Search for exotic decay of Higgs boson to a pair of light (pseudo-)scalar Higgs boson in e^+e^- collider

Bryan Nee,

Abdollah Mohammadi,

Sridhara Dasu

(UW-Madison)

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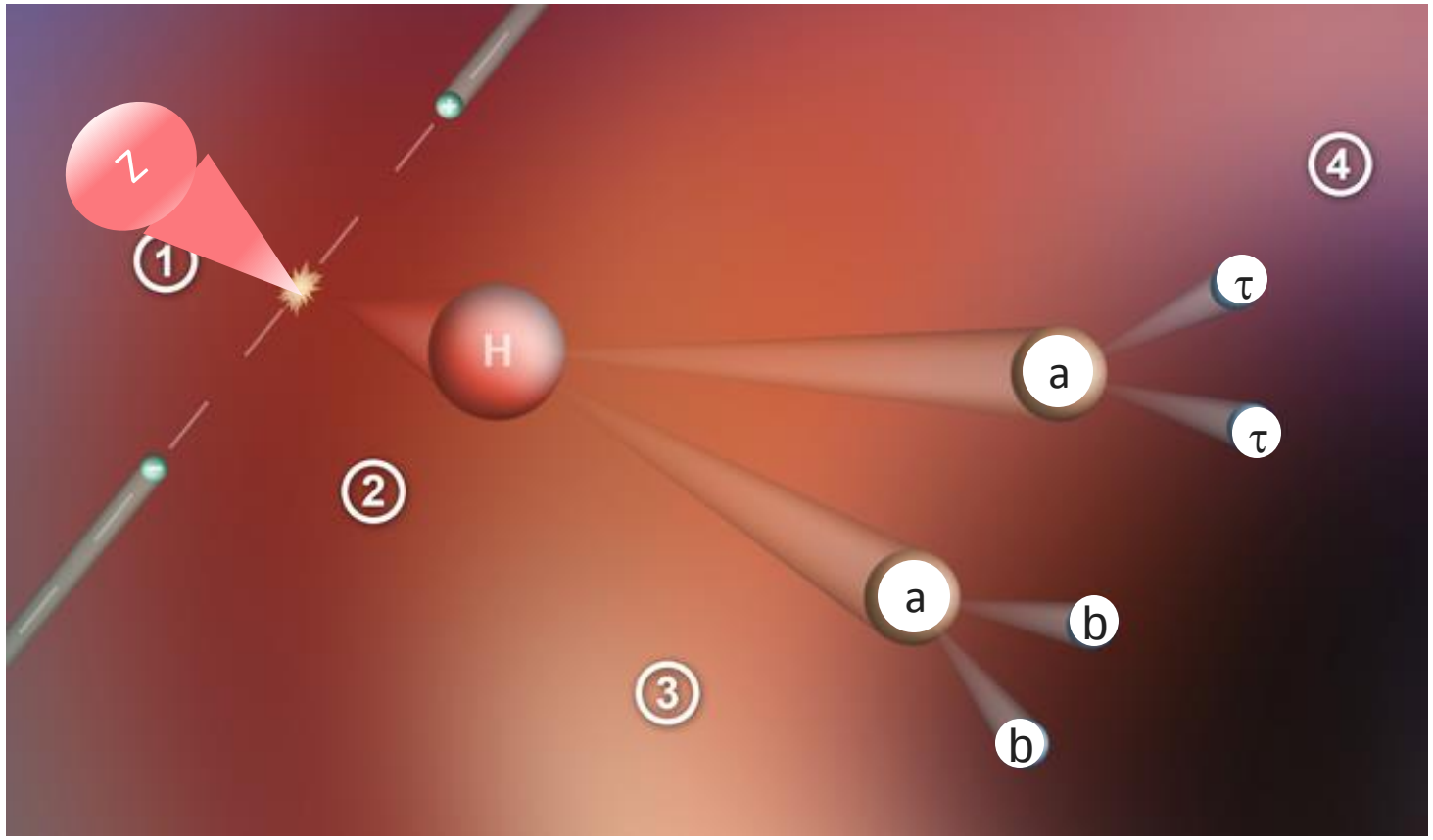


Motivation

- Needless to stress the importance of search for Exotic decay of the Higgs boson in a clean Higgs factory!
- Current analysis is a search for a pair of light (20-60 GeV) Higgs bosons from SM Higgs decay produced in association with a Z boson in 250 GeV e^+e^- collider.

$$e^+e^- \to Z\,(\to \boldsymbol{\mu^+\mu^-})\; H \to a\big(\to \boldsymbol{b\bar{b}}\big)\; a(\to \boldsymbol{\tau^+\tau^-})$$

$$e^+e^- \to Z\,(\to \boldsymbol{e^+e^-})\; H \to a\big(\to \boldsymbol{b\bar{b}}\big)\; a(\to \boldsymbol{\tau^+\tau^-})$$

- The two considered backgrounds are ZZ and ZH
- Samples have been generated using Madgraph5, hadronized with Pythia8, simulated for detector responses with Delphes

Channels	XS (b)	# of Events Generated
$e^+e^- \to Z(\to ll)\; H \to a(\to b\bar{b})\; a(\to \tau^+\tau^-)$	6.60×10^{-15}	10000
$e^+e^- \to Z(\to ll)\; H$	6.60×10^{-15}	1000000
$e^+e^- \to Z(\to ll)\; Z(\to f\bar{f})$	3.52×10^{-14}	1000000

Event Selection

Z→ll selection:

- ❑Pair of OS leptons consistent w/ Z boson

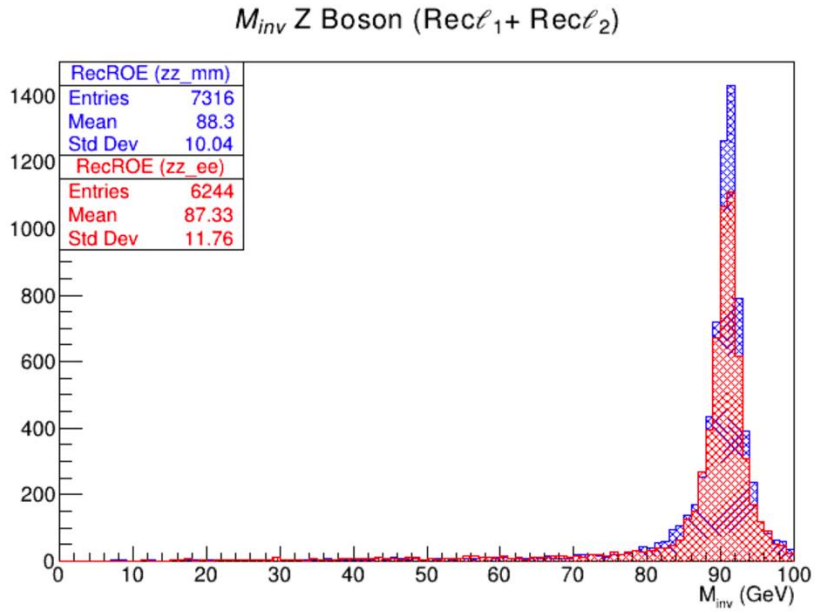
a→ττ selection:

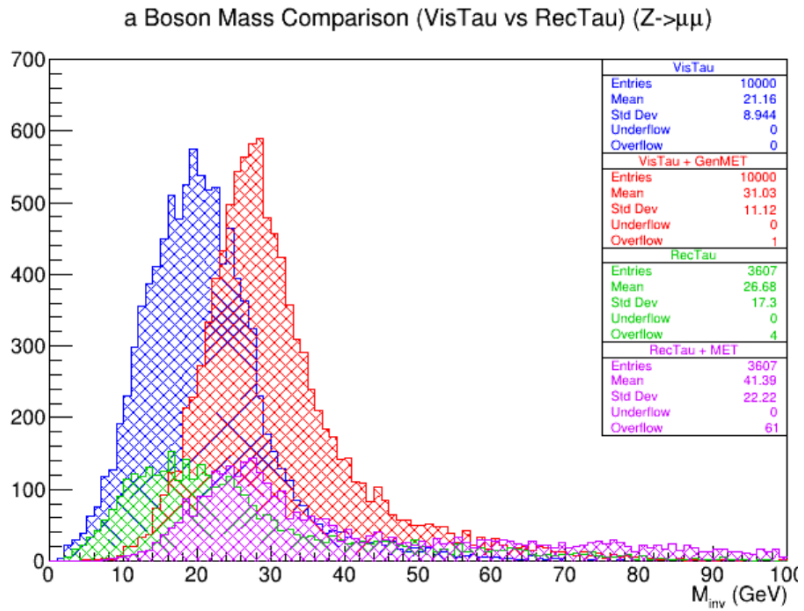
- ❑Pair of OS τ, adding MET (in lie of neutrinos) to mass
- ❑A dedicated tau Reco algo developed

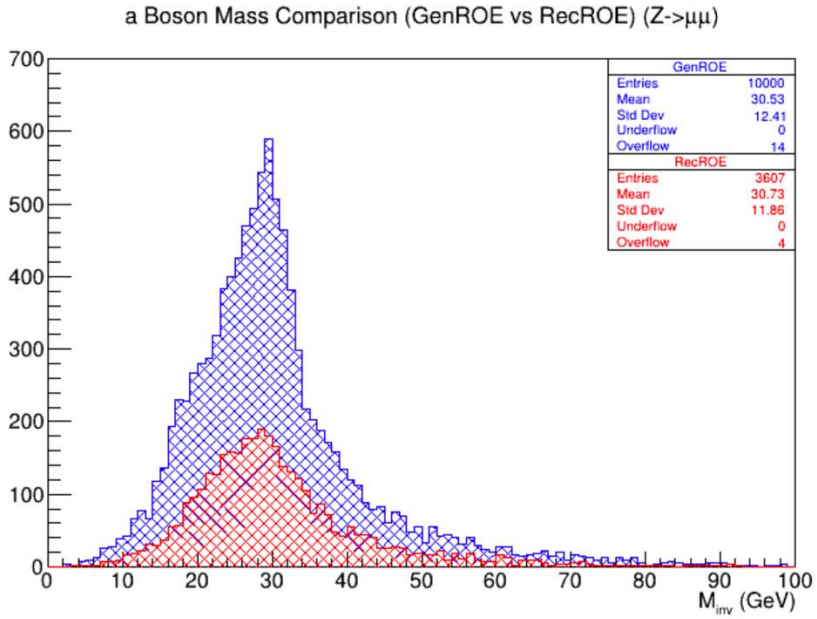
a→bb selection (ROE):

- ❑ B-Jet reco efficiency is low, thus ROSE is defined

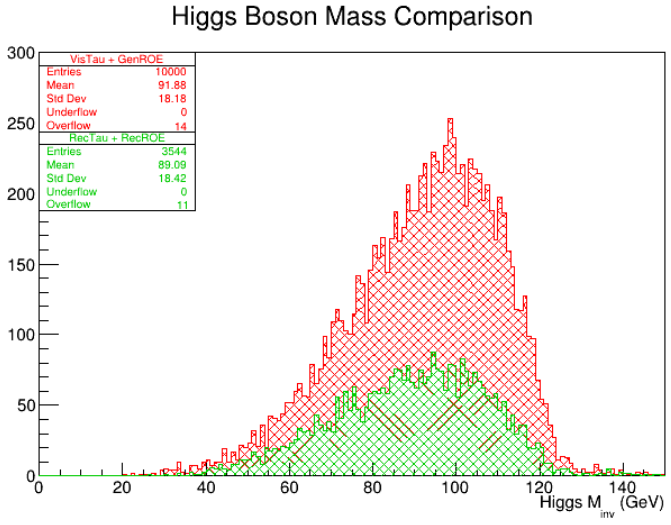
$$\text{RecROE} = \sum_{i}^{\text{excl } \mu \,\&\, \tau} \text{tracks}_i + \sum_{i}^{\text{excl } \mu \,\&\, \tau} \text{Photons}_i + \sum_{i}^{\text{excl } \mu \,\&\, \tau} \text{NHadrons}_i$$

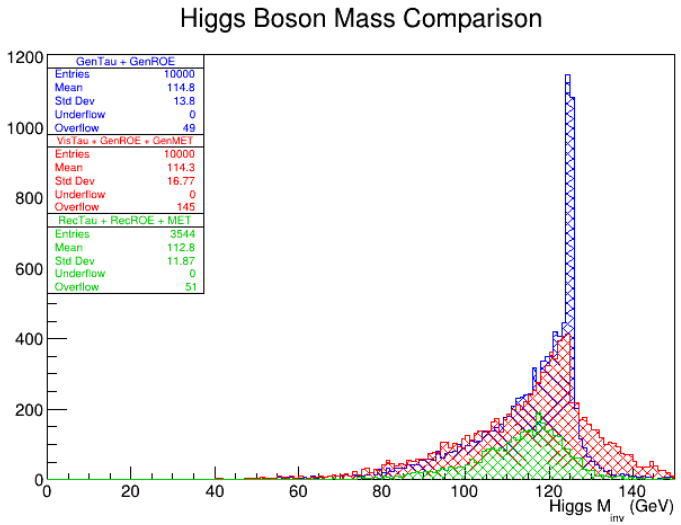


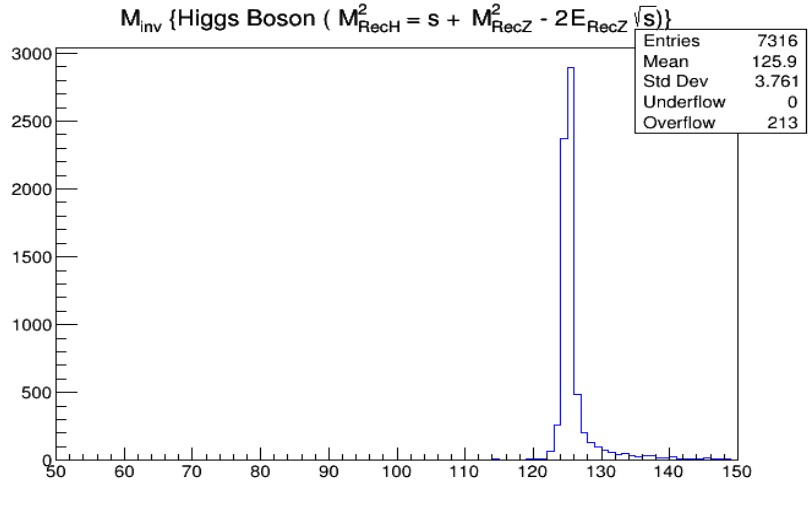




Higgs boson reconstruction

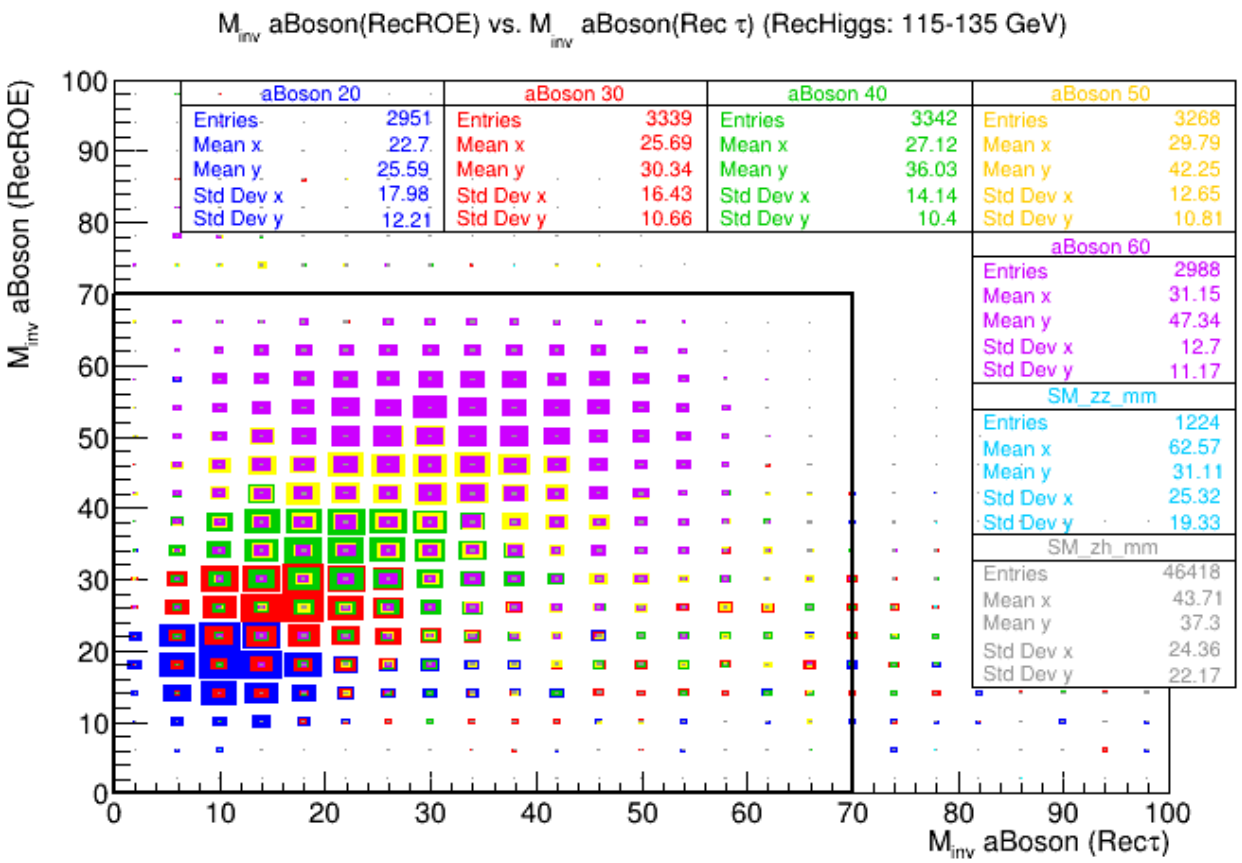




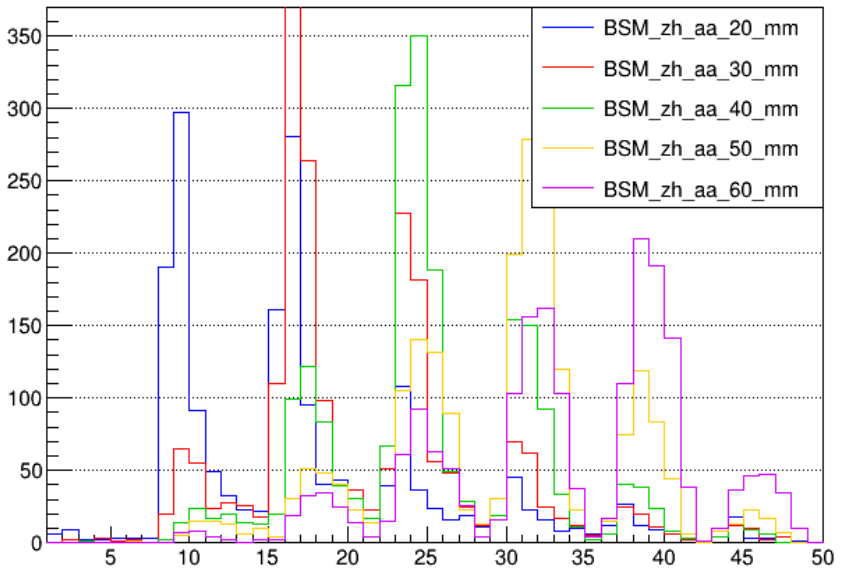


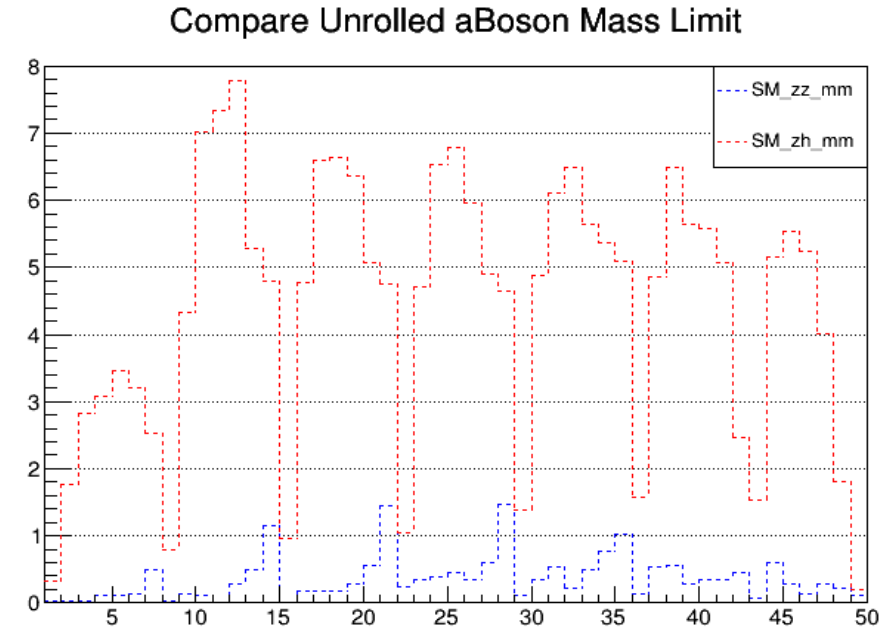
- The visiblel Higgs Boson $Minv$(VisTau + GenROE) and Reco level Higgs Boson $Minv$ (RecTau + RecROE) both peak at around 100 GeV.
- Improving the mass resolution by adding MET, or even further improving by Energy of COM constrains
- $M^2_{\text{Higgs}} = s + M_Z^2 - 2E_Z\sqrt{s} \quad s = 250\,\text{GeV}$
- M_{inv} peaks at 125 GeV, Thus the reconstruction of the Higgs Boson has significantly improved with the beam constraint method compared to the method constructed from diτ and ROE.

2D observable



- Apply a series of kinematic cuts
  - Higgs Boson Mass Cuts: 115-135 GeV
  - A Boson (diτ) Mass Cuts: 0-70 GeV
  - A Boson (ROE) Mass Cuts: 0-70 GeV

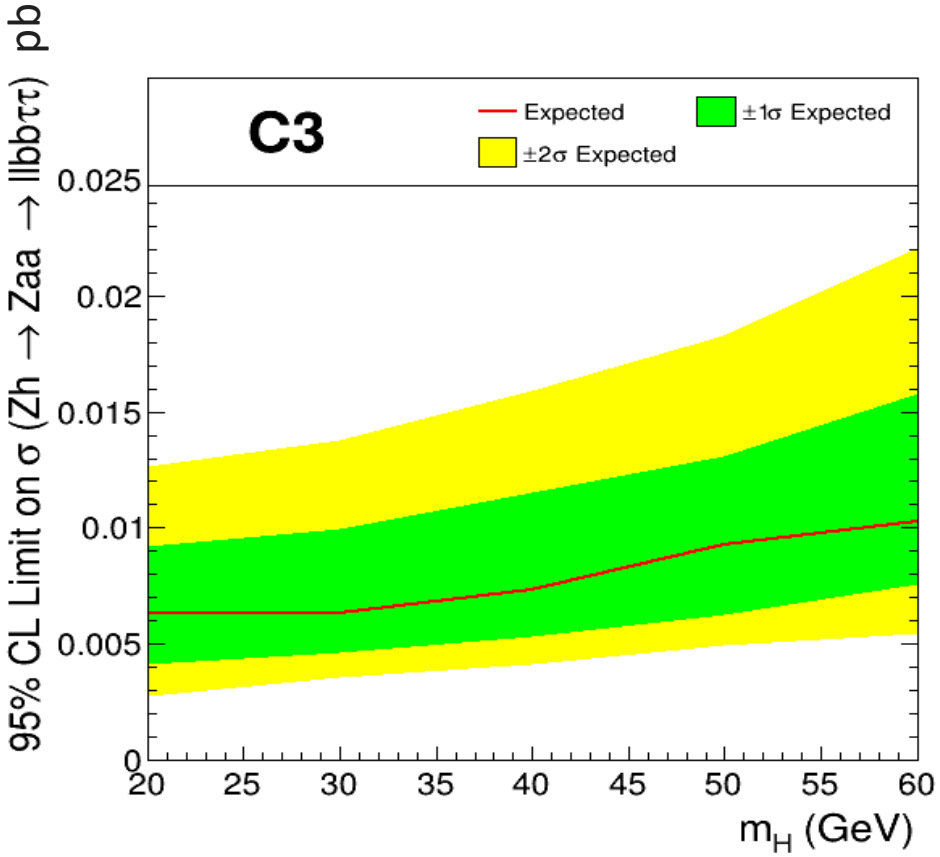


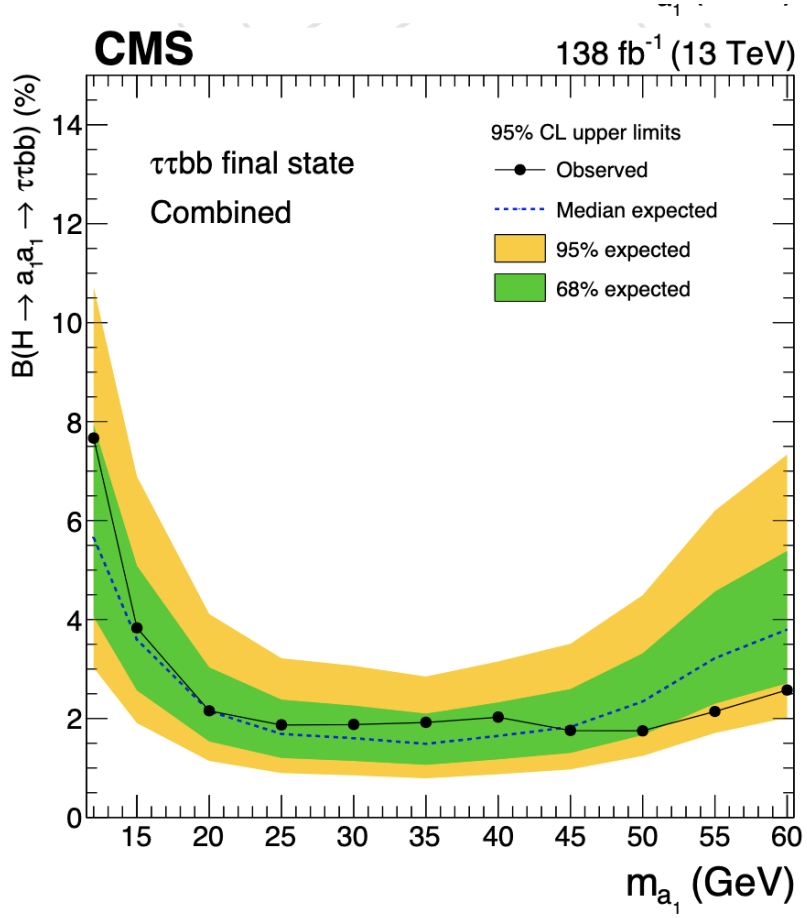


Model-Independent limit

- Ran a maximum likelihood fit to extract the expected limit on cross section times the branching fraction
- A minimum set of systematics is used

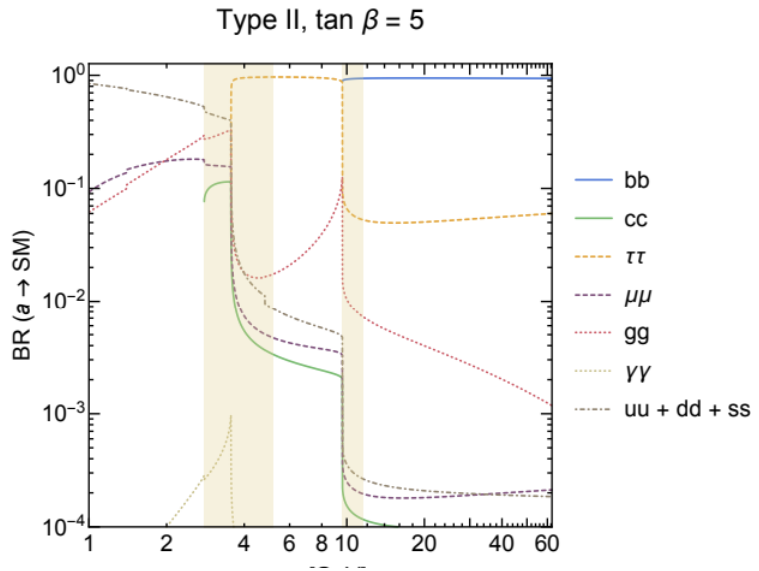
https://arxiv.org/abs/2402.13358

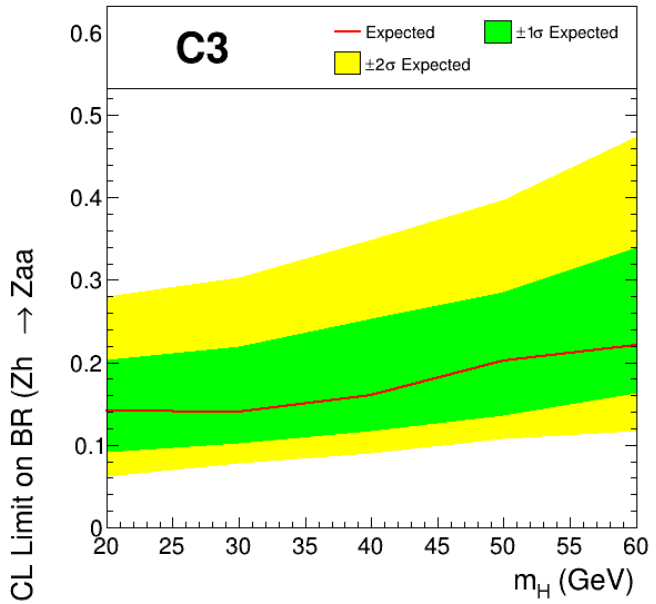


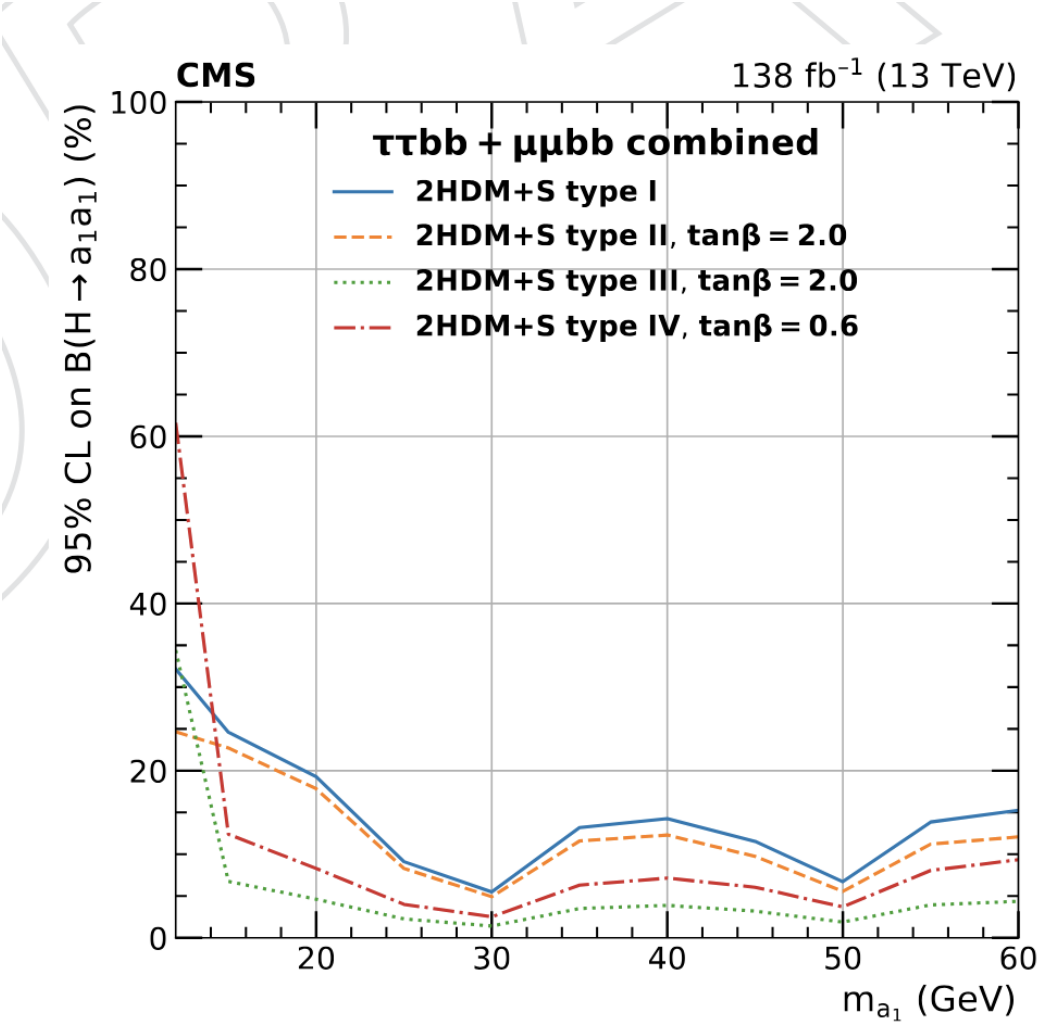


- The limit on the left side must be divided by 6.6 pb to match the y-axis of the right side
- Better limit (with 1 ab^{-1}) compared to the full Run II CMS data

Model-Dependent limit (Type II 2HDM)







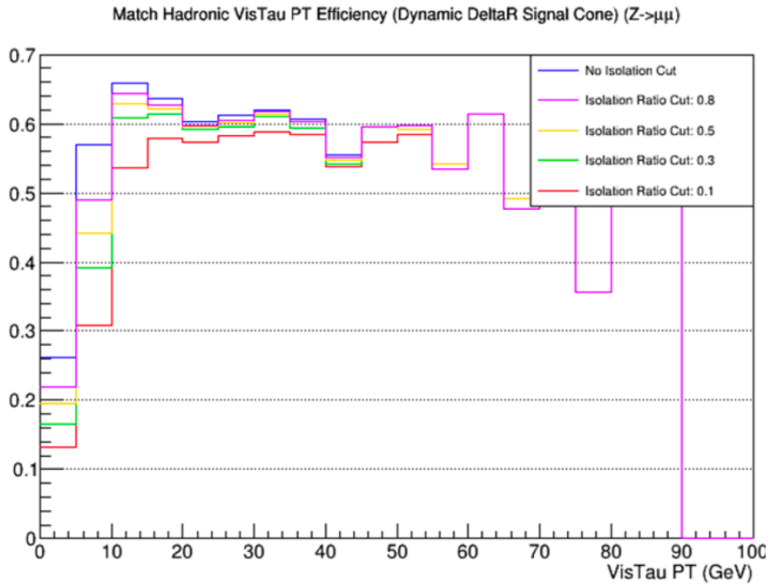
- Not an apple to apple comparison (different model parameters)
- Limit is comparable with combination of CMS 2b2mu and 2b2tau results

Summary

- Feasibility study of exotic decay of Higgs boson to a pair of *a* bosons in association with a Z boson
- Mass of a boson ranges from 20 to 60 GeV (below 20 GeV the *a* bosons become boosted, need a dedicated strategy)
- Dedicated tau reconstruction algorithm is employed to increase the signal selection efficiency
- The results look promising and comparable/better than the CMS Run II results
- One can add all of the Z boson decays and increase the signal yield by more than a factor of ~ 10, thus there is still room for improvement.

Back up

Tau Lepton Reconstruction



- Reconstructing tau particles using energy flow (EFlow) from tracks, photons, and neutral hadrons.
  - tracks with PT > 2.0 GeV as potential tau cand.
  - Candidates (track, photons, neutral photons) within a signal cone of 0.1-0.2 around leading track
  - Only consider tau candidates with a maximum of 5 charged prongs.
- Relative isolation cut has been applied on taus

CMS Model-Independent and dependent limits

https://arxiv.org/abs/2402.13358