SM/MSSM Higgs production at LHC

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HERA-LHC workshop - DESY 14/03 2007

Pile-up studies for CEP H→bb

MSSM scan for CEP H→bb/WW/tautau

H->bb and H->WW in SM

All details such as event yields, PU bg, non-PU bg studies described in
CMS/Totem Note CERN-LHC 2006-039/G-124:

Jet algorithm:
o) Iterative cone, Cone radius = 0.7
o) Jet energy scale corections applied to detector level jets

Signal for H->bb composed of two main categories:

1) b-dijets – 85% of signal, challenging channel
2) muons from b-hadron decays ….. 15% of signal, clean, no problems

Electrons from b-hadron decays may also add something. Needs to study

Phojet generation of PU events

All processes	118 mb
Non-diff.inelastic	68 mb
Elastic	34 mb
Single Diffr.(1)	5.7 mb
Single Diffr.(2)	5.7 mb
Double Diffr.	3.9 mb
DPE	1.4 mb

Number of pile-up events per bunch crossing (BX) $\equiv N^{PU}$ =
Lumi x cross section x bunch time width x LHC bunches/filled bunches =

$10^{34}cm^{-2}s^{-1} x 10^{4}cm^{2}/m^{2} \times 10^{-28}m^{2}/b \times 110mb \times 10^{-3}b/mb \times 25*10^{-9}s$
$X\ 3564/2808 \sim 35$

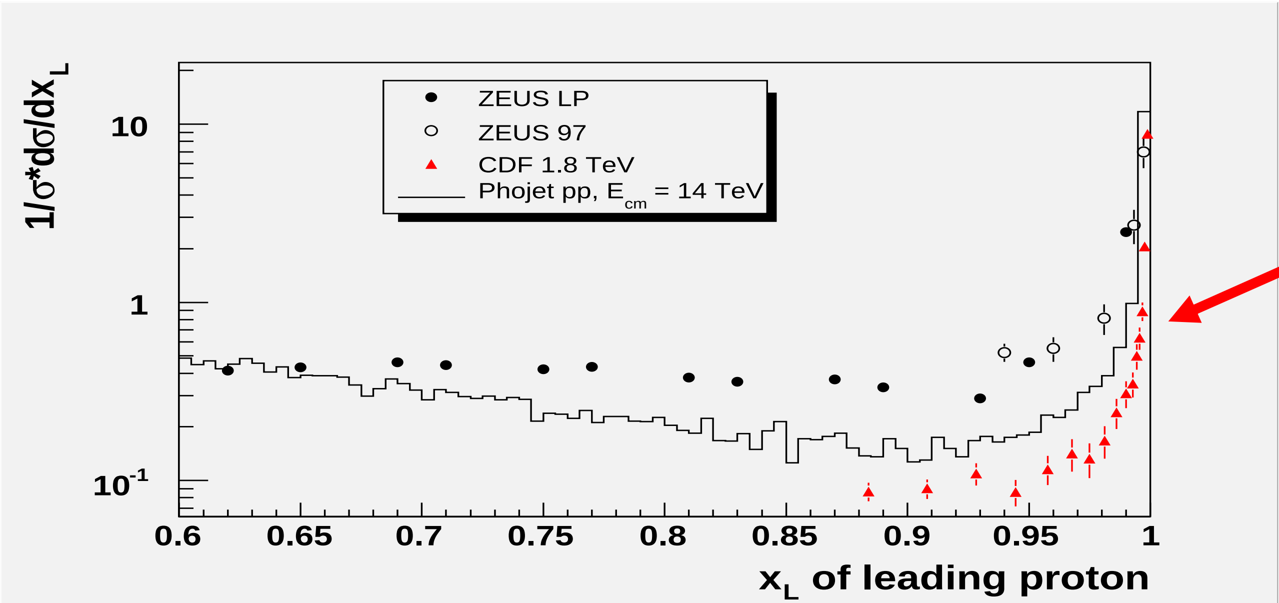
$5*10^{33} \sim 17.6$, $2*10^{33} \sim 7.0$, $1*10^{33} \sim 3.5$, $1*10^{32} \sim 0$

PU mixing to S and B for H->bb

Generated and fast simulated: PHOJET MB : σ = 118 mb, 200k

Prob. to se a proton in one RP per interaction:

420: 1.0%, **220**: 3.1% - These numbers are crucial for the PU study! Unfortunately, they are model-dependent. Which data to take to tune our MC models??? ZEUS? CDF?



CDF points just tentative!

The main idea from KMR: concentrate on CDF measurement rather than on ZEUS because of closer type of collision and closer Ecm.

The xL spectrum expected to be almost Ecm independent between 1.8 TeV and 14 TeV. Still need to check the CDF data…. What about t-ranges of CDF and ZEUS measurements and of Phojet?

Fake rates of protons in RPs

The big danger of PU events for diffraction signal: they contain a lot of diffractive processes.Typical mimics of DPE H->bb: mixture of three events: 2 SD protons + hard-scale dijet

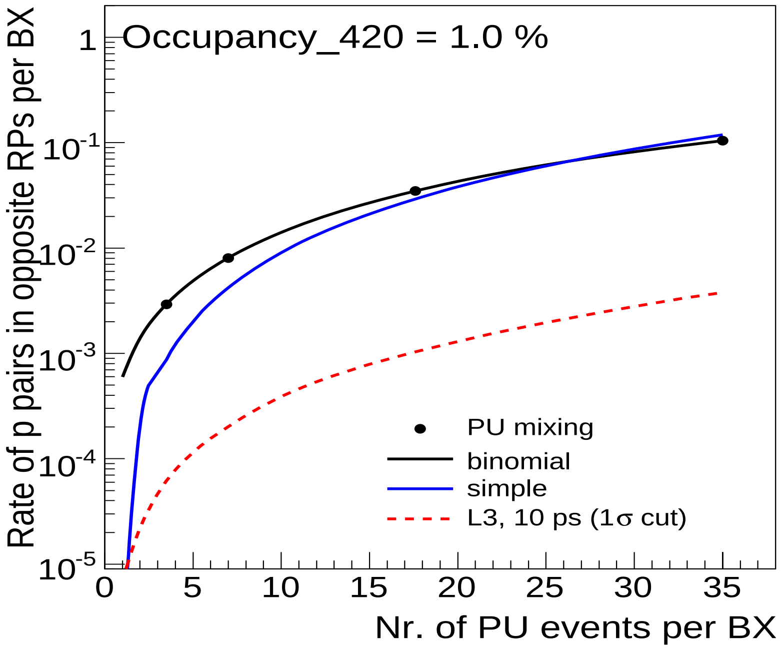
Mix PU events with signal or bg – using FAMOS: Sum RP acceptances over all possible proton pairs in all PU events in on BX and then look at mean over all signal or bg events. N^{PU} properly smeared using Poisson dist.

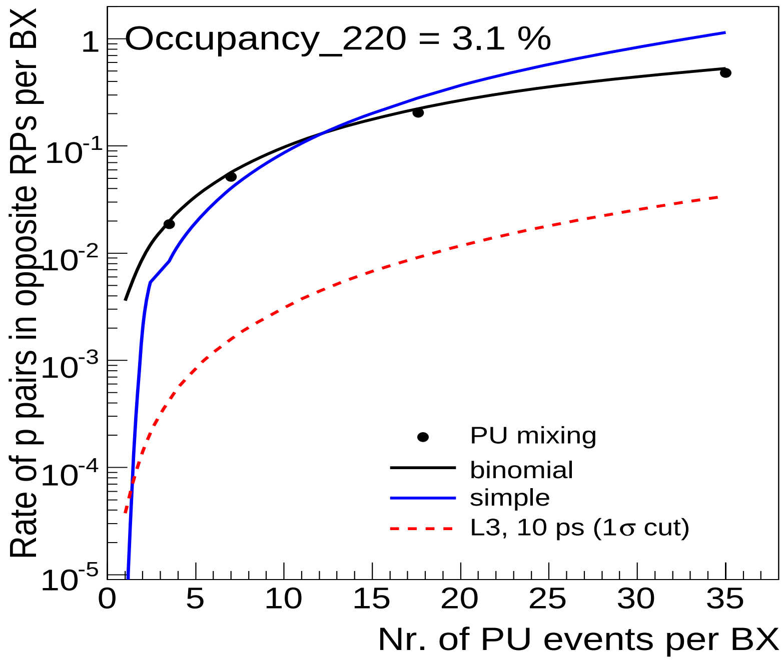
E.g. $R^{RP}_{420} = \langle \Sigma_i^{NPU(n)} \Sigma_j^{NPU(n)} A^L_{420}(i) \times A^R_{420}(j) \rangle_{n=90k}$ signal or bg events

Rate of PU events with 2 p's seen in opposite 420 RPs

$\langle N^{PU} \rangle$	R_{420}	R_{220}	R_{comb}	R_{total}
3.5	0.003	0.019	0.014	**0.032**
7.0	0.008	0.052	0.037	**0.084**
17.6	0.033	0.205	0.153	**0.300**
25.0	0.063	0.280	0.246	**0.417**
35.0	0.101	0.480	0.380	**0.620**

Rates of fake protons





Analytical formula for Rate of p pairs seen in opposite RPs per BX:

$\mu = Acc*N^{PU}$, $\mu_{LR} = Acc_{LR}*N^{PU}$

$N^{RP}/BX(\text{binomial}) = 2*\exp(-\mu)*[\cosh(\mu) - 1] + 1 - \exp(-\mu_{LR})$

$N^{RP}/BX(\text{simple}) = N^{PU}*(N^{PU}-1)*Acc*Acc$

Courtesy Sasha Kupčo (Prague)

L3 = $(N^{RP}/BX)/Q$, Q = red.fact.from quartic det. based on σ_t=10 ps

Q ~ 30 for 220 and 420, for N^{PU} = 3.5

~ 13 for 220 and 23 for 420, for N^{PU} = 35

Selection cuts for H->bb at mh=120 GeV

cut 1 $= \mathbf{N_{jet} > 1}$

cut 2 $= \mathbf{E_{T,jet1}} * \mathrm{JES} > \mathbf{45}\ \mathrm{GeV} \quad \wedge \quad \mathbf{E_{T,jet2}} * \mathrm{JES} > \mathbf{30}\ \mathrm{GeV}$

cut 3 $= |\eta_{jet1}| < \mathbf{2.5} \quad \wedge \quad |\eta_{jet2}| < \mathbf{2.5}$

cut 5 $= \mathbf{2.85} < |\phi_{jet1} - \phi_{jet2}| < \mathbf{3.43}$

cut 7 $= \mathbf{0.85 < M_{dijet}/M_{420} < 1.15,\ 0.8 < M_{dijet}/M_{comb} < 1.2}$

cut 9 $= \mathbf{118 < M_{420} < 122, \quad 115 < M_{comb} < 125}$

cut 10 = **both jets b-tagged (Discr > 1.0)**

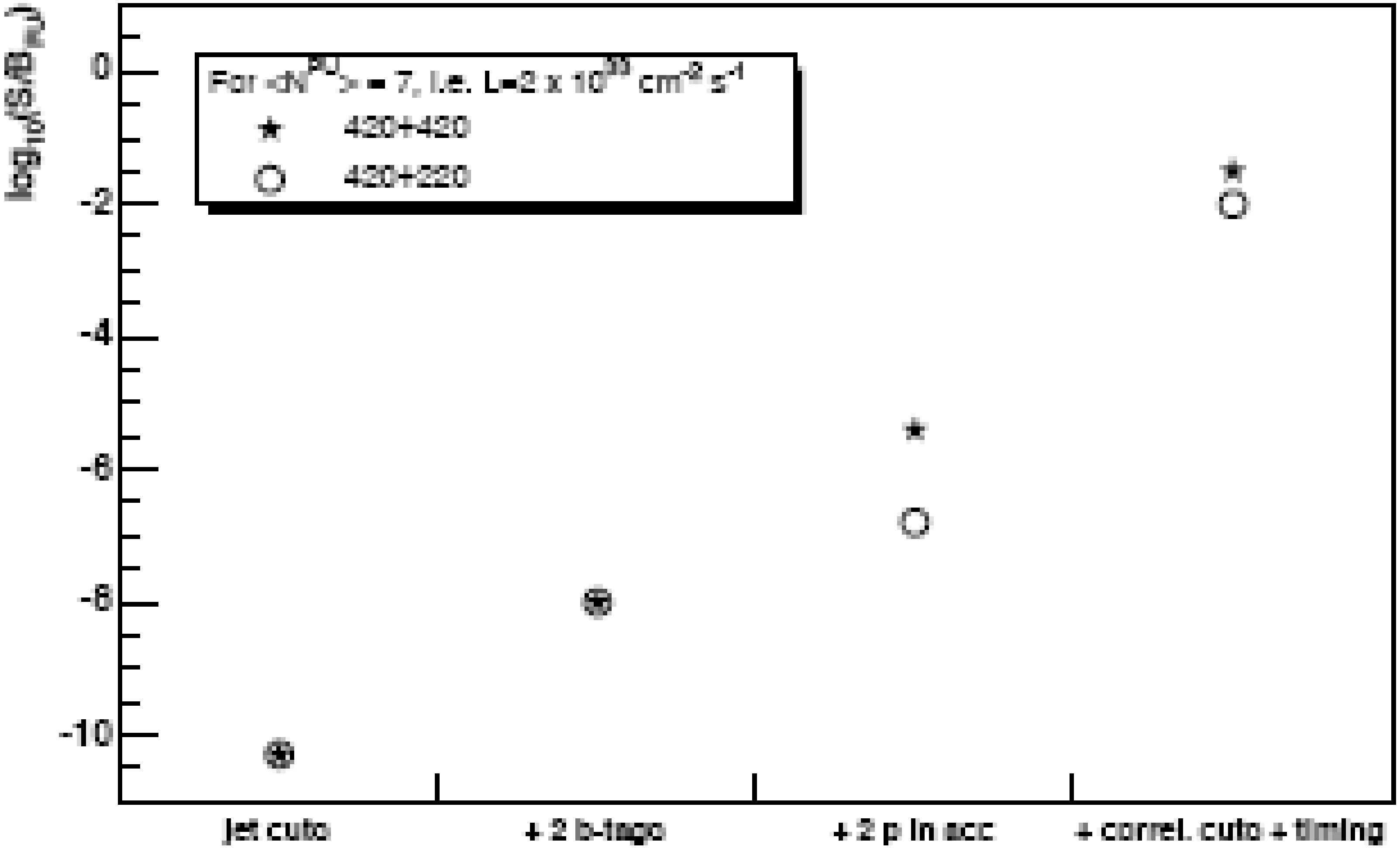
cut 11 $= |\xi^{\mathbf{L}}_{jet} - \xi^{\mathbf{R}}_{\mathbf{420}}|/\xi^{\mathbf{R}}_{\mathbf{420}} < \mathbf{0.3} \quad \wedge \quad |\xi^{\mathbf{R}}_{jet} - \xi^{\mathbf{L}}_{\mathbf{420}}|/\xi^{\mathbf{L}}_{\mathbf{420}} < \mathbf{0.3},$

$|\xi^{\mathbf{L}}_{jet} - \xi^{\mathbf{R}}_{comb}|/\xi^{\mathbf{R}}_{comb} < \mathbf{0.3} \quad \wedge \quad |\xi^{\mathbf{R}}_{jet} - \xi^{\mathbf{L}}_{comb}|/\xi^{\mathbf{L}}_{comb} < \mathbf{0.3},$

$\mathbf{0.002} < \xi_{\mathbf{420}} < \mathbf{0.04} \quad \wedge \quad \mathbf{0.002} < \xi_{comb} < \mathbf{0.04}$

cut L1 $= (\mathrm{Acc}^{\mathbf{L}}_{\mathbf{220}} > \mathbf{0} \vee \mathrm{Acc}^{\mathbf{R}}_{\mathbf{220}} > \mathbf{0}) \quad \wedge \quad (\mathbf{E_{T,jet1,2}} > \mathbf{40}\ \mathrm{GeV})$

Suppressing PU bg



S/B for Lumi = 30 fb^{-1}

CMS/Totem Note CERN-LHC 2006-039/G-124:

lumi $[cm^{-2}s^{-1}]$	$\langle N^{PU} \rangle$	S/B 420+420	S/B 220+420
$1 \cdot 10^{33}$	3.5	0.6/20	0.9/40
$2 \cdot 10^{33}$	7.0	0.6/30	0.9/120
$5 \cdot 10^{33}$	17.5	0.6/190	0.9/340
$1 \cdot 10^{34}$	35.0	0.6/900	0.9/1900

Very large reduction of PU effect achieved but still not yet at S/B~1. We need another handle – try track multiplicity cut.

Multiplicity cuts at detector level

Main idea: exploit the difference between particle multiplicities of CEP and non-diffr. processes. CEP should show rapidity gaps.

Construction: only good tracks ($p_{T,track}$ > 0.5 GeV, 0.2 GeV), $|\eta_{track}|<2.5$ (tracker acceptance)

$N_{charged}$ – Nr. of tracks outside cones of R=0.7 around axes of two lead. jets

$N_{charged}^{perp}$ – dtto + perp. to jet axes

$(\pi/3<|\Phi_{jet}-\Phi_{track}|<2\pi/3,\quad 4\pi/3<|\Phi_{jet}-\Phi_{track}|<5\pi/3)$

Observation: the cut inefficient if tracks from all vertices counted

Help: take only vertices in a z-coord. window:

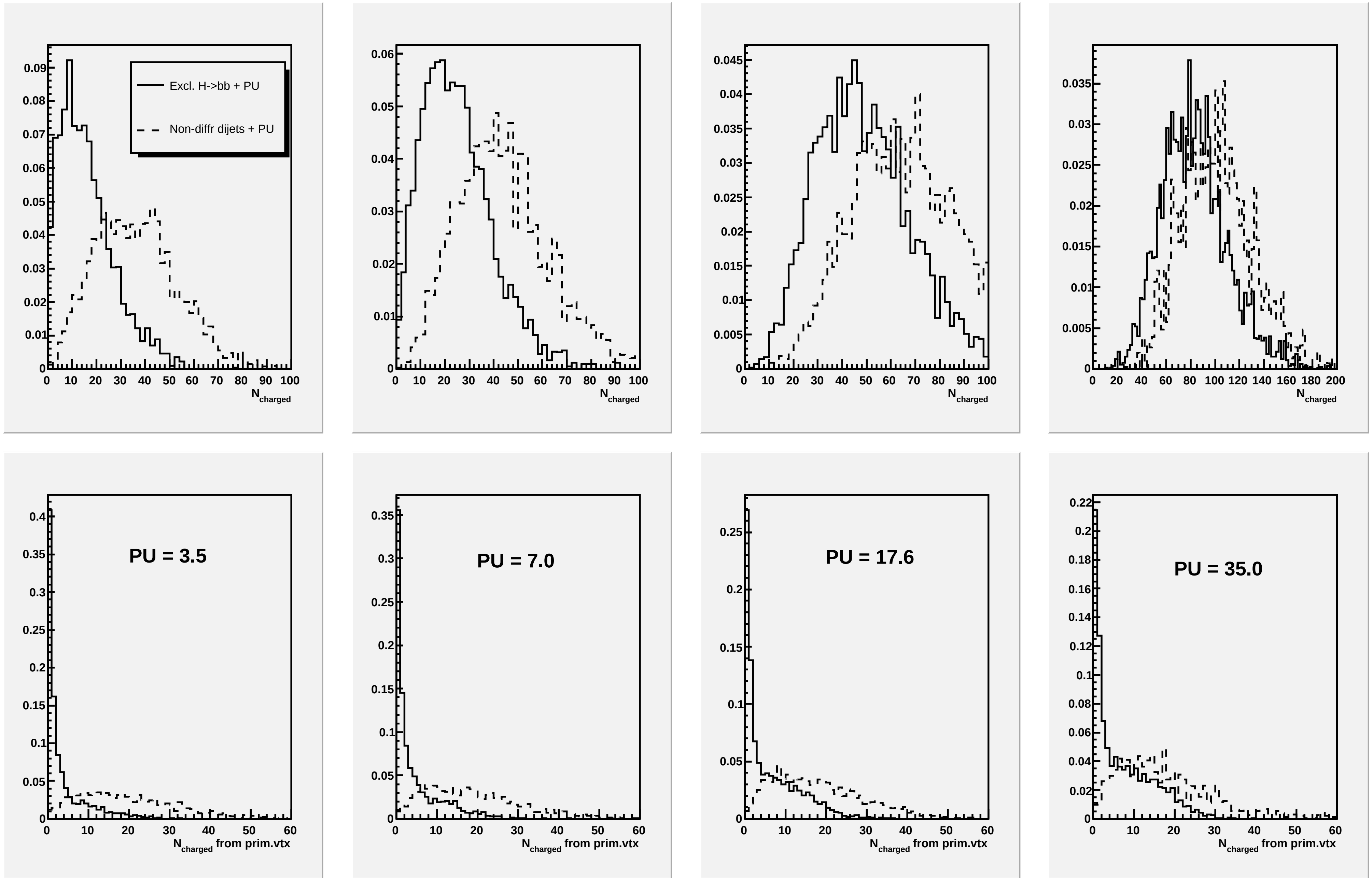
a) $2^*\sigma_Z(\text{beam})/\sqrt{2} = 2^*7.5/\sqrt{2} = 10.6$cm – doesn't help too much

b) $2^*\sigma_Z(\text{vtx})[\text{timing}] = 6$ mm - needs timing det.

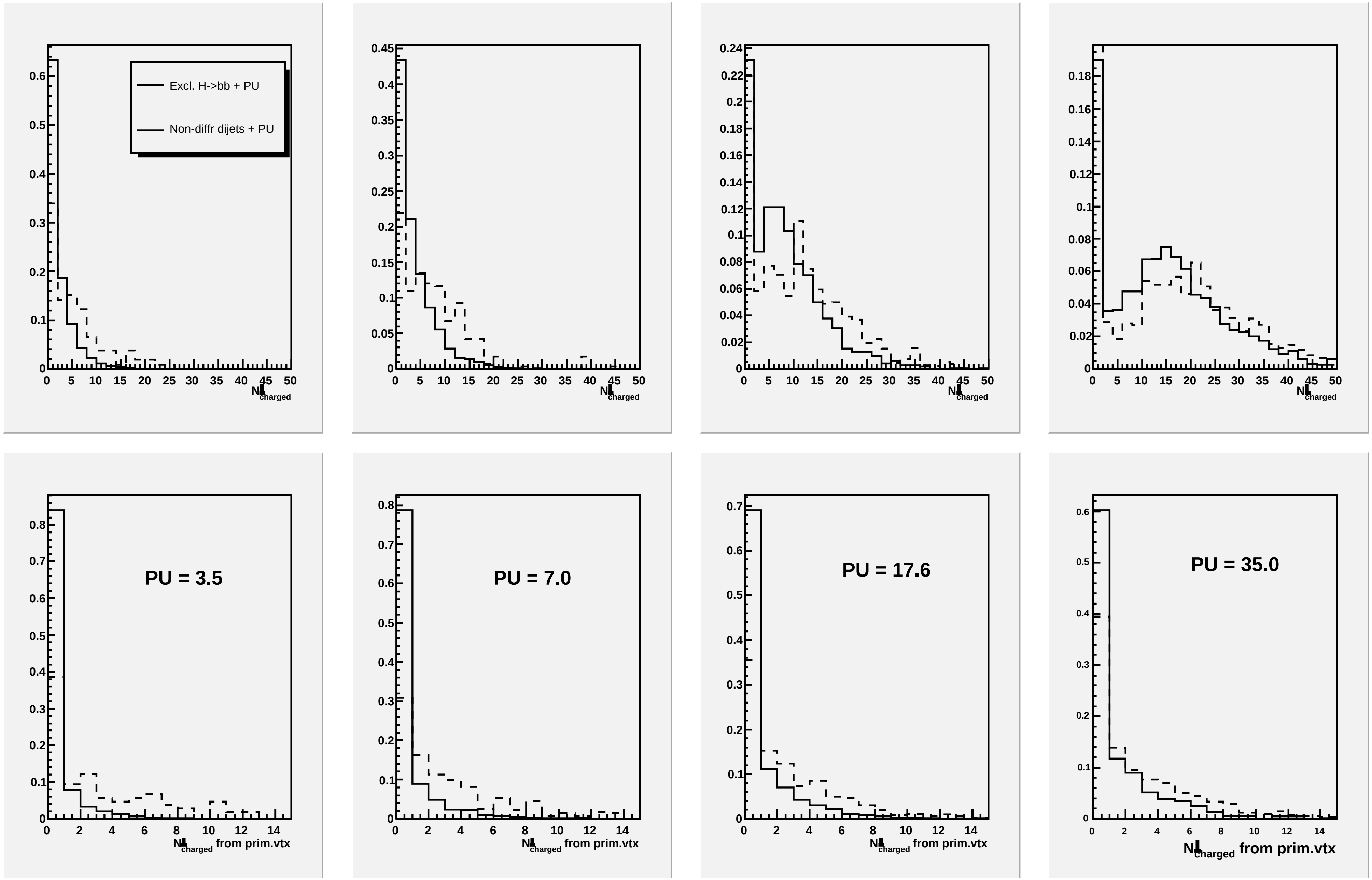
c) Count just tracks associated with primary vertex!

Primary vertex comes from a hard-scale event. The prim.vtx finding algorithm may not be sufficiently efficient in case of high lumi – then tracks from hard jets should help to constraint the prim.vtx better.

$N_{charged}$ from all vertices vs. from prim.vtx



$N^T_{charged}$ from all vertices vs. from prim.vtx



Reduction factors from $N_{charged}$ cut

Two options tried:

$N_{charged} \leq 7$ .and. $N^{perp}_{charged} \leq 1$

$N_{charged} \leq 6$

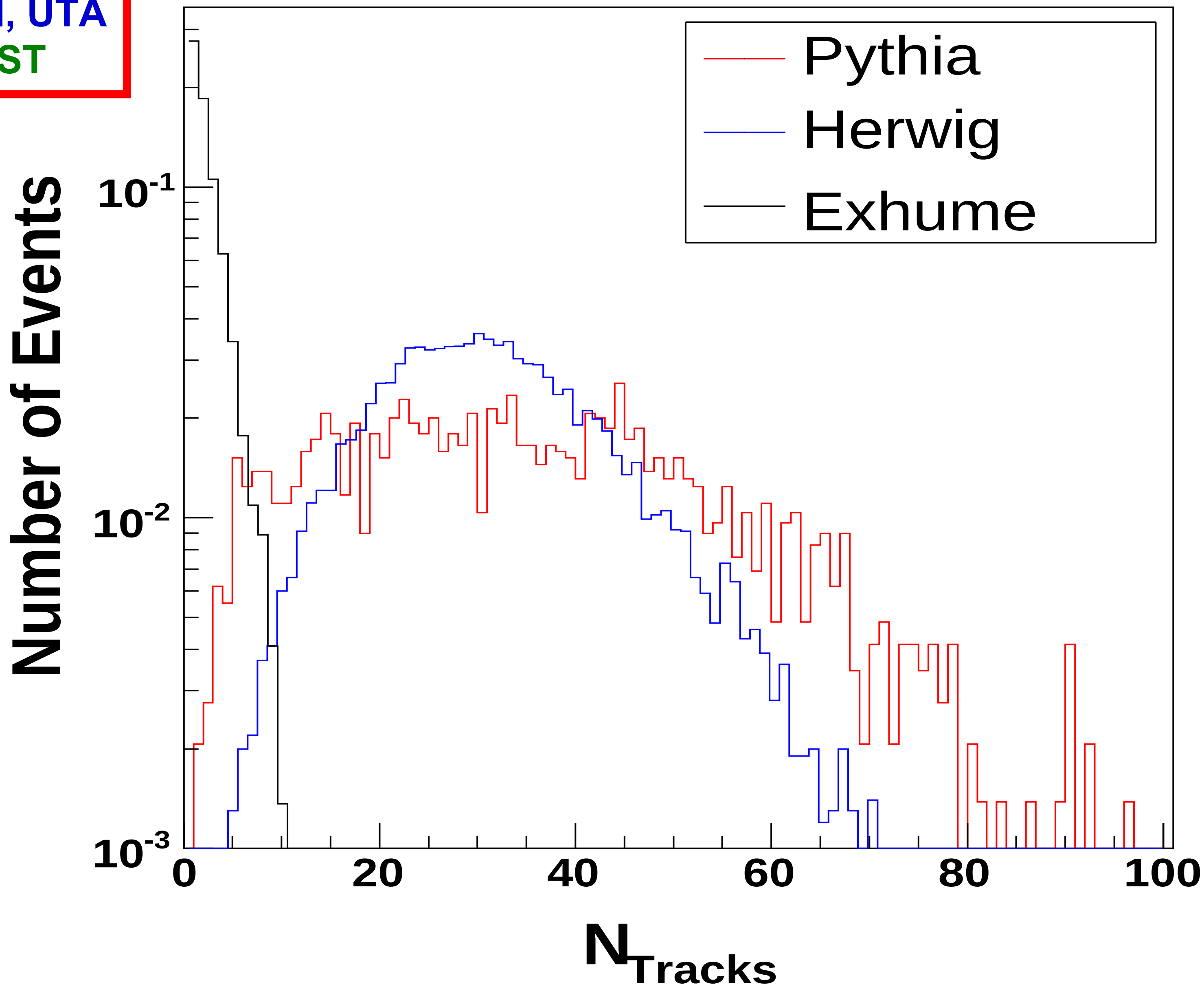
Red.factors obtained after applying all selection cuts on signal and only jet selection cuts on bg. The two options give the same.

$\langle N^{PU} \rangle$	Signal + PU		Non-diffr.dijets + PU	
	420	comb	420	comb
3.5	1.2	1.2	6	5
7.0	1.4	1.3	7	6
17.6	1.8	1.8	5	5
35.0	1.5	1.8	5	5

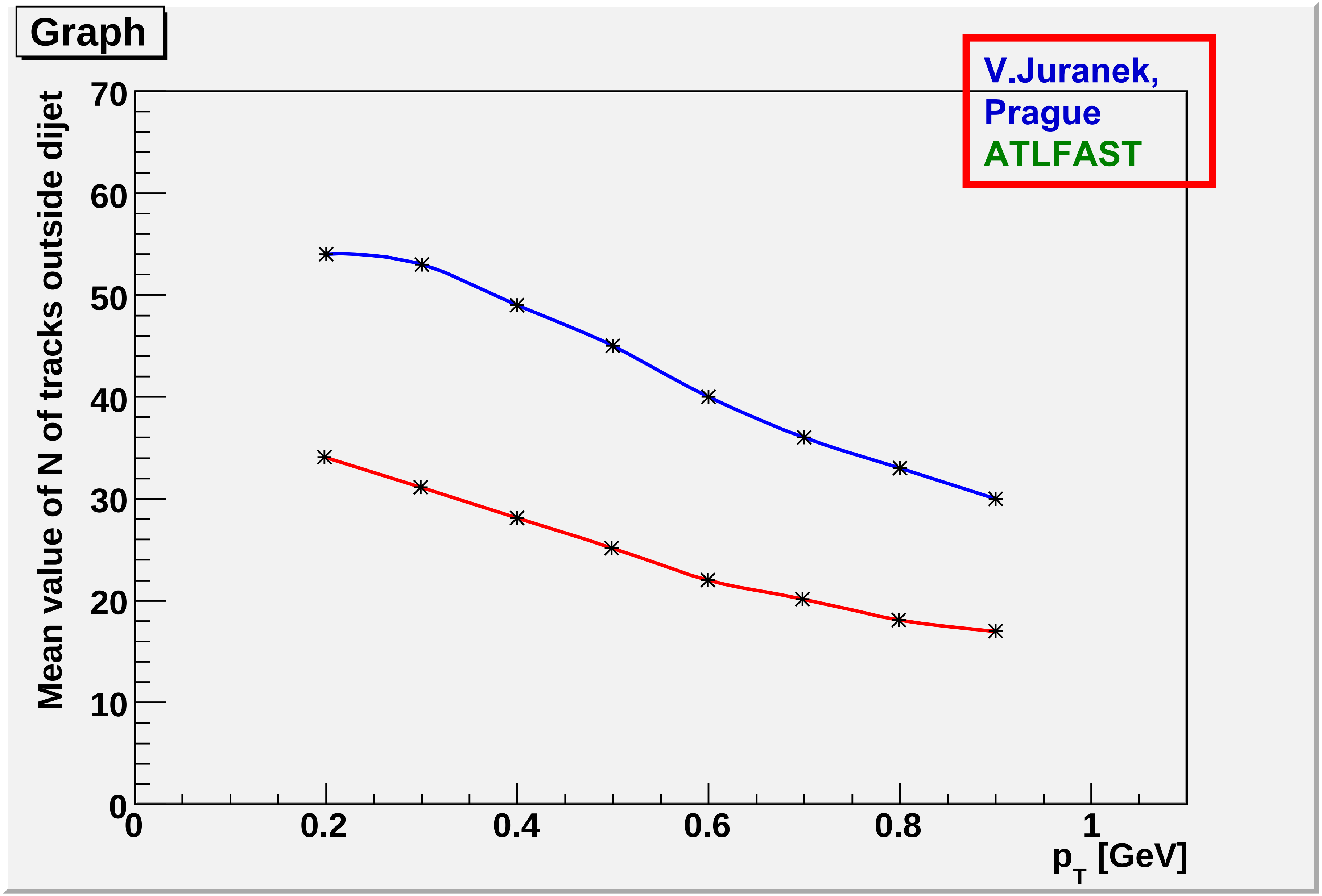
This is for Pythia 6.2 and default CMS tune for soft underlying event (SUE). It differs significantly from A.Pilkington result (reduction ~ 100) obtained From hadron level Herwig+Jimmy tune.

Another big uncertainty: underlying event

A.K.Pal, UTA
ATLFAST



Mean of number of tracks outside dijet



Summary of PU effect in H->bb channel

- PU has a little effect on signal.
- PU has a little effect on jets.

- The main effect comes from fake protons in RPs overlaied with hard jets from dijet events.

2 big uncertainties:

1) The track multiplicity cut can reduce PU effect by a factor of 10—100. The big spread is caused by model-dependence, SUE tune-dependence and min. $p_{T,track}$ (i.e. detector)-dependence. Several people working hard on this and hoping to squeeze the spread quite soon. The data of early LHC running are desirable. Meanwhile use HERA-LHC proceedings and R.Field's results

2) One-sided RP acceptance for PU events (1.0% for 420, 3.1% for 220) The data of early LHC running are desirable.

Enhancement in MSSM?

Idea of V.Khoze, M.Ryskin, S.Heinemeyer, G.Weiglein

The enhancement is evaluated using

$\text{Ratio} = [\Gamma(H\to gg) * BR(H\to pp)]^{MSSM} / [\Gamma(H\to gg) * BR(H\to pp)]^{SM}$

H = h, H, A;   p = W, b, tau

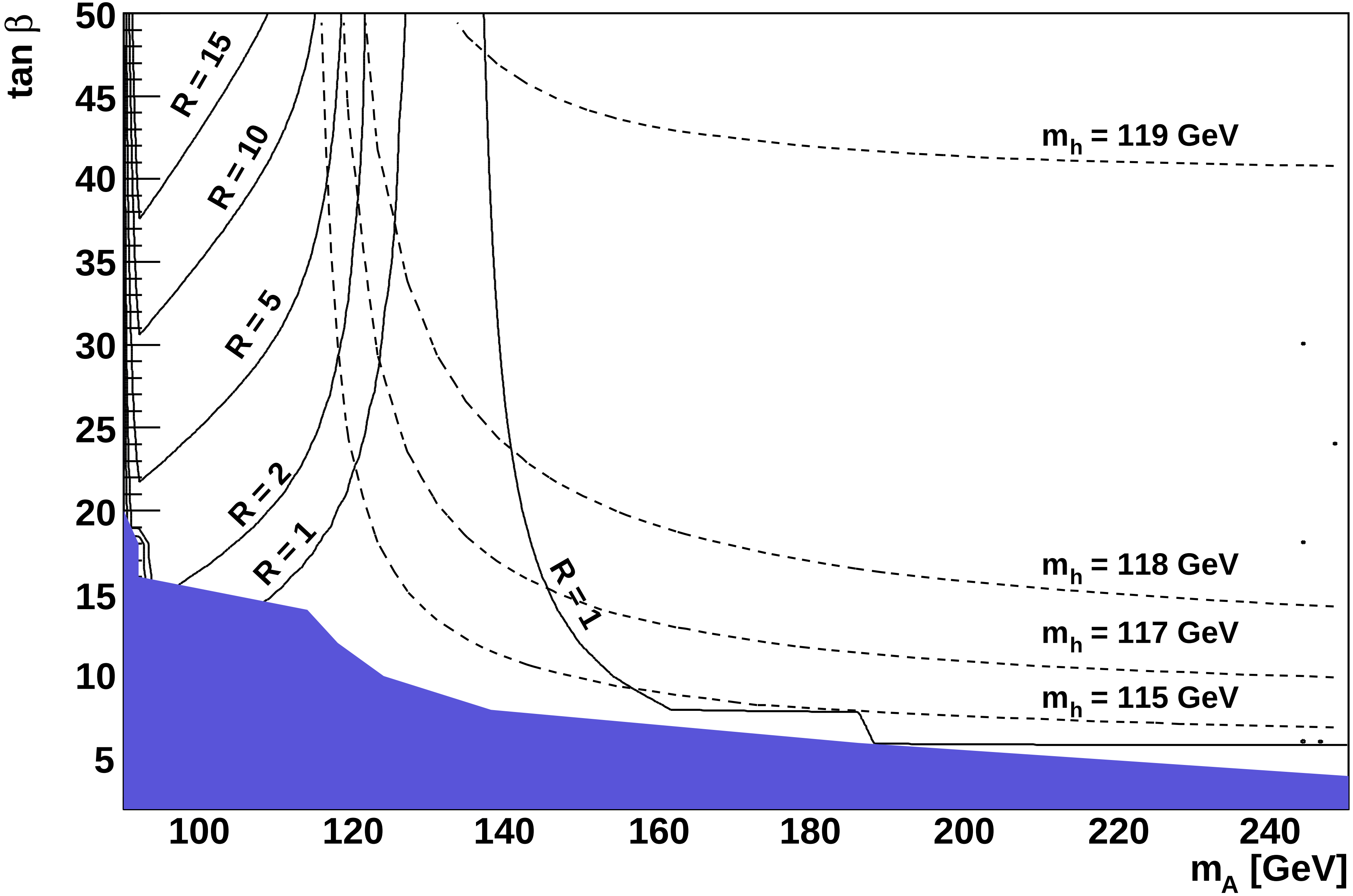
The cross section is calculated as

$\sigma^{MSSM} = \sigma^{SM} * \text{Ratio}$

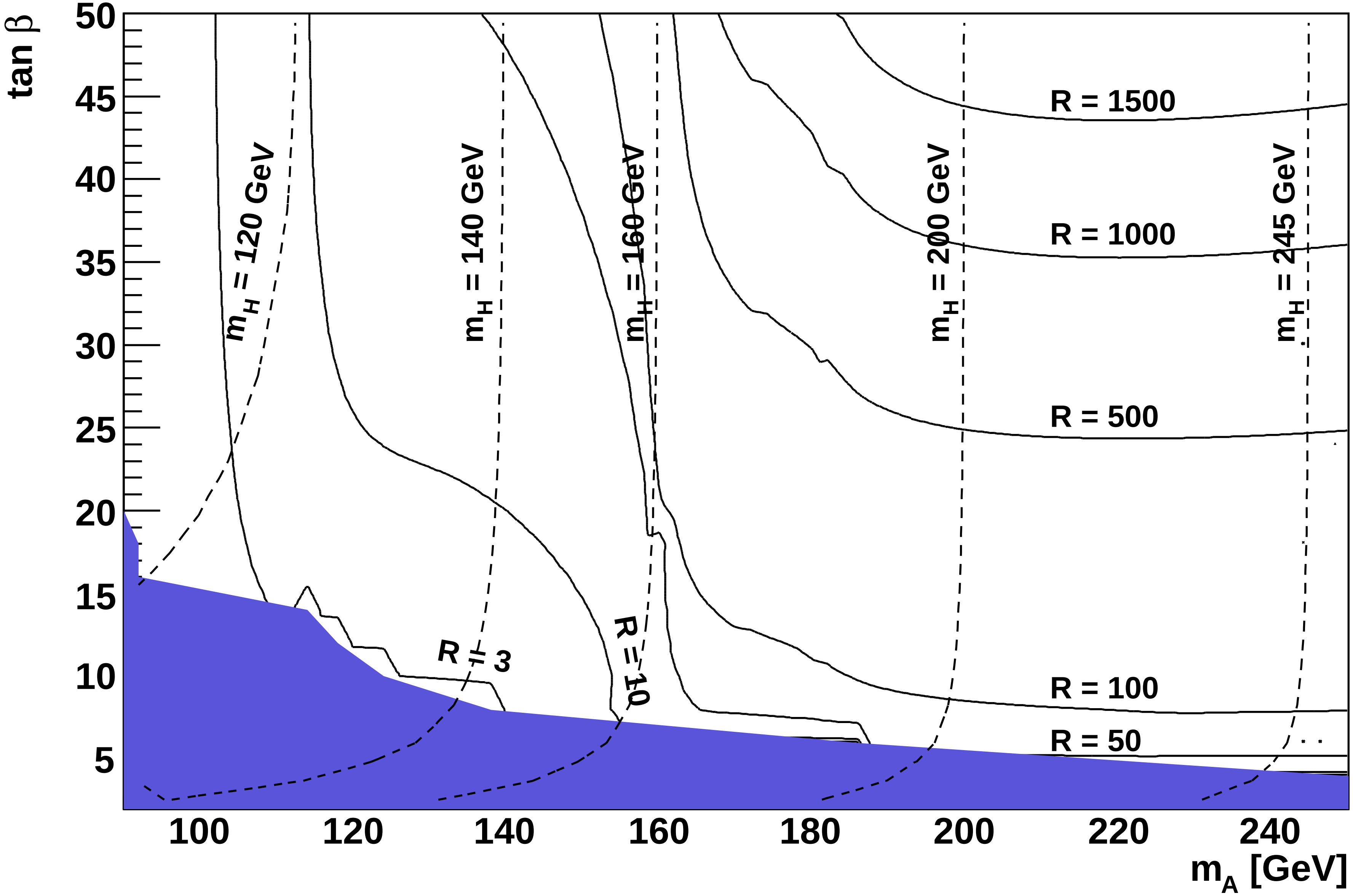
$\sigma^{SM} = \sigma(\text{KMR,excl.H}) * BR(H\to pp)^{SM}$

All MSSM quantities obtained using FeynHiggs code

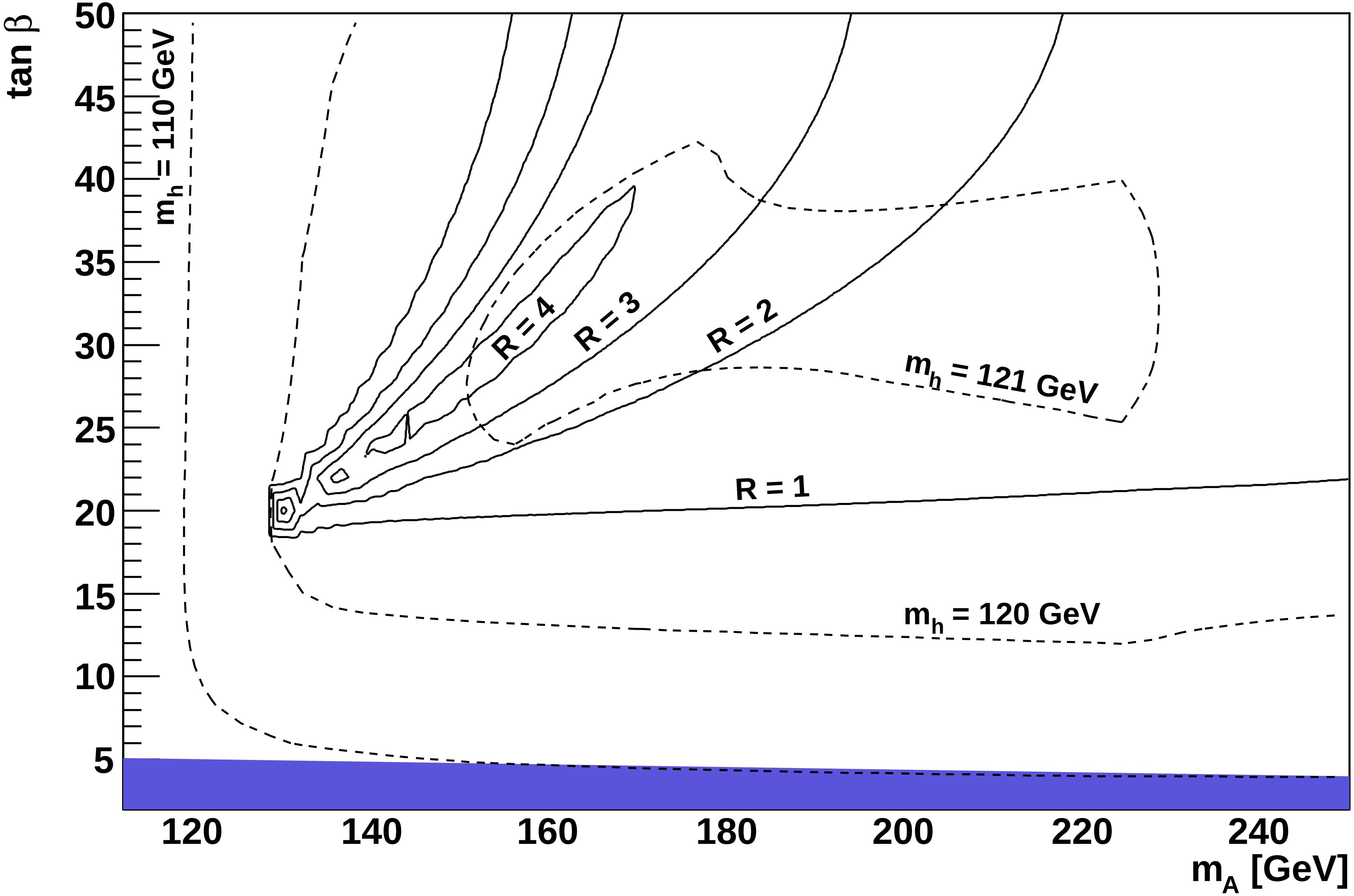
R=MSSM/SM:h->bb, nomixing scenario, μ=200 GeV



R=MSSM/SM:H->bb,nomixing scenario, μ=200 GeV



R=MSSM/SM:h->WW, small α_{eff} scenario, μ=200 GeV



Signal significance

Signal significance S_{cP} found by solving equations (using program scpf by S.Bityukov)

$\beta = 1/\sqrt{2\pi}\int^{\infty}_{ScP} e^{x*x/2}dx$, $\beta = \sum^{\infty}_{S+B}$ Pois(i|B) (Type II error)

CEP Signal and CEP Bg calculated using KMR formulas and FeynHiggs code:

$S = Lumi*\sigma^{MSSM}*[\varepsilon_{420}*I(\Delta M_{420}) + \varepsilon_{comb}*I(\Delta M_{comb})]$, I = reduction due to mass window

$B = Lumi*[\varepsilon_{420}* \int\sigma^{BG}\Delta M_{420} + \varepsilon_{comb}* \int\sigma^{BG}\Delta M_{comb}]$

S and B taken without stat. and syst.errors

σ^{BG} : Only exclusive processes considered because:

1) Contribution of inclusive processes considered to be negligible after including new HERA Pomeron pdfs – see Valery's talk
2) Contribution of PU bg assumed to be negligible anticipating a big progress in developing cuts suppressing PU bg, such as track mult. and vtx rejection

ε_{420}, ε_{comb} : taken from CMS/Totem Note CERN-LHC 2006-039/G-124

Optimum mass windows

To get high stat.significance but also reasonable signal statistics, we need to choose an optimum mass window.

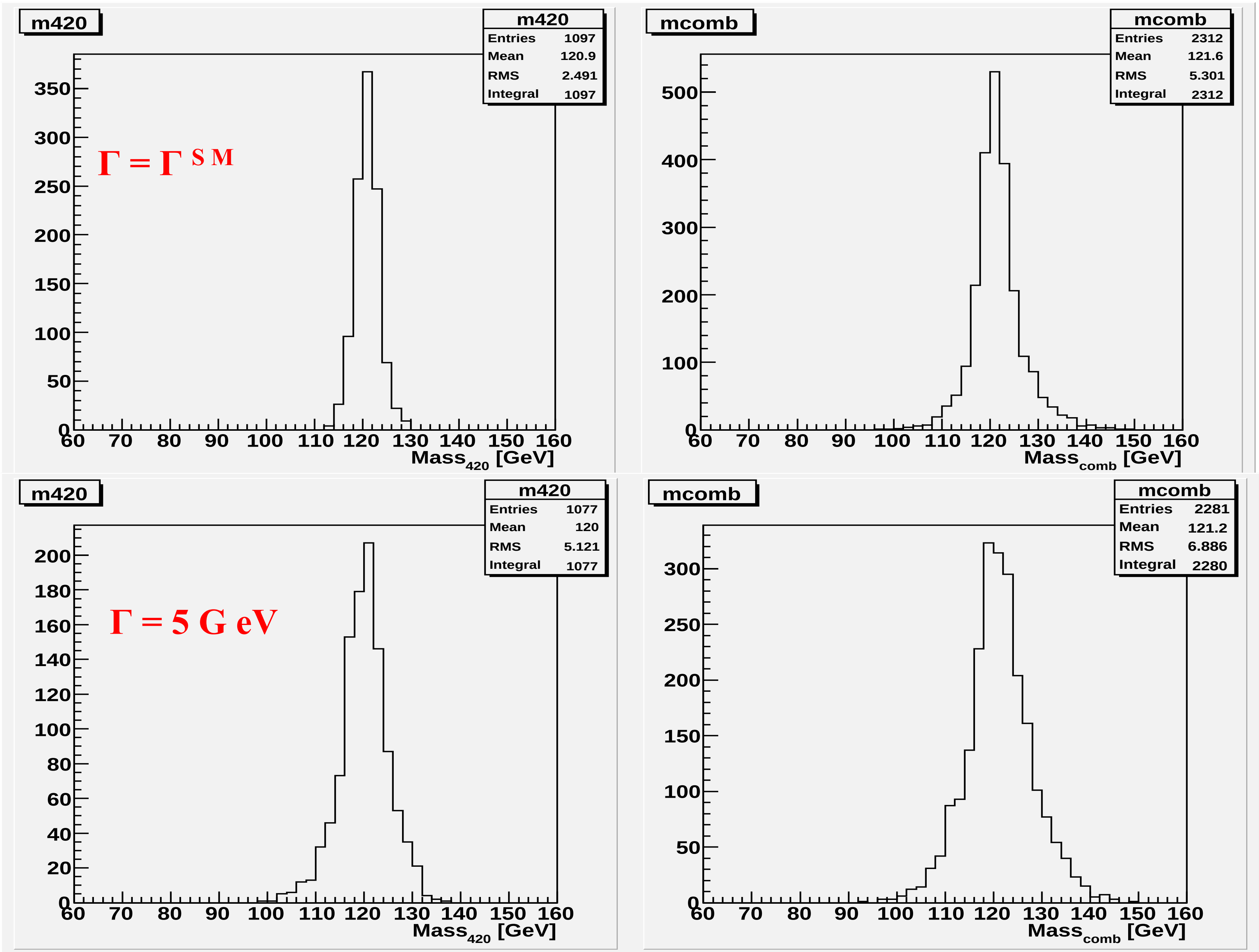
S ~ $\Gamma(H\to gg)$ - increases with increasing tanβ:

Mass spectrum at large tanβ is then a convolution of Breit-Wigner function with Gaussian function given by RP resolution => optimum mass window thus depends on $\Gamma(H\to gg)$ and mass (or tanβ and mass).

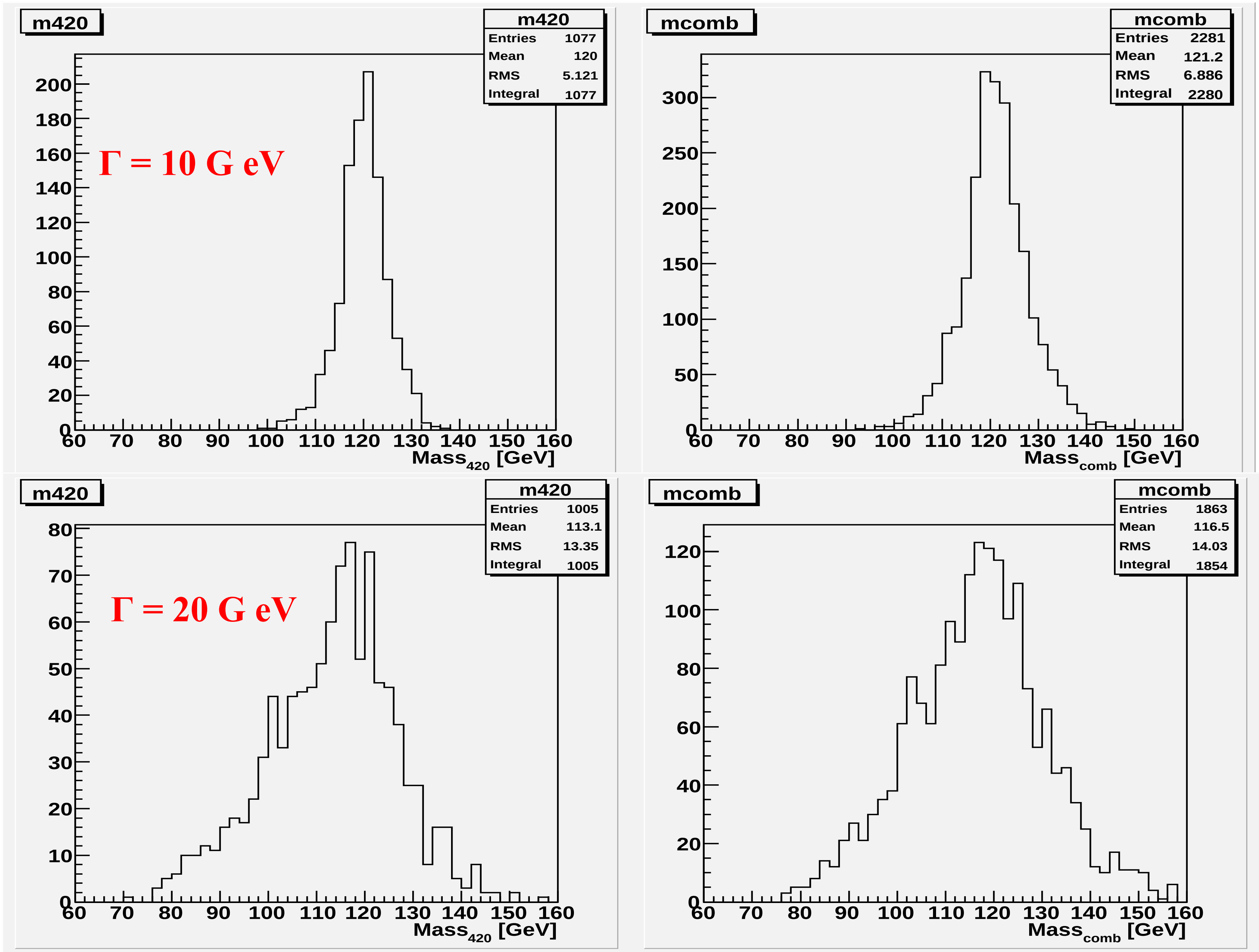
B: depends linearly on a mass window

A natural choice: $\Delta M_{420} = 2 * \mathrm{sqrt}((\sigma^M{}_{420})^2 + \Gamma^2)$, $\Delta M_{comb} = 2 * \mathrm{sqrt}((\sigma^M{}_{comb})^2 + \Gamma^2)$,
All following figures correspond to this choice. Other choices still to be examined to find really the optimum mass window.

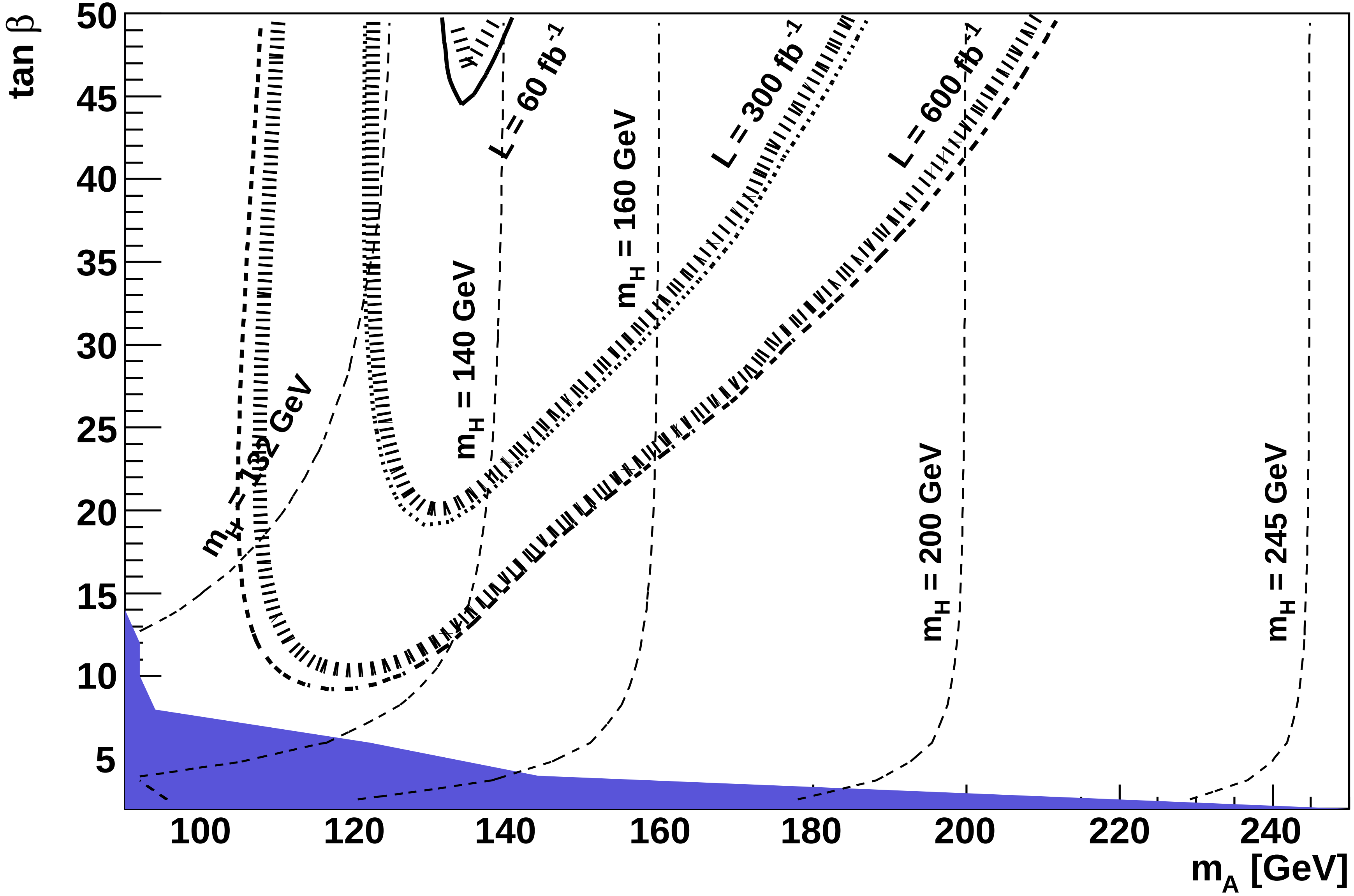
Mass spectra for different $\Gamma(H \rightarrow gg)$: ExHuMe



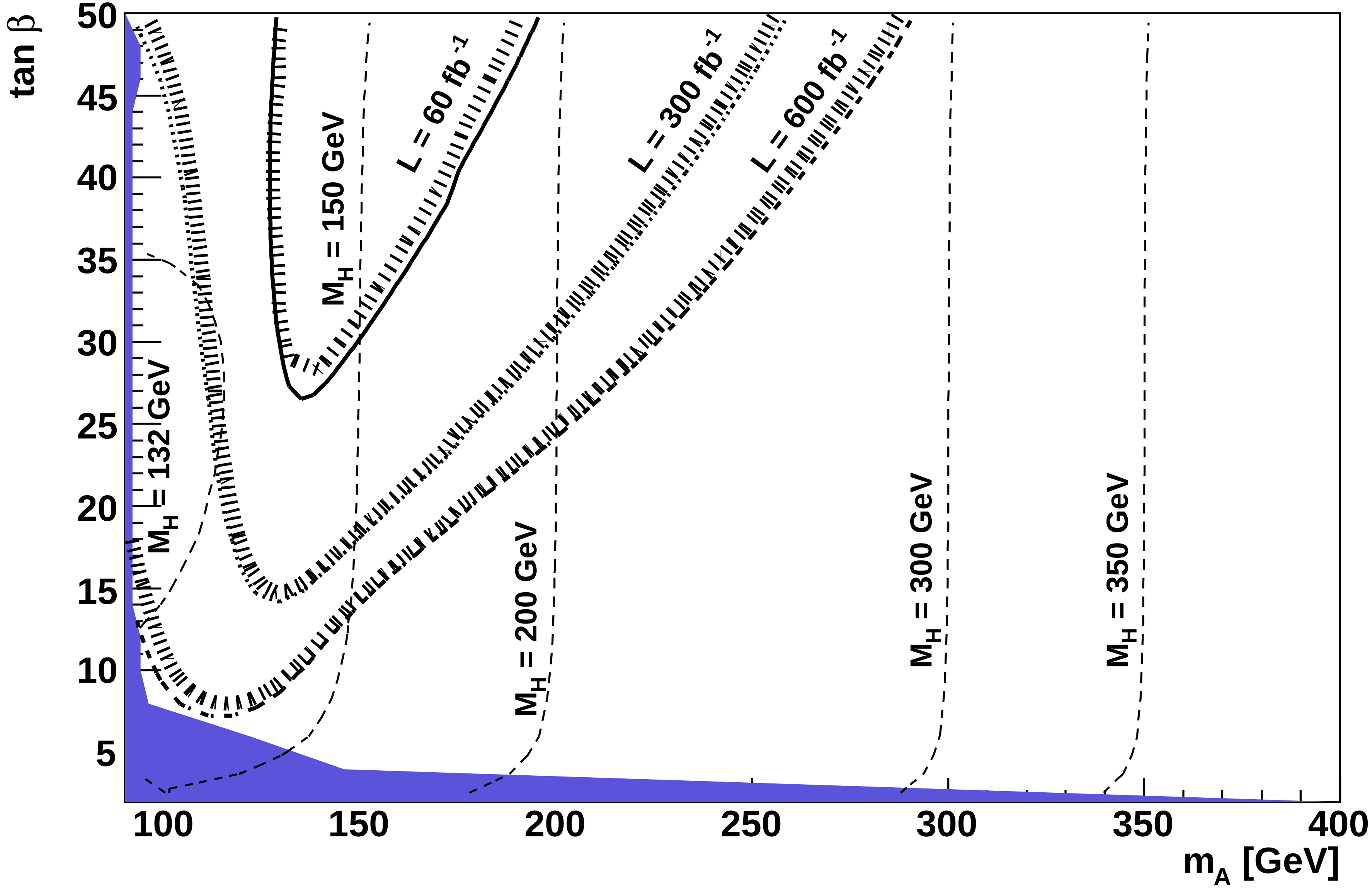
Mass spectra for different Γ(H→gg): ExHuMe



Stat.sig=5 for H→bb, mhmax sc.,μ=200 GeV



Stat.sig=5 for H→bb, mhmax sc.,μ=-500 GeV



Summary on MSSM enhancement

Xsections for bb and tautau enhanced most in mhmax scenario.
Xsections for WW enhanced most in small α_{eff} scenario.

Enhancement increasing with tanβ.

H→bb: up to 2000 for M_H~180—300 GeV and tanβ ~ 50
h→bb (tautau): up to 15 for M_h~ 115 GeV and tanβ ≈ 50
h→WW: max. 4 for M_h~120—123 GeV

Discovery contour plots being finalized now – still a few tests on the optimum mass windows need to be done. Interesting discovery regions observed, especially at large tanβ.

BACKUP SLIDES

Selection cuts for H->bb at mh=120 GeV

cut 1 $= \mathrm{N_{jet}} > 1$

cut 2 $= \mathrm{E_{T,jet1} * JES} > 45\ \mathrm{GeV} \quad \wedge \quad \mathrm{E_{T,jet2} * JES} > 30\ \mathrm{GeV}$

cut 3 $= |\eta_{\mathrm{jet1}}| < 2.5 \quad \wedge \quad |\eta_{\mathrm{jet2}}| < 2.5$

cut 4 = $|\eta_{jet1} - \eta_{jet2}| < 1.1$ – equiv. to 60°<$\eta_{jet1,2}$<120° in Higgs cms (used in KMR formulas)

cut 5 $= 2.85 < |\phi_{\mathrm{jet1}} - \phi_{\mathrm{jet2}}| < 3.43$

cut 7 $= 0.85 < \mathrm{M_{dijet}/M_{420}} < 1.15,\ 0.8 < \mathrm{M_{dijet}/M_{comb}} < 1.2$

cut 9 $= 118 < \mathrm{M_{420}} < 122, \quad 115 < \mathrm{M_{comb}} < 125$

cut 10 = both jets b-tagged (Discr > 1.0)

cut 11 $= |\xi^{\mathrm{L}}_{\mathrm{jet}} - \xi^{\mathrm{R}}_{420}|/\xi^{\mathrm{R}}_{420} < 0.3 \quad \wedge \quad |\xi^{\mathrm{R}}_{\mathrm{jet}} - \xi^{\mathrm{L}}_{420}|/\xi^{\mathrm{L}}_{420} < 0.3,$

$|\xi^{\mathrm{L}}_{\mathrm{jet}} - \xi^{\mathrm{R}}_{\mathrm{comb}}|/\xi^{\mathrm{R}}_{\mathrm{comb}} < 0.3 \quad \wedge \quad |\xi^{\mathrm{R}}_{\mathrm{jet}} - \xi^{\mathrm{L}}_{\mathrm{comb}}|/\xi^{\mathrm{L}}_{\mathrm{comb}} < 0.3,$

$0.002 < \xi_{420} < 0.04 \quad \wedge \quad 0.002 < \xi_{\mathrm{comb}} < 0.04$

cut L1 $= (\mathrm{Acc}^{\mathrm{L}}_{220} > 0 \vee \mathrm{Acc}^{\mathrm{R}}_{220} > 0) \quad \wedge \quad (\mathrm{E_{T,jet1,2}} > 40\ \mathrm{GeV})$

Efficiencies for SM $\Gamma(H \rightarrow gg) \sim MeV$

Mh [GeV]	Acc_{420}	Acc_{comb}	Acc_{220}	ε_{420}	ε_{comb}	ε_{220}
100	0.62	0.21	0.0	0.012	0.008	0.0
120	0.31	0.25	0.0	0.017	0.025	0.0
140	0.25	0.37	0.0	0.016	0.051	0.0
160	0.19	0.49	0.0	0.015	0.076	0.0
180	0.14	0.60	0.0	0.012	0.096	0.0
200	0.09	0.69	0.0	0.004	0.11	0.0
300	0.0	0.76	0.13	0.0	0.12	0.025

S/B for Lumi = 30 fb^{-1}

	3.5		7.0		17.6		35.0	
Jetcuts	19.2/33.3E10		19.2/35.7E10		19.2/39.2E10		19.2/35.6E10	
Jetcuts +2btag	6.4 / 7.5E8		6.4 / 8E8		6.4 / 8.5E8		6.4 / 7.7E8	
	420	comb	420	comb	420	comb	420	comb
Jetcuts +2btag +RP	2.1 / 2.3E6	1.6 / 10.5E6	2.1 / 5.4E6	1.6 / 29.6E6	2.1 / 28E6	1.6 / 130E6	2.1 / 77.8E6	1.6 / 293E6
All cuts +timing	0.6 / 85	0.9 / 80	0.6 / 190	0.9 / 300	0.6 / 1600	0.9 / 970	0.6 / 8200	0.9 / 5700