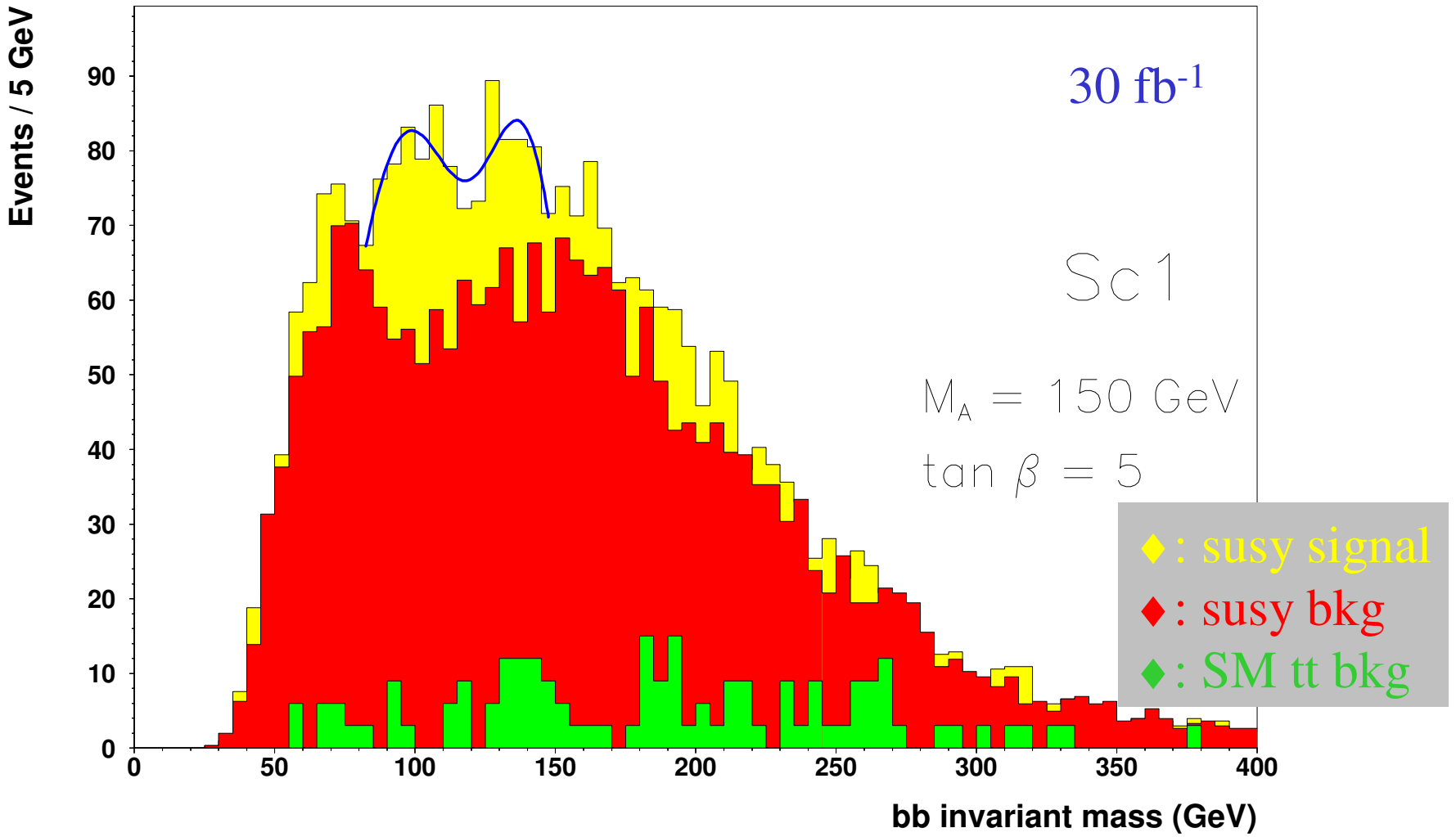
$$E_T^{total} = \sum_{jets} E_T + E_T^{miss}$$



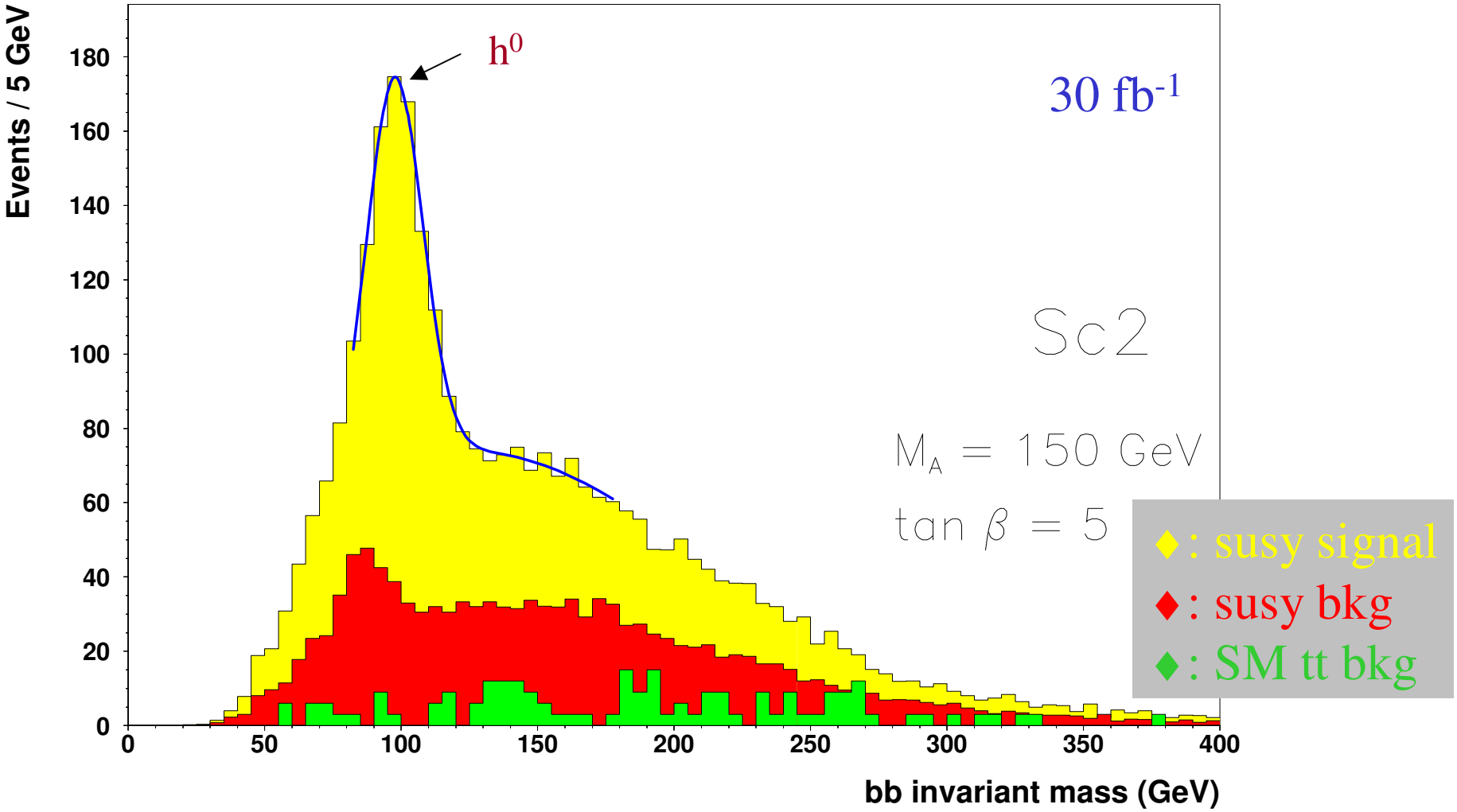
Selection criteria for neutral Higgses

- we require the event to contain at least 5 jets
- the hardest jet in the event should have $E_T > 300$ GeV
- the transverse missing energy $E_T^{miss} > 150$ GeV
- the effective mass $E_T^{total} = \sum_{jets} E_T + E_T^{miss} > 1200$ GeV
- the event should contain at least two *b*-tagged jets, with $45 \text{ GeV} < E_T < 120 \text{ GeV}$. *b*-tagged means that both jets should contain at least two tracks with $\sigma(ip) = ip_{xy}/\Delta ip_{xy} > 3$.

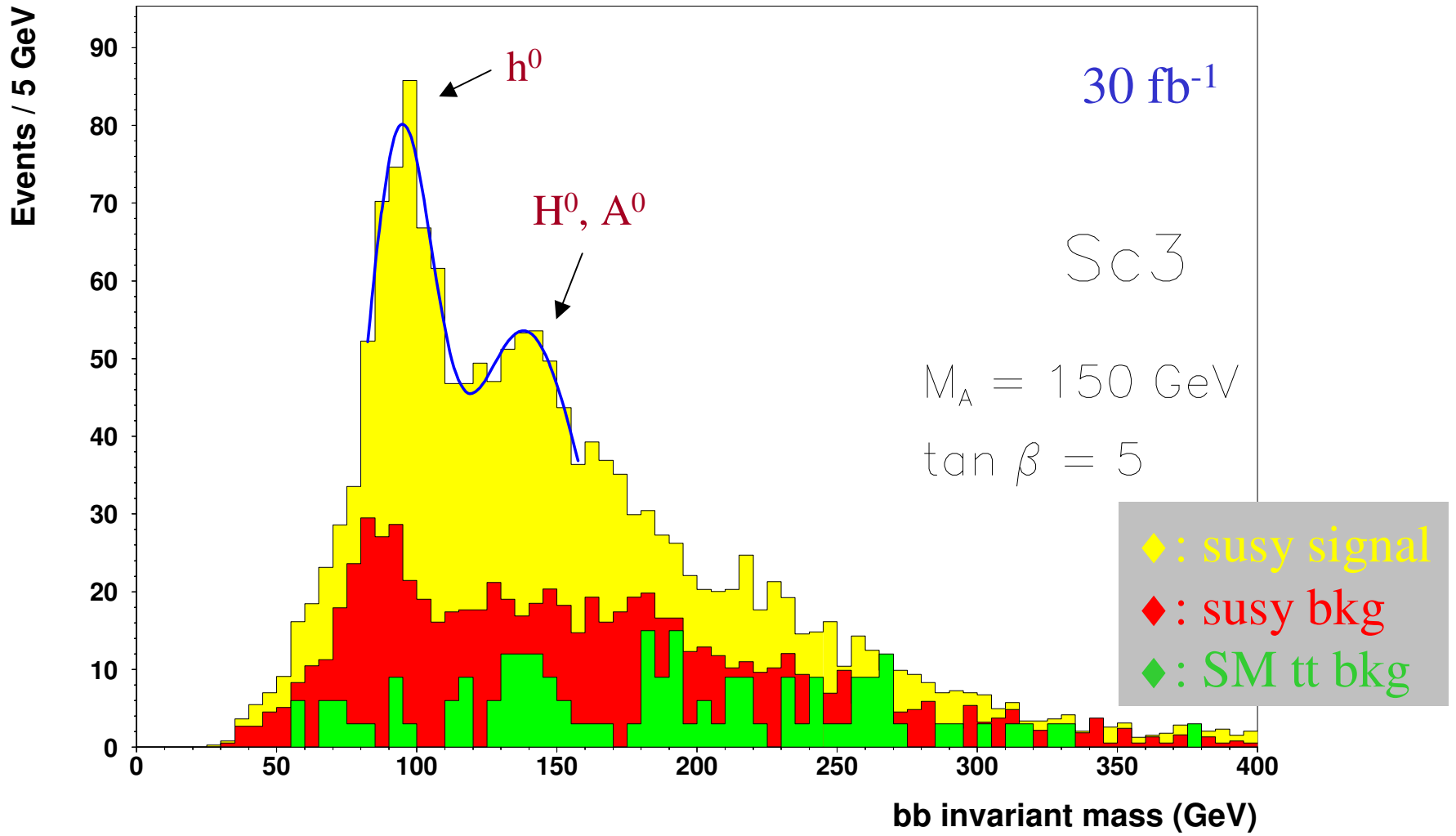
Results: scenario 1



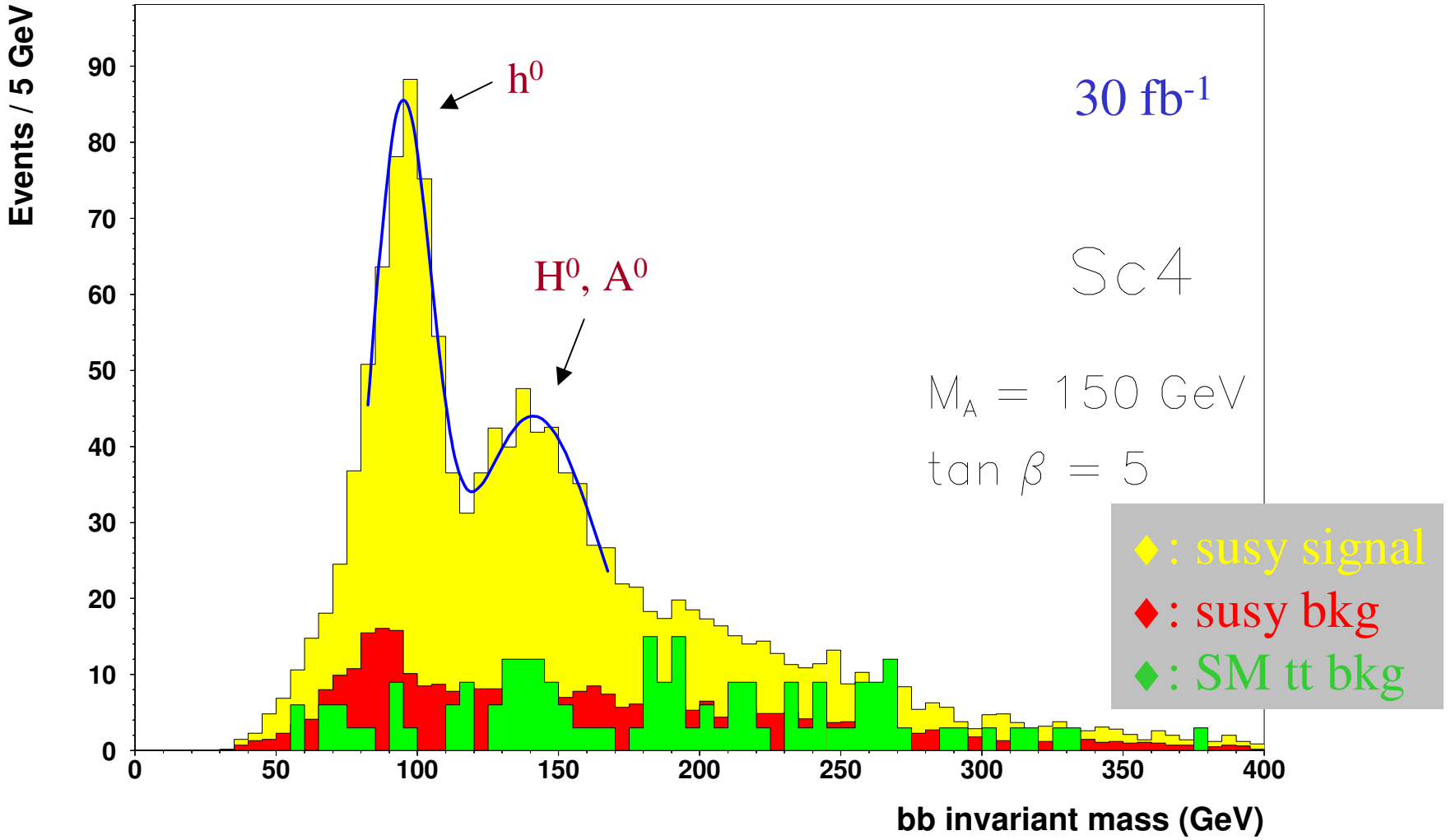
Results: scenario 2



Results: scenario 3



Results: scenario 4

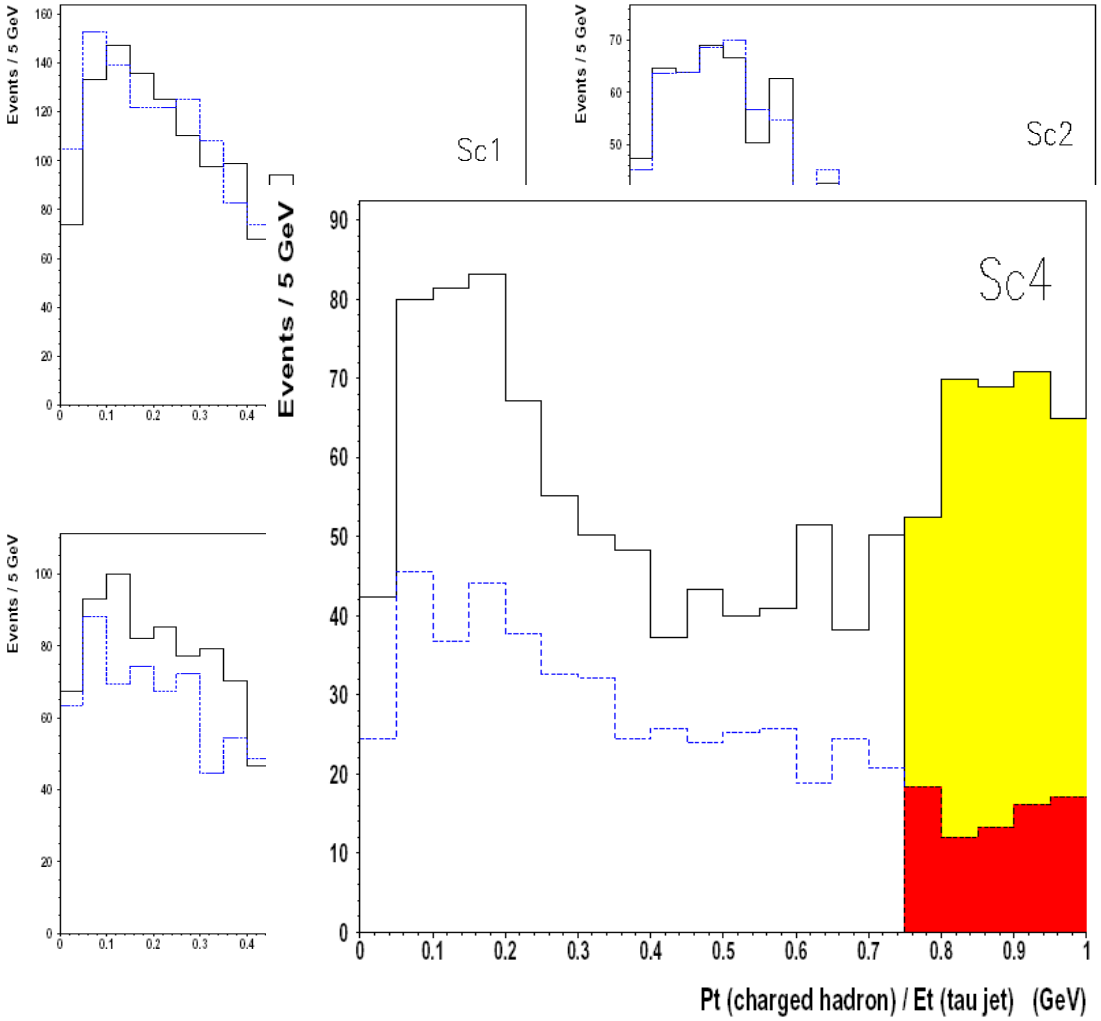


Selection criteria for charged Higgses

- we require the event to contain at least 5 jets
- the hardest jet in the event should have $E_T > 300$ GeV
- the transverse missing energy $E_T^{miss} > 200$ GeV
- the event should at least contain one hadronic τ-jet, *i.e.* a narrow jet with a hard charged track (one prong), isolated in calo and tracker, with $E_T > 80$ GeV
- more than 75% of the τ-jet transverse energy should be carried by the charged track (= polarization effect)

Charged Higgs results

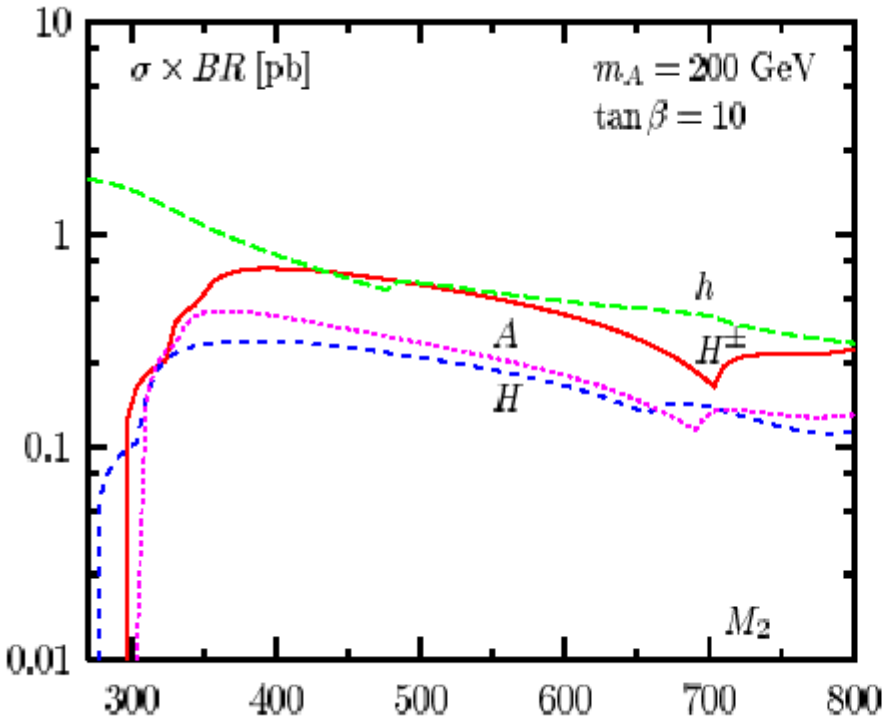
$$\frac{p_T^{\pi}}{E_T^{\tau-jet}}$$



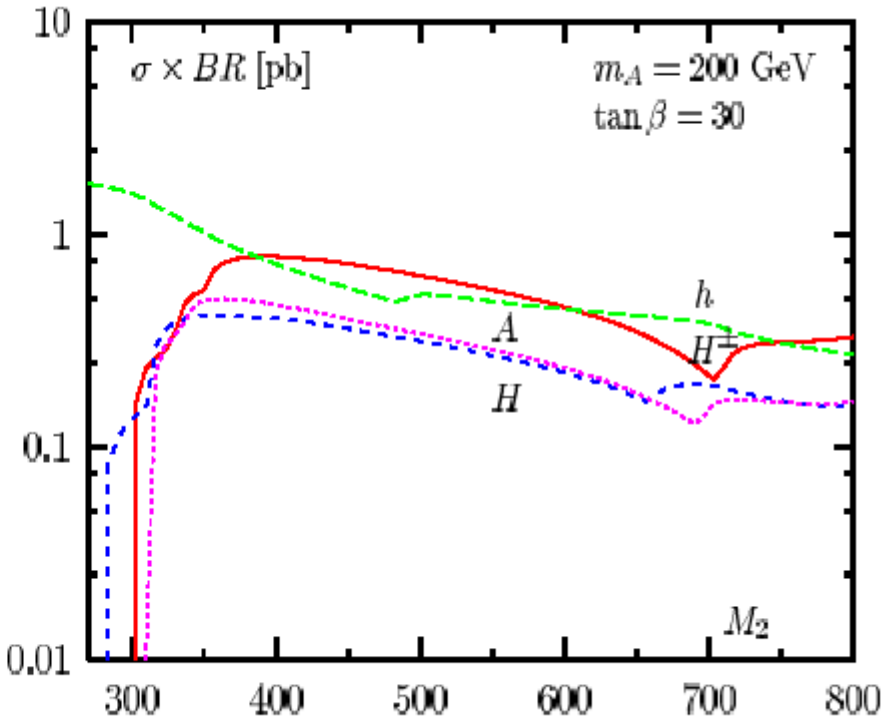
H^+ effect visible in Sc4,
but not so convincing
since no invariant mass peak

$m_{H+} = 170$ GeV
$\tan\beta = 5$

tan β dependence



tan β = 10

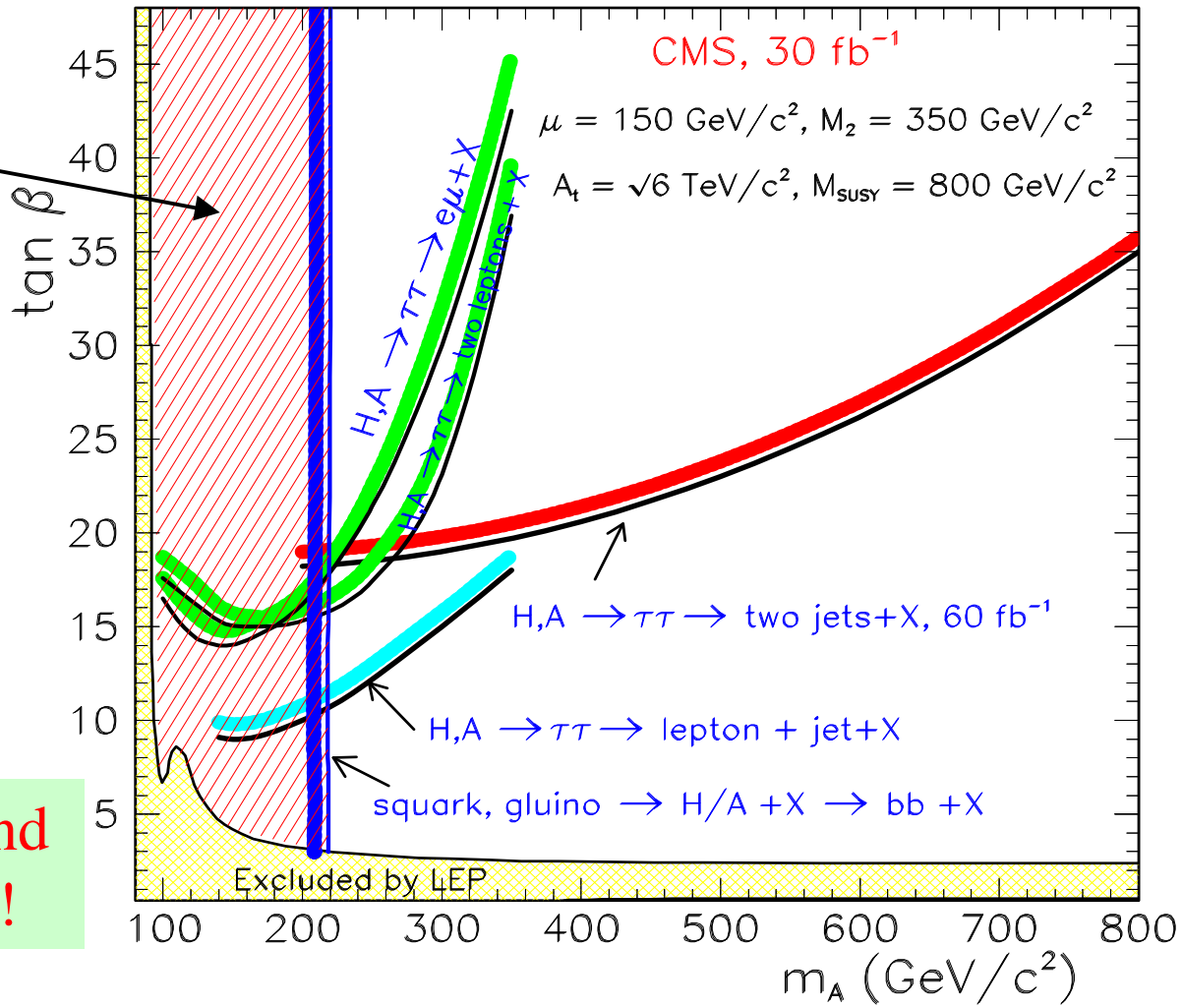


tan β = 30

Scenario 3

Discovery reach at 30fb^{-1}

region where H^0 and A^0 can be found in SUSY cascade decays



h^0 can be found in full plane!!

Scenario 3

Conclusions

- we have studied supersymmetric decay channels of the MSSM Higgs bosons in CMS

- for the heavy neutral Higgs bosons, we have found an interesting complementarity between the reach of the A, H $\rightarrow \chi_2^0 \chi_2^0 \rightarrow 4l + E_T^{miss}$ and the SM channels

- works also for charged Higgses, but only in small region of parameter space

Conclusions (2)

• we also explored a new mechanism that can abundantly produce neutral and charged Higgs bosons

• we have shown a discovery potential for heavy MSSM Higgs bosons with this production mechanism, complementary to both the standard channels and the sparticle channels

• we have shown a potential for the production of the light Higgs from *heavy* gauginos, which could complement the standard searches in the difficult $100 < m_h < 130$ GeV region.

Outlook

Higgs → SUSY

- look again at A, H → χ_i^0 χ_j^0 and try to access high mass region

(Bisset-Moortgat-Moretti)

SUSY → Higgs

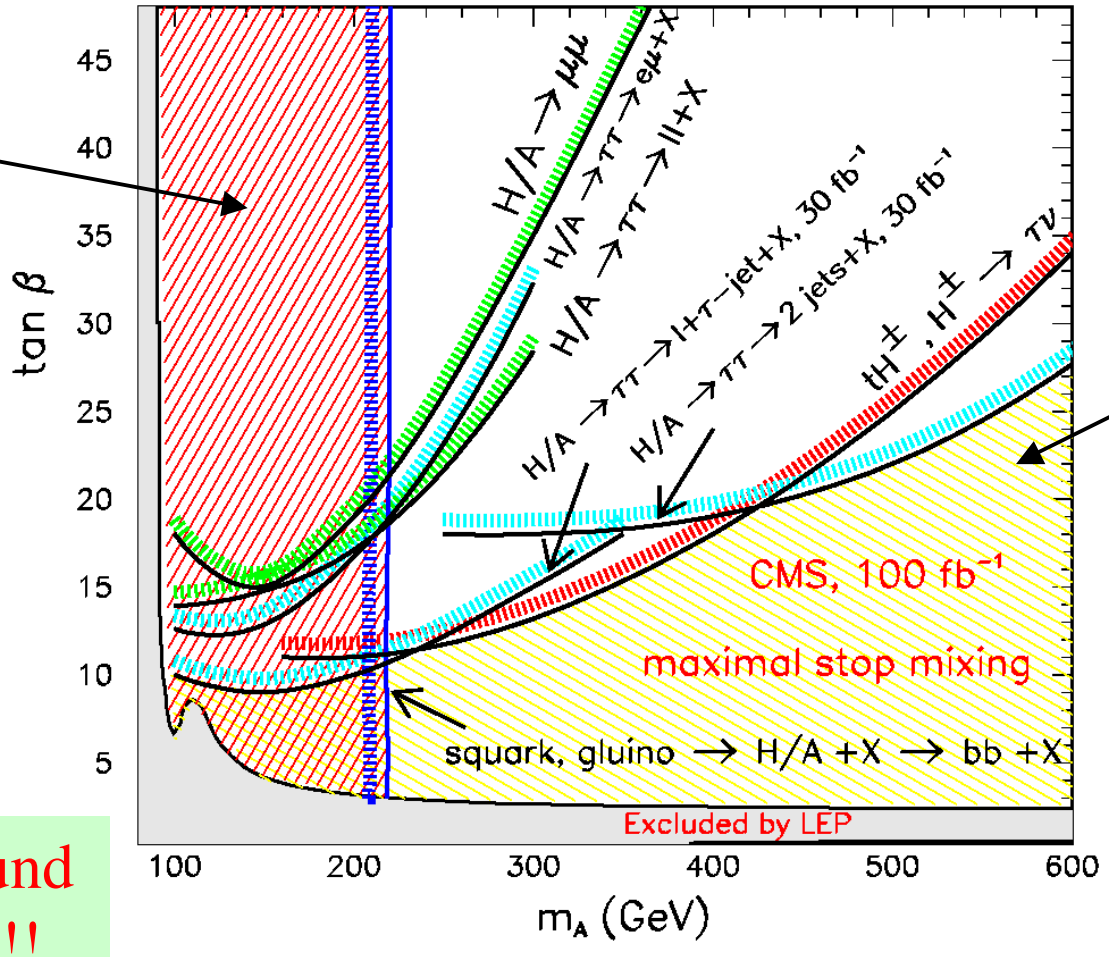
- look at A, H → ττ instead of A, H → bb
- look closer at scenario 1 and 2 (squarks heavier than gluinos)
- look closer at $H^{\pm}$, especially interested in mass region around m_{top} where other channels don't work
- can we reconstruct cascade decay chains with Higgs bosons in the final state (bb instead of dileptons)?

(Datta-Djouadi-Guchait-Moortgat)

Backup slides

Discovery reach at 100fb^{-1}

region where H^0 and A^0 can be found in SUSY cascade decays



region where only h^0 can be found

h^0 can be found in full plane!!

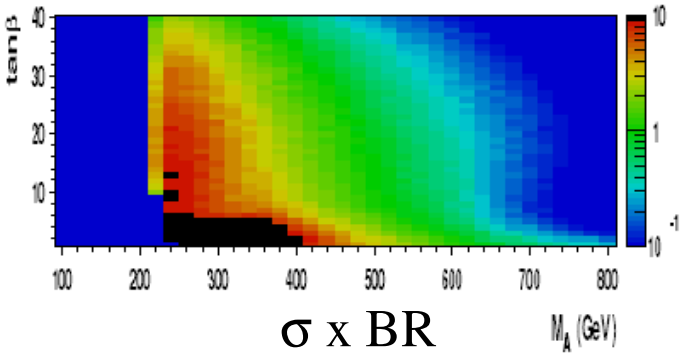
Scenario 3

Results

Let's consider two cases:

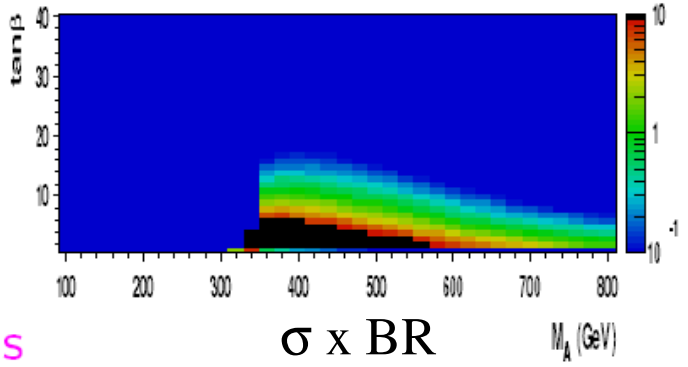
Case 1:

χ_2^0 gaugino-like,
$m_{\tilde{l}} > m_{\chi_2^0}$
$\rightarrow$ virtual slepton exchange



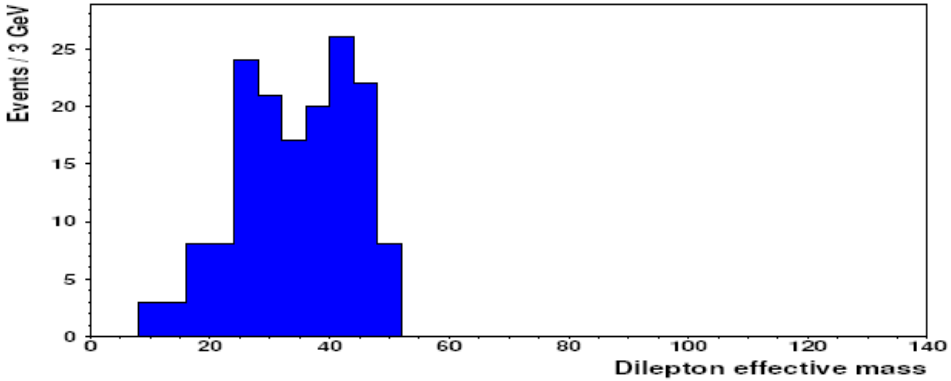
Case 2:

χ_2^0 gaugino-like,
$m_{\tilde{l}} < m_{\chi_2^0}$
$\rightarrow$ decays into real sleptons

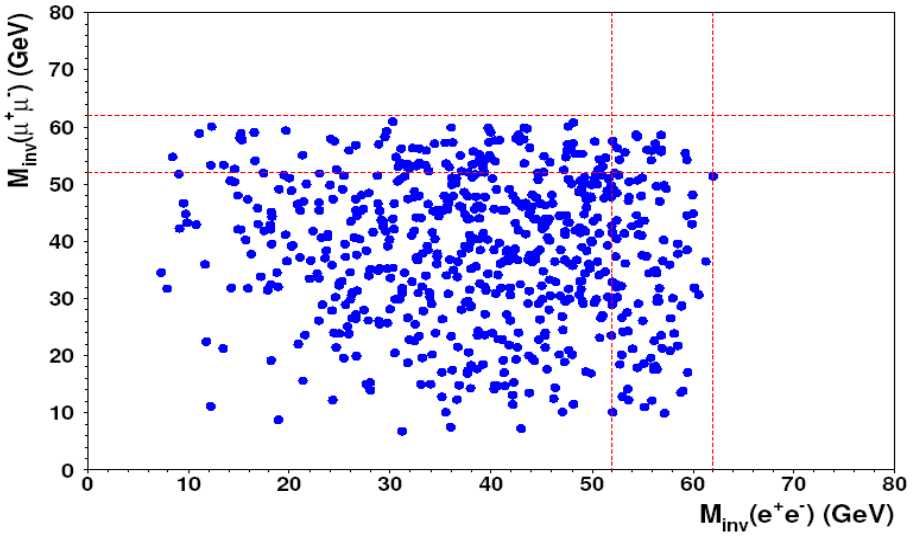


Dilepton edges

Dilepton edge at M_2-M_1 is clearly visisble



Double dilepton edge!!



Slepton mass effect

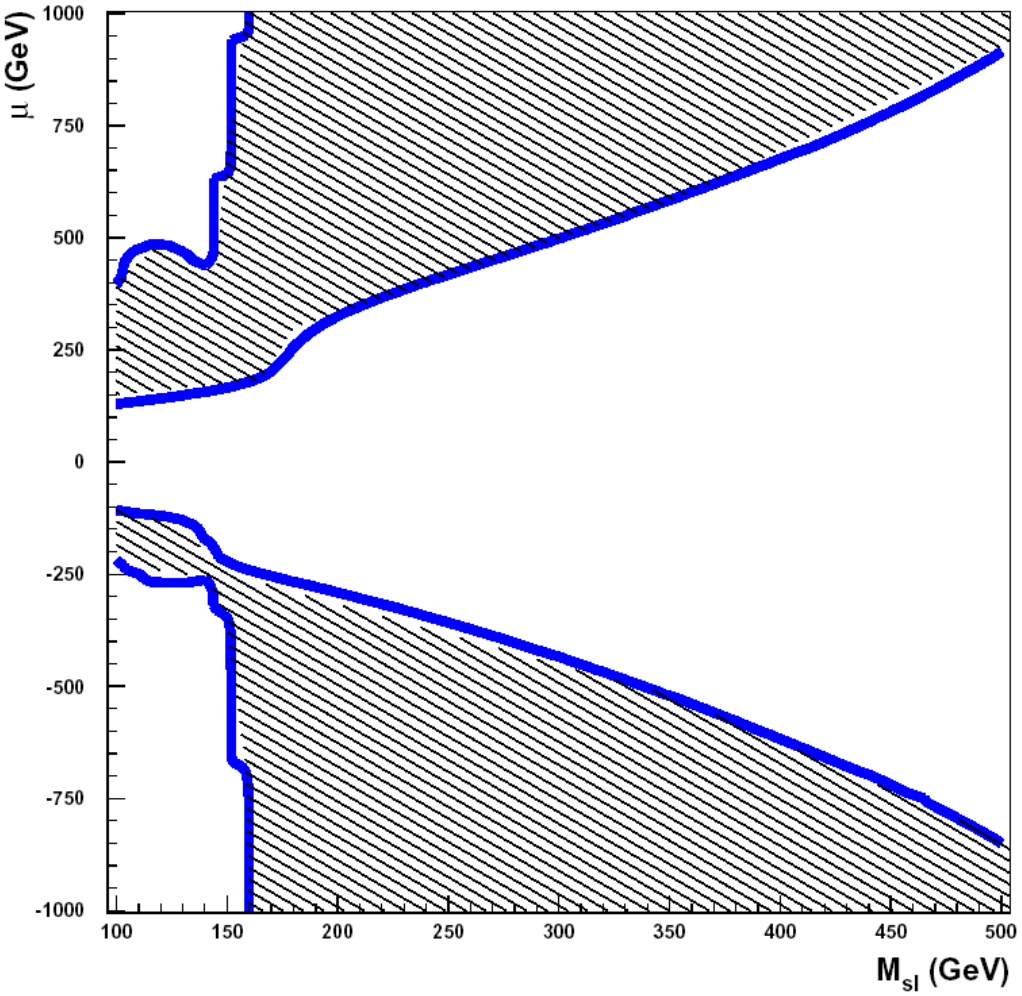
Dependence of

$$BR(\chi_2^0 \to \ell^+\ell^-\chi_1^0)$$

on higgsino and slepton masses:

Other MSSM parameters:

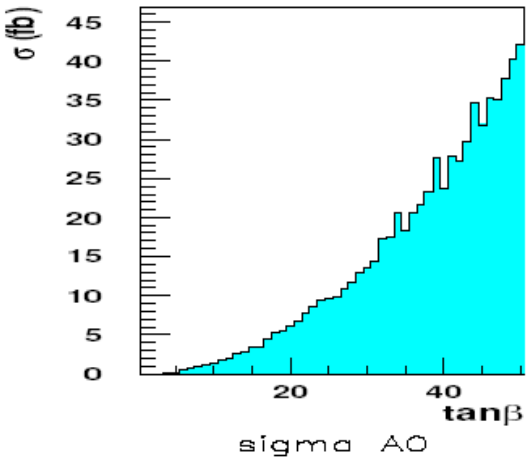
M_A = 350 GeV,
tan β = 5,
M_1 = 75 GeV,
M_2 = 150 GeV,
$M_{squark,\ gluino}$ = 1TeV



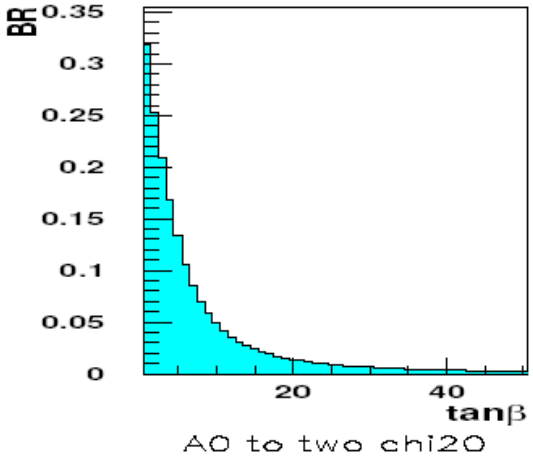
Why is low tan β prefered?

events = A x B x C^2

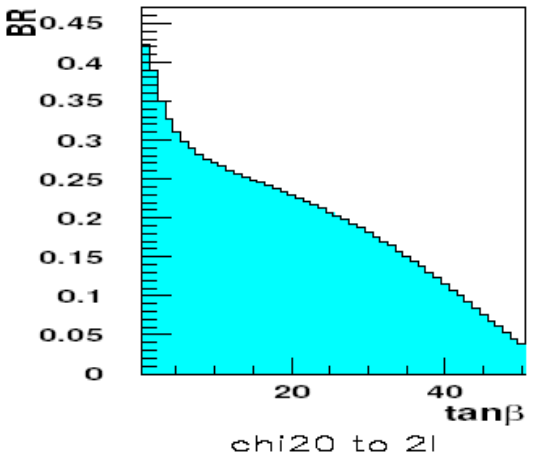
A



B



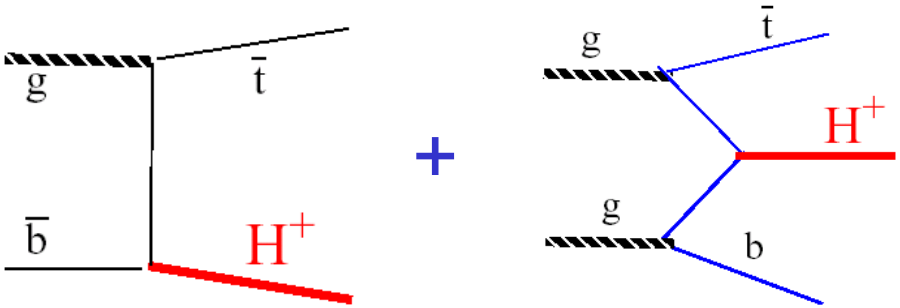
C

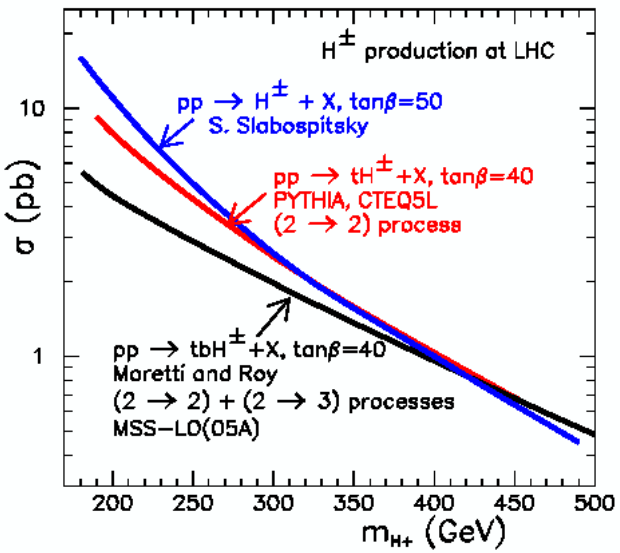


At higher tan β: taus instead of electrons/muons …

Charged Higgs search

Dominant production:



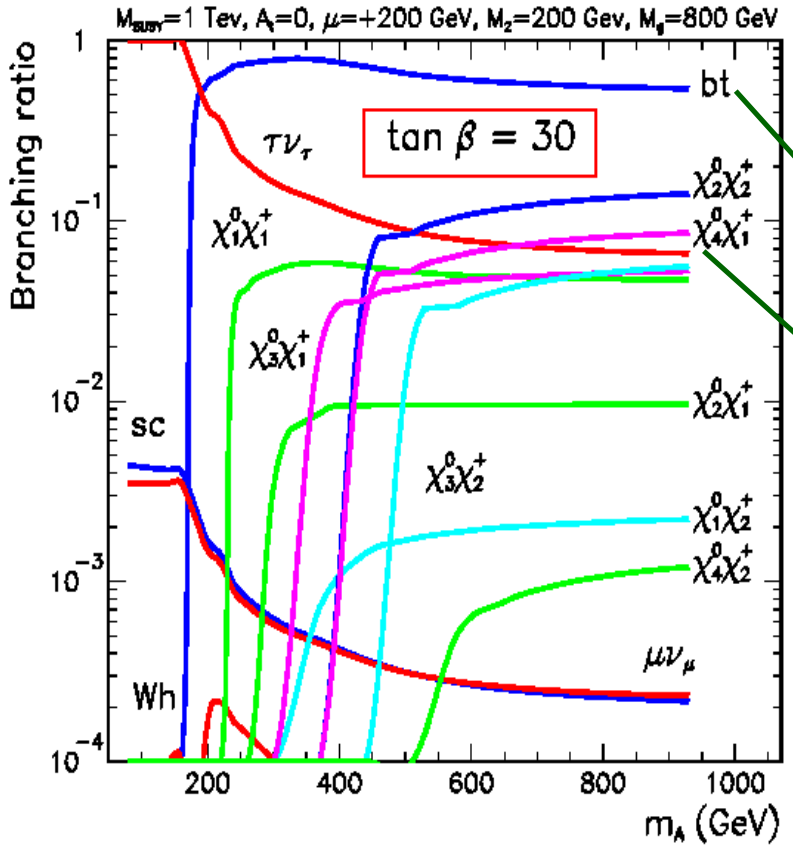


We can exploit t(b)H± associated production!

↓

reconstruct additional top (t→bjj)

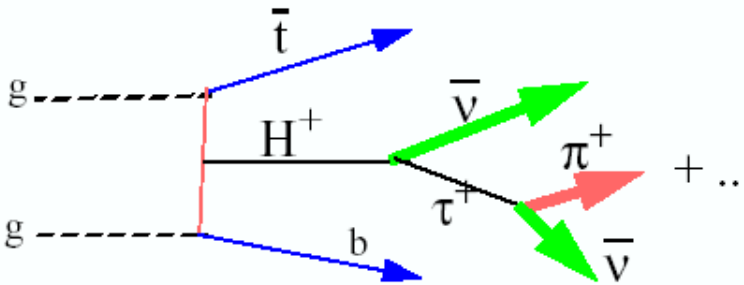
Branching ratios



Main channels:

- $H^{\pm} \rightarrow \tau\nu$
- $H^{\pm} \rightarrow tb$

$H^{\pm} \rightarrow \tau\nu$: polarization effect



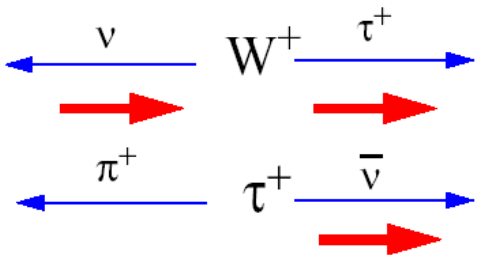
Strategy:

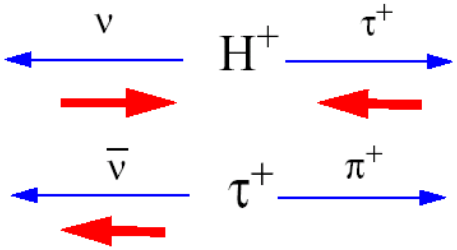
- reconstruct hadronic τ
- reconstruct hadronic top ($t \rightarrow bjj$)

Main backgrounds: $t\bar{t}$, Wtb, W + jets

W and $H^{\pm}$ have different spin $\rightarrow$ exploit τ polarization effects !!

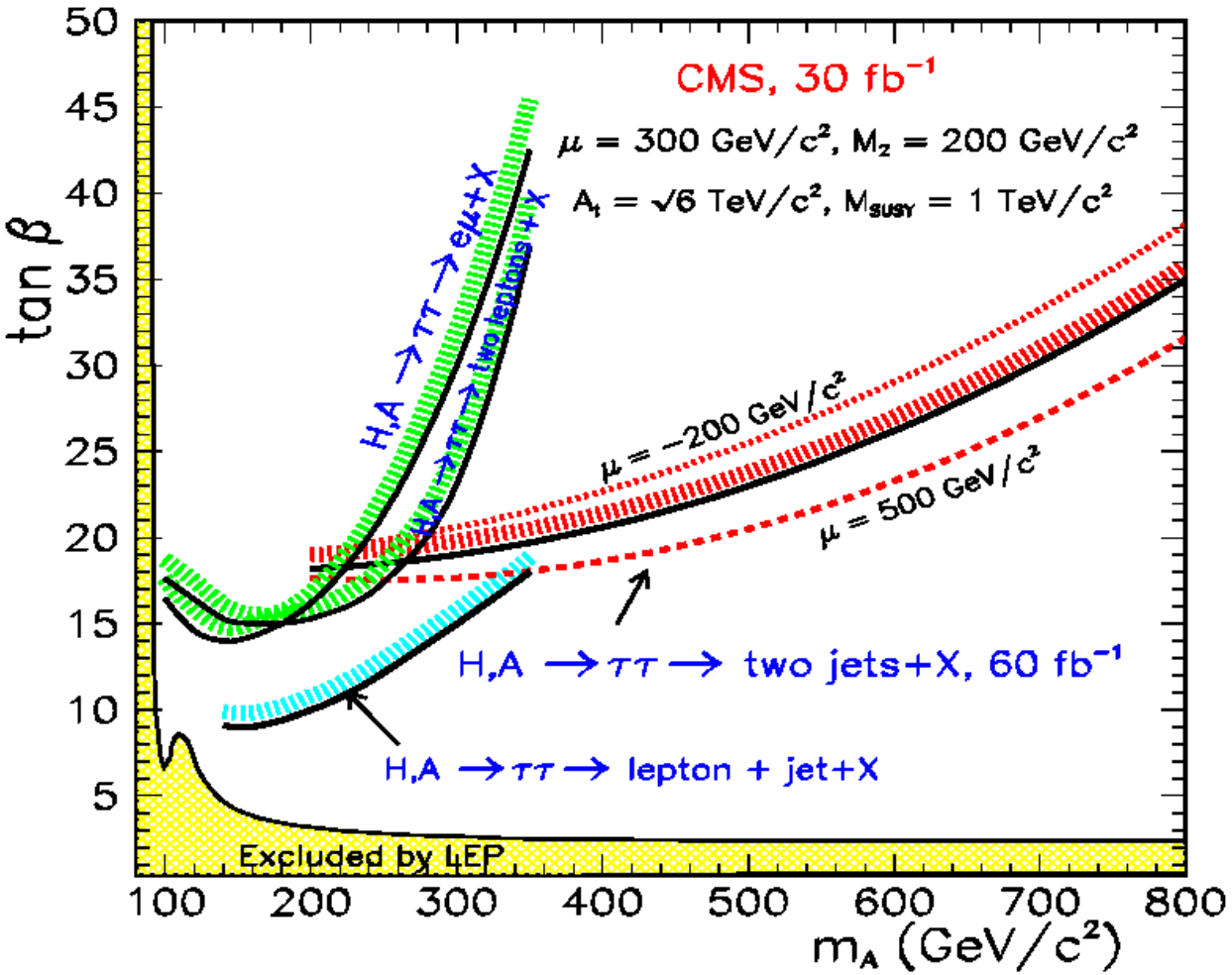
(*D.P. Roy*)





→ harder pions from $H^{\pm}$ …

Discovery reach



all τ channels:

- ττ → jet + jet
- ττ → lepton + jet
- ττ → lepton + lepton