ATLAS Searches in Higgs Sectors Beyond the Standard Model

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Overview: Outline of the Talk

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- Higgs Sectors in SUSY: Minimal SUSY (MSSM), Next-to MSSM (NMSSM)
- MSSM Neutral Higgs $\phi = h/A/H$ (SM $\phi \to b\bar{b}$ channel not considered)
  - MSSM ϕ Phenomenology
  - Tevatron Exclusion Limits on MSSM from ϕ Searches
  - ATLAS $\phi \to \mu^+\mu^-, \tau^+\tau^-, Invisible$ Sensitivity
- MSSM Charged Higgs H^+
  - MSSM H^+ Phenomenology
  - Tevatron Exclusion Limits on MSSM from H^+ Searches
  - ATLAS $H^+ \to t\bar{b}, \tau^+\nu$ Sensitivity
  - ATLAS Ongoing Studies: $H^+ \to \tau^+\nu, c\bar{s}$
- NMSSM Charged and Neutral Higgs
  - NMSSM Motivation and Phenomenology
  - Tevatron Exclusion Limits from h_1 Searches
  - ATLAS Ongoing Studies: $h_1 \to 2a_1 \to 2\mu 2\tau$ and $h^+ \to a_1 W$

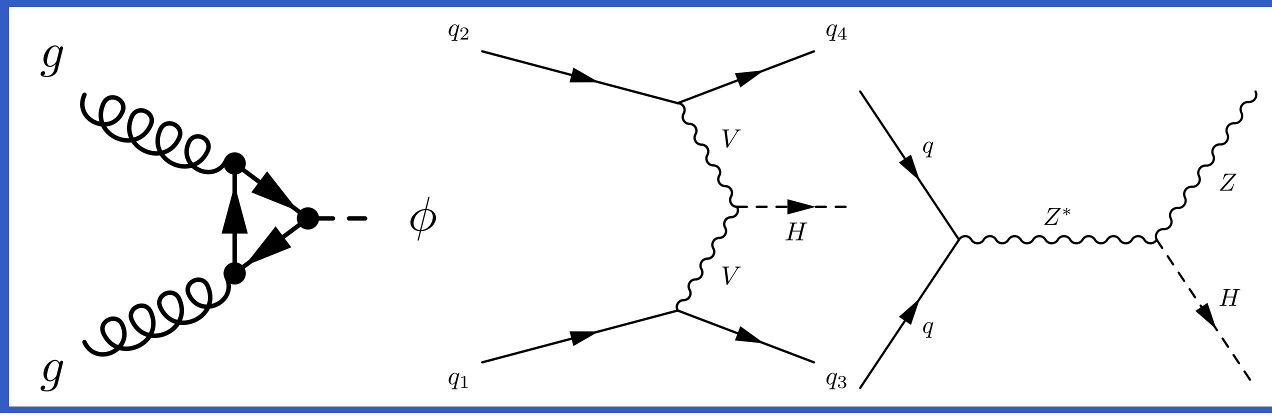
ATLAS results from CERN-OPEN-2008-020, Geneva, 2008. UOI, all ATLAS results assume $\sqrt{s} = 14$ TeV and the $m_h - max$ scenario of the MSSM.

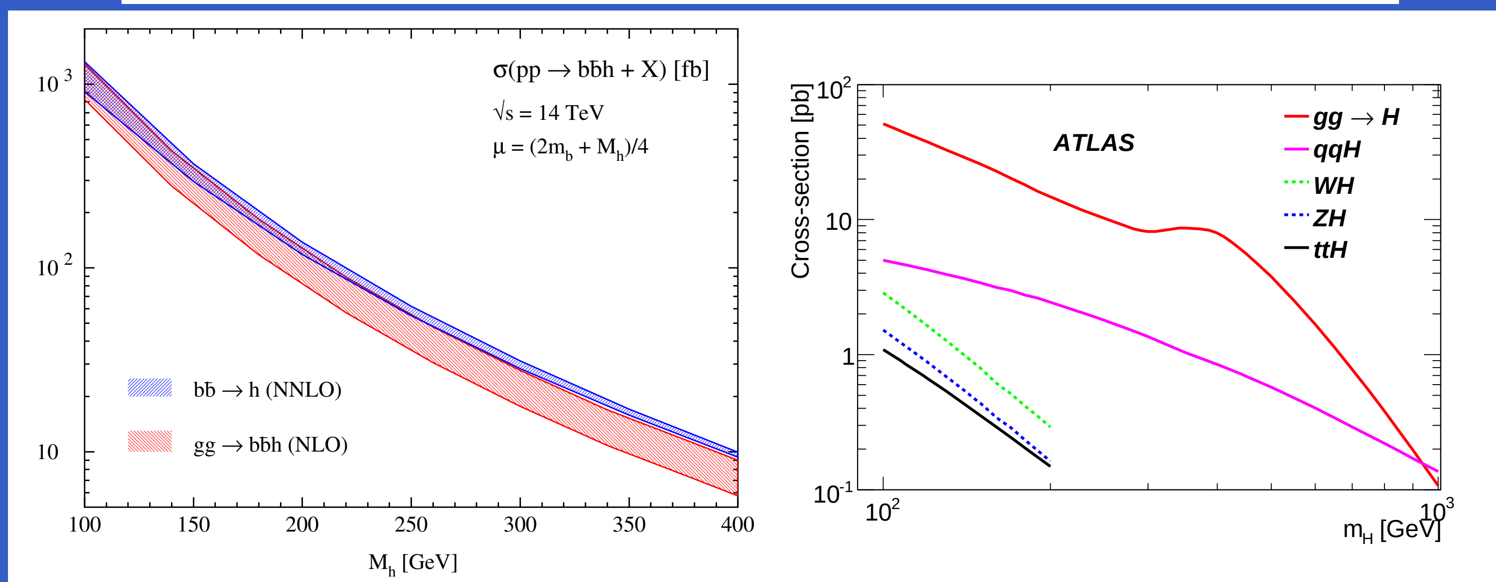
Overview: SUSY, MSSM, NMSSM

- SUSY: S. Martin, hep-ph/9709356
  - Provides an elegant solution to the Hierarchy Problem of the SM.
  - Predicts that gauge couplings are unified at the GUT scale.
  - Provides a good candidate for Dark Matter - the neutralino χ^0.
- The MSSM: S. Martin, hep-ph/9709356
  - Introduces soft supersymmetry breaking term to the SUSY potential to account for the broken symmetry.
  - Reduces the number of free parameters in SUSY to a manageable number and thereby provides a convenient benchmark for simulation studies.
  - Contains two neutral scalars (h, H), one neutral pseudoscalar (A) and two charged scalars (H^+, H^-).
- The NMSSM: M. Maniatis, arXiv:0906.0777v1; R. Dermisek and J. Gunion, arXiv:0811.3537
  - Solves the μ-term problem in the MSSM without fine tuning by adding a single field to the MSSM.
  - Accounts for the anomalous muon magnetic moment (the MSSM cannot).
  - Accounts for the combined LEP 2.3σ excess in the $m_{b\bar{b}}$ distribution from $\ell^+\ell^-b\bar{b}$ events.
  - Contains three scalars (h_1, h_2, h_3), two pseudoscalar (a_1, a_2) and two charged scalars (h^+, h^-).

MSSM ϕ Phenomenology

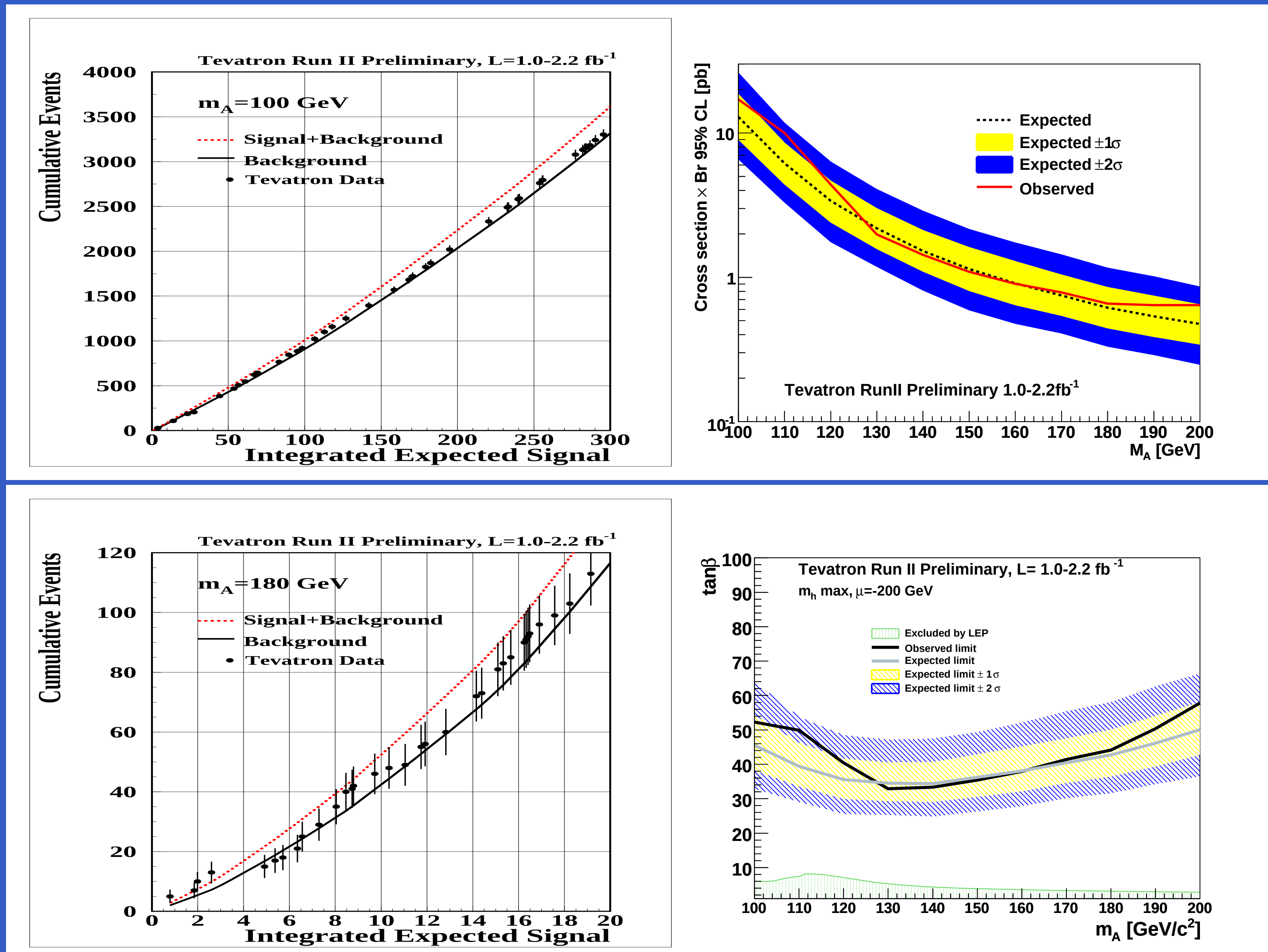
AP+VBF: ATLAS $\phi \rightarrow Inv.$; gg Fusion: ATLAS $\phi \rightarrow \mu^+\mu^-$, Tev. $\phi \rightarrow \tau^+\tau^-$; $bb\phi$: ATLAS and Tev. $\phi \rightarrow \tau^+\tau^-$





Left, the inclusive cross-sections for the processes $bb \rightarrow \phi$ (blue hatched region) and $gg \rightarrow \phi$ (red hatched region) are shown on the right-hand side. Right, cross-sections for the five production channels of the Standard Model Higgs boson at the LHC at 14 TeV.

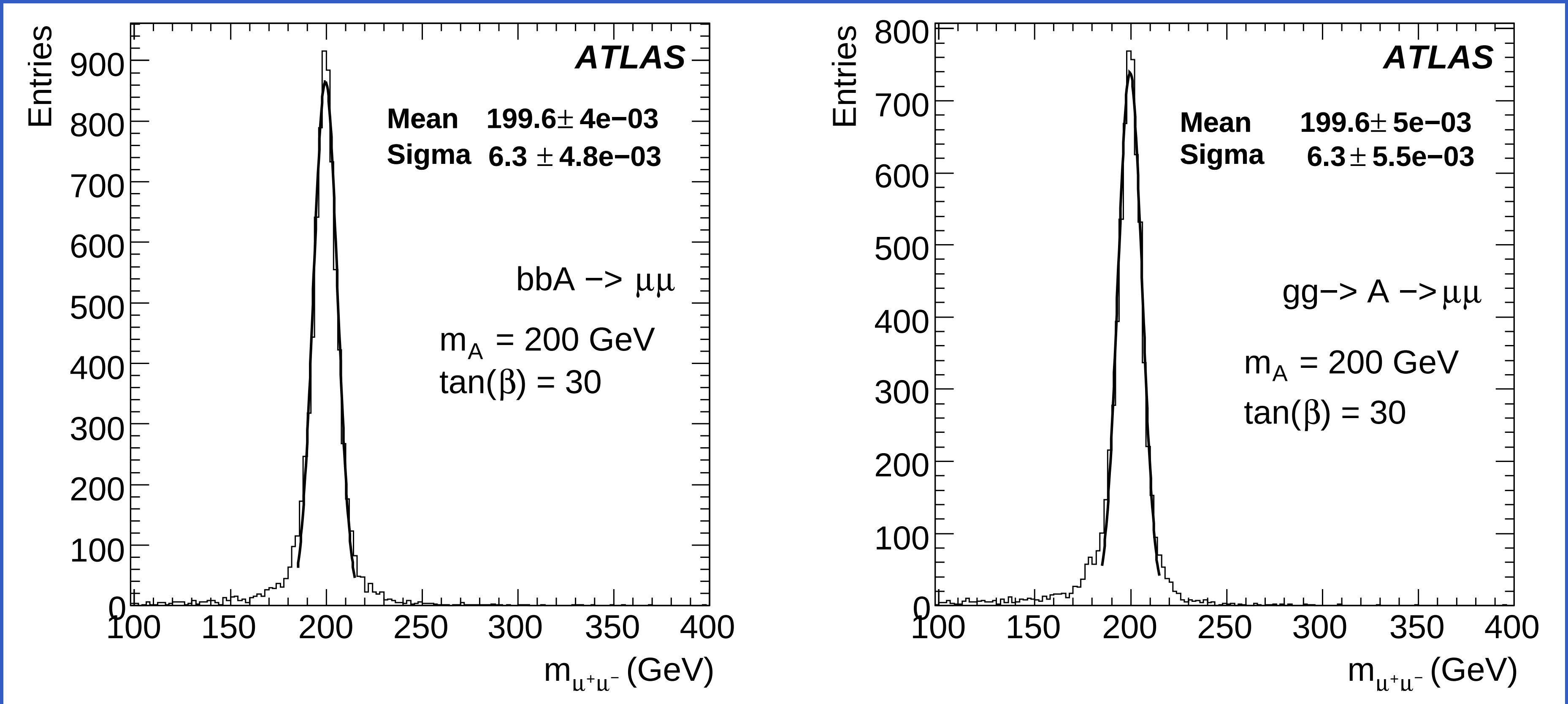
Tevatron Limits on the MSSM ϕ



Combined CDF and D0 limits on MSSM Higgs boson production in tau-tau final states with up to 2.2 fb-1 of data (Conference Note 5980-CONF).

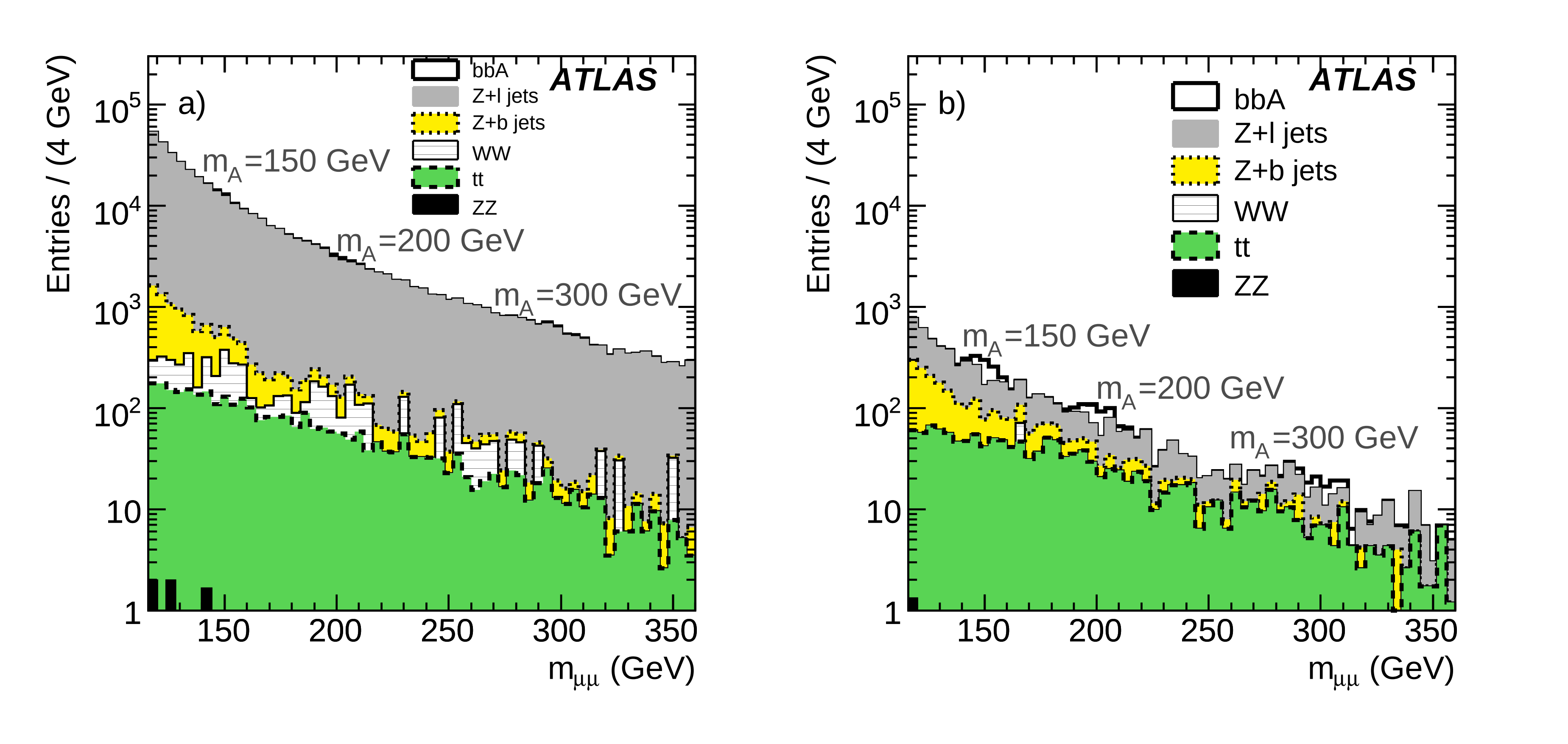
MSSM Neutral Higgs: $\phi \rightarrow \mu^+\mu^-$ Signal

The Tevatron does not study this channel.



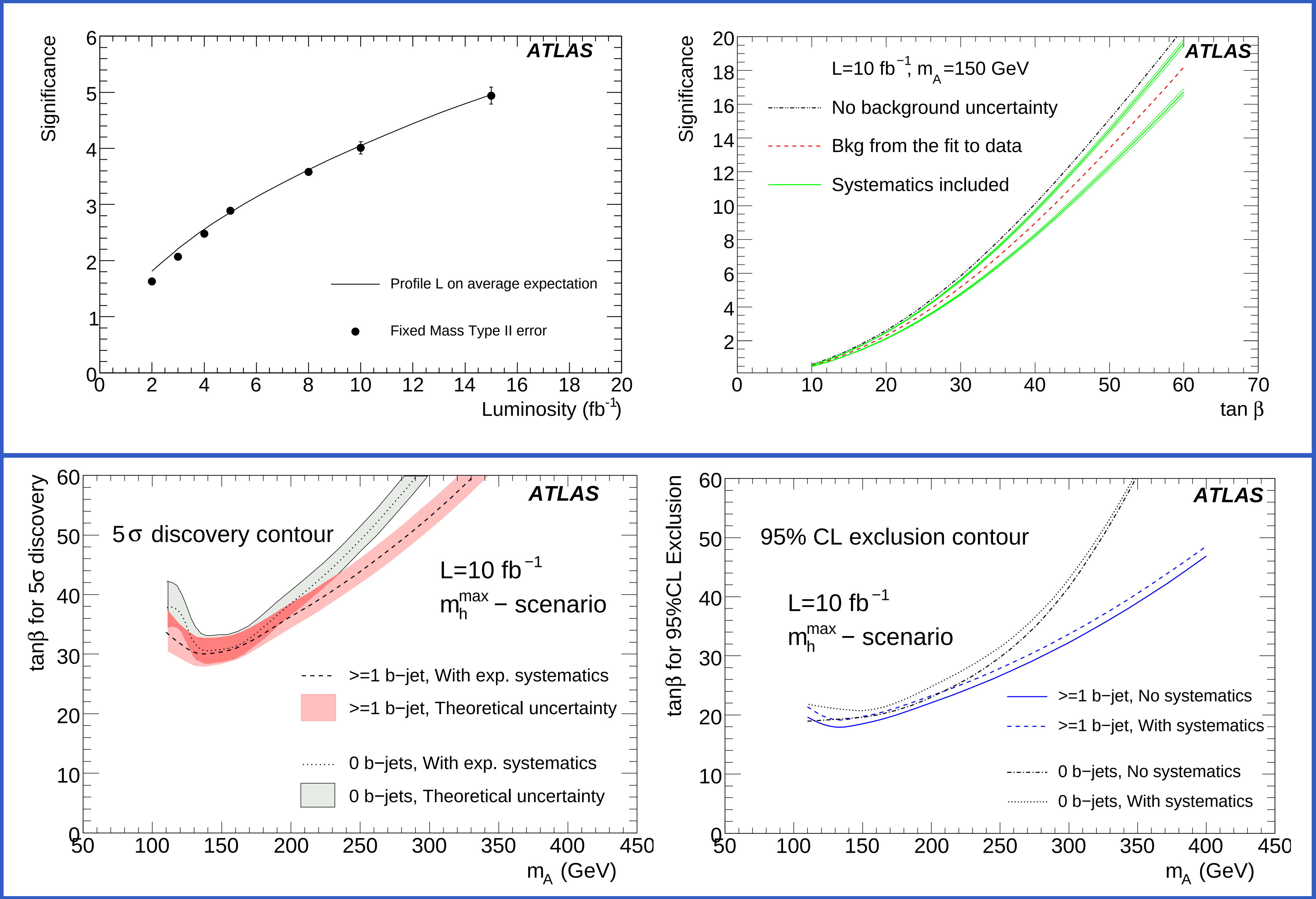
Dimuon mass distribution for the bbA and gg -> A signal samples with an A boson mass of 200 GeV and $\tan\beta = 30$. The distributions are fitted by the Gauss function.

MSSM Neutral Higgs: $\phi \to \mu^+\mu^-$ Background



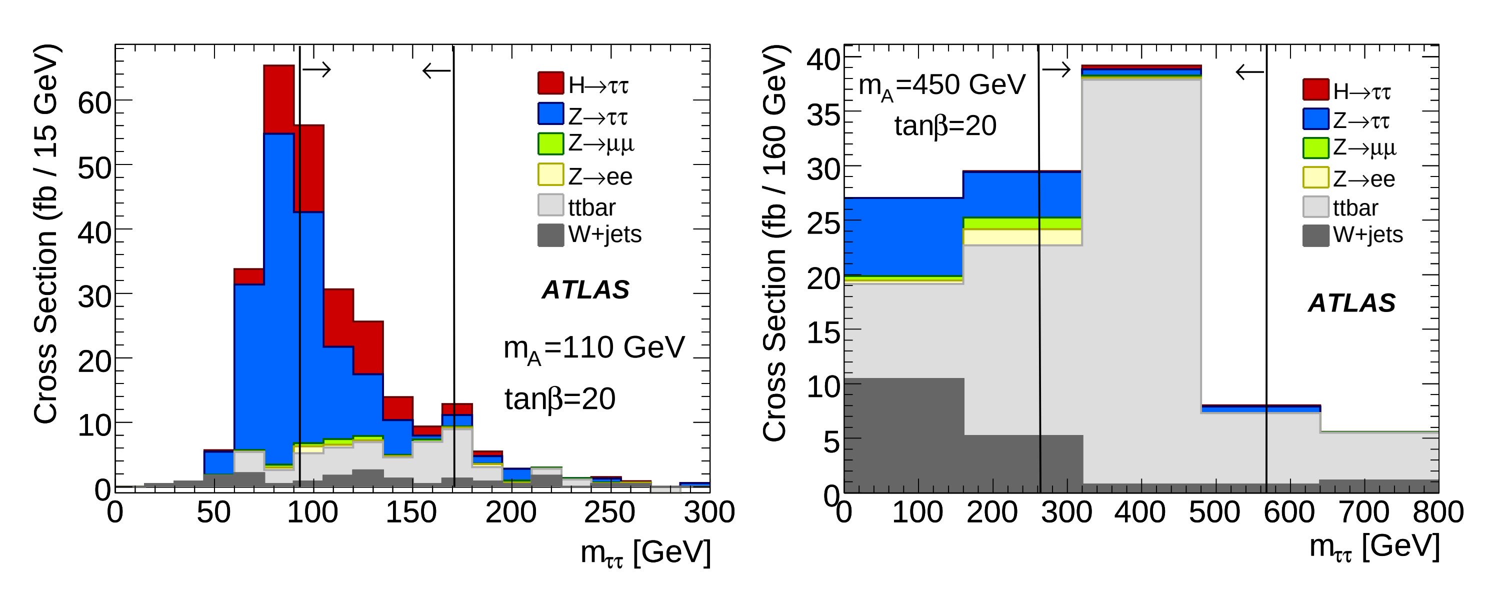
Invariant dimuon mass distributions of the main backgrounds and the A boson signal at masses mA =150, 200 and 300 GeV and $\tan\beta = 30$, obtained for the integrated luminosity of 30 fb-1. B-tagging has been applied for the event selection. The production rates of H and A bosons have been added together. a) for the 0 b-jet final state and b) for the final state with at least 1 b-jet.

MSSM Neutral Higgs: $\phi \to \mu^+\mu^-$ 10 fb^{-1} Sensitivity



MSSM Neutral Higgs: $\phi \to \tau^+\tau^-$ Results

ATLAS considers $ee, \mu\mu$ channels while the Tevatron does not; Tevatron considers τ_{had}.

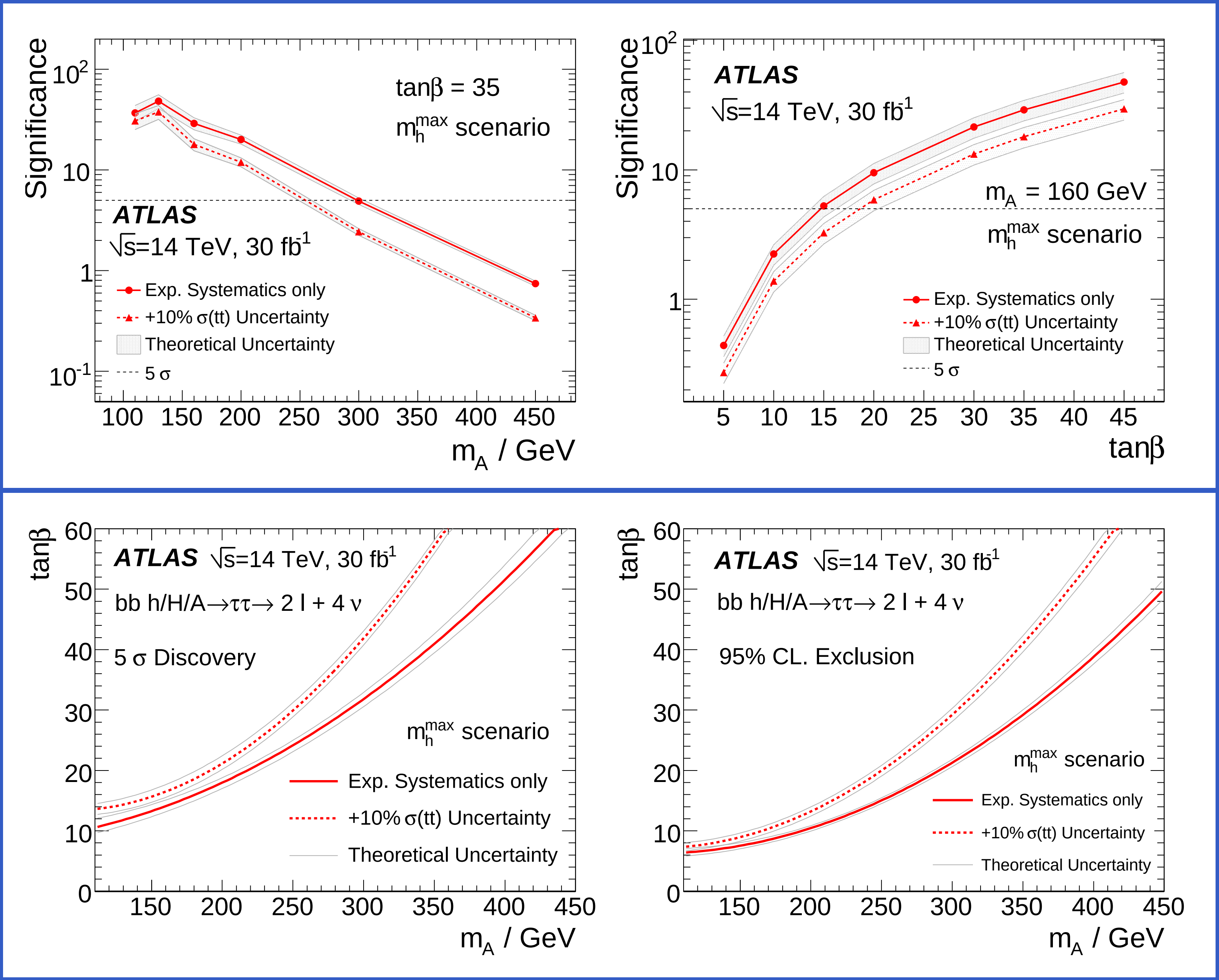


Invariant $m_{\tau^+\tau^-}$ distribution for Higgs boson candidates with nominal masses as indicated in the plots. The distributions are shown after all selection cuts for $\tan\beta = 20$.

	$H \to \tau^+\tau^-$	$t\bar{t}$	$Z \to \tau^+\tau^-$	$Z \to e+e^-$	$Z \to \mu^+\mu^-$	W+jets
$m_A = 110$ GeV	51.8 ± 3.5	39.3 ± 6.6	152.3 ± 9.5	3.9 ± 4.2	4.6 ± 4.3	17 ± 15
$m_A = 130$ GeV	43.3 ± 3.1	32.8 ± 6.0	107.5 ± 8.8	3.6 ± 3.1	3.8 ± 4.0	21 ± 16
$m_A = 160$ GeV	28.8 ± 1.5	71.0 ± 8.8	67.5 ± 6.3	3.6 ± 4.1	4.9 ± 4.5	16 ± 14
$m_A = 200$ GeV	14.1 ± 0.7	80.8 ± 9.4	26.9 ± 4.0	2.8 ± 3.6	4.6 ± 4.4	20 ± 16
$m_A = 300$ GeV	3.8 ± 0.2	102 ± 10	16.1 ± 3.1	2.2 ± 3.2	4.2 ± 4.1	19 ± 16
$m_A = 450$ GeV	0.60 ± 0.03	93 ± 10	12.5 ± 2.7	2.0 ± 3.1	1.7 ± 2.7	18 ± 15

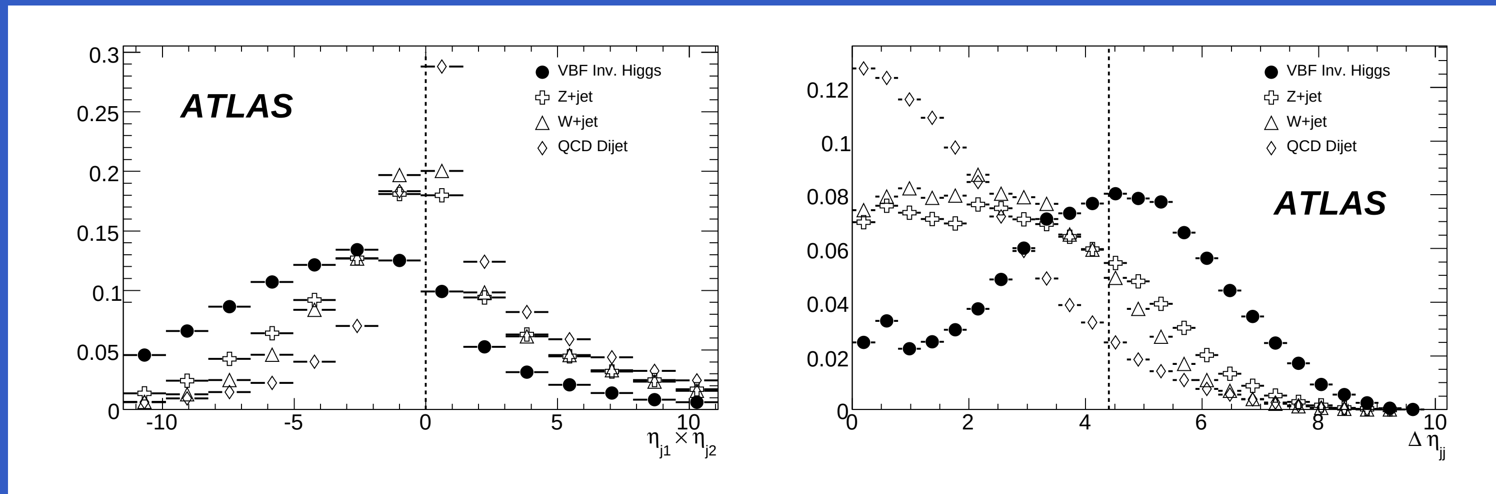
Accepted cross-section for all Higgs boson mass hypotheses analyzed. The cross-section in fb for signal and background after all selection cuts is given (except for the cut on the mass window) for $\tan\beta = 20$.

MSSM Neutral Higgs: $\phi \to \tau^+\tau^-$ 30 fb^{-1} Sensitivity

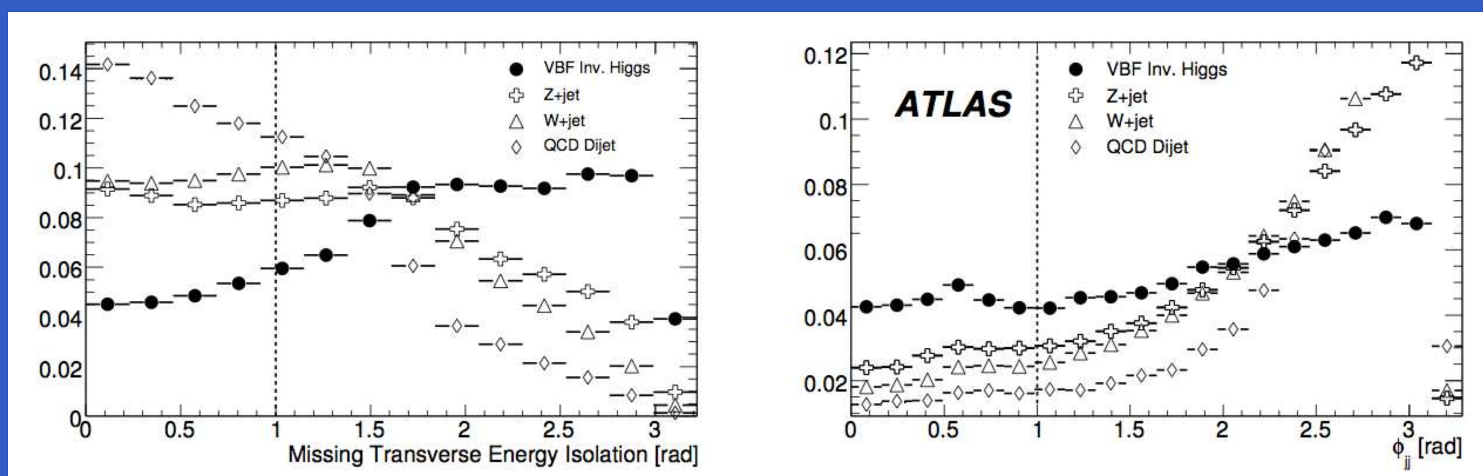


MSSM Neutral Higgs: VBF $\phi \rightarrow Invisible[\chi^0\chi^0]$ Results

The Tevatron does not study this channel.

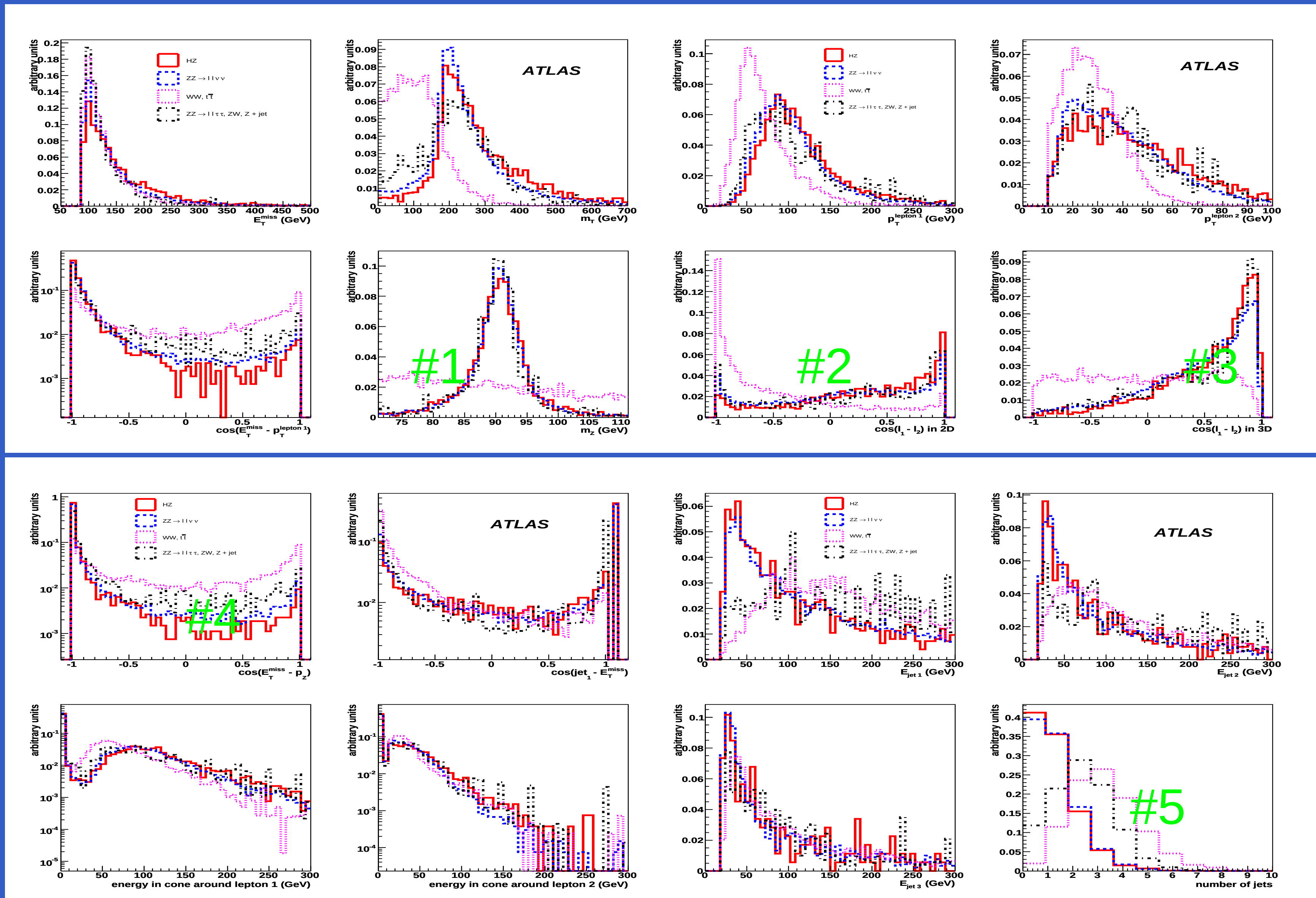


VBF signal events (mH = 130 GeV) and backgrounds: $\eta_1 \times \eta_2$ (left) and $\eta_1 - \eta_2$ (right).



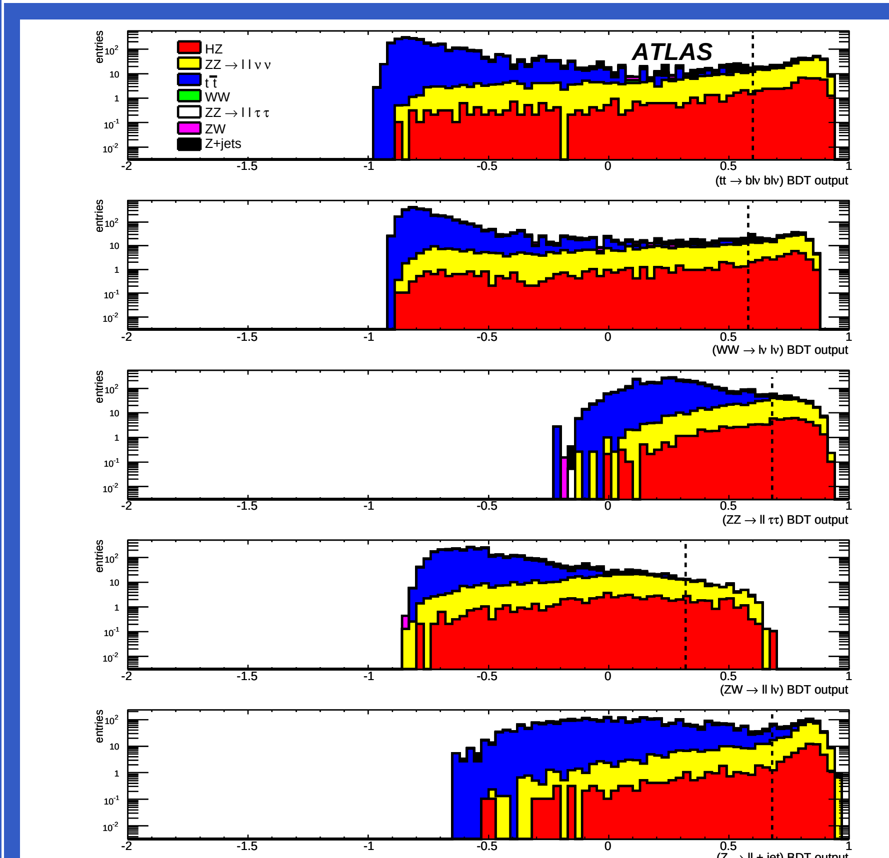
The distribution of the reconstructed E_T^{miss} isolation variable (I) is shown in the right hand plot and the azimuthal angle between the tagging jets is shown in the righthand plot for the invisible Higgs boson signal (m=130GeV) and the three main backgrounds.

MSSM Neutral Higgs: AP $\phi \to Invisible[\chi^0\chi^0]$ Results

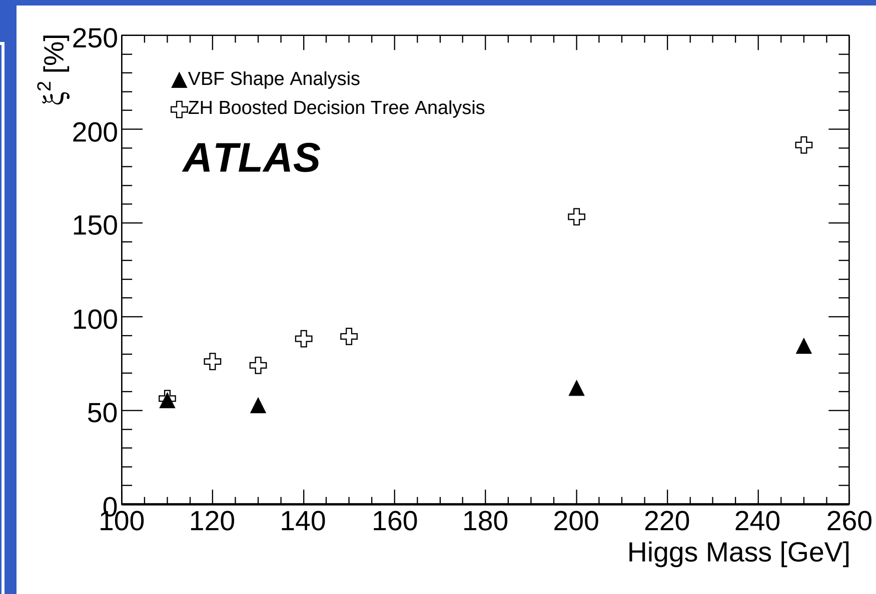


Associated production ZH with $H \to Invisible$. Input variables used by the Boosted Decision Tree for the signal with mH = 130 GeV and the main backgrounds. Numbers are BDT rank for discriminatory power.

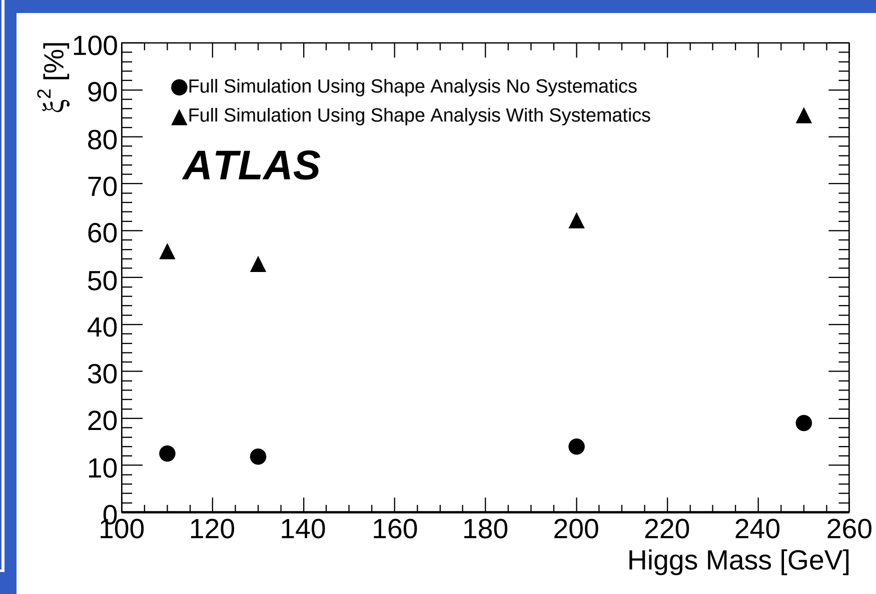
MSSM Neutral Higgs: $\phi \to Invisible[\chi^0\chi^0]$ 30 fb^{-1} Sensitivi



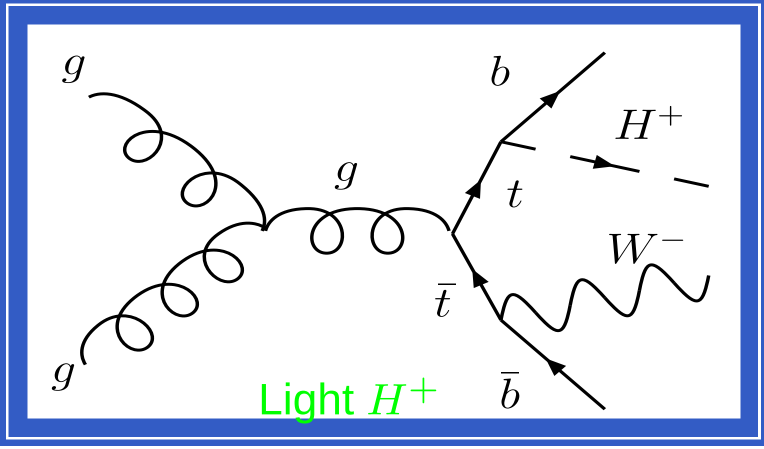
The Boosted Decision Tree (BDT) output variables obtained after comparing half the signal events to five different backgrounds separately, namely, from top to bottom: tt->blnublnu, WW->lnulnu, ZZ->llnunu, ZW->lllnu and Z->ll+jets.

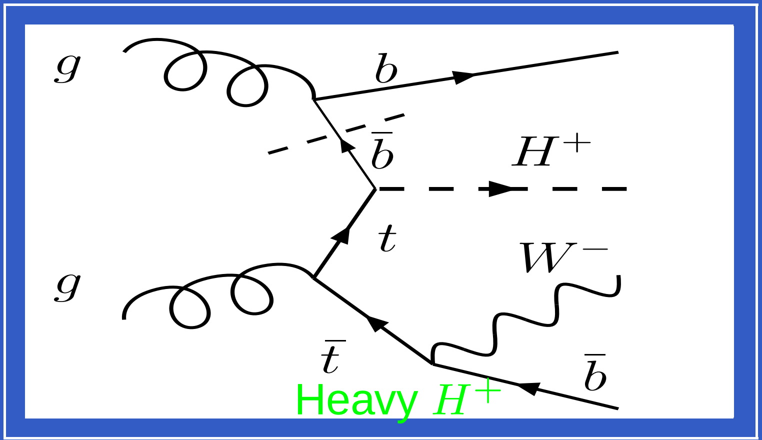


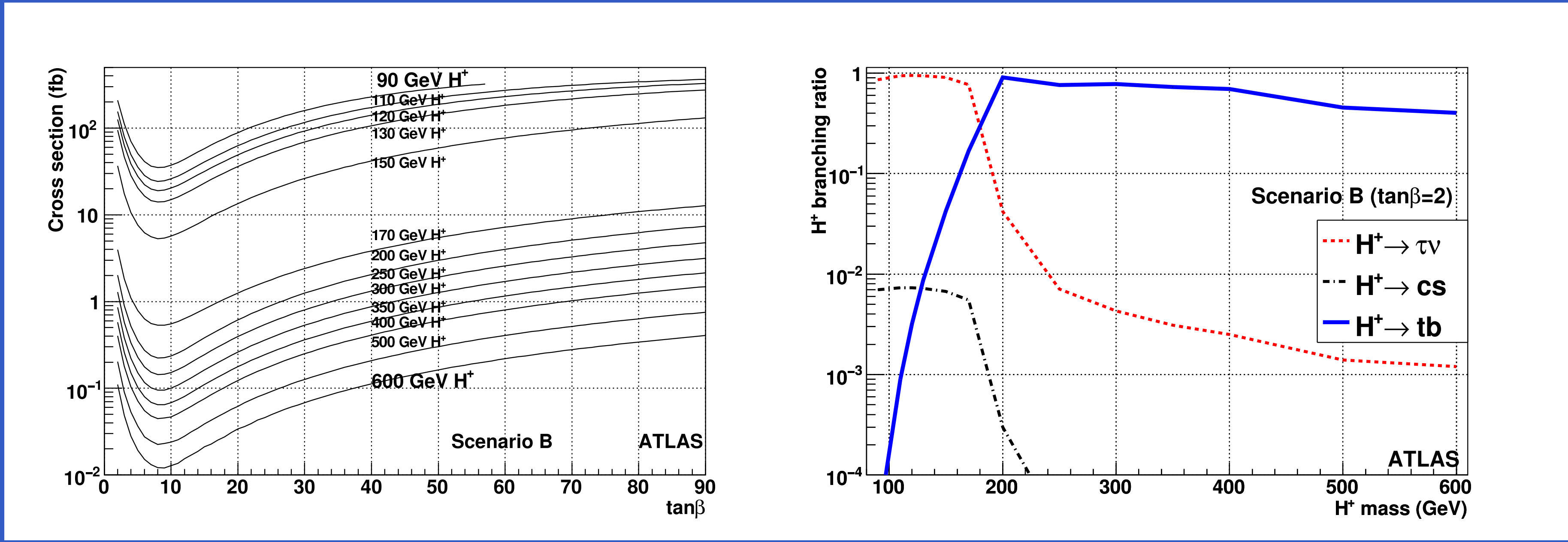
95% C.L. Exclusion



MSSM Charged Higgs H^+ Phenomenology



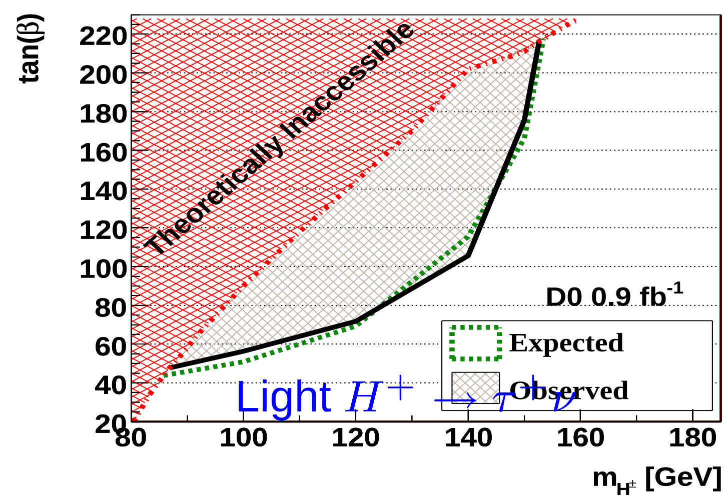


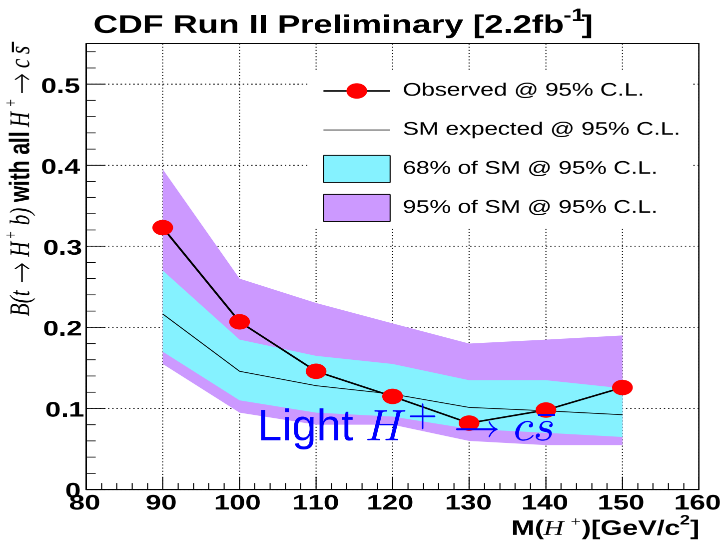


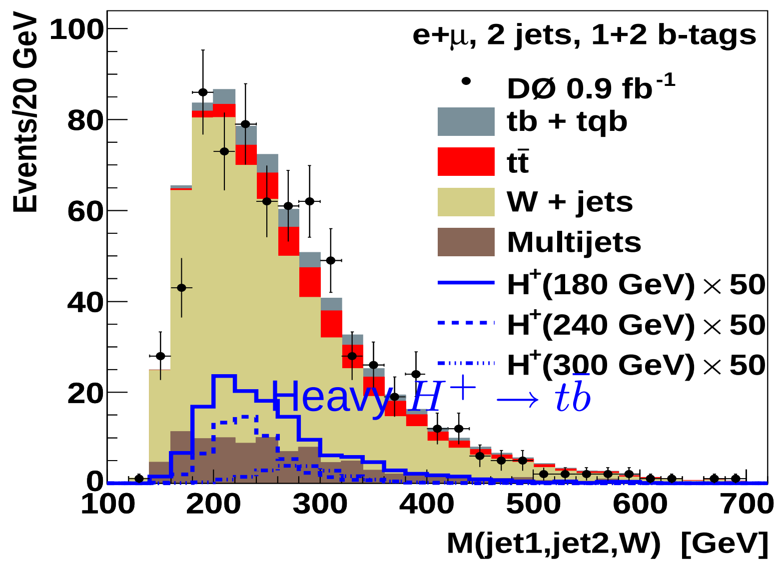
Left: expected charged Higgs boson production cross-section at $\sqrt{s} = 14$ TeV in the MSSM for the mh-max scenario. Right: charged Higgs boson branching ratios as a function of mass for the mh-max scenario for $\tan\beta = 2$ and three selected decay modes.

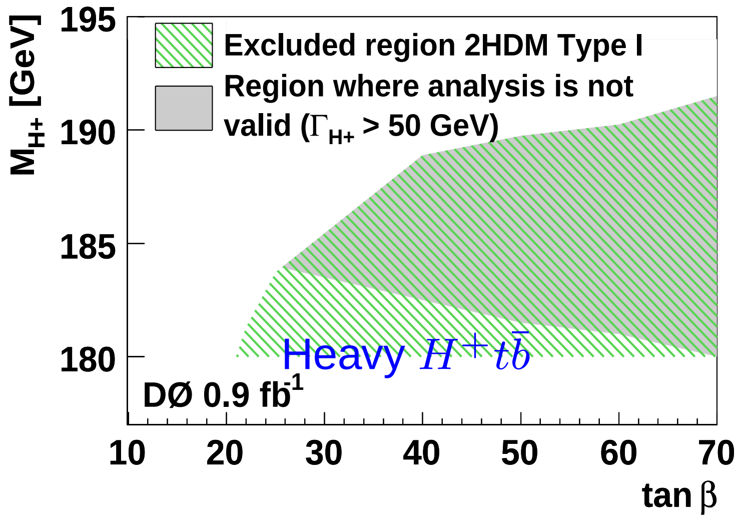
Tevatron Limits on the Charged MSSM Higgs

Phys. Rev. D 80, 051107 (2009) (left) and CDF Conference Note 9322 (right)



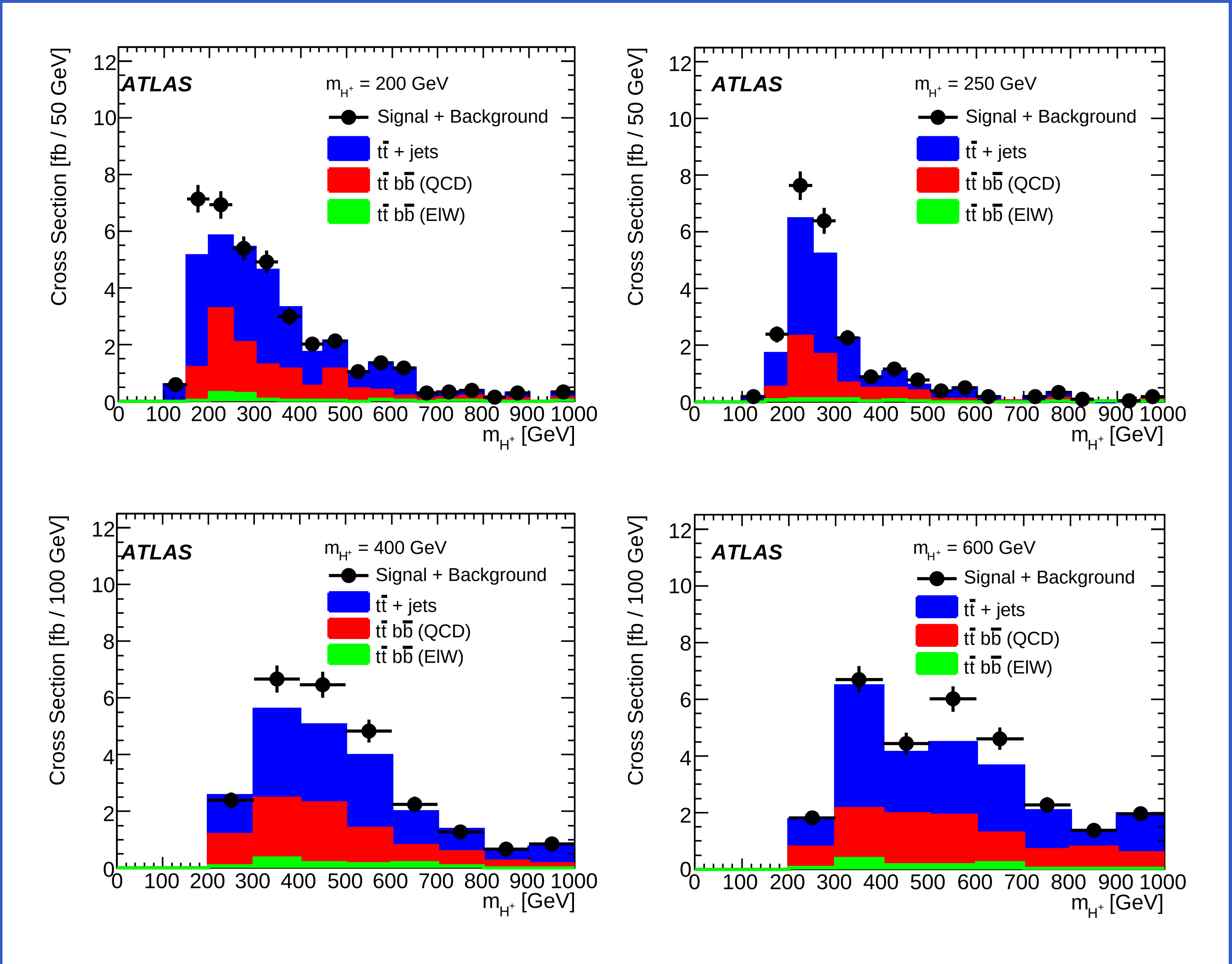






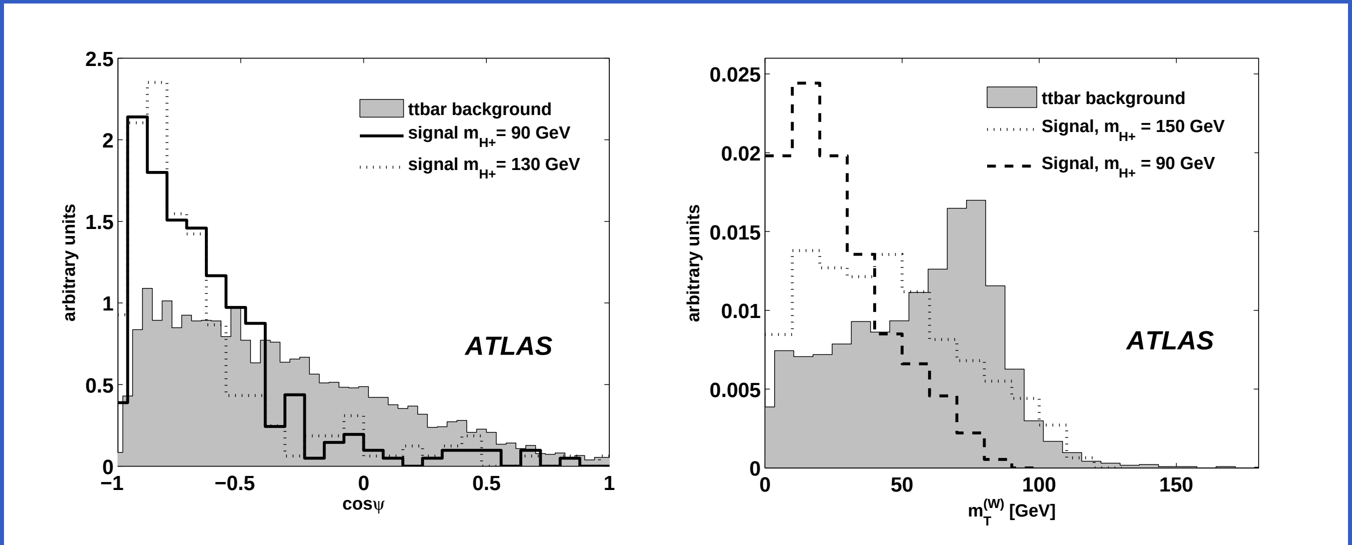
Phys. Rev. Lett. 102 , 191802 (2009).

MSSM Charged Higgs: $H^+ \to t\bar{b}$ Results

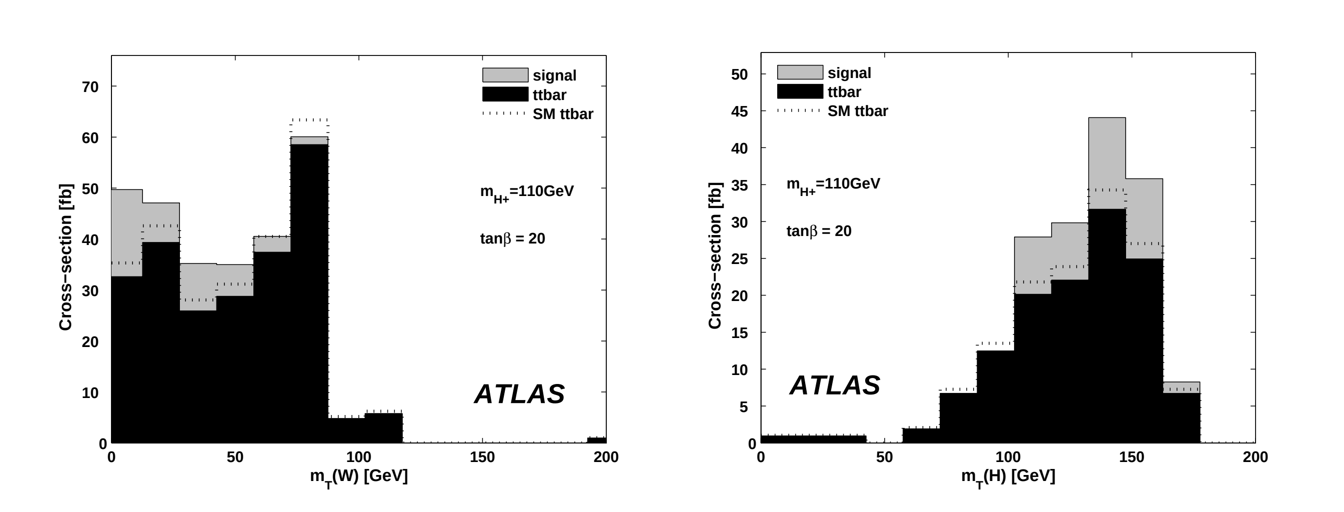


$gg \to tbH^+ \to tbtb \to 4bW_{lep}W_{had}$: Reconstructed H^+ mass. The value of $\tan\beta$ has been chosen such that the pure statistical significance results in a value of 5.

MSSM Charged Higgs: $H^+ \to \tau^+\nu$ Results

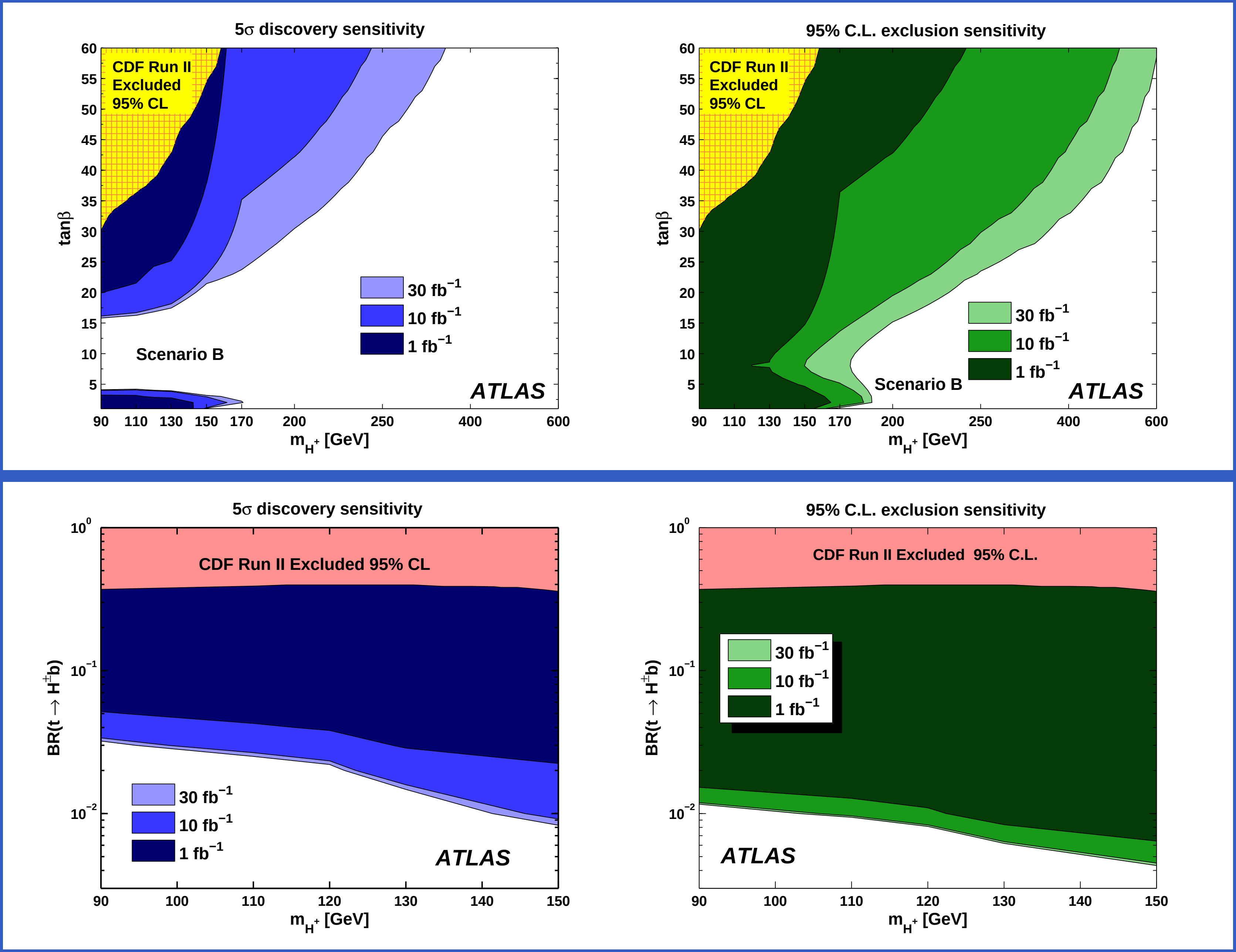


$t\bar{t} \to bH^+bW^- \to b\tau_{lep}\nu bqq'$: (a) $\cos\theta^\star$ distribution, (b) W transverse mass distribution, for signal and background, after selection cuts.



$t\bar{t} \to bH^+bW^- \to b\tau_{lep}\nu bqq'$: Transverse mass differential cross-section for signal and background, for $\tan\beta = 20$, and for the hypothesis of (a) W, and (b) H+.

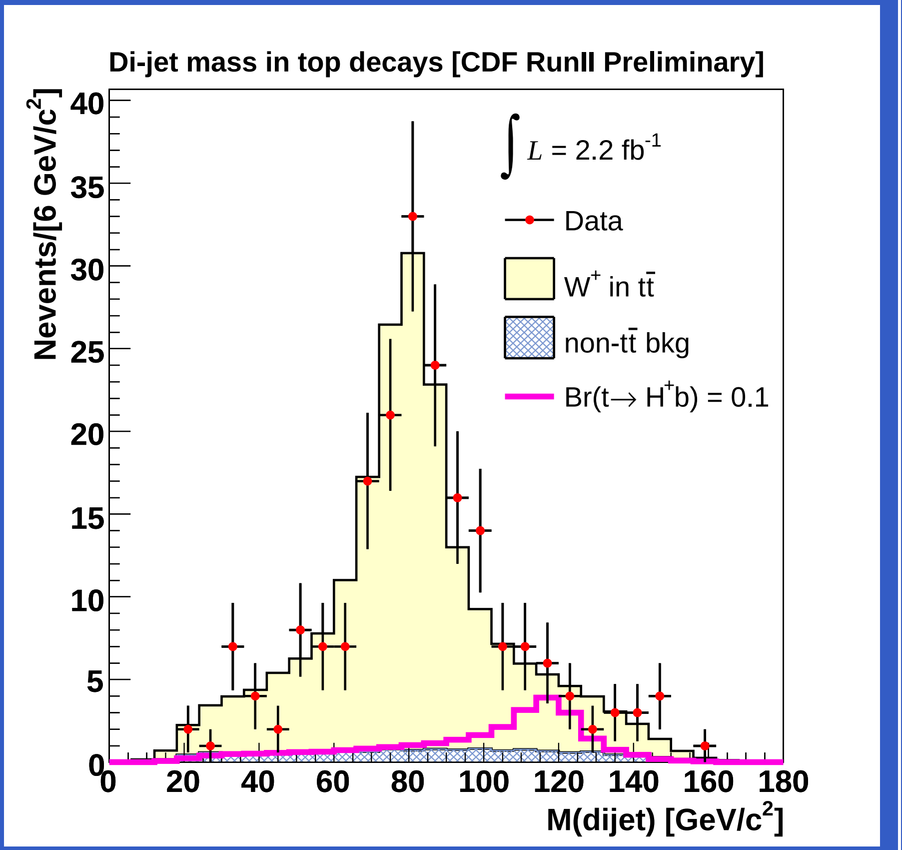
MSSM Charged Higgs: $H^+ \rightarrow \tau^+\nu$ Sensitivity



$H^+ \to \tau^+\nu$ Ongoing Studies: ATL-COM-PHYS-2009-390

$H^+ \to c\bar{s}$ in Semileptonic $t\bar{t}$

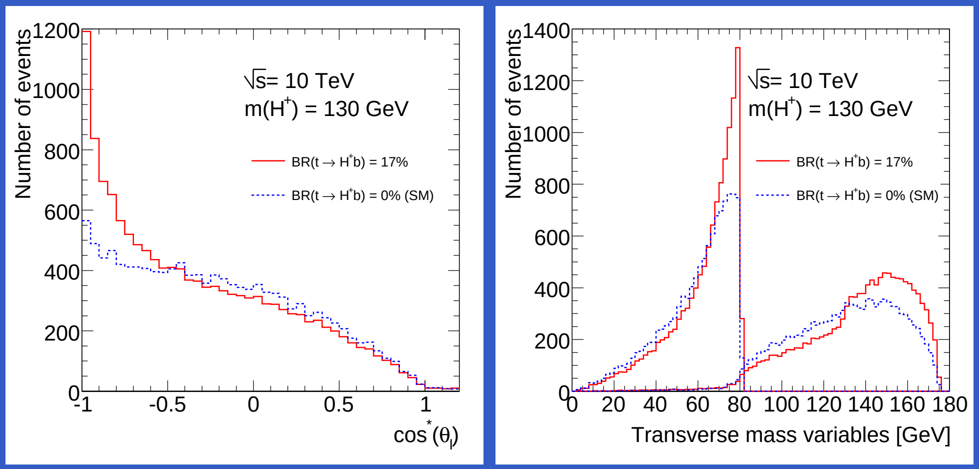
The Manchester group, who were involved in the $H^+ \to c\bar{s}$ search at CDF, have repeated their analysis on ATLAS simulated data.



Di-jet mass distribution with 120 GeV/c2 Higgs events assuming Br($t \to H^+ b$) = 0.1. (See CDF Note 9322).

$H^+ \to \tau_{lep}\nu$ in Dilepton $t\bar{t}$

The Uppsala and McGill groups have performed a search for $H^+ \to \tau_{lep}\nu$ in Dilepton $t\bar{t}$ events. They use the same variables used by the Weizman group for $H^+ \to \tau_{lep}\nu$ in Semileptonic $t\bar{t}$ events.

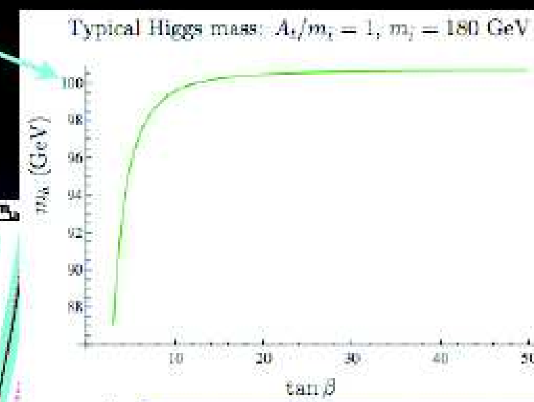


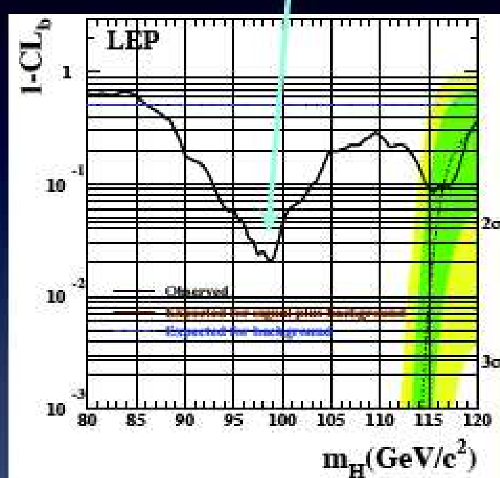
At left, the helicity angle calculated at the event generator level for signal events ($m_{H^+} = 130$ GeV) and background (blue). At right, the generalized transverse invariant mass for signal events ($m_{H^+} = 130$ GeV) and background (blue). Both $\sqrt{s} = 10$ TeV studies in review at ATLAS - preliminary results competitive with Tevatron.

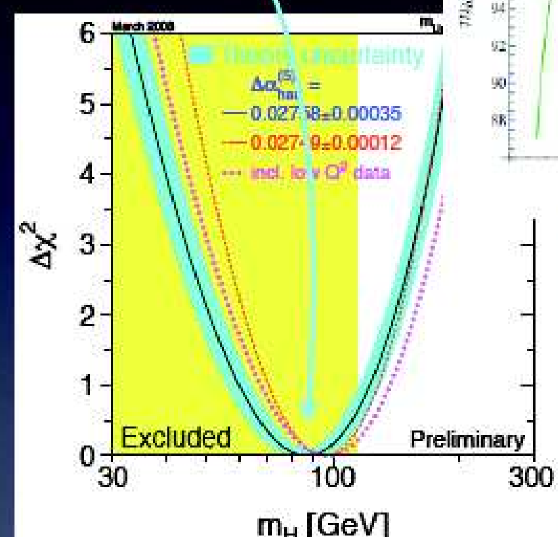
NMSSM: Experimental Motivation

Motivation for modified Higgs decays:

- arise in many models beyond the SM
- allow the SM-like Higgs significantly below LEP limits
  - wanted by generic SUSY/natural EWSB
  - preferred by precision EW data
  - indicated by LEP data

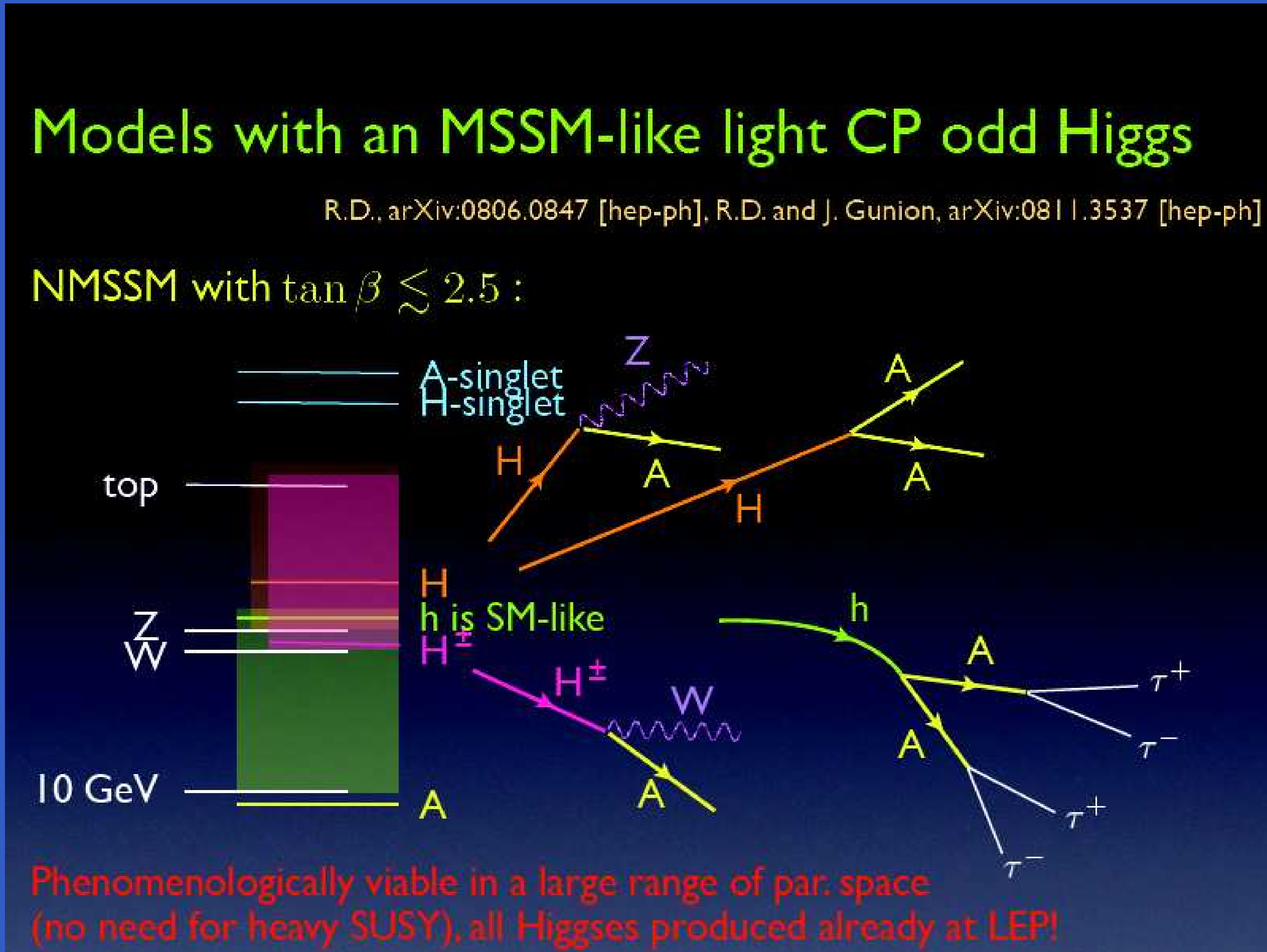






R. Dermisek talk at CERN Theory Group, 20 Aug. 2009.

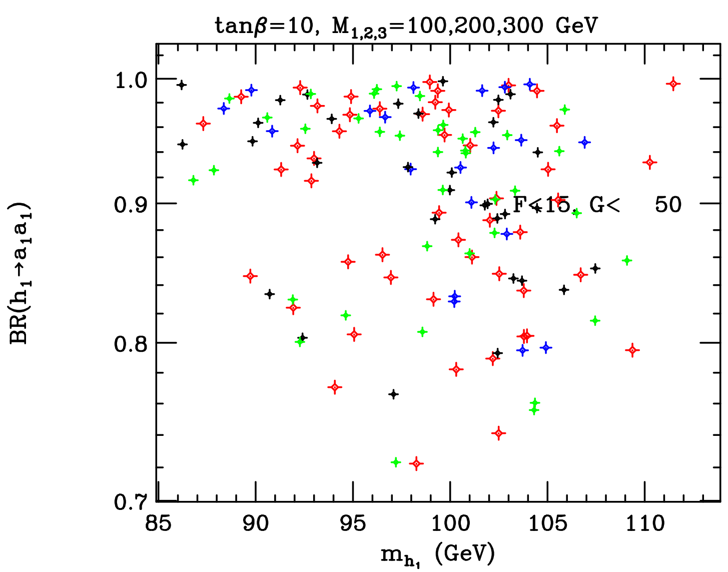
NMSSM: Phenomenology I

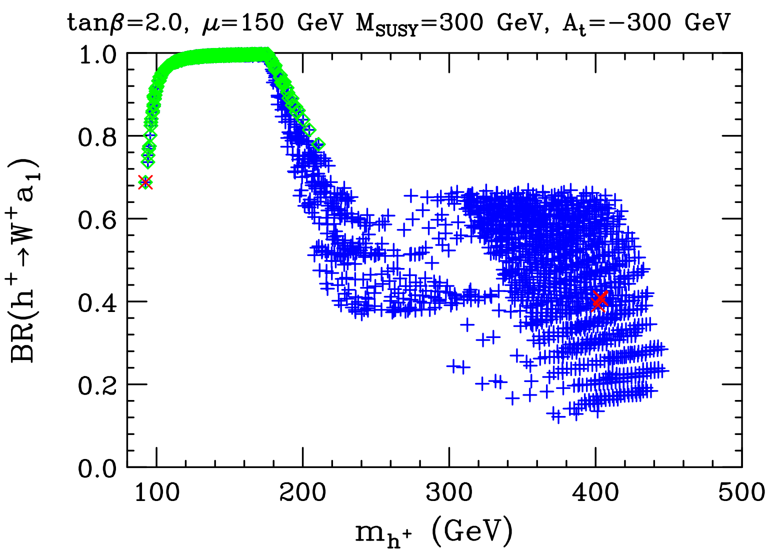


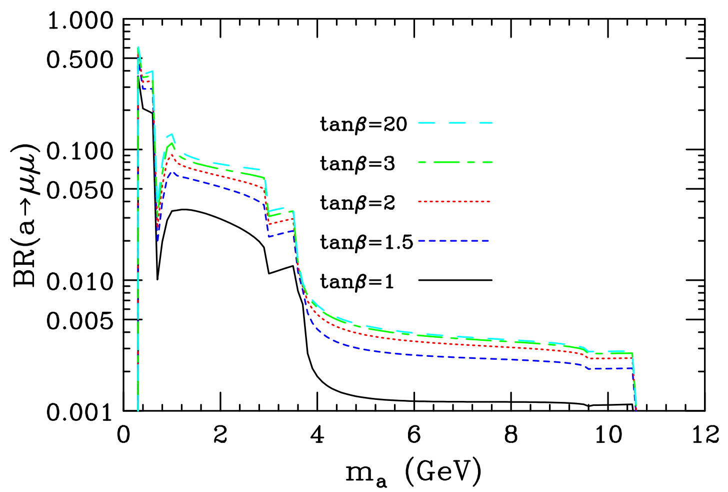
R. Dermisek talk at CERN Theory Group, 20 Aug. 2009.

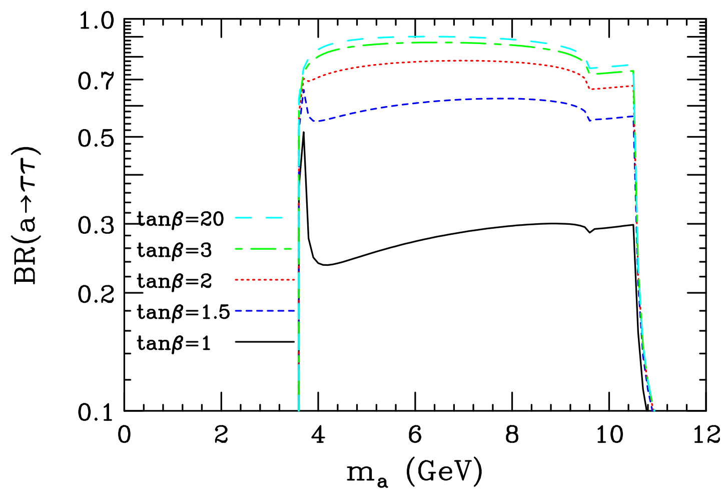
NMSSM Phenomenology II

Branching ratios for $h_1 \to 2a_1$, $H^+ \to a_1 W^+$, $a_1 \to \tau^+\tau^-$ and $a_1 \to \mu^+\mu^-$ versus relevant mass in the Ideal Higgs scenario of the NMSSM (courtesy of J. Gunion and R. Dermisek).

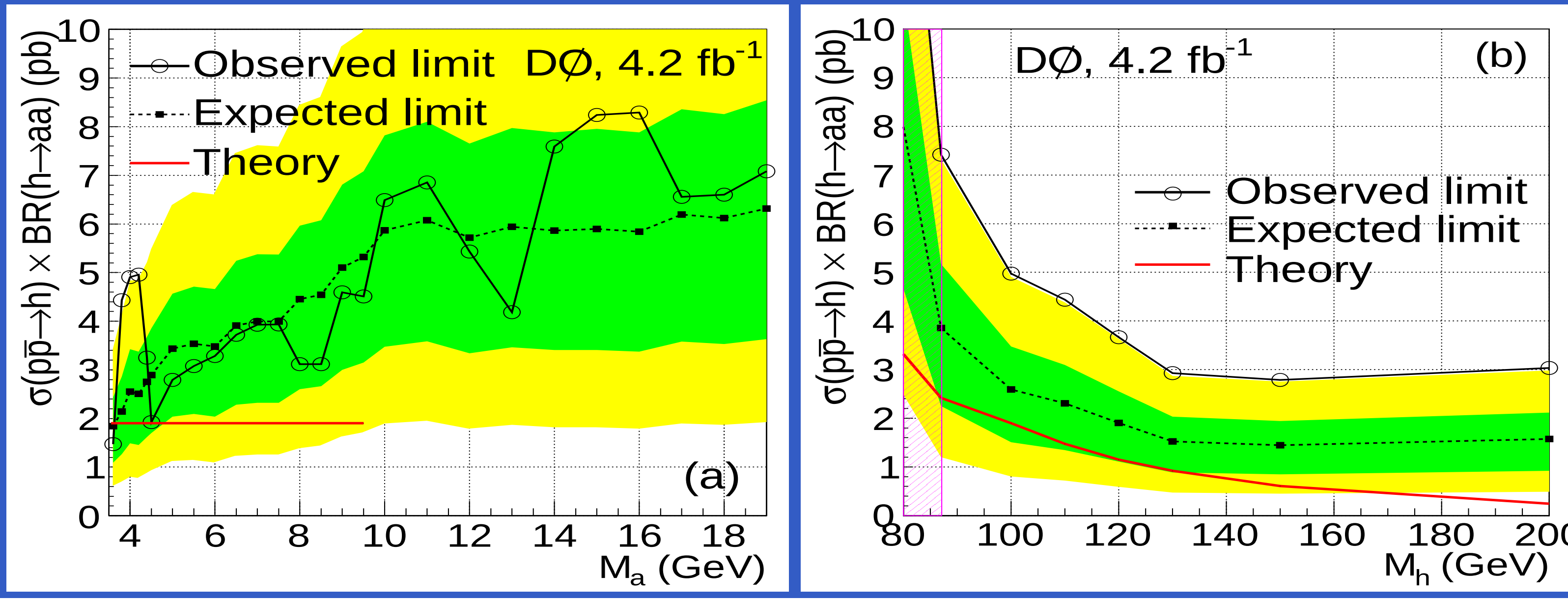


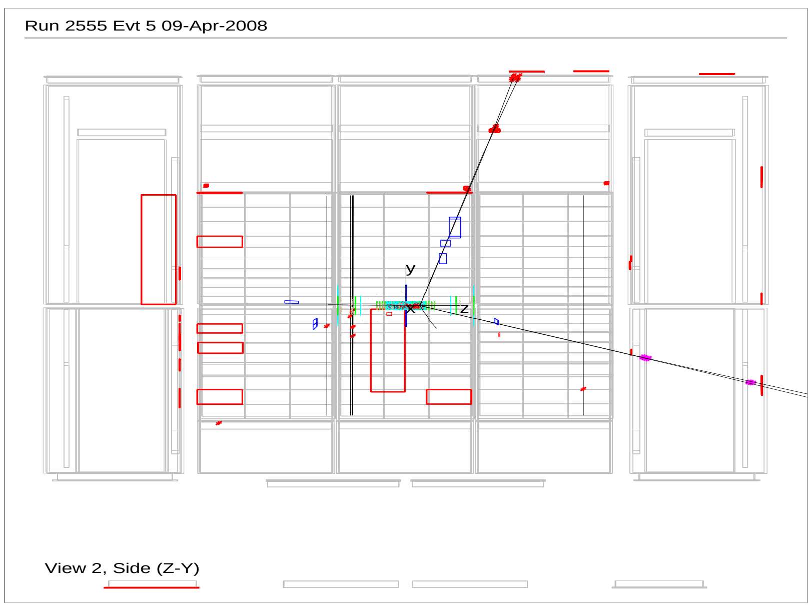


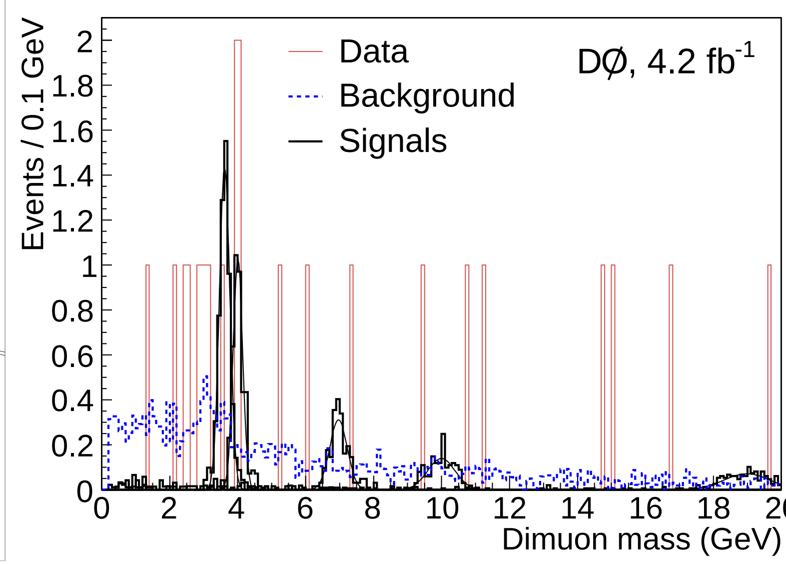




Tevatron Limits on the NMSSM Neutral Higgs

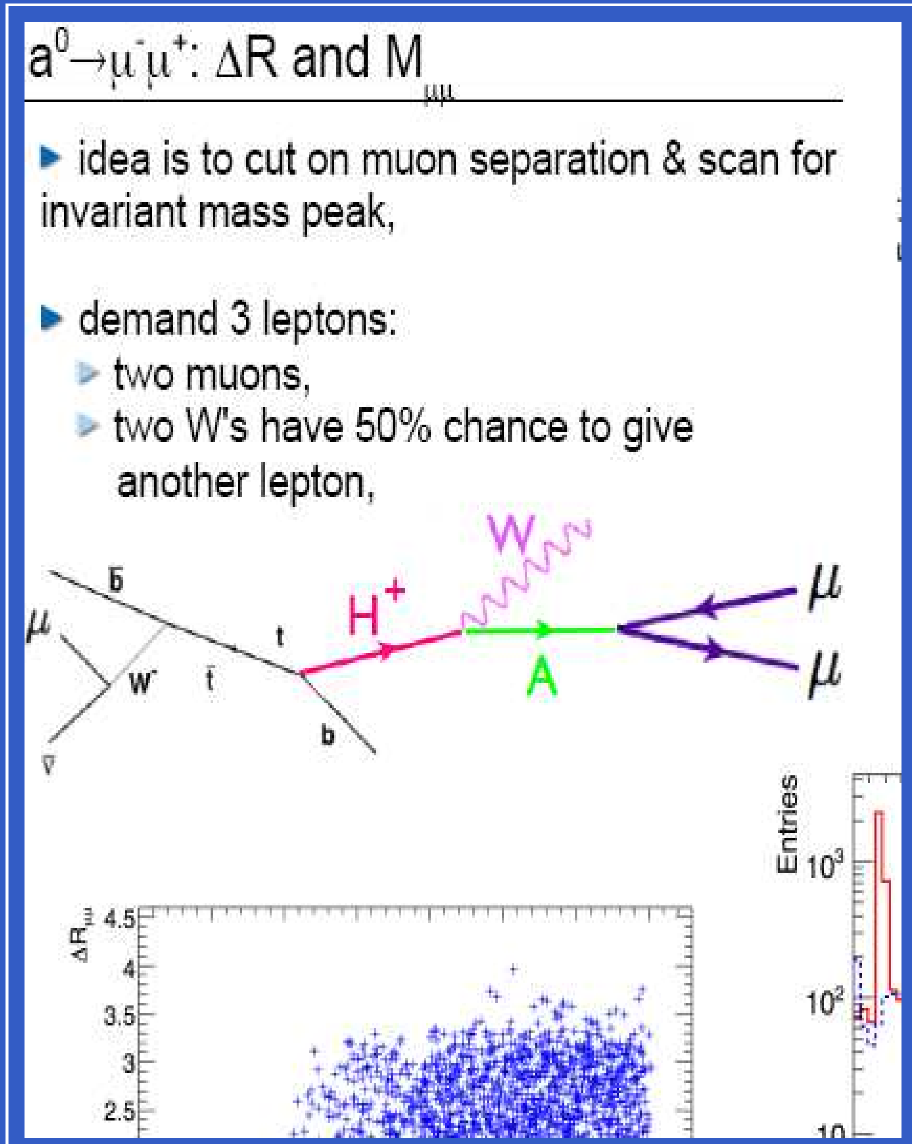


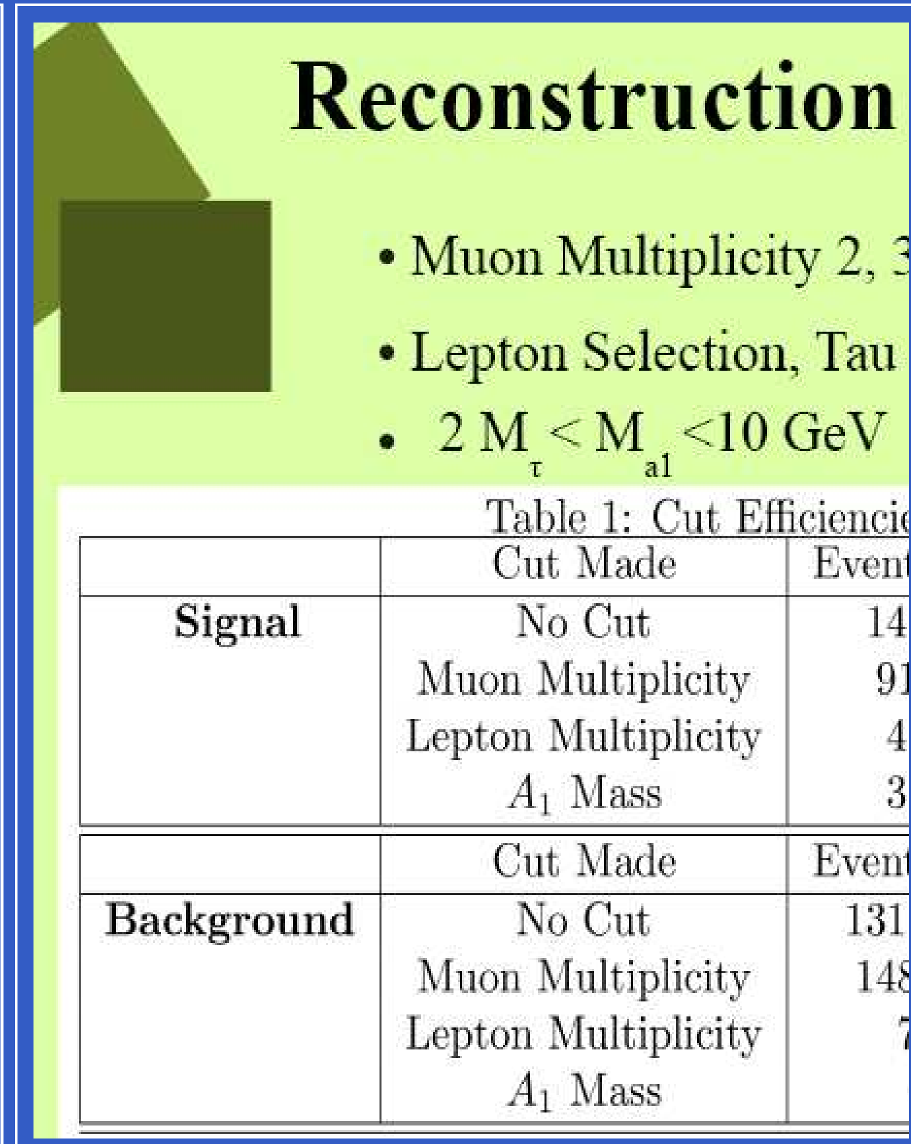




Phys. Rev. Lett. 103 , 061801 (2009)

NMSSM Ongoing Progress: ATL-COM-PHYS-2009-???

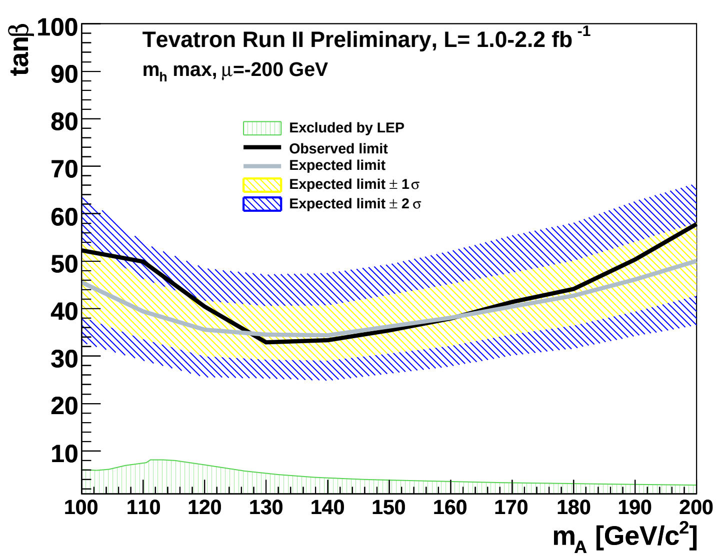


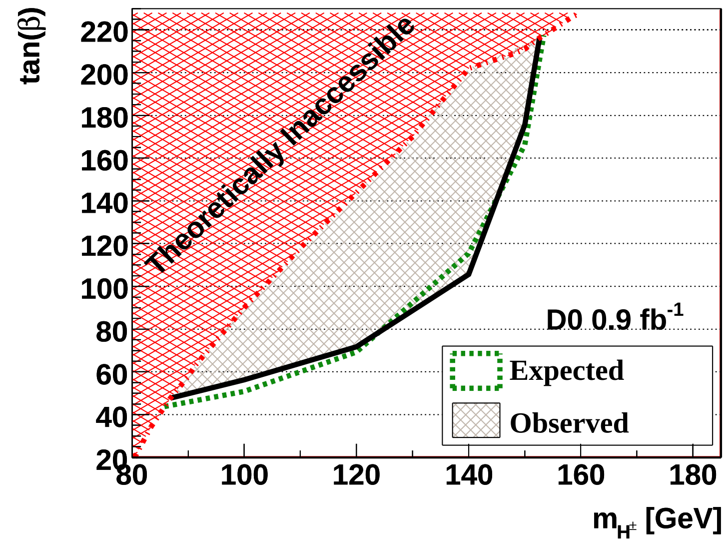


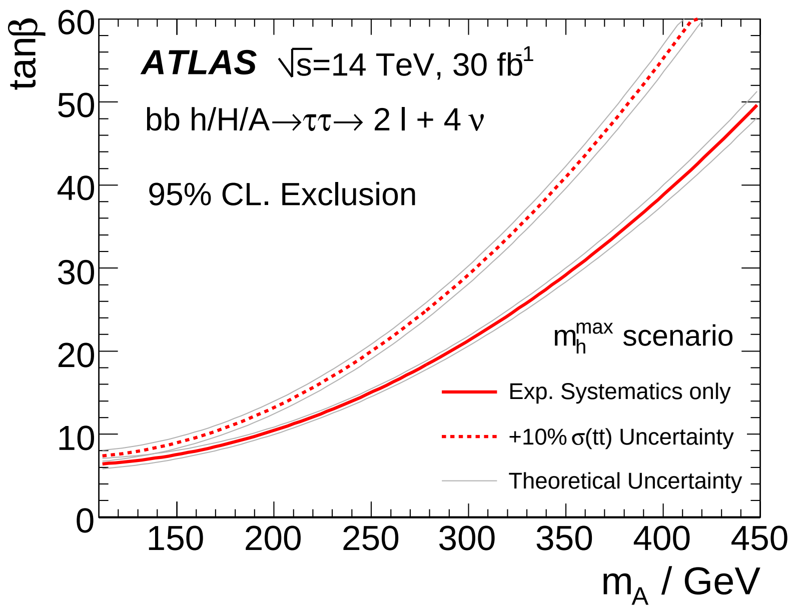
	Cut Made	Event
Signal	No Cut	14
	Muon Multiplicity	91
	Lepton Multiplicity	4
	A_1 Mass	3
	Cut Made	Event
Background	No Cut	131
	Muon Multiplicity	148
	Lepton Multiplicity	7
	A_1 Mass	

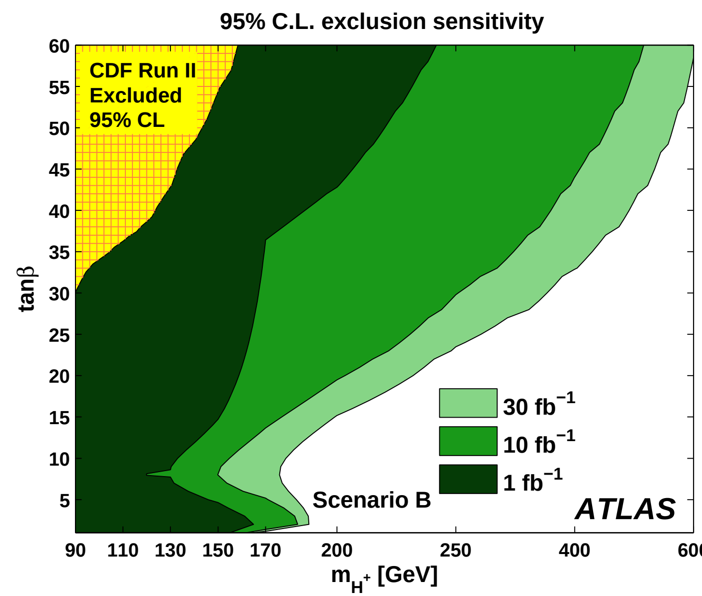
Student works in progress at McGill: Miika Klemetti (left) on $H^+ \to a_1 W^+ \to 2\mu W^+$ and Catherine Laflamme (right) on $h_1 \to 2a_1 \to 2\mu 2\tau$. No public results are yet available.

Conclusion: Recap Tevatron and ATLAS Exclusion



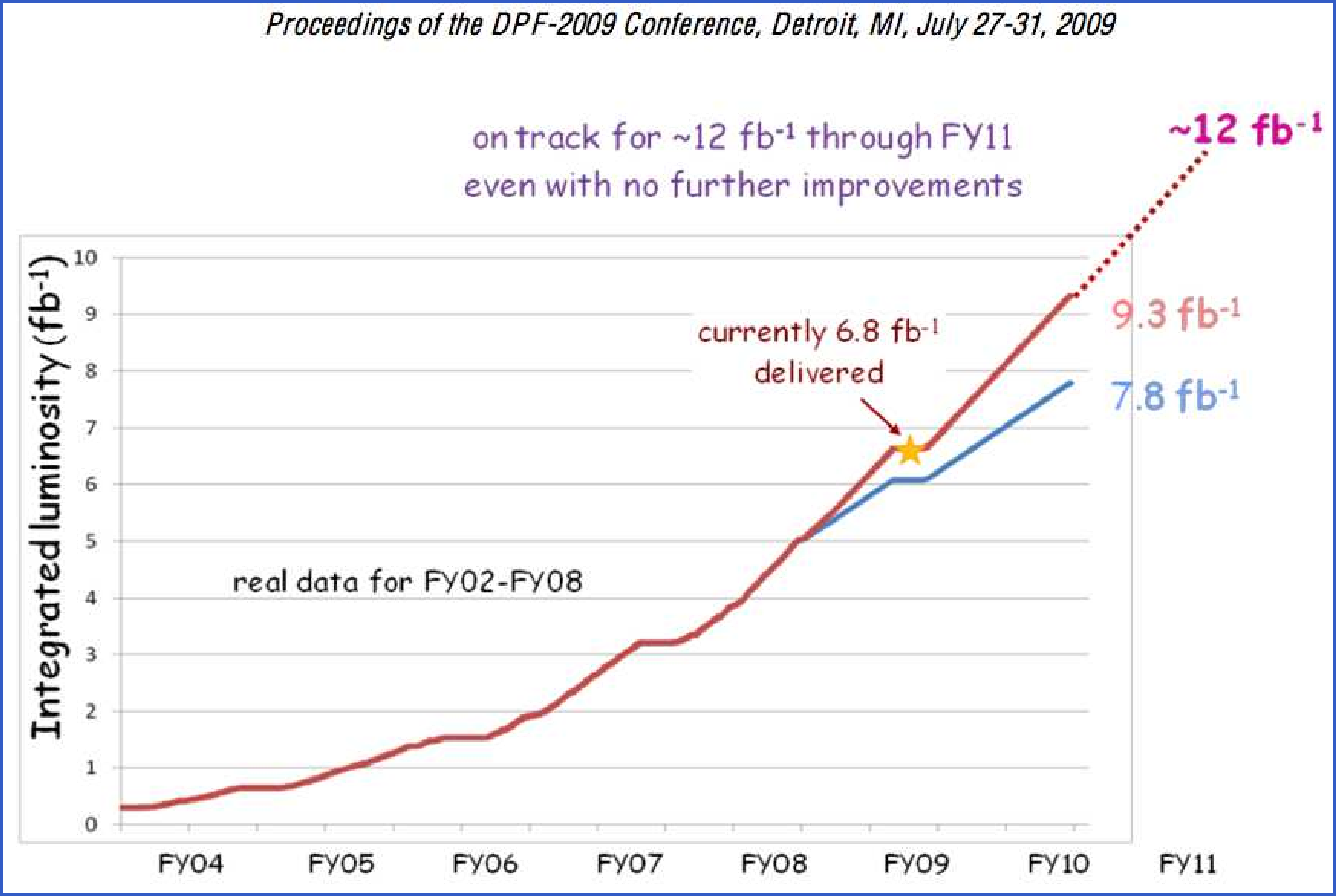






Conclusion: Luminosity Caveat

arXiv:0910.3612



What is the LHC Luminosity profile?

Conclusion: Tevatron and ATLAS Channels

- ATLAS expected sensitivity is competitive with the Tevatron sensitivity, though actual luminosity profiles and bureaucratic throughput will determine actual sensitivity profiles.
- Limited Datasets (6.8 fb^{-1} delivered) at the Tevatron:

Channel	$\int dt\mathcal{L}$
$\phi \to Invisible$	NA
$\phi \to \mu^+\mu^-$	NA
$H^+ \to a_1 W^+$	NA
$H^+ \to \tau^+\nu$	0.9fb^{-1}
$H^+ \to t\bar{b}$	0.9fb^{-1}
$\phi \to \tau^+\tau^-$	1.0-2.2fb^{-1}
$H^+ \to c\bar{s}$	2.2fb^{-1}
$h_1 \to 2a_1$	4.2fb^{-1}

- Search Strategies at ATLAS and Tevatron are strikingly different:
  - $\phi \to \tau^+\tau^-$: ATLAS does not use gg fusion; Tevatron does not use ee, $\mu\mu$.
  - $H^+ \to \tau^+\nu$: ATLAS relies heavily on $\tau_{had}\nu$ with opposite W_{had}.
- A warning to ATLAS: bureaucratic efficiency and search strategies are not optimized.