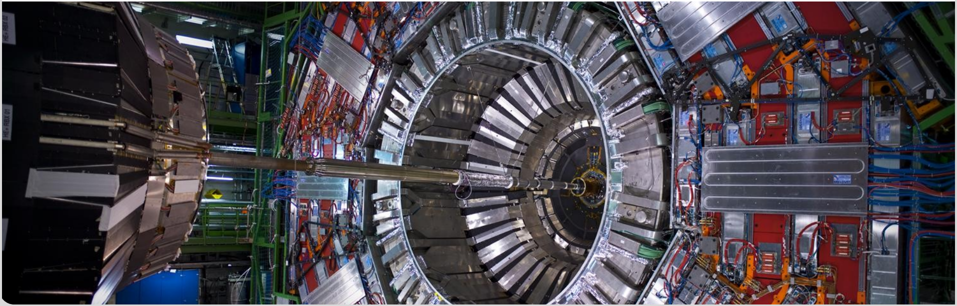
Search for $H \to \tau\tau$ in the Di-Muon Channel

GRK KCETA Workshop 2013, Bad Liebenzell

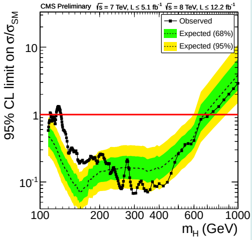
Thomas Müller | October 2nd, 2013

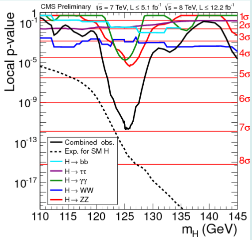
Institut für Experimentelle Kernphysik (IEKP)



Higgs Search at CMS – Recent Results

CMS Higgs combination

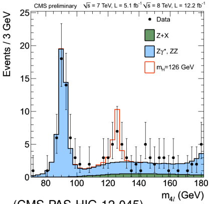




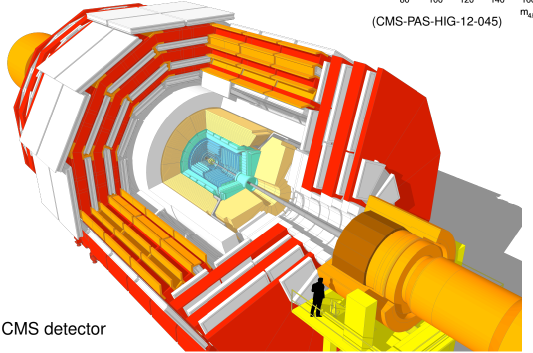
HCP 2012, CMS-PAS-HIG-12-045

- Discovery of a new boson with mass $\sim 125\,\mathrm{GeV}$ at the LHC
- Evidence for decays into gauge bosons ($\gamma\gamma$, ZZ, WW)
- Evidence for decays into fermions ($b\bar{b} + \tau\tau$)
- Decay into leptons not yet established

E.g. $H \to ZZ \to 4l$



(CMS-PAS-HIG-12-045)

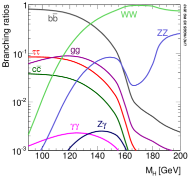


CMS detector

Higgs Bosons Decaying into Tau Pairs

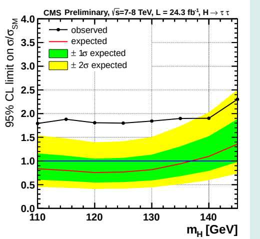
Promising channel to study the fermionic Higgs couplings

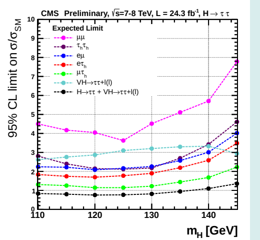
(LHC Higgs Cross Section Working Group)



- Large branching ratio
- Several production mechanisms can be exploited
- Main backgrounds are well cotrolled
  - Z+jets, $t\bar{t}$, W+jets, dibosons
- Apart from $H \rightarrow bb$ the only decay to fermions accessible at the moment at the LHC

$H \rightarrow \tau\tau$ channels





Moriond 2013, CMS AN-2013/004

$H \rightarrow \tau\tau \rightarrow \mu\mu$ subchannel

- Small topological branching fraction $BR(\tau\tau \rightarrow \mu\mu) \approx 3\%$
- Large $Z \rightarrow \mu\mu$ and $Z \rightarrow \tau\tau \rightarrow \mu\mu$ backgrounds

➜ Sophisticated background suppression methods needed

➜ Focus in this presentation

- Electron channel is analysed coherently
- German contribution (KIT, DESY)
- Emphasis on SM analysis, but show slightly different MSSM analysis in comparison

SM/MSSM Analysis Strategy – Overview

- **Aims**
  - Account for different production processes
  - Account for different kinematic properties
  - ➜ Enhance the signal fraction

Preselection

- Dimuon trigger
- Kinematic cuts
- Isolation criteria
- Simulation corrected for muon ID, isolation and trigger efficiencies (Tag & Probe)

Event categorisation

- VBF
- 1 jet, high pt
- 1 jet, low pt
- 0 jets, high pt
- 0 jets, low pt
- B-tag
- No b-tag

MVA-based background suppression

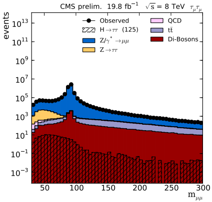
- BDT1: discrimination againts $Z \rightarrow \mu\mu$
- BDT2: discrimination againts $Z \rightarrow \tau\tau$
- 2D PDF-based combination of these two MVA classifiers

- After preselection still large $Z \rightarrow \mu\mu$ background needs further suppression
- Cut on single BDT output

Statistical inference

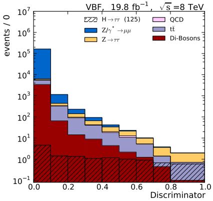
- Limit on SM signal cross section based on 1D PDF discriminator
- Limit in ($\tan\beta$, m_A)-plane based on 2D mass discriminator

Di-muon mass after preselection



work in progress

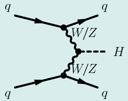
Final discriminator in the VBF category



Event Categorisation in the SM/MSSM Analysis

KIT Karlsruhe Institute of Technology

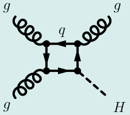
2 Jets – VBF

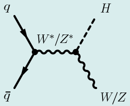


- 2 forwards jets
- Rapidity gap in between with low hadr. activity

➜ Good distinction from SM processes

1 Jet – Boost

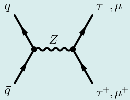




- Jet recoils from boosted Higgs

➜ Better MET and mass resolution

0 Jets



- Large background

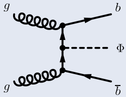
➜ Used only for background evalutation

Subcategories

- **Low pt** category
- **High pt** category

➜ Muons from Higgs decays have larger momentum due to larger mass of the intermediate boson

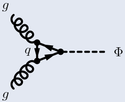
B-Tag



- Couplings to down-type fermions enhanced in MSSM

➜ Measurement of the $b\bar{b} \rightarrow \Phi$ cross section

No B-Tag



➜ Measurement of the $gg \rightarrow \Phi$ cross section ($\Phi = H, h, A$)

Discriminating Variables (1)

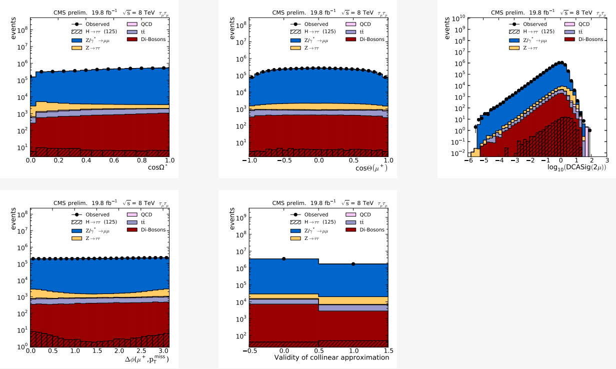
work in progress

Karlsruhe Institute of Technology

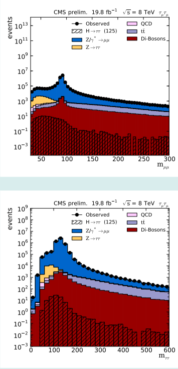
- Variables identified to discriminate between Higgs signal and various backgrounds
  - Dilepton kinematic variables
  - Distance of closest dimuon approach (DCA) identifies $\tau\tau$ final states
  - Variables to evaluate the origin of missing transverse energy

➜ All variables well described by the simulation (including correlations)

Common variables in all BDTs



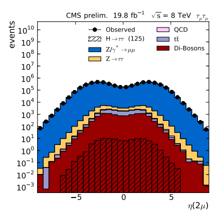
Mass Variables

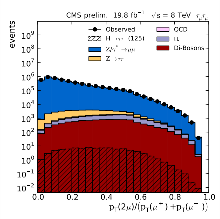


Discriminating Variables (2)

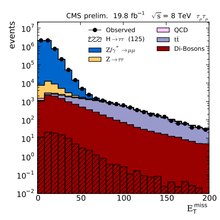
work in progress

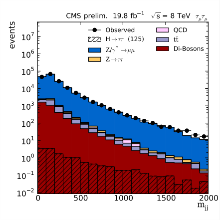
Additional kinematic variables in the 0/1 Jet categories

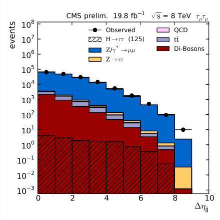




Additional variables for the VBF category







MVA-based Enhancement of the S/B Ratio

work in progress

Karlsruhe Institute of Technology

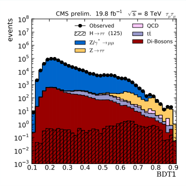
- Here: focus on the SM analysis. Slightly different MSSM can be found on slide 15

- **Two main backgrounds to account for**: $Z \rightarrow \mu\mu$ and $Z \rightarrow \tau\tau$

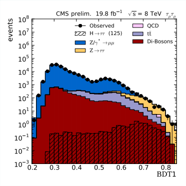
➜ Two dedicated trainings of Boosted Disicion Trees (BDTs)

BDT1

- Rejection of the most dominant $Z \rightarrow \mu\mu$ background through identification of di-τ final states
- Highest discrimination power: visible mass $m_{\mu\mu}$



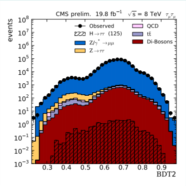
1 jet, high pt



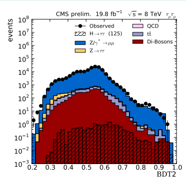
VBF

BDT2

- Discrimination between $Z \rightarrow \tau\tau$ background and $H \rightarrow \tau\tau$ signal
- Highest discrimination power: SVfit mass $m_{\tau\tau}$



1 Jet, high pt



VBF

- Four separate trainings for the 0/1 Jets and VBF category
- Signal samples with different mass hypotheses are combined

Final MVA Discriminator

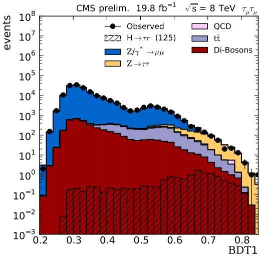
work in progress

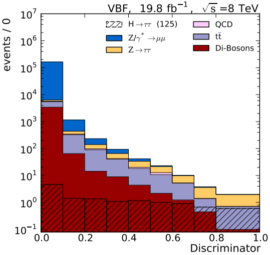
Combination of the two BDTs

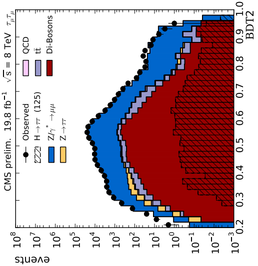
- The two BDTs define a 2D PDF $f_{\mathrm{cat}}^{\mathrm{sig}}(\mathrm{BDT}_1, \mathrm{BDT}_2)$ for signal events.
- Integration forms the final discriminator $D_{\mathrm{cat}}(\mathrm{BDT}_1, \mathrm{BDT}_2)$

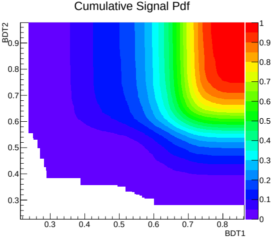
$$D_{\mathrm{cat}} = \int_{-\infty}^{\mathrm{BDT}_1} \int_{-\infty}^{\mathrm{BDT}_2} f_{\mathrm{cat}}^{\mathrm{sig}}(\mathrm{BDT}_1', \mathrm{BDT}_2')\, \mathrm{dBDT}_1'\, \mathrm{dBDT}_2'$$

- The limit calculation is performed based on this one-dimensional discriminator





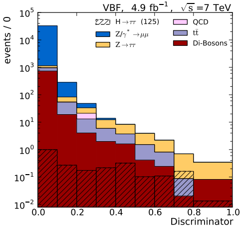


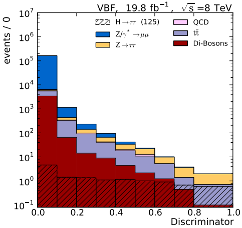


Modelling of the Backgrounds

work in progress

Karlsruhe Institute of Technology





$Z/\gamma^* \rightarrow \mu\mu$

➜ **Shape:** MC simulation
➜ **Normalisation:** Template fits of muon DCA performed in bins of other variables

$Z \rightarrow \tau\tau$

➜ **Shape:** Embedded data
➜ **Normalisation:** Measured from $Z \rightarrow \mu\mu$ yield

QCD

➜ **Shape:** Data with same-sign muon charge selection
➜ **Normalisation:** From comparison with data after inverted isolation cuts

Electroweak (W+jets, dibosons)

➜ **Shape:** MC simulation
➜ **Normalisation:** NLO theory prediction

$t\bar{t}$

➜ **Shape:** MC simulation
➜ **Normalisation:** Extracted from sideband region (large MET)

Closer Look at the $Z \to \mu\mu$ Background

work in progress

Karlsruhe Institute of Technology

❶ Calibration of the DCA variable in the simulation

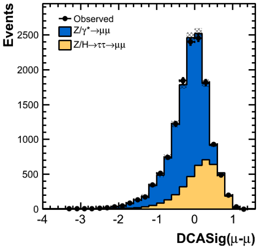
- Select events around the Z peak, dominated by $Z \to \mu\mu$
- Fit DCA shape in $Z \to \mu\mu$ simulation and in data (other backgrounds substracted) with analytic function in different bins depending on the muon kinematics

➜ Isomorphic mapping of quantiles in data and simulation defines the calibration

❷ DCA template fits from $Z \to \mu\mu$ and $Z \to \tau\tau$ background to data

- Perform template fits of the calibrated DCA quantity in bins of the visible mass $m_{\mu\mu}$ and the reduced MVA discriminator
- Reduced MVA discriminator does not include the DCA and the mass variables as inputs to avoid a bias

➜ Both normalisation and shape is corrected to match the data



- **Advantage**: Control most dominant background in a semi-data-driven way

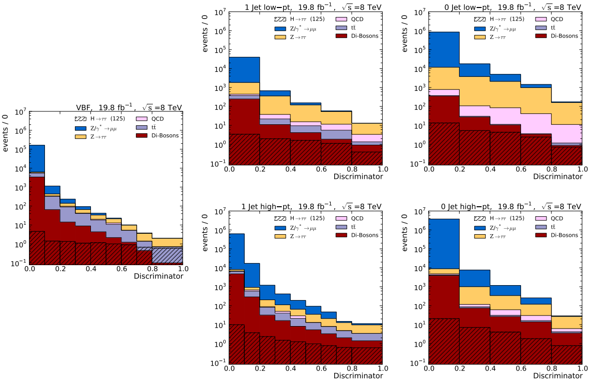
Expected Significance in the SM Analysis

work in progress

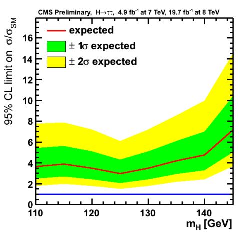
Karlsruhe Institute of Technology

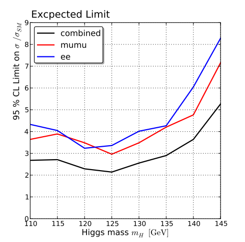
- Five categories are statistically combined
- Normalisation and shape uncertainties considered
- Expected limit improved with respect to the Moriond analysis

Final discriminators:



Results





Summary and Outlook

- **SM analysis updated w.r.t. Moriond 2013**
  - Presented two-stage BDT analysis to account for the two main backgrounds
  - Showed modelling of the backgrounds

  - All $\tau\tau$ decay modes are now studied
  - Improvement in sensitivity w.r.t. Moriond 2013 in all subchannels
  - ➜ Hope to find evidence for $H \to \tau\tau$ by applying the analysis on data
  - ➜ Plan to publish results soon

- **MSSM analysis updated w.r.t. HCP 2012**
  - Analysis of the full 2012 dataset is now beeing finished
  - Plan to synchronise analysis strategy with the SM analysis for the legacy paper

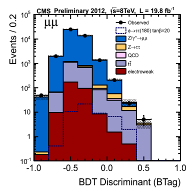
Backup

Slightly Different Approach for MSSM

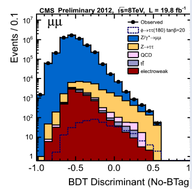
work in progress

- Covers larger Higgs mass range: up to 1000 GeV (instead of 110-145 GeV)
- 2-stage BDT approach not yet translated to the MSSM analysis *(but planned)*
- **Single-stage BDT is trained to separate MSSM Higgs signal from all backgrounds**
  - Same inputs variables as in the SM analysis except for the masses
  - Signal like events are selected after cut on BDT output
  - → Mainly the $Z \rightarrow \mu\mu$ background is suppressed

BDT

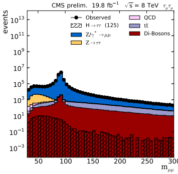


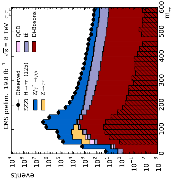
B-tag

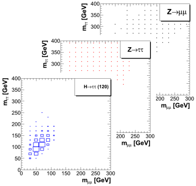


No b-tag

- **Subsequent 2D mass likelihod analysis**
  - Two masses carry the most discriminating power: Visible mass and SVfit mass (fully reconstructed $\tau\tau$ system)
  - 2D Likelihood of these two variables is used for the limit calculation





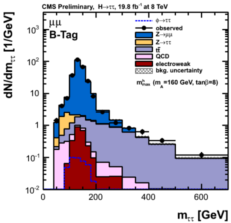


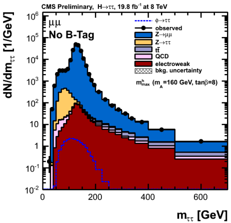
Exp. Significance in the MSSM Analysis

work in progress

- Two categories are statistically combined
- Normalisation uncertainties considered
- Update plans to the same strategy as for the SM analysis

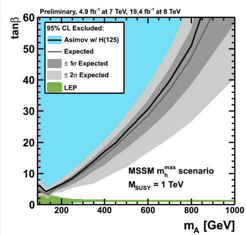
Final (1D) SVfit mass distributions (2D PDFs difficult to visualise)

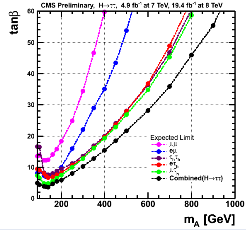




Results

All $\tau\tau$ channels combined





Norm. Uncertainties in the Di-Lepton Ch.

- **Correlated uncertainties**
  - Luminosity: 2.6 %
  - Lepton efficiency: 4 % (μ), 4 % (*e*, 7 TeV), 6 % (*e*, 8TeV)
  - *b*-tag efficiency: 1 — 3 %, depending on category
  - *b*-tag fake rate: 1 — 3 %, depending on category
  - ZTT normalisation: 3 %
  - TTJ normalisation: 8 % (7 TeV), 10 % (8 TeV)
  - Diboson normalisation: 30 %
  - Theory uncertainties ➜ *Separate talk by Joram Berger*
- **Uncorrelated uncertainties**
  - ZTT extrapolation for various event categories: 6 — 9 %, depending on channel and category *(from study of embedding bias and contamination of embedded data with other backgrounds)*
  - QCD normalisation: 8 — 100 %, depending on channel, period and category *(from comparison of OS/SS and DirIso/InvIso selections)*

Shape Uncertainties in the Di-Lepton Ch.

- **Shapes alternating uncertainty sources**
  - MET scale
  - Jet energy scale
  - Electron energy scale *(only in EE)*
  - DY background estimation
  - Theory uncertainties ➜ *Separate talk by Joram Berger*

- **Procedure for each uncertainty source**
  - Shift initially affected quantity by $\pm 2\,\sigma$

  ➜ Pulls should to be smaller than $\pm 2\,\sigma$, so no extrapolation is needed
  - Modify affected BDT input variables and propagate them through both BDTs and the subsequent combination of the BDTs
  - Fill shift up/down histograms into the limit inputs
  - **Implementation:** each shift requires a new run of our analysis code, which brings the advantage, that the propagation through the entire analysis is done consistently

Shape Uncertainties (MET, JES, ES)

- **MET Scale Uncertainty** *(not changed since Moriond 2013)*
  - DY: 0.5 % *(from MET template fits)*
  - Diboson, WJets: 0.5 % *(same as for DY)*
  - TTJ: 2 % *(from MET template fits)*
  - Signal: 2 % *(from recoil variations within its uncertainties)*
- **Jet Energy Scale Uncertainty**
  - $3-7$ %, depending on η
    (according to prescription of the JetMET POG)
- **Electron Energy Scale Uncertainty** *(only in EE)*
  - 1 % (barrel) to 2.5 % (endcap)
    (according to prescription of the Egamma POG)