Report from the Higgs Working Group

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PHYSICS AT THE TERASCALE
Helmholtz Alliance

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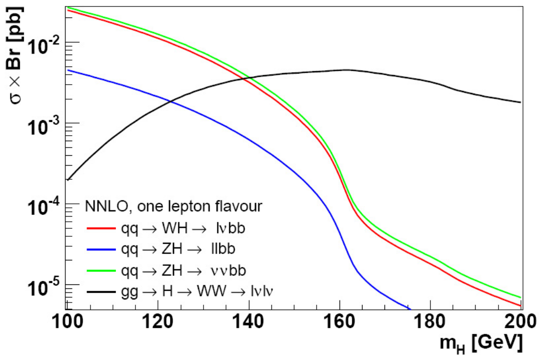
Higgs Searches at the Tevatron

Michiel Sanders



Low m_H: $(W,Z)H$ with $H \to b\bar{b}$

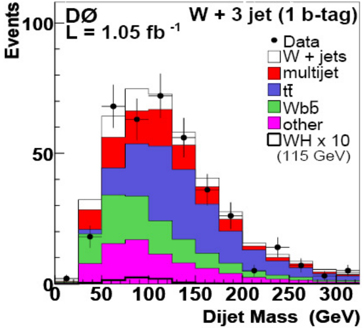
- Signal: high-p$_T$ leptons, (E_T^{miss}), at least 2 (b-)jets
- Backgrounds: $W/Z + jets$, $t\bar{t}$, single top, multijet, dibosons.
- Using neural network and boosted decision trees to increase the sensitivity.

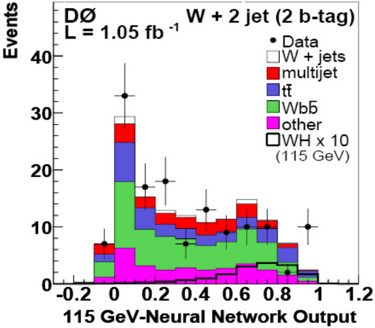
High m_H: $gg \to H$ with $H \to WW$

- Signal: $e^+e^-, \mu^+\mu^-, e^{\pm}\mu^{\mp}$, E_T^{miss}
- Backgrounds: dibosons, $t\bar{t}$, DY dilepton, W+jets.
- Spin correlations for the background suppression ($\Delta\phi_{\ell\ell}$). Use of neural network analysis.

Higgs at the Tevatron: Search Results

Michiel Sanders

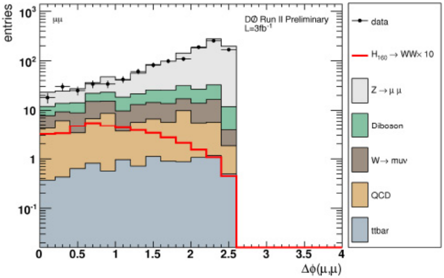


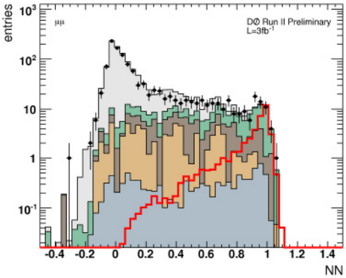


$WH \to \ell\nu b\bar{b}$

$m_H = 115$ GeV:

NN gives 15% improvement in the sensitivity.





$H \to WW \to \ell\nu\ell\nu$

$m_H = 160$ GeV:

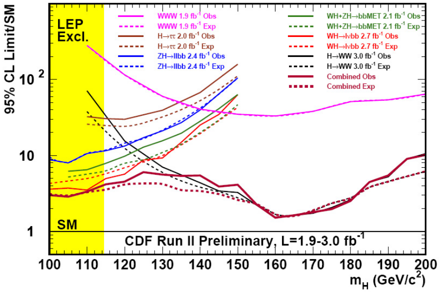
NN gives better separation than $\Delta\phi$.

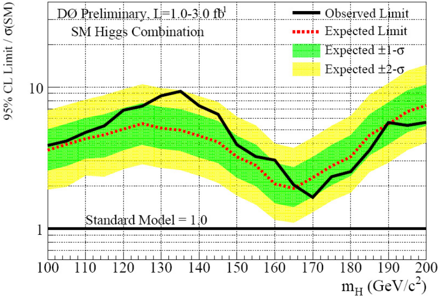
Tevatron: Combined Results, July 2008

Michiel Sanders

Combine all search channels:

at m_H=115 GeV: 4.2 x SM (CDF), 5.3 x SM (D0)

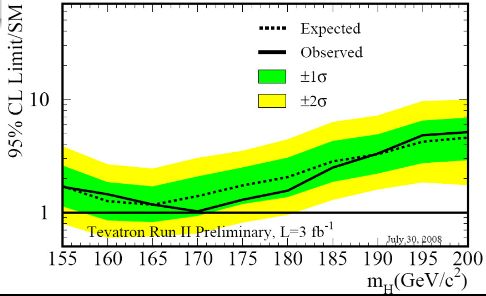




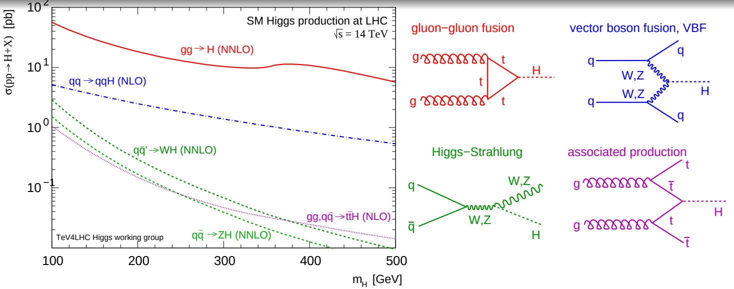
Tevatron Combination

For $H \to WW, WH \to WWW$:

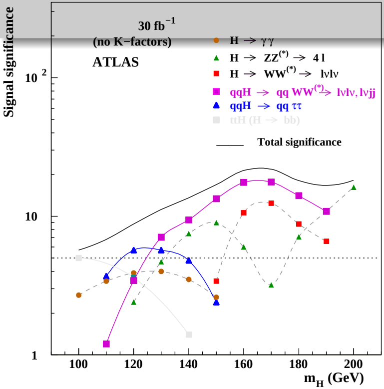
- 170 GeV excluded at 95% CL!
- Publication(s) soon;
  low-m_H combination in winter.



SM Higgs Boson at the LHC



Higgs discovery potential:

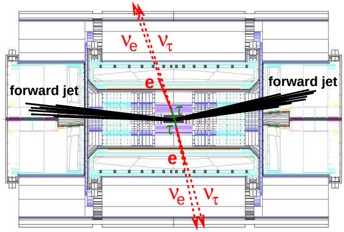


In addition to the gluon fusion (for the $H \to ZZ, H \to WW$ searches),

there is important contribution from the vector boson fusion: $VBF\ H \to \tau\tau$, $VBF\ H \to WW$ channels.

Central jets in the VBF Higgs Process

Christoph Hackstein

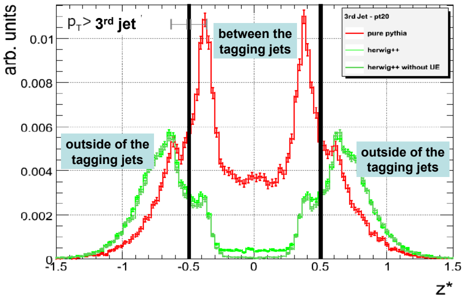


VBF topology:

- Higgs decay products in central region.
- Two forward jets.
- Large rapidity gap (no central jets):
  it is important to investigate this gap after the parton shower, hadronization and underlying event.

The gap is strongly model dependent ⇒ comparing different generators.

VBFNLO w. Herwig++ showering, Pythia w. Pythia showering



⇒ Significant difference between Herwig++ and Pythia, originating from the parton shower.

From the parton shower one expects mostly emission in forward region.

Under investigation, collision data may be giving us the only answer.

SUSY corrections to VBF Higgs production

Michael Rauch

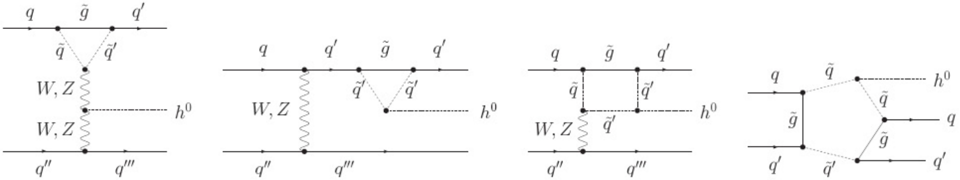
VBF Higgs production cross-section:

SM NLO corrections are fully known, O(α_s) ~5-10%, O(α) ~5%.

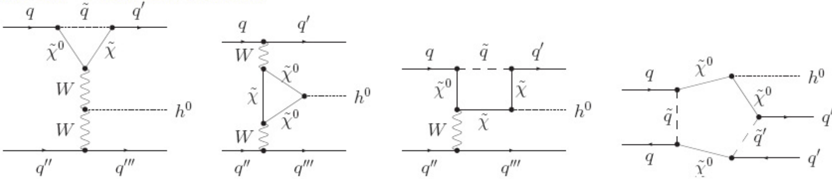
- Replace the SM Higgs boson with the SM-like MSSM h^0 boson.
- Therefore, change total cross-section as $\sigma^{MSSM} = \sigma^{SM} \cdot \sin(\beta-\alpha)^2$.
- $\sin(\beta-\alpha) \approx 1$ for large part of SUSY parameter space.

* However, additional loop diagrams with SUSY particles appear:

Strong corrections (only left diagram known so far [Djouadi, Spira]):



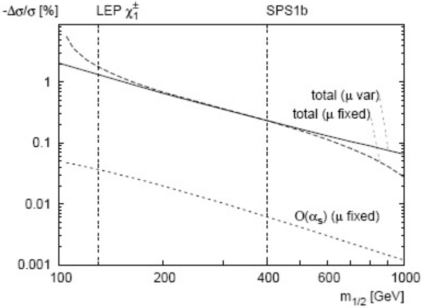
Electro-weak corrections:



SUSY corrections to VBF: Results

Michael Rauch

(SPS: Set of reference points which probe "typical" parts of the supersymmetric parameter space)



$\Delta\sigma/\sigma$ [%]

	WWh $+ZZh$	$\mathcal{O}(\alpha)$	$\mathcal{O}(\alpha_s)$	all
SPS1a	-0.329	-0.469	-0.015	-0.484
SPS1b	-0.162	-0.229	-0.006	-0.235
SPS2	-0.147	0.129	-0.002	-0.131
SPS3	-0.146	-0.216	-0.006	-0.222
SPS4	-0.258	-0.355	-0.008	-0.363
SPS5	-0.606	-0.912	-0.010	-0.922
SPS6	-0.226	-0.309	-0.010	-0.319
SPS7	-0.206	-0.317	-0.006	-0.323
SPS8	-0.157	-0.206	-0.004	-0.210
SPS9	-0.094	-0.071	-0.003	-0.074

$\Rightarrow$ Strong corrections heavily suppressed

$\Rightarrow$ Typical corrections at or below 1%

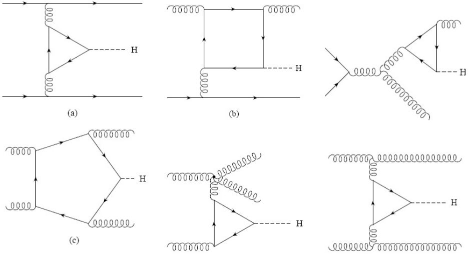
$\Rightarrow$ Can reach up to 4% for parameter points still allowed

$\Rightarrow$ Need to be considered for a precision analysis of the Higgs sector

SUSY contributions to $gg \to H + 2jets$

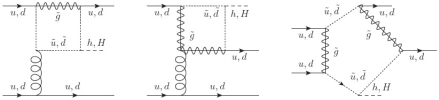
Michael Kubocz

As a background for the VBF Higgs searches:



a) $qq \to qqH$; b) $qg \to qgH$; c) $gg \to ggH$

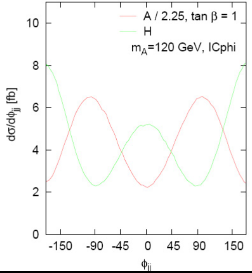
- squark-gluino vertices allow box and pentagon diagrams also for quark-scattering

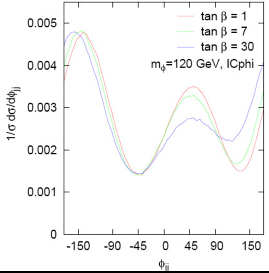


Full one-loop calculations are available for quark-loop induced Hjj production, squark-loop contributions also consdered.

As a signal:

Azimuthal angle ϕ_{jj} between the tagging jets may provide information on CP-violation.

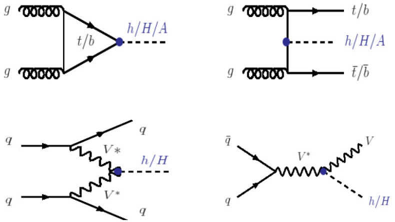


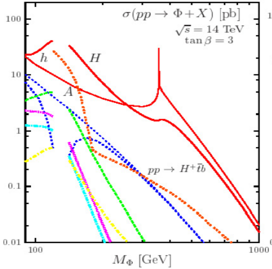


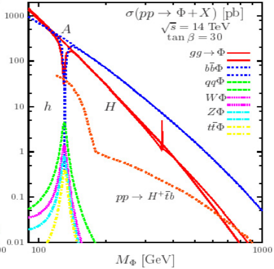
MSSM Higgs Bosons

Two Higgs doublets $\Rightarrow$ 5 Higgs bosons:

h^0, H^0: light and heavy CP-even neutral Higgs boson
A^0: CP-odd neutral Higgs boson
$H^{\pm}$: charged Higgs boson







- h and H production is very similar to the SM case.
- A-boson has no tree-level couplings to vector bosons $\Rightarrow$ two dominant production modes are gluon fusion and associated $b\bar{b}A$.
  - Importance of bottom loops to the gluon-Higgs coupling increases with $\tan\beta$, so higher order calculations are much more difficult. Additional contributions may come from top and botom squarks.
  - For large $\tan\beta$ values, the $b\bar{b}A/H/h$ production is enhanced.

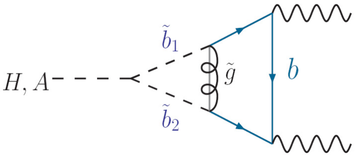
SUSY QCD corrections for neutral MSSM Higgs

Franziska Hofmann

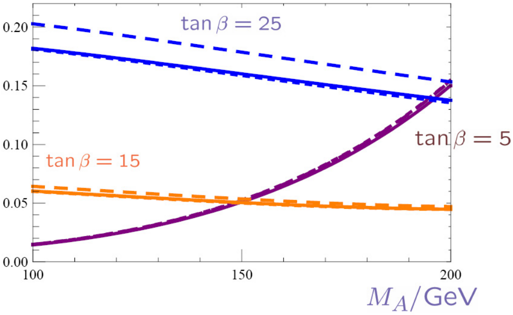
The contribution of stop and bottom quarks to the $gg \to A$ production is closely related to the calculation $A^0 \to \gamma\gamma$ decays, since the calculations are done in a similar fashion.

$A \to \gamma\gamma$ decay width ($\Gamma \cdot 10^{-6}$/GeV)

Including bottom-sbottom contributions, in addition to previous top-stop.



NLO: QCD.vs.QCD+Stops.vs.SQCD

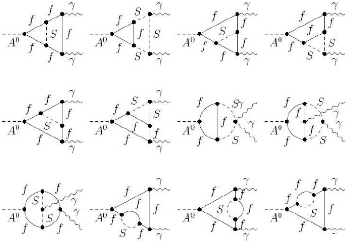


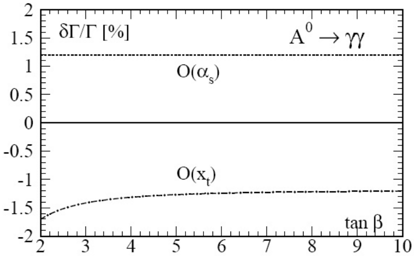
$\Rightarrow$ Bottom-Sbottom contributions become important for large $\tan\beta$.

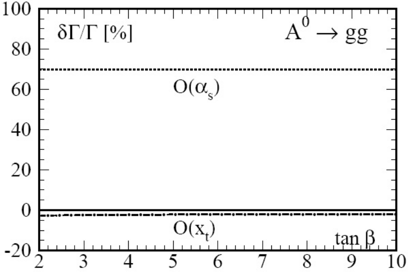
SUSY EW corrections for neutral MSSM Higgs

Joachim Brod

Electroweak corrections for $\Gamma(A^0 \to \gamma\gamma)$ and $\Gamma(A^0 \to gg)$.







$A^0 \to \gamma\gamma$: corr. of the same size and opposite sign as QCD corrections.
$A^0 \to gg$: corrections are small.

b-associated MSSM Higgs production

Markus Warsinsky

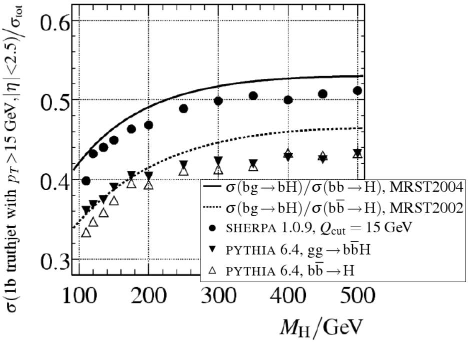
Two approaches to calculate production cross-section at NLO:

- $gg \to b\bar{b}H$: reliable for high-p_T^b, collinear logs for low-p_T^b
- $gb \to bH$, $bb \to H$: move one or both gluon splitings to a b-pdf.

Typical Higgs search requires *exactly* 0 or *at least* 1 b-jet in final state

$\Rightarrow$ need all mentioned approaches, but cannot simply add them.

Can our generators describe well the proportion of different event topologies (with 0, 1,and 2 high-p_T b-jets)?



- Sherpa agrees better with the prediction from MRST2004 pdf
- Pythia agrees better with the prediction from MRST2002 pdf
- Observed differences of up to 20% have been used as an estimate of the systematic signal uncertainty in recent ATLAS analyses.

Neutral MSSM Higgs Searches at the LHC

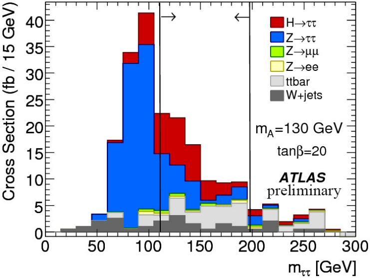
Jana Schaarschmidt, Markus Warsinsky

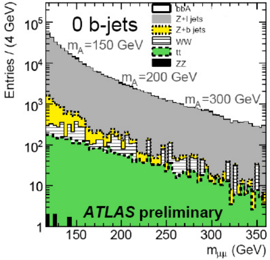
$A/H/h \to \tau\tau \to 2\ell 4\nu$

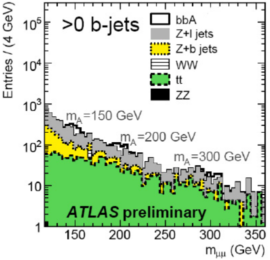
- $m_{\tau^+\tau^-}$ reconstruction by means of collin. approximation (resolution 20-50%).
- Backgrounds:
  $Z + jets$, $t\bar{t}$, $W + jets$
- Event selection:
  leptons, E_T^{miss}, $\geq 1b - tag$

$A/H/h \to \mu\mu$

- Excellent $m_{\mu\mu}$ mass-resolution (resolution 2-8%).
- Backgrounds: $Z + jets$, $t\bar{t}$
- Event selection:
  muons, no E_T^{miss} and
  a) $= 0b - tag$ or
  b) $\geq 1b - tag$.
  Combine (a) and (b).





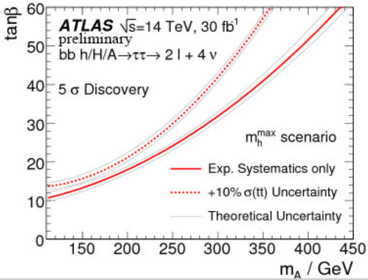


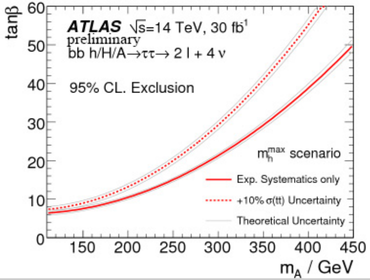
Background estimation from data is essential!

Neutral MSSM Higgs Searches: Potential

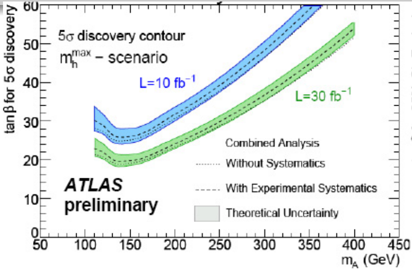
Jana Schaarschmidt, Markus Warsinsky

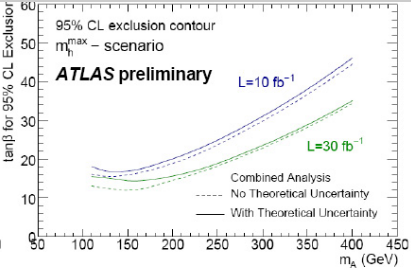
MSSM $A \to \tau\tau \to 2\ell 4\nu$





MSSM $A \to \mu^+\mu^-$



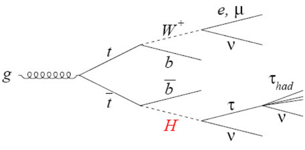


Charged MSSM Higgs Searches

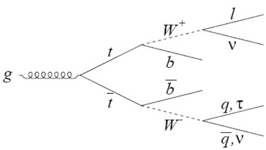
Susanne Mohrdieck-Möck

- Complex final state with $m_{H^\pm} < m_{top}$.
- No full event reconstruction possible (3nu, on both sides.)

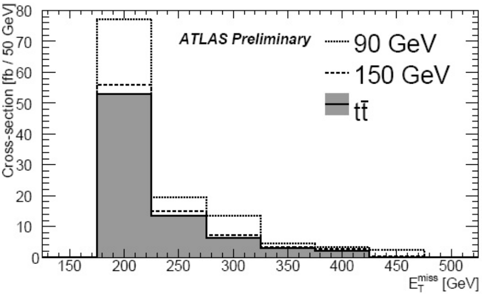
Signal



Main Background ($t\bar{t}$)

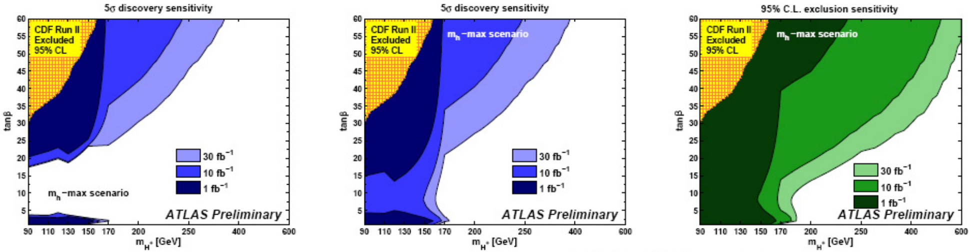


tanβ=20



Susanne Mohrdieck-Möck

- light $H^{\pm}(m_{H^{\pm}} < m_{\text{top}})$:
  - $t\bar{t} \rightarrow (H^{\pm}b)(Wb) \rightarrow (\tau_{\text{had}}\bar{\nu}_{\tau}\nu_{\tau}\ b)(\ell\nu_{\ell}\ b)$
  - $t\bar{t} \rightarrow (H^{\pm}b)(Wb) \rightarrow (\tau_{\text{had}}\bar{\nu}_{\tau}\nu_{\tau}\ b)(qq\ b)$
  - $t\bar{t} \rightarrow (H^{\pm}b)(Wb) \rightarrow (\ell\nu_{\ell}\bar{\nu}_{\tau}\nu_{\tau}\ b)(qq\ b)$
- heavy $H^{\pm}(m_{H^{\pm}} > m_{\text{top}})$:
  - $H^{\pm} \rightarrow tb : gg/gb \rightarrow t[b]H^{\pm} \rightarrow W_{qq}b[b](\ell\nu_{\ell}bb)$
  - $H^{\pm} \rightarrow \tau\nu : gg/gb \rightarrow t[b]H^{\pm} \rightarrow W_{qq}b[b](\tau_{had}\bar{\nu}_{\tau}\nu_{\tau})$

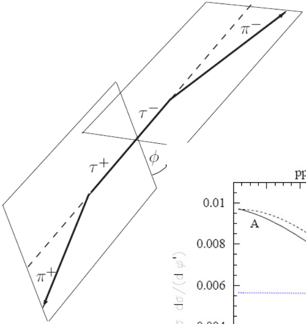


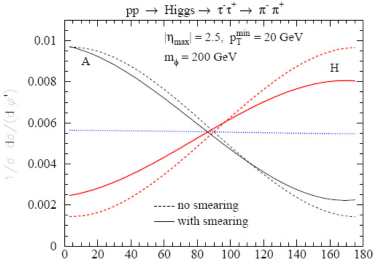
infinite MC statistics

Stefan Berge

$\phi^0 \to \tau^+\tau^- \to \pi^+\pi^- + 2\nu$ carries the information about the CP=± 1 states of the Higgs boson.

Experimantally very challenging analysis!





- Smearing parameters, $l_\tau^{min} = 2$mm:

$\sigma^T_{\hat{\vec{n}}} = 10\,\mu m$

$\sigma^\theta_{\vec{q}_\pi} = 1$ mrad

$\delta E_\pi = 5\%$

$\sigma^{PV}_z = 30\,\mu m$

$\sigma^{PV}_{x,y} = 10\,\mu m$

Oliver Brein

HiggsBounds:

Test theoretical predictions of models with arbitrary Higgs sectors against exclusion bounds obtained from Higgs searches at LEP and the Tevatron.

– basic idea

- Evaluate model prediction Q_{model} for cross section times BR (normalised to a reference value or not) of all search channels X for given Higgs masses and deviations from the SM and compare to experimental limit.

- Depending on the way the exclusion result (table) for a particular search channel (topology) has been published (relative or absolute limit, BR assumed to be 1), we evaluate

$$Q_{\text{model}} = \frac{[\sigma \times \text{BR}]_{\text{model}}}{[\sigma \times \text{BR}]_{\text{ref}}} \quad \text{or} \quad [\sigma \times \text{BR}]_{\text{model}}.$$

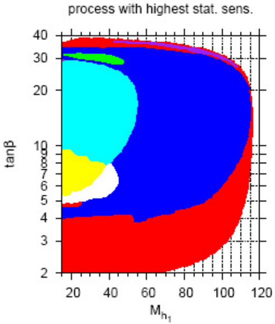
- From the experimental results we read off the value $Q_{\text{observed}}(X)$ corresponding to the observed 95% C.L. limit.

- If $\frac{Q_{\text{model}}(X)}{Q_{\text{observed}}(X)} > 1$ the model is excluded by this channel at 95% C.L.

HiggsBounds: Application for CPX MSSM Higgs

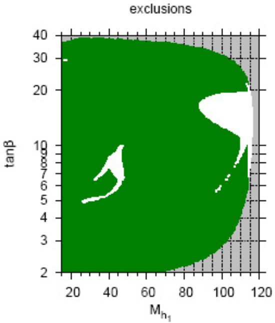
Oliver Brein, Karina Williams

New exclusion plots for the CPX scenario



Channel with the highest statistical sensitivity

- ■ $= h_1 Z \to b\bar{b}Z$
- ■ $= h_2 Z \to b\bar{b}Z$
- □ $= h_2 Z \to h_1 h_1 Z \to b\bar{b}b\bar{b}Z$
- ■ $= h_2 h_1 \to b\bar{b}b\bar{b}$
- ■ $= h_2 h_1 \to h_1 h_1 h_1 \to b\bar{b}b\bar{b}b\bar{b}$
- ■ $= h_3 h_1 \to b\bar{b}b\bar{b}$
- ■ = other channels



Exclusion region at 95 % CL

green = excluded
white = unexcluded

(results for $m_t = 170.9$ GeV are in K.W. and G.Weiglein 2008)

Instead of the Summary

A few open questions:

- Can we improve our understanding of the rapidity gap in the VBF Higgs searches?
- Can we reduce the theoretical uncertainty on the neutral MSSM Higgs production in association with two b-quarks?

And still more things to work on:

- Optimization of the present and development of new methods for the data-driven background estimation.