Search for a very light NMSSM Higgs Boson produced in decays of the 125 GeV scalar boson, decaying into a pair of muons and a pair of τ leptons at $\sqrt{s} = 13 TeV$

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Abstract

A search for a very light NMSSM pseudoscalar Higgs Boson is being performed. Expected signal signature is: H(125)→ aa → $(\mu\mu)(\tau_\mu\tau_{1-prong})$. One a_1 boson decays into a pair of muons and another into a pair of τ leptons. The analysis is being developed and applied to 2016 p-p collision data collected with CMS detector, probing low mass a_1 region. The selection of events consistent with the signal signature explodes kinematics of muons and visible τ decay products. Signal extraction procedure uses the invariant mass of the dimuon system. At the last step of the analysis, a statistical inference procedure of examining data for a presence of the signal will be done.

Signal Signature and Analysis Strategy

- gg → H(125)→ aa → $(\mu\,\mu)(\tau_\mu\tau_{1-prong})$
- Probe low m_a region $2m_\tau < m_a < 2m_b$
- Final state with three muons, one pair has same sign
- In the decay of one of the a, one of the τ leptons is identified via its muon decay
- The other τ lepton is required to decay into one charged particle and one or more neutral particles
- Decays identified by the presence of one reconstructed track with charge sign opposite to that of the closest muon
- Neutral particles not considered in the event selection
- The decay of the other a, identified via its double muon decay

Event selection

Two SS muons:

Matched to HLT_Mu17_Mu8_SameSign

$p_T > 9$ GeV, $\eta < 2.4$, matches Mu8 leg

$p_T > 18$ GeV, $\eta < 2.4$, matches Mu17 leg

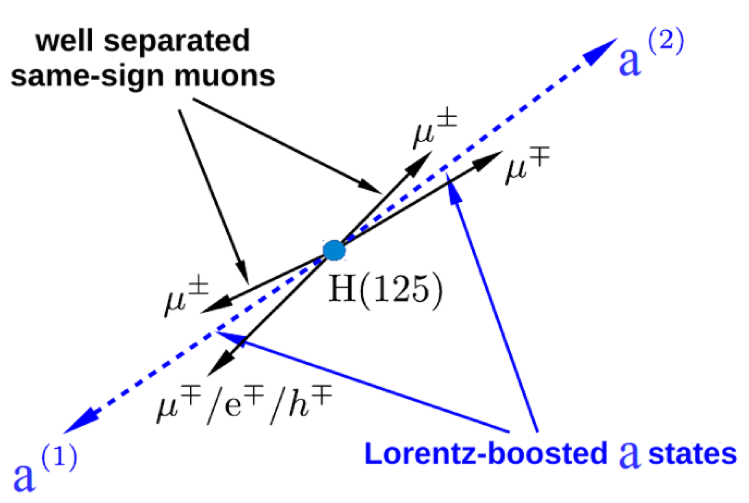
- both muons must pass HIP-safe medium muon Id
- no isolation requirement imposed
- impact parameter w.r.t. primary vertex:

$|d_0| < 0.05$cm $\quad |d_z| < 0.1$ cm

$\Delta R(\mu_1, \mu_2) > 1$

Muons are selected around leading (trailing) muon requiring them:

- to have opposite charge respect to leading (trailing) muon
- to have a $p_T Sum = \sqrt{(p_{x_{\mu^+}} + p_{x_{\mu^-}})^2 + (p_{y_{\mu^+}} + p_{y_{\mu^-}})^2} > 45$ GeV
- to pass along with leading (trailing) muon the following cuts on impact parameter: d_{xy} <0.01 cm and d_z <0.03 cm
- The muons of the pair with the highest p_TSum are identified as: a → $\mu\mu$ candidates (pair must be isolated)
- The remaining leading (trailing) muon identified as: a → $\tau\tau$ candidate
- 1-prong tau-lepton is selected around a → $\tau\tau$ candidate (pair must be isolated)
- Cut on visible mass (invariant mass of the 4 objects)



Same-sign Dimuon Trigger

Quite appropriate for this topology:

- Muons do not need to be isolated
- Low thresholds on p_T legs

HLT_Mu17_Mu8_SameSign_DZ (Run < 274954 or Run ≥ 280919): 10.8 fb^{-1}

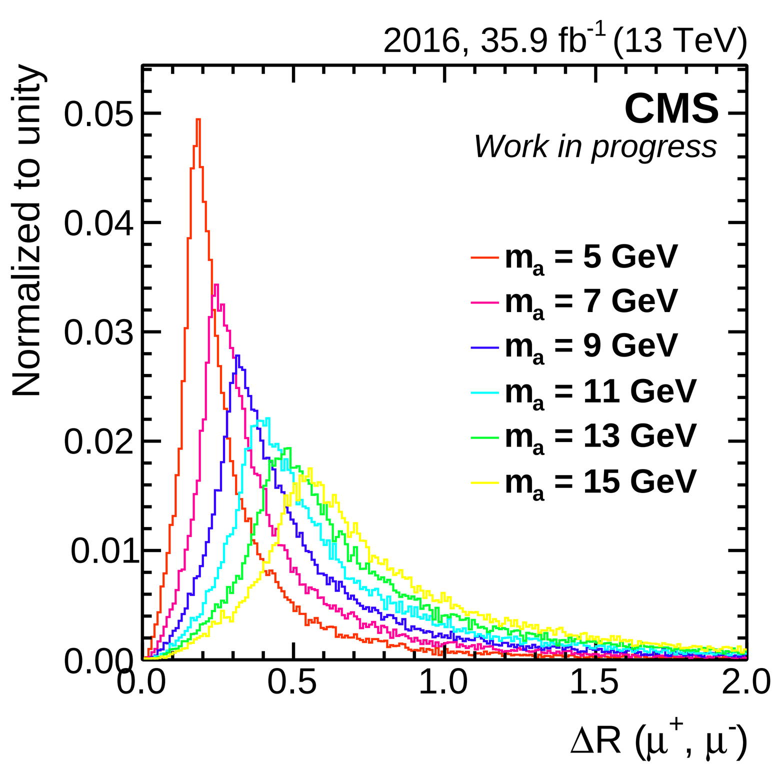
HLT_Mu17_Mu8_SameSign (Run ≥ 274954 and Run < 280919): 25.1 fb^{-1}

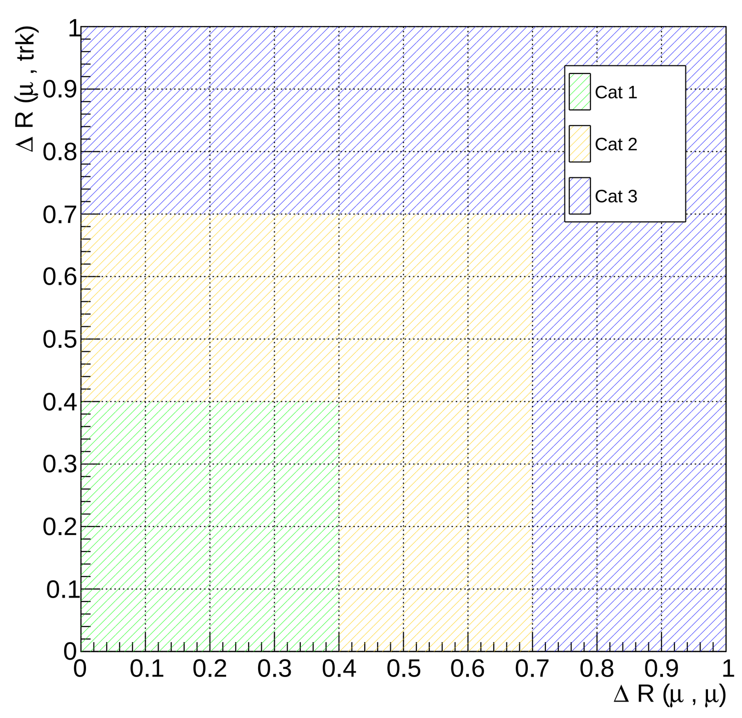
Signal acceptance vs mass

Degradation of Signal acceptance with increasing of m_a

Higher m_a results in:

- Lower boost of the a boson
- Softer p_T spectrum of tracks around $a \to \tau\tau$ candidate muon
- Higher values of $\Delta R_{\mu,\mu}$ and $\Delta R_{\mu,trk}$
- Solution: Make use of several ΔR intervals when selecting muons around muons and tracks around muons: ΔR=[0.0,0.4,0.7,1.0] (nine different regions in $\Delta R \otimes \Delta R$ phase space)





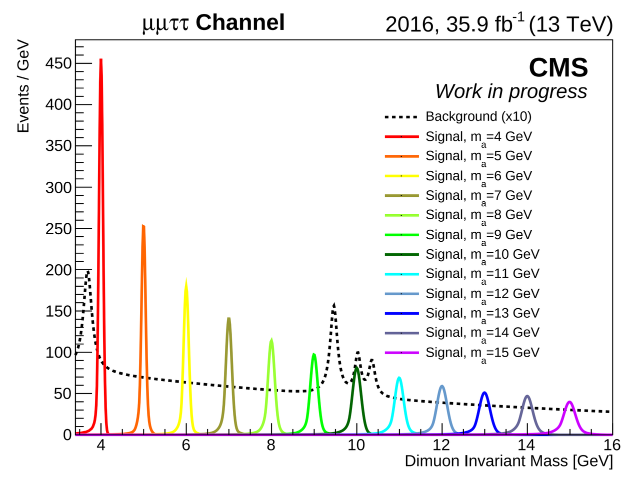
Signal Model

Signal normalization:

- $\sigma(gg \to H(125)) = \sigma_{SM}(13TeV) \equiv 43.9$ pb
- $B(H(125) \to aa) \cdot B^2(a \to \tau\tau) = 20\%$

Background:

- Asimov data set with shape from sideband, normalized to data yield in signal region

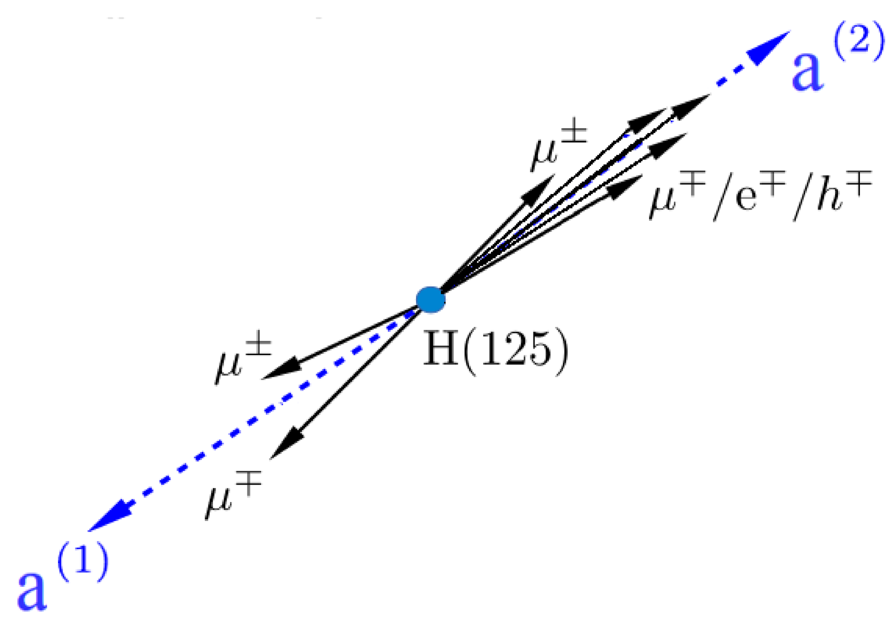


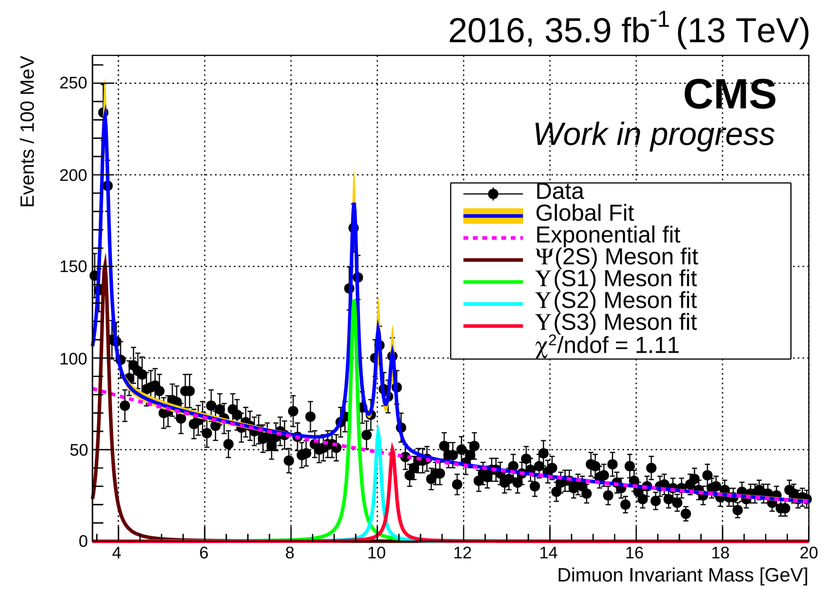
- Expected signal and background distribution in signal region

Background Model

Constructed and validated in side band region:

- $a \to \mu\mu$ candidate required to be isolated
- No additional requirements imposed to $a \to \tau\tau$ candidate muon (no isolation requirement applied)





- The full background model consists of SM resonances [$\Upsilon(1s), \Upsilon(2s), \Upsilon(3s), \Psi(2S)$] and a non resonant continuum background (low mass DY background, $t\bar{t}$ and QCD)

The Background Model pdf is constructed with:

- An exponential decay function for continuum background
- Four Lorentz peaks corresponding to four meson resonances

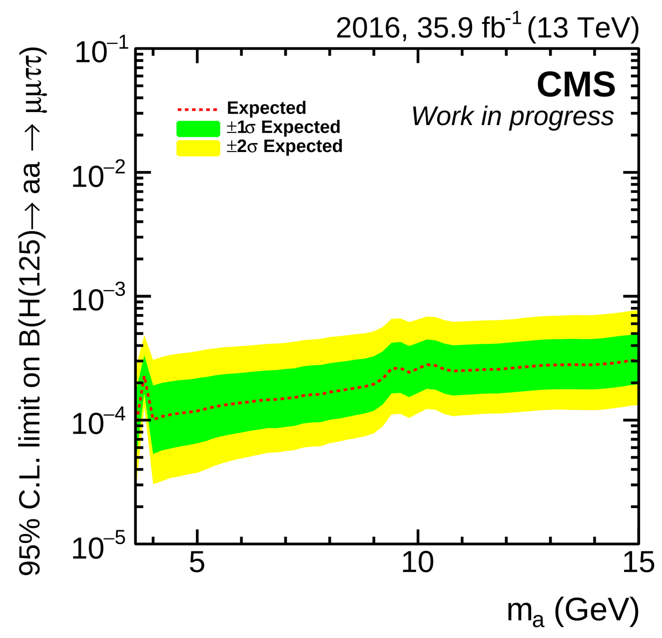
Systematic uncertainties

- Muon Id efficiency
- Muon-track isolation efficiency
- Trigger efficiency
- Pileup reweighting
- Luminosity
- Muon energy scale
- Fit model

Results

Sensitivity for 2016 dataset evaluated in terms of expected **95%** CL limits on: $B(H(125)) \to aa \to \mu\mu\tau\tau$, assuming B(a− >mumu)+B(a− >tautau) = 1.

Under the assumption that: $\frac{\Gamma(a\to\mu\mu)}{\Gamma(a\to\tau\tau)} = \frac{m_\mu^2\sqrt{(1-\frac{2m_\mu}{m_a})^2}}{m_\tau^2\sqrt{(1-\frac{2m_\tau}{m_a})^2}}$



References

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[2] Search for a very light NMSSM Higgs boson produced in decays of the 125 GeV scalar boson and decaying into τ leptons in pp collisions at $\sqrt{s}$ = 8 TeV, JHEP 01 (2016) 079

[3] Search for Higgs bosons decaying to aa in the $\mu\mu\tau\tau$ final state in pp collisions at $\sqrt{s}$ = 8 TeV with the ATLAS experiment, Phys. Rev. D92 (2015), no. 5, 052002