Study of heavy MSSM-Higgs bosons A/H in hadronic τ decays in ATLAS

$$\mathrm{b\bar{b}\ A/H \rightarrow b\bar{b}}\ \tau(\mathrm{had})\ \tau(\mathrm{had})$$

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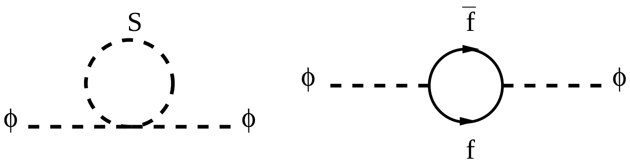
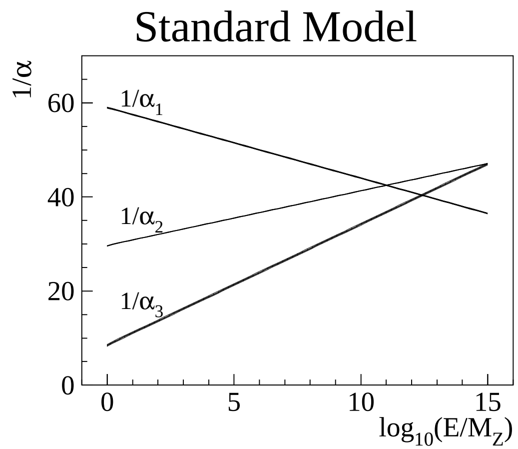
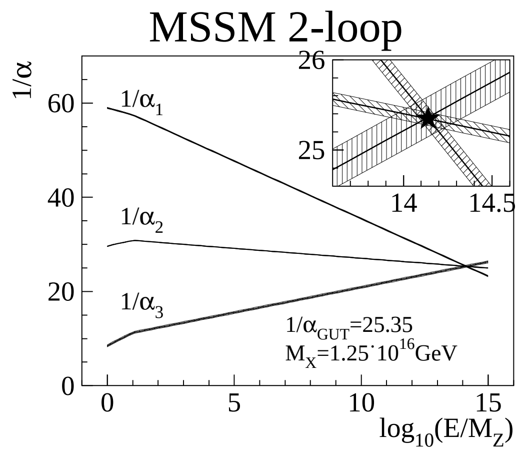
Motivations for Supersymmetry

- Symmetry between Fermions and Bosons:
  $Q\,|S\rangle \;\sim\; |S \pm 1/2\rangle \Rightarrow$
  $$\begin{cases} Q\,|\mathrm{Boson}\rangle & \sim \quad |\mathrm{Fermion}\rangle \\ Q\,|\mathrm{Fermion}\rangle & \sim \quad |\mathrm{Boson}\rangle \end{cases}$$
- Radiative corrections on the Higgs mass have quadratic divergence: Hierarchy-, Finetuning Problem. Loop correction from SUSY particles: Loops with Bosons would exactly cancel out loops with Fermions
- Coupling constants are known to be running, but will not meet in Standard Model calculations. Grand Unified Theory (GUT) possible with SUSY.
- Lightest Supersymmetric Particle (LSP) is stable, candidate for dark matter in space
- No supersymmetric particles discovered until now (LEP): $\rightarrow$ Supersymmetry is broken.







Minimal Supersymmetric Model (MSSM)

- MSSM requires two Higgs doublets instead of one in the SM
  $\longrightarrow$ Four additional scalar fields, which manifest in four additional Higgs bosons
- MSSM has 5 Higgs bosons: neutral: h, H, A, charged: $H^{\pm}$
  - two CP-even, scalar and neutral Higgs bosons:
    h (light) and H (heavy)
  - pair of charged Higgs bosons: H^{+} and H^{-}
  - CP-odd, pseudoscalar neutral Higgs boson: A
- Lightest Higgs h is indistinguishable from the SM Higgs !
  $\longrightarrow$ Detection of at least one of the other four MSSM Higgs necessary to confirm MSSM via Higgs sector
- MSSM Higgs production cross sections scale with model parameter tanβ (roughly $\sigma \sim \tan\beta$):
  - Discovery potential is illustrated in contour in $m_A - \tan\beta$ plane
  - Goal of study: estimate minimal tanβ value, where MSSM Higgs can just be detected according to:
    $$\frac{\text{No. of Signal Events}}{\sqrt{\text{No. of Background Events}}} = 5.0$$

MSSM Higgs boson searches

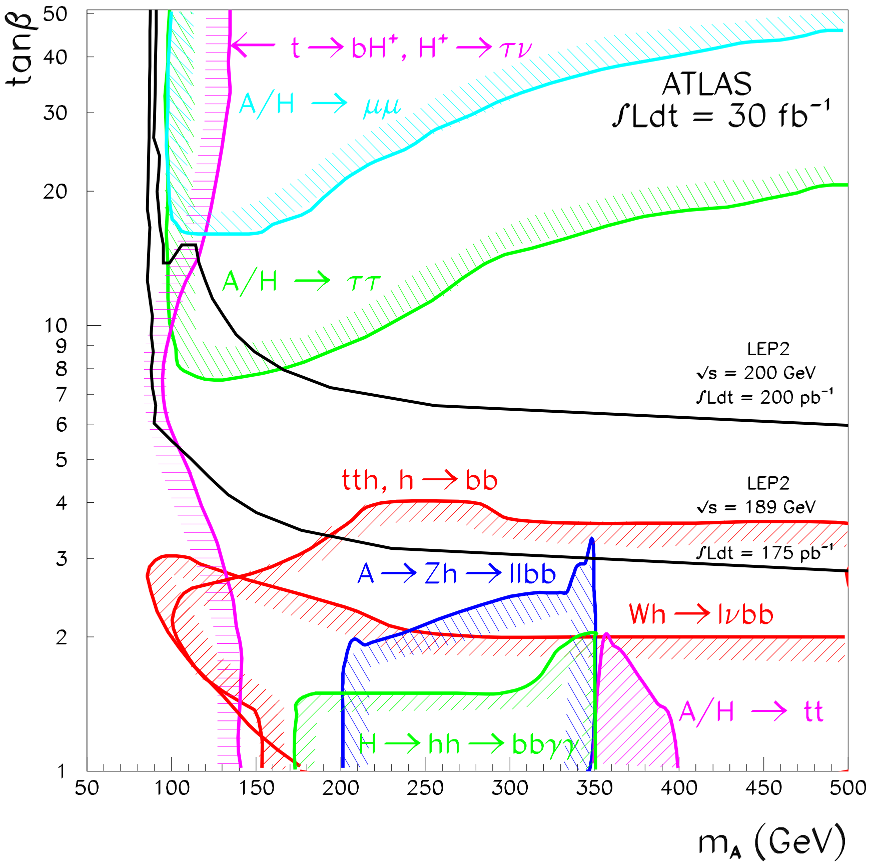
A/H mass-degenerated for $m_{A/H} > 150$ GeV (single analysis).
Dominant decay channels of A and H for large $\tan\beta > 10$:
$A/H \to \tau\tau$, $A/H \to \mu\mu$, $A/H \to b\bar{b}$

Decay modes of $A/H \to \tau\tau$:

- leptonic and semileptonic
- fully hadronic

$\to$ Study of fully hadronic decay mode offers additional sensitivity to A/H signal, improves discovery potential

Main problem: No lepton in final state (trigger, event selection)



Discovery potential of ATLAS illustrated by coverage of the ($\tan\beta$ - m_A)-plane (from Physics Performance TDR)

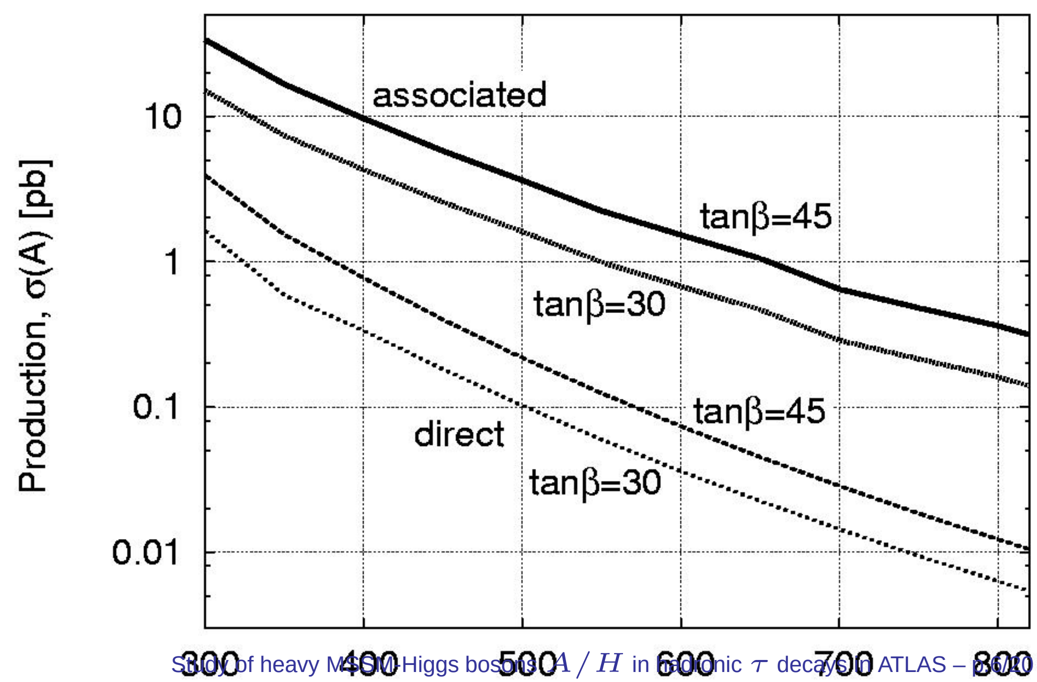
Production cross sections of A/H and branching ratios

Programs by M. Spira et. al. **HQQ, HDECAY** used to calculate the production cross sections of A and H and the branching ratio to $\tau\ \tau$. Leading Order (LO) only, no K-Factors

- Consistency with PYTHIA 6.205 with same parameter settings has been checked
- For consistency with previous studies we chose: Associated production from gluon-gluon collisions, b-quark on polemass, CTEQ5L PDF
- Considerable theoretical uncertainties
  (see note by E. Ros et al.: ATL-PHYS-2002-028)

Associated production is dominant for large m_A; e.g. for m_A = 800 GeV, $tan\beta = 45$:
σ (direct prod.) = 12 fb,
σ (associated prod.) = 381 fb

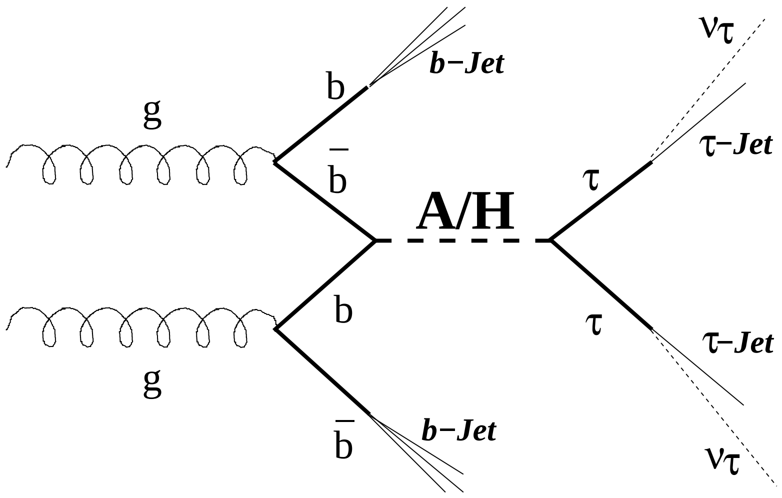
Branching ratio $A/H \to \tau\ \tau$:
10-11 %



Signals and relevant backgrounds

Signal:

- $gg \to \mathrm{b\bar{b}(A/H)} \to \mathrm{b\bar{b}}\ \tau\tau$
- masses: $\mathrm{m}_{A/H} = 450,\ 600,\ 700$ and $800\ \mathrm{GeV}$,
- $\sigma \times \mathrm{BR} = 88\ \mathrm{fb}$ ($\mathrm{m}_A = 800\ \mathrm{GeV}$, $\tan\beta = 45$)



Background signatures:

- QCD jet-production, $\sigma = 1.57\ \mathrm{mb}$
- W+jet production, $\sigma = 85400\ \mathrm{pb}$
- $(\mathrm{t\bar{t}})$ production, $\sigma = 520\ \mathrm{pb}$
- Z background (γ^*/Z, Z+jet), $\sigma = 3980\ \mathrm{pb}$

Monte Carlo production

Signal:

- 200000 events associated production ($b\bar{b}A$), m_A = 450, 600, 700 and 800 GeV

Background:

- W+jet: 1.2 Mio. in p_T-bins
- $t\bar{t}$: 10 Mio.
- Z+jet: 2.4 Mio.
- QCD jets: 24 Mio. in mass bins, $p_{\mathrm{T,min}}$ = 20 GeV

Monte Carlo samples generated using ATLFAST (Fortran-Version 2.53) with PYTHIA 6.152 (CTEQ5L).
Parametrisations for τ acceptance and b-tagging from ATLFAST-B.
Extended τ acceptance for $p_{T,jet} > 150$ GeV to optimize background rejection (D. Cavalli).

Large rejection factors for QCD in τ identification $\longrightarrow$ weighting technique needed and used to calculate signal significance. τ identification efficiencies and corresponding rejection factors for QCD used. ϵ_τ = 0.55, ϵ_b = 0.70.
Study for low luminosity of LHC
$\mathcal{L} = 10^{33}\ cm^{-2}\ s^{-1}$

Study of Level-1 trigger (I): Trigger types

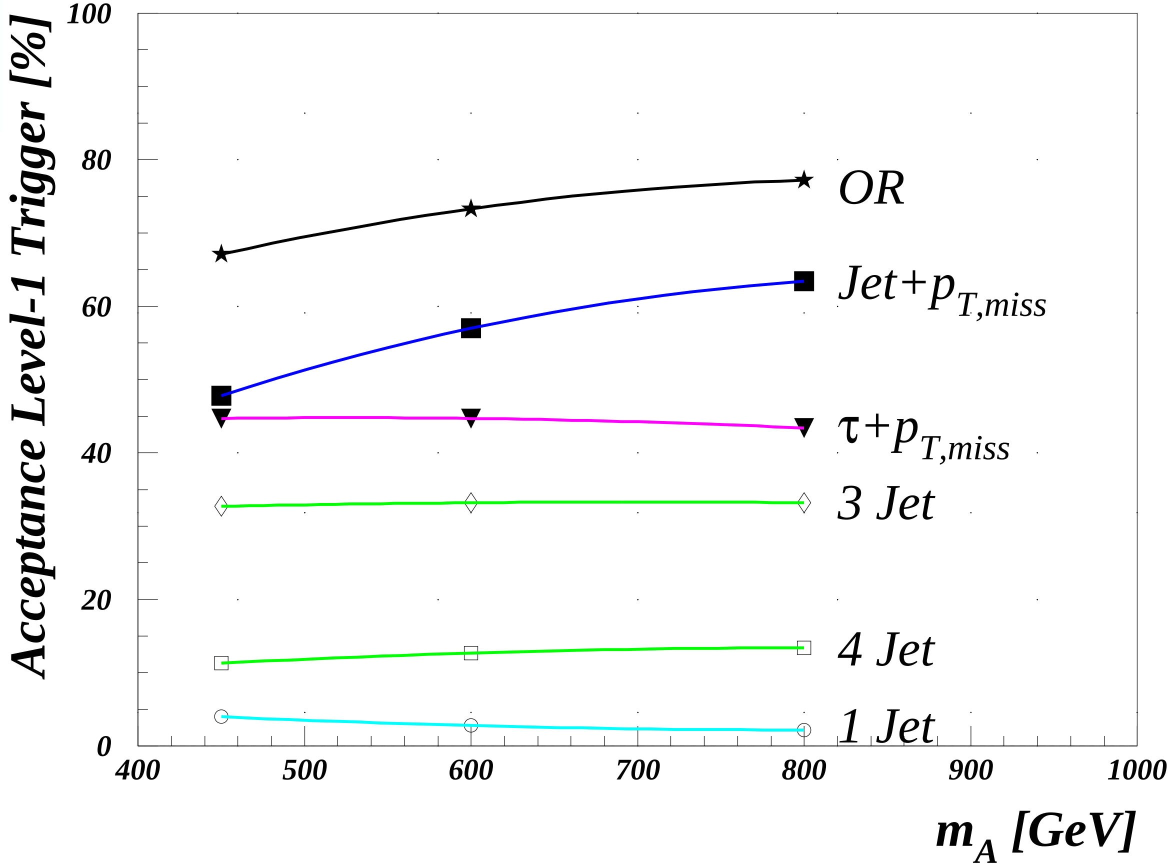
No trigger lepton and low production cross section:

Acceptance of the Level-1 trigger is crucial.

Most valuable: Combined Jet- and- τ triggers with $E_{t,miss}$ trigger.
$\rightarrow$ Signal events $m_{\mathrm{A}} = 450, 600$ and $800\ \mathrm{GeV}$ studied using fast trigger simulation (ATL1CT, K. Mahboubi et al.) using standard First Level Trigger TDR threshold settings (!)

- **Jet +** $E_{T,miss}$ (thresholds: $E_{T,jet} > 50\ \mathrm{GeV}$, $E_{T,miss} > 50\ \mathrm{GeV}$)
- τ **+** $E_{T,miss}$(thresholds: $E_{T,\tau} > 20\ \mathrm{GeV}$, $E_{T,miss} > 30\ \mathrm{GeV}$)
- **Single Jet** ($E_{T,jet} > 180\ \mathrm{GeV}$)
- **Three Jets** ($E_{T,jet} > 75\ \mathrm{GeV}$)
- **Four Jets** ($E_{T,jet} > 55\ \mathrm{GeV}$)

Study of Level-1 trigger (II): Acceptance before selection cuts



Level-1 trigger acceptance before any selection criteria are applied:

62.5% for $m_{A/H} = 450$ GeV, 76.3% for $m_{A/H} = 800$ GeV.

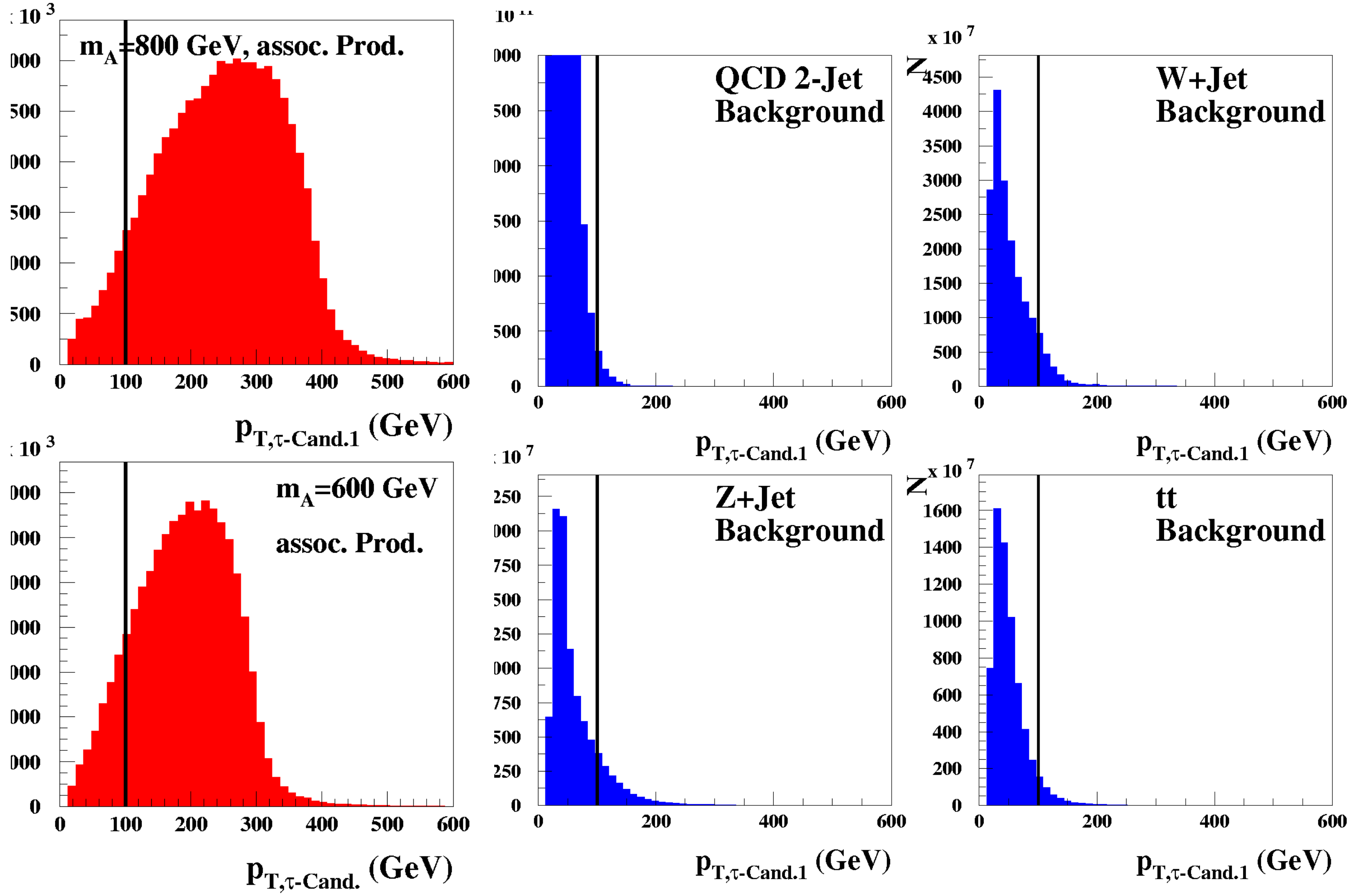
Most important triggers: Jet+E_T^{miss} and τ+E_T^{miss}.

BUT: For impact on discovery potential combination with offline analysis needed !

Selection cuts on signal and background

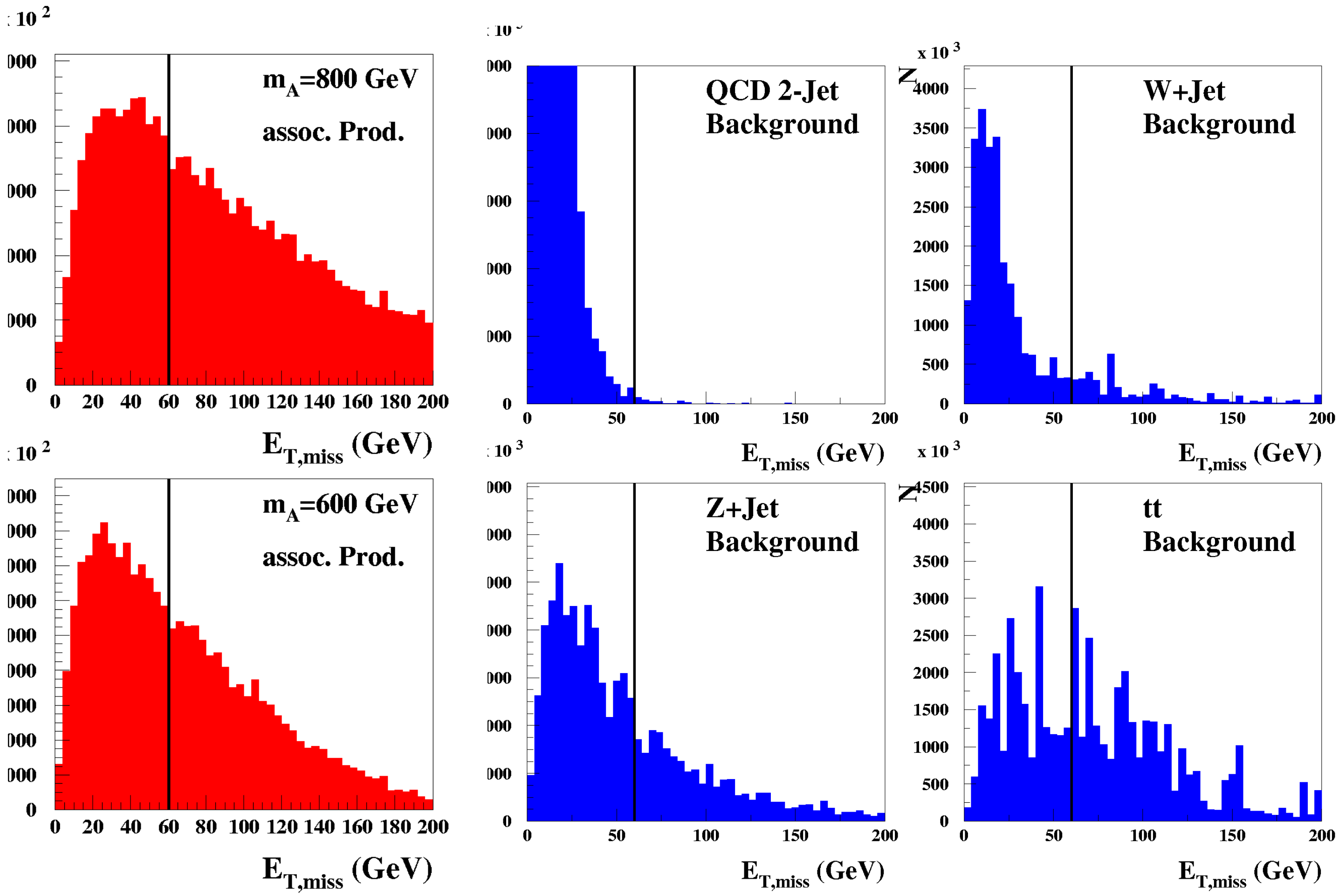
1. Two hadronic τ candidates
   with $p_T > 100 \text{ GeV}$ within $|\eta| < 2.5$
2. Not more than 4 Jets in $|\eta| < 3.2$ with $p_T >$ 20 GeV
3. No lepton $p_T > 10 \text{ GeV}$ found
4. At least one b-jet tagged
5. Missing transverse momentum $p_{T,miss} > 65 \text{ GeV}$
6. Angle between τ-candidates: $\Delta\phi$ = 145-175°
7. Transverse mass: min($m_{T,1/2}$) $< 50 \text{ GeV}$
8. Mass reconstruction of $m_{A/H}$ using collinear
   approximation, mass window of 1.5 σ

Transverse momentum of leading τ-candidate



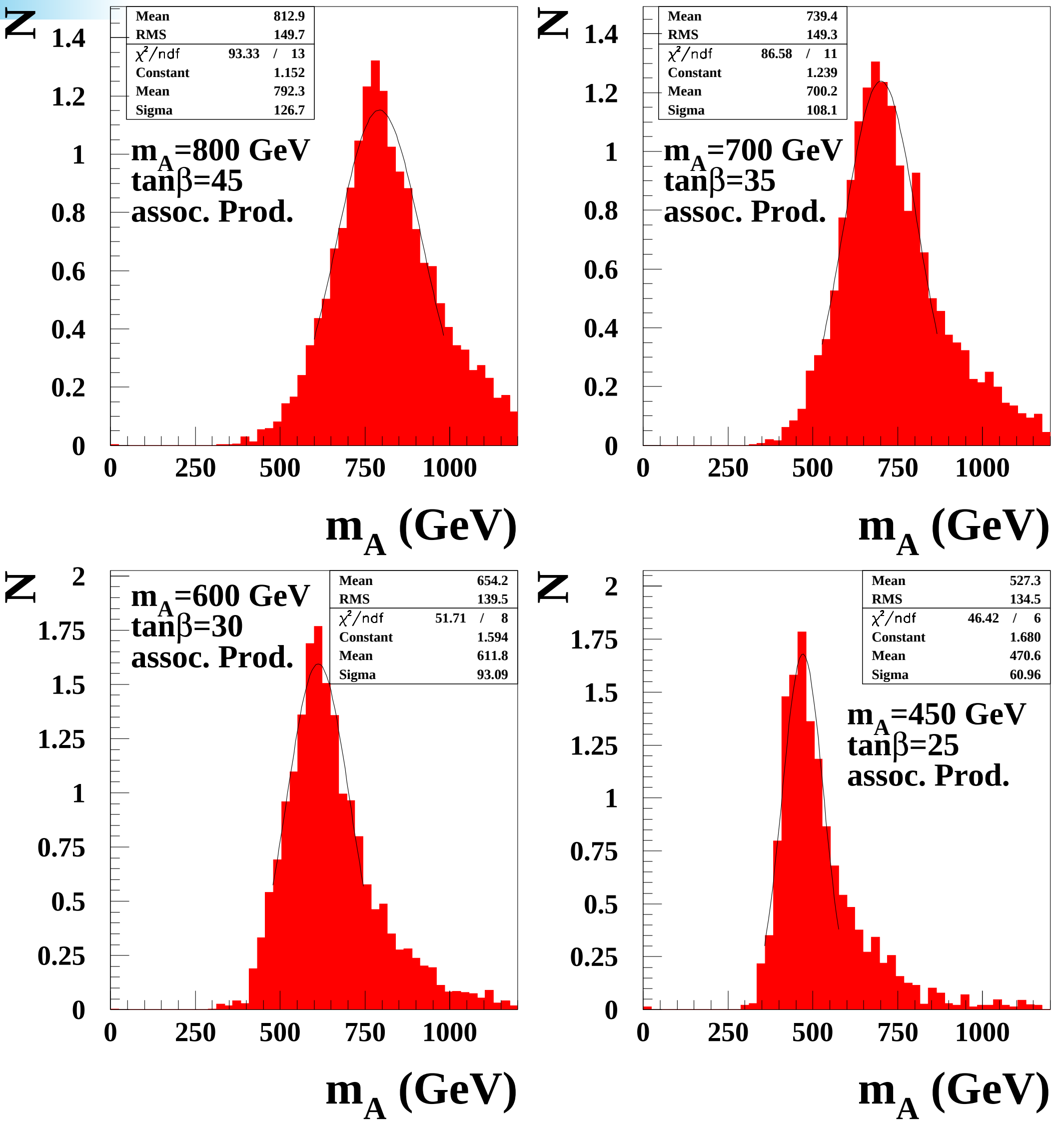
Selection: $p_{T,\tau} > 100$ GeV in $|\eta| < 2.5$

Missing transverse momentum ($p_T, miss$)



Selection: $p_{T,miss} > 65\ \mathrm{GeV}$

Reconstructed mass of A/H from $\tau\,\tau$-System

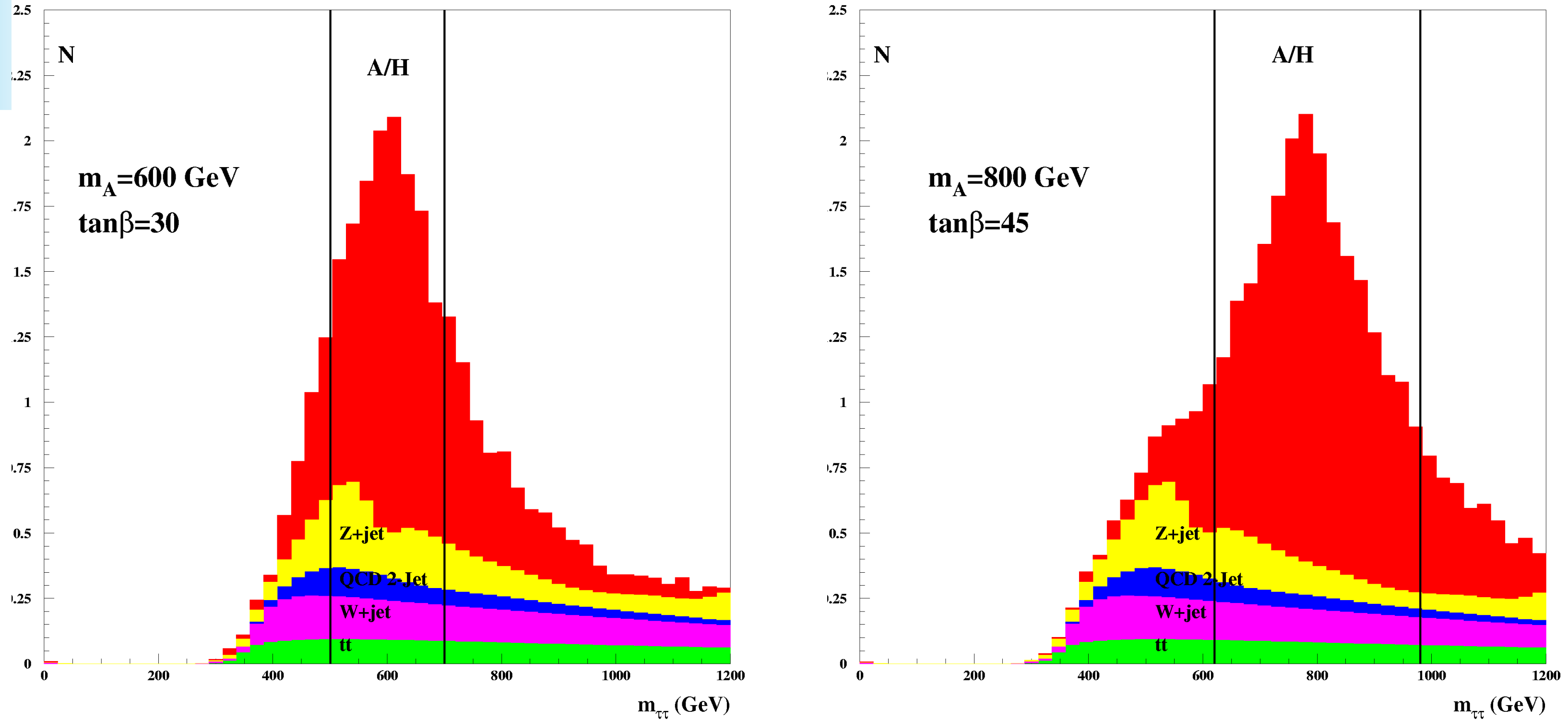


Gaussian fits around the reconstructed mass.

Mass window of 1.5 σ (RMS) used as final selection criterium.

In agreement with mass resolution of lepton/hadron channel (D. Cavalli, G. Negri, Milano)

Expected signal



Signal A/H for masses $m_A = 600 \text{ und } 800 \text{ GeV}$ above the backgrounds, composed of $\mathrm{t\bar{t}}$, W+jet, QCD jet and Z+jet events. Integrated luminosity of 30 fb^{-1} is assumed.

Rates of signal and backgrounds

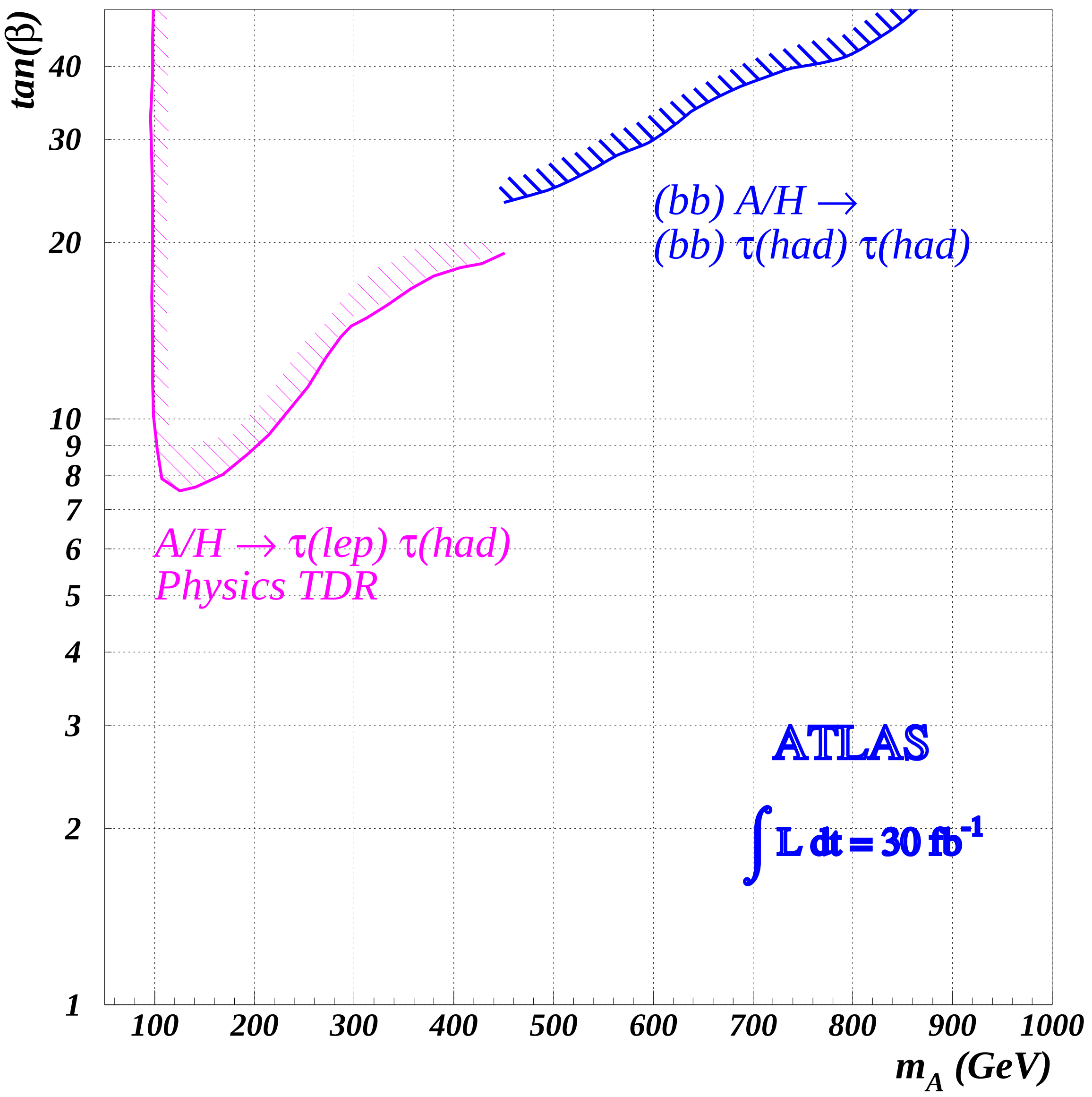
$m_{A/H}$	450 GeV	600 GeV	700 GeV	800 GeV
	tanβ=25	tanβ=30	tanβ=35	tanβ=45
$\sigma(\mathrm{b\bar{b}A/b\bar{b}H}) \times \mathrm{BR}(\tau\tau)$				
Associated production	408 fb	160 fb	103 fb	88 fb
Width of the reconstructed mass	60.9 GeV	93.0 GeV	108.1 GeV	126.7 GeV
Mass window	± 85 GeV	± 130 GeV	± 160 GeV	± 180 GeV
Acceptance of analysis in 10^{-3}	1.3	4.2	5.8	7.4
Event rates in 30 fb^{-1}:				
Total signal (A+H assoc. prod.)	16.5	20.4	18.0	19.6
$\mathrm{t\bar{t}}$	1.3	3.0	2.9	2.2
(Z/γ^*)+jet	1.3	2.2	1.9	1.9
W+jet	0.5	1.2	1.5	1.9
QCD jets	1.4	1.0	0.8	0.8
Total background	4.5	7.4	7.1	6.8
Significance 30 fb^{-1} (Poisson)	5.7	5.8	5.3	5.8
5σ limit on tanβ	23.2	27.6	34.0	39.8

Acceptance of trigger for events accepted offline

		$m_A =$ 450 GeV	$m_A =$ 600 GeV	$m_A =$ 800 GeV
1	two τ(had)-Candidates no lepton (μ, e)	62.5%	71.5%	76.3%
2	less than 4 jets, one b-jet	71.3%	78.5%	82.5%
3	$E_T^{miss} > 65$ GeV	92.0%	93.5%	93.7%
4	$\Delta\phi = 145 - 175°$	92.3%	93.9%	94.4%
5	transv. Mass $m_T < 50$ GeV	92.4%	94.1%	94.5%
6	Mass reconstruction	91.8%	94.7%	94.9%

$\longrightarrow$ Very good acceptance of the Level-1 trigger towards the offline selected events. Influence on signal significance and discovery contour is minimal.
Similar kinematic criteria in both the trigger and the offline analysis: Jets/τ's with high transverse momentum $p_T > 100$ GeV and large values of missing transverse energy/momentum E_T^{miss}
$\longrightarrow$ Background rates controllable: Total rate of less than 2 kHz fit within the limitations of the trigger architecture (Level-2 input rate)

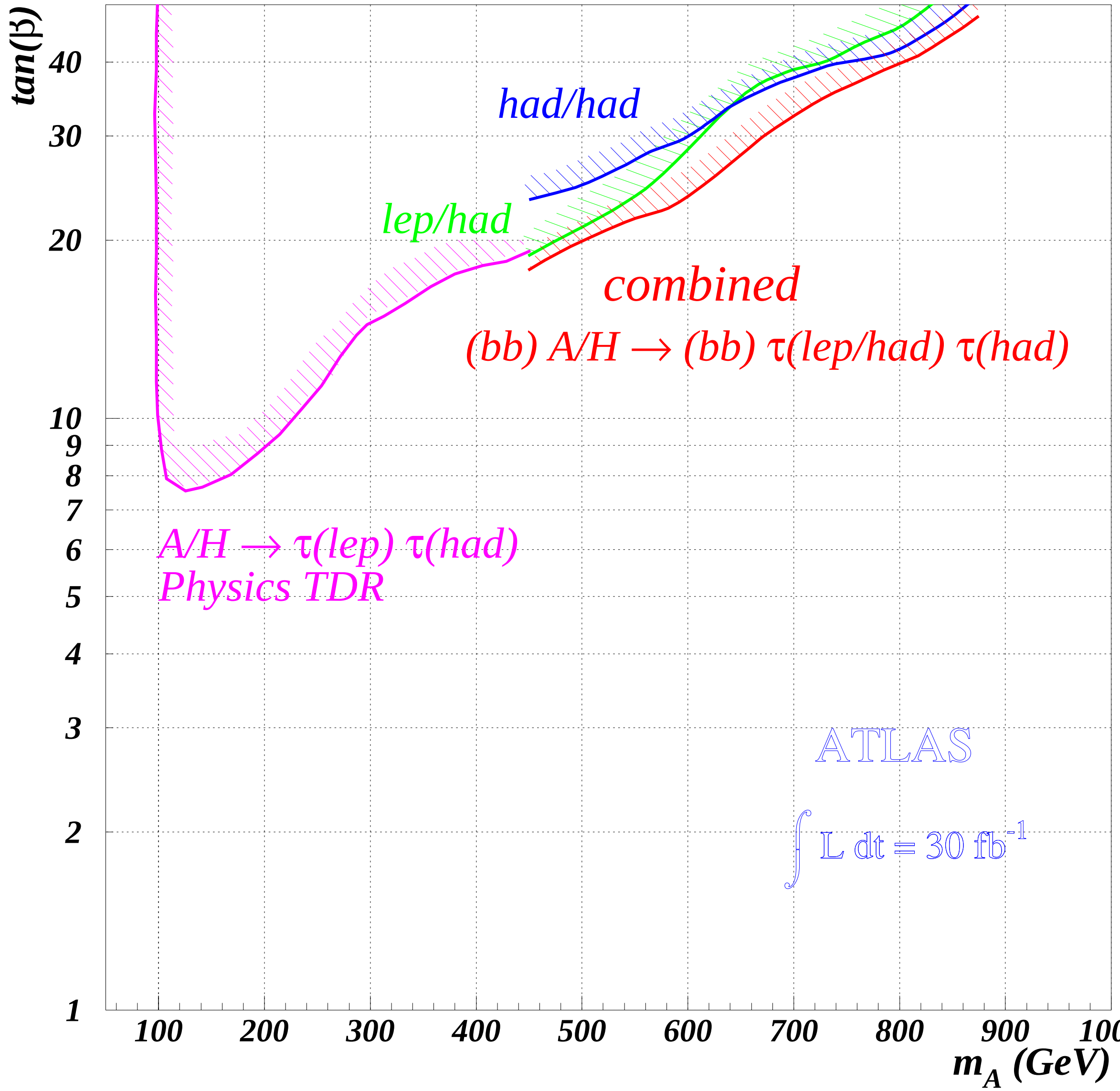
Discovery contour of fully hadronic decay mode



Combined discovery contour

Combination of fully hadronic decay mode with complementary (semi)leptonic decay modes further enhances discovery potential.

Values for semileptonic decay modes provided by D. Cavalli and G. Negri (Milano), internal note in preparation



Preliminary

Summary

- Study of the fully hadronic τ decay channel of the MSSM-Higgs bosons A/H shows that heavy MSSM-Higgs bosons A/H can be discovered at ATLAS in the large tanβ region:
  - $m_{A/H} = 600\ \mathrm{GeV}$ for tan$\beta > 30$
  - $m_{A/H} = 800\ \mathrm{GeV}$ for tan$\beta > 45$

  Results are for integrated luminosity of $30\ \mathrm{fb}^{-1}$ and low luminosity.
- Event selection has been optimised to reject the huge hadronic backgrounds from QCD jet production and $\mathrm{t\bar{t}}$ using kinematical cuts, τ-identification and b-tagging.
- Level-1 trigger causes only minimal reduction of signal significance: 90%-95% of events accepted by offline analysis are expected to be triggered by standard τ- and jet-triggers with E_T^{miss} signatures.
- Further improvement of the discovery potential can be achieved by combining the results with the complementary leptonic decay channels:
  - $m_{A/H} = 600\ \mathrm{GeV}$ for tan$\beta > 23$
  - $m_{A/H} = 800\ \mathrm{GeV}$ for tan$\beta > 34$
- This study is documented in: ATL-PHYS-2003-003

bmb+f - Förderschwerpunkt
ATLAS
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