Searches for Additional Scalars at Future e^+e^- Colliders

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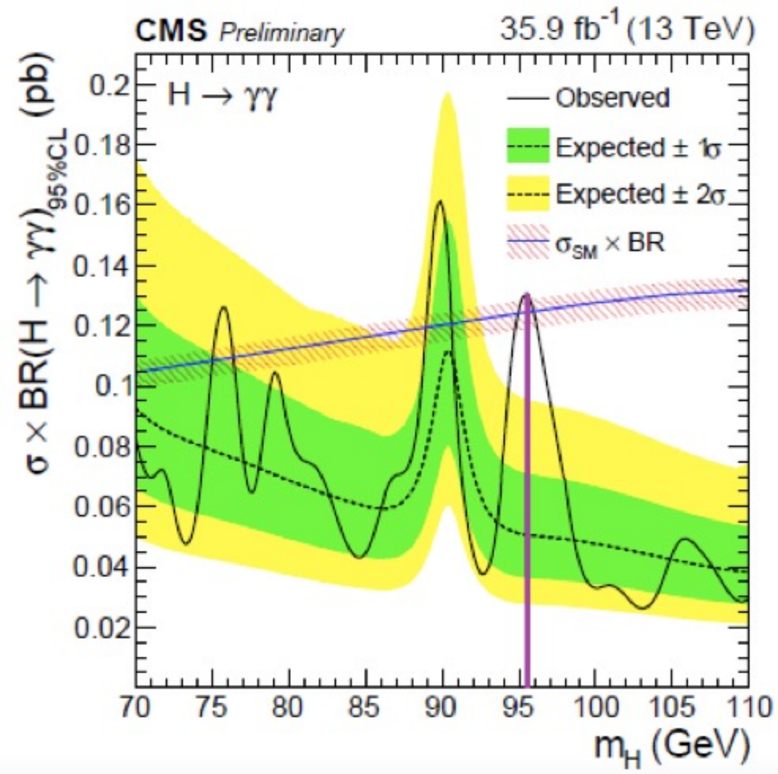
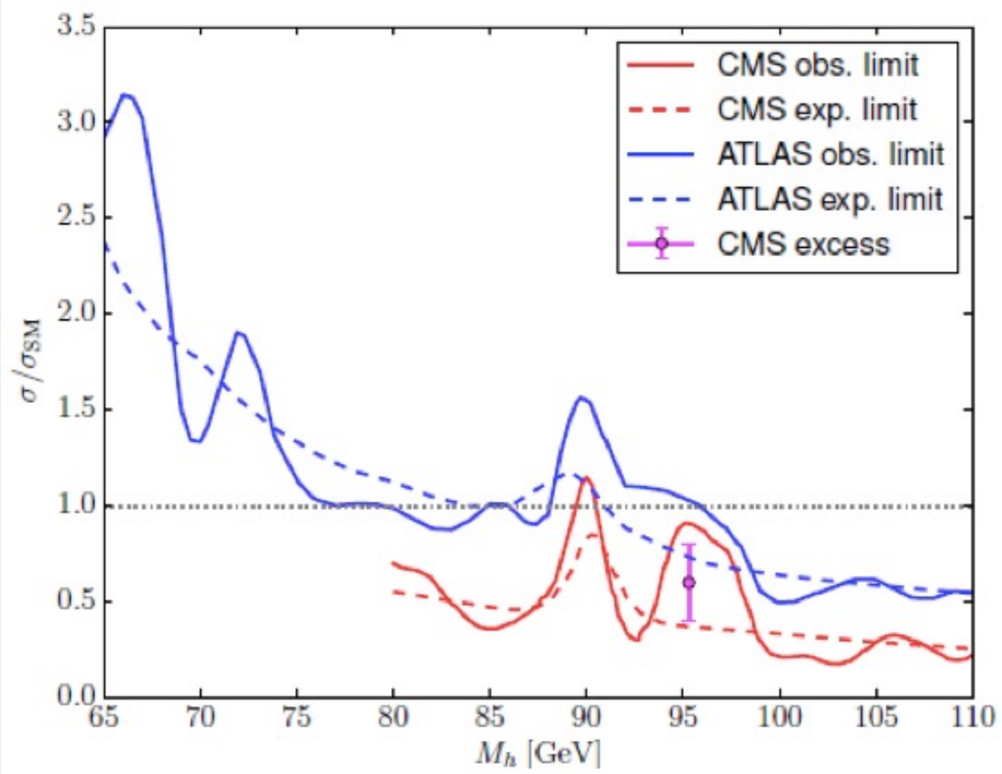
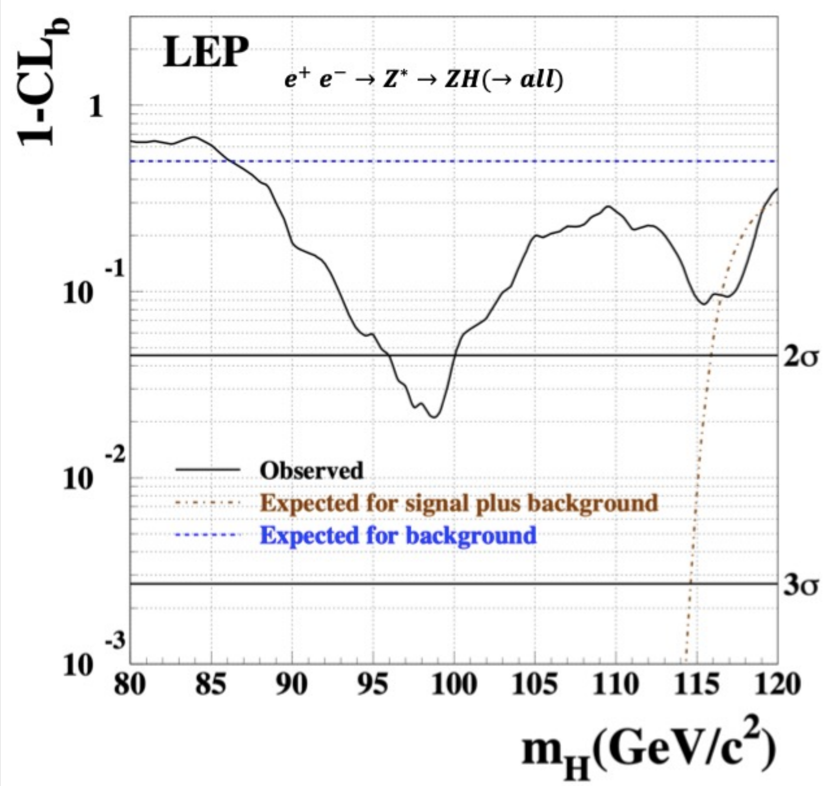
Motivation: Additional Scalars (Note: $h \to \gamma\gamma$)





[arXiv:2001.04770 [hep-ex]]

Motivation: Additional Scalars (Our Probing Channel)



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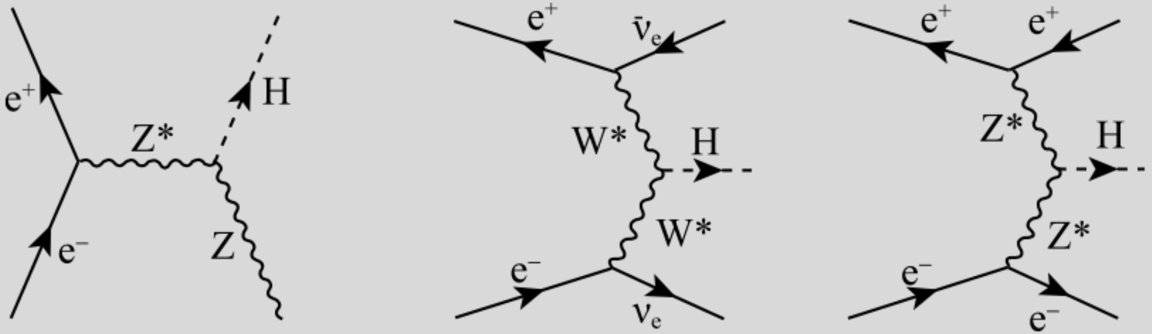
LEP, Phys. Lett. B 565 (2003) 61–75

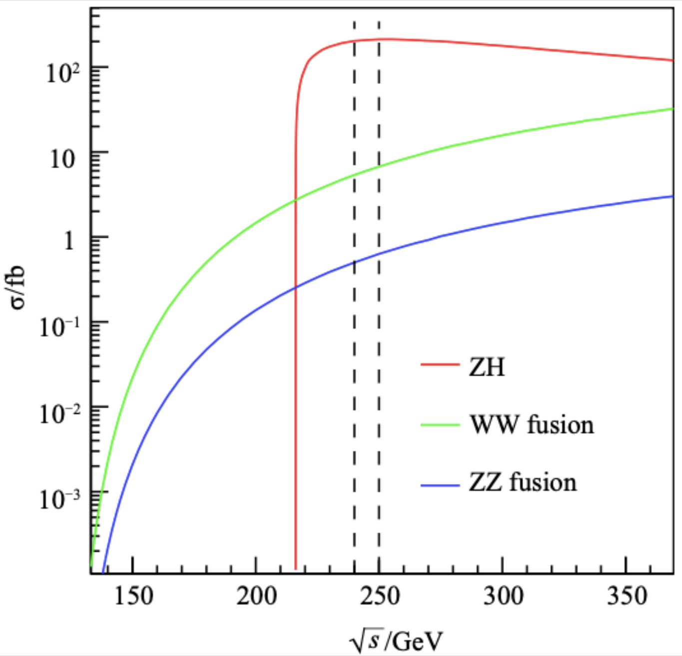
Additional Scalars

- The multi-lepton anomalies seem to be relatively well accommodated by $2HDM + S$ model with a sizeable direct production of $\boldsymbol{H \rightarrow SS, Sh}$
- This motivates the search for narrow resonances pertaining to $\boldsymbol{S \rightarrow \gamma\gamma, \gamma Z}$ in association with light jets, ***b*-jets** or missing transverse energy, $\boldsymbol{p_T}$.



arXiv:1601.05352

Additional Scalars



- Production cross sections of the Higgsstrahlung, WW − fusion and ZZ − fusion processes as functions of center-of-mass energy,$\sqrt{s}$.

arXiv:1601.05352

Measurement of m_S: Recoil Mass

- The inclusive ZS cross section, σ_{ZS} and the coupling, g_{SZZ} can be determined in a model-independent manner.
- The measured g_{SZZ}, combined with exclusive Scalar boson decay measurements, could be used to determine the Scalar boson width and absolute values of couplings between the Scalar boson and its decay final states.
- Meanwhile, the Higgs mass m_S can be extracted from the M_{recoil} distribution. The method allows better exclusive measurement of Scalar decay channels.
- Many new physics models predict a significant branching ratio of the Scalar boson decaying to invisible products.

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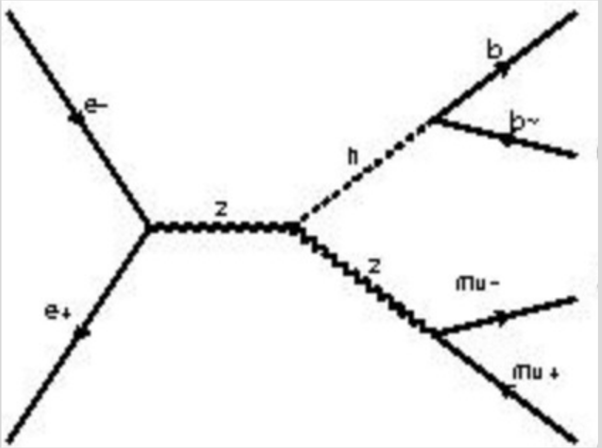
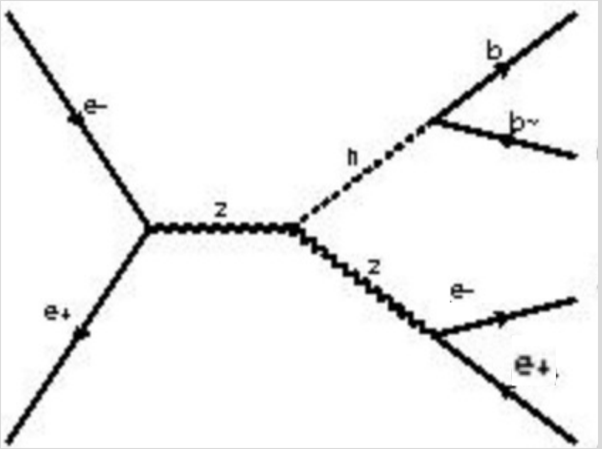
Measurement of m_S: Recoil Mass [Our Approach]

- The recoil mass, M_{recoil} is given as

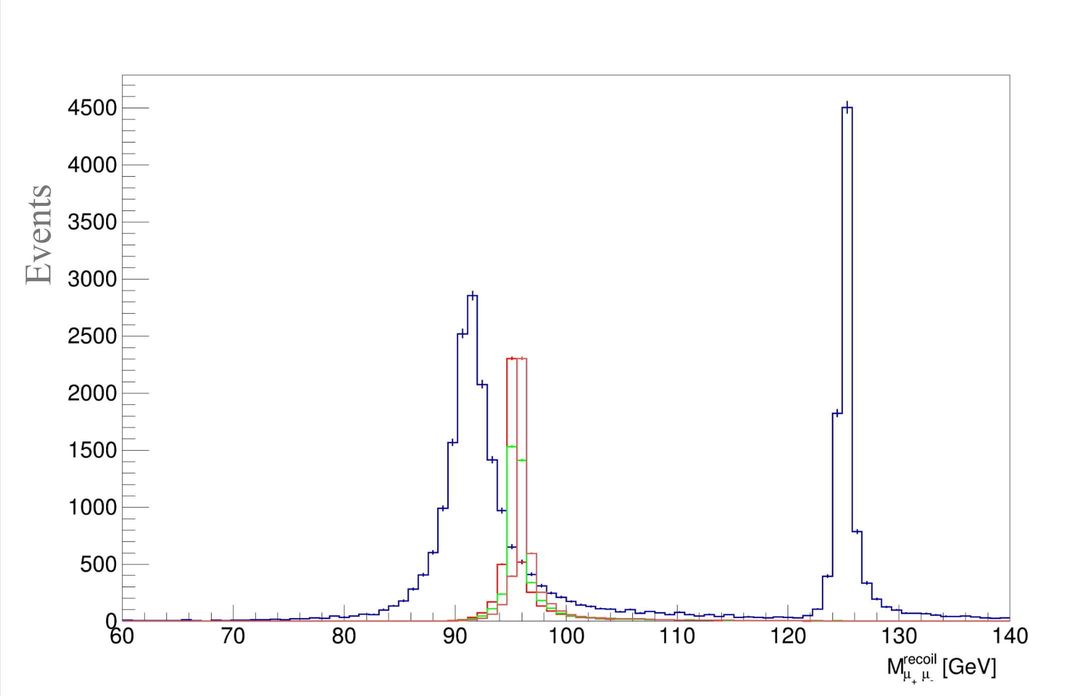
$$M_{recoil} = \sqrt{s + M^2_{\mu^+\mu^-} - 2\left(E_{\mu^+} + E_{\mu^-}\right)\sqrt{s}}$$





Excluded!

Measurement of m_S: Recoil Mass [Our Approach]



Measurement of m_S: Recoil Mass [Take-away]

- Classically, the measurement of Scalar Mass, m_S is possible but precision is the problem.

- Using Recoil Mass, M_{recoil} applied at future e^+e^- colliders, provide a precision improvement!

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Can we do better?

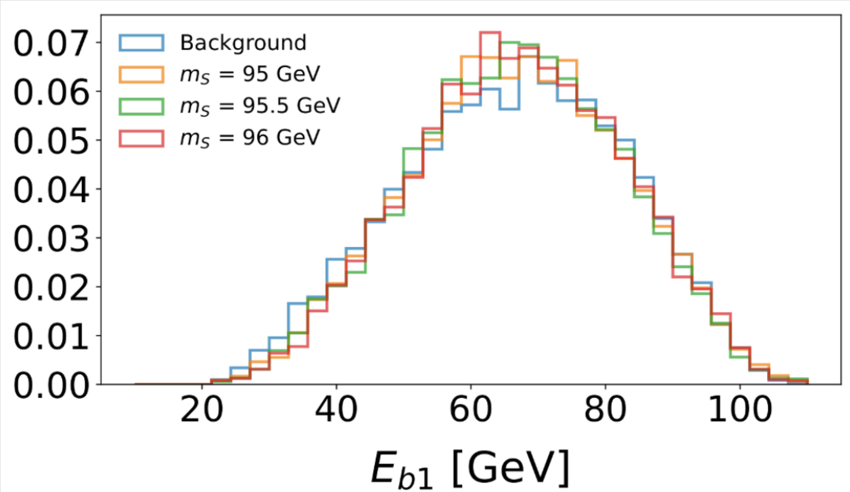
Measurement of m_S: [Our Approach but Different!!]

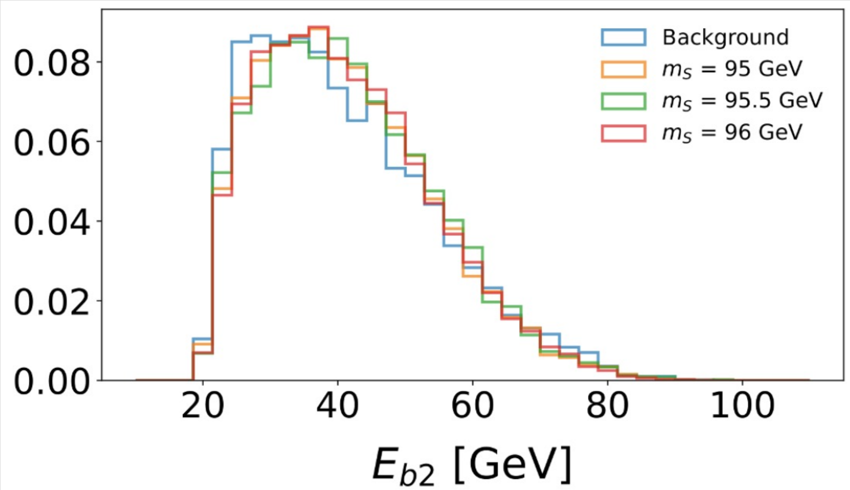
DNN

Measurement of m_S: Recoil Mass [DNN Approach]

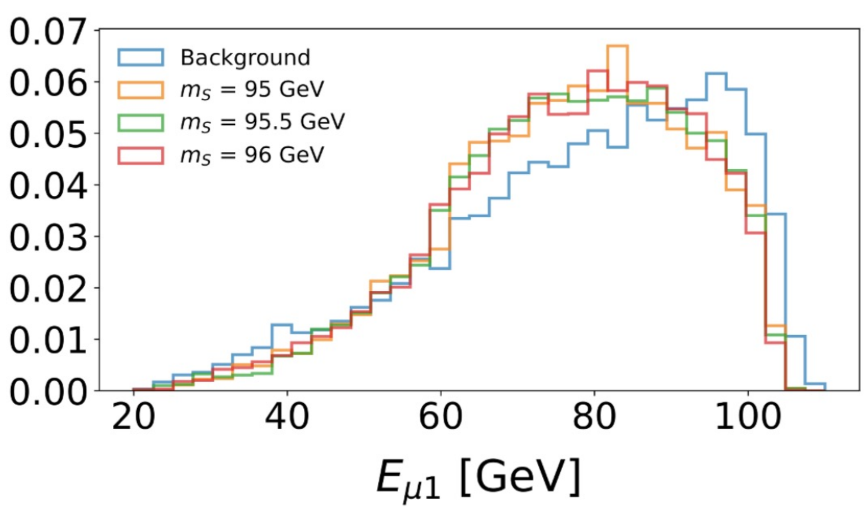
- We depend on 14 sensitive distributions as our input variables due to our final state particles ($\boldsymbol{2\ b - jets + \mu^+\mu^-}$).

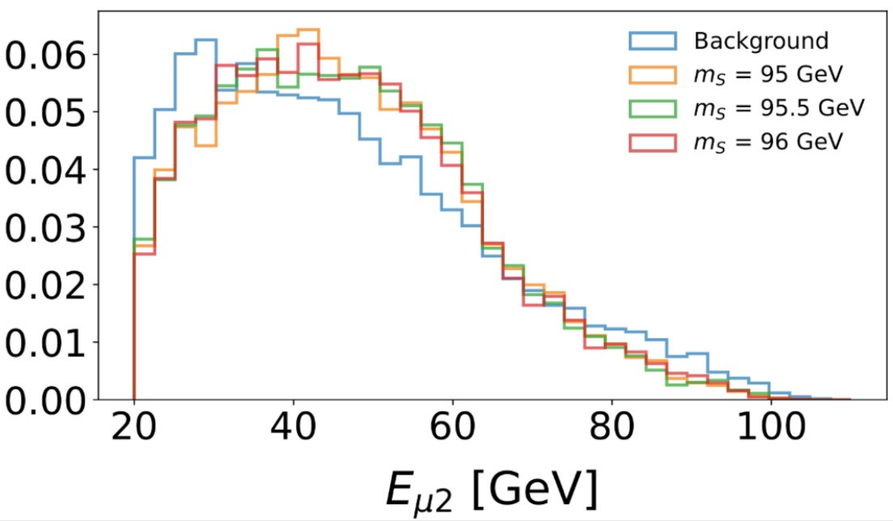
- We deploy a binary classification algorithm to train the model on the 14 variables:





Measurement of m_S: Recoil Mass [DNN Approach]





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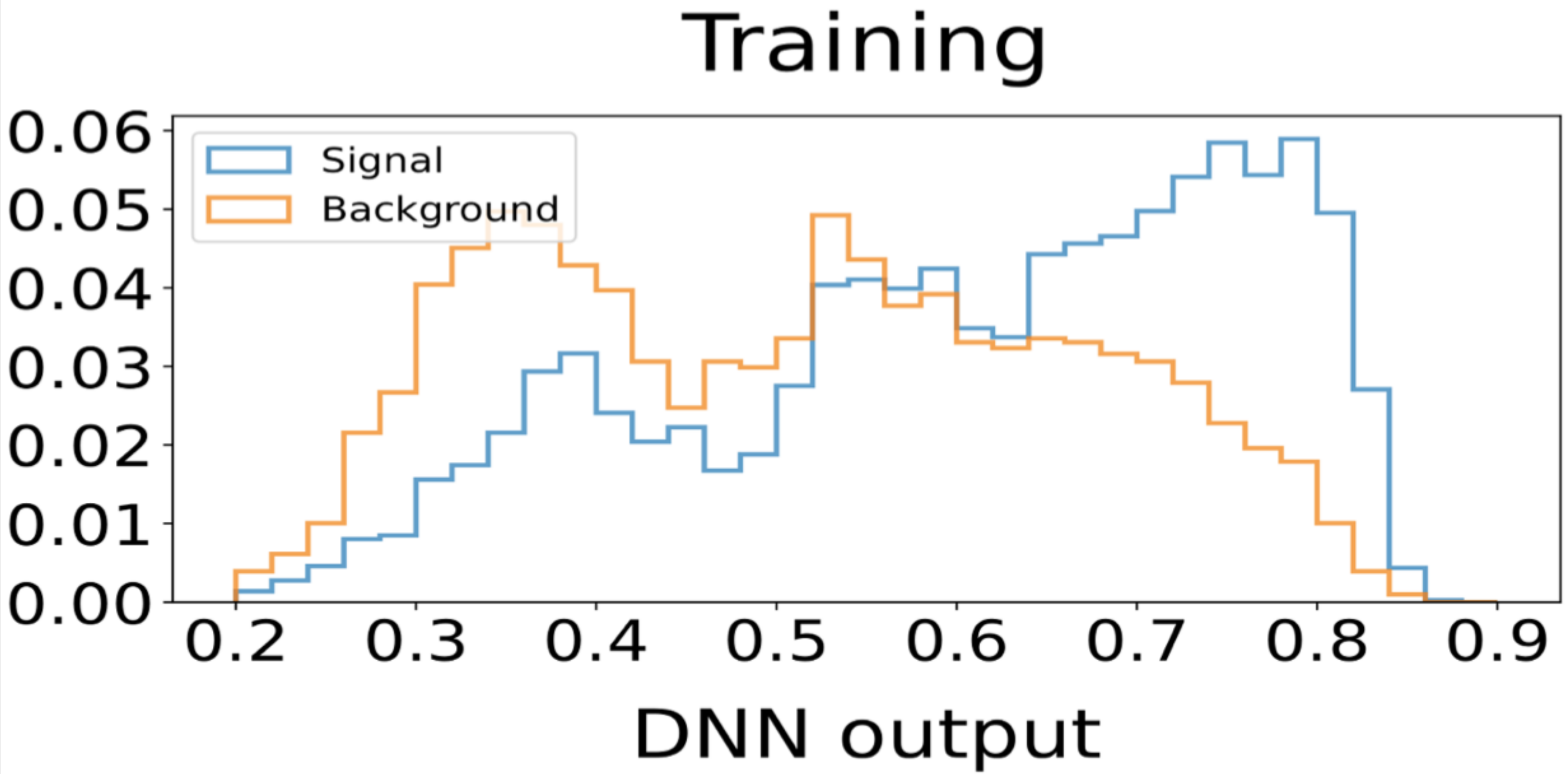

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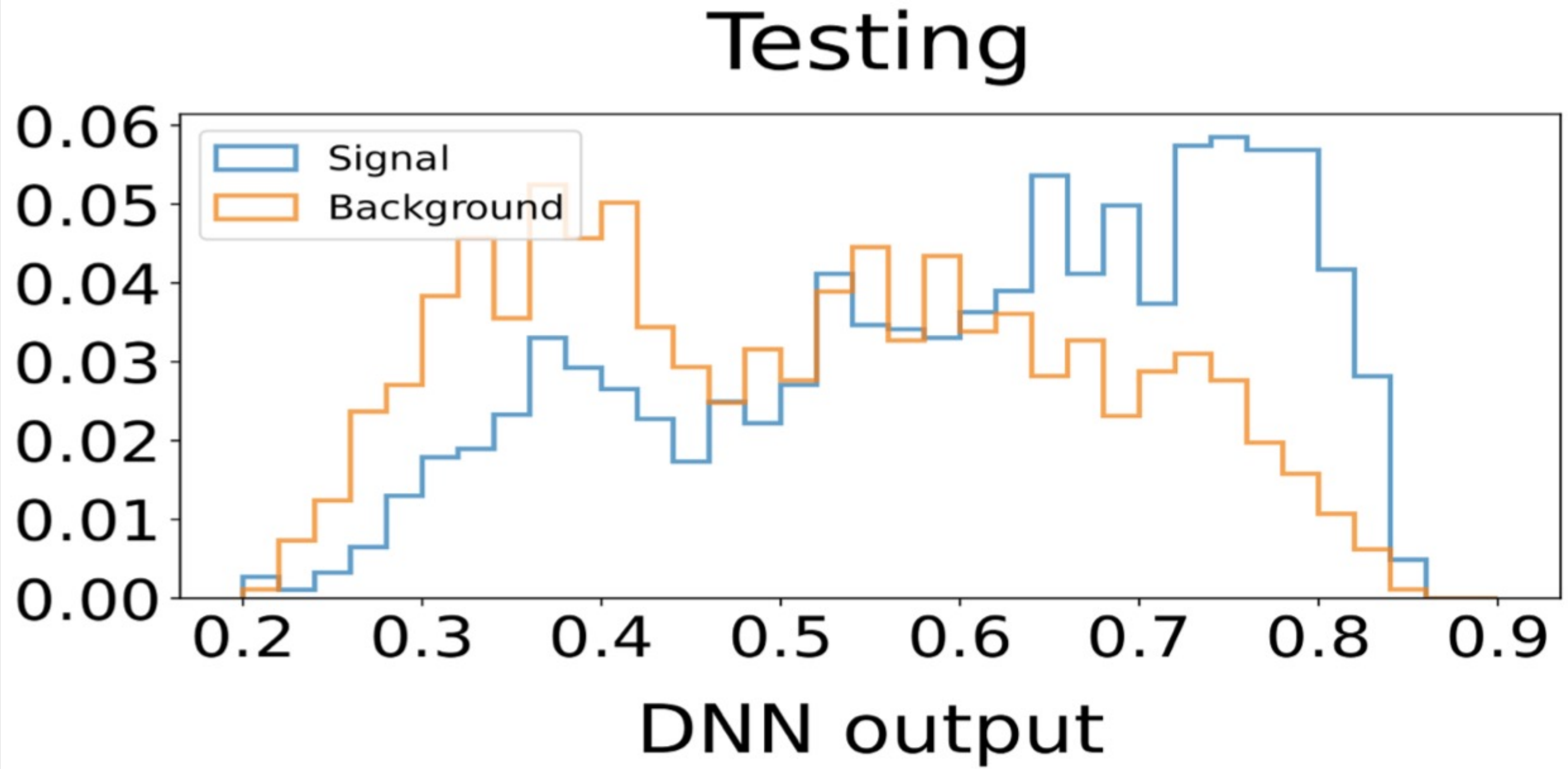

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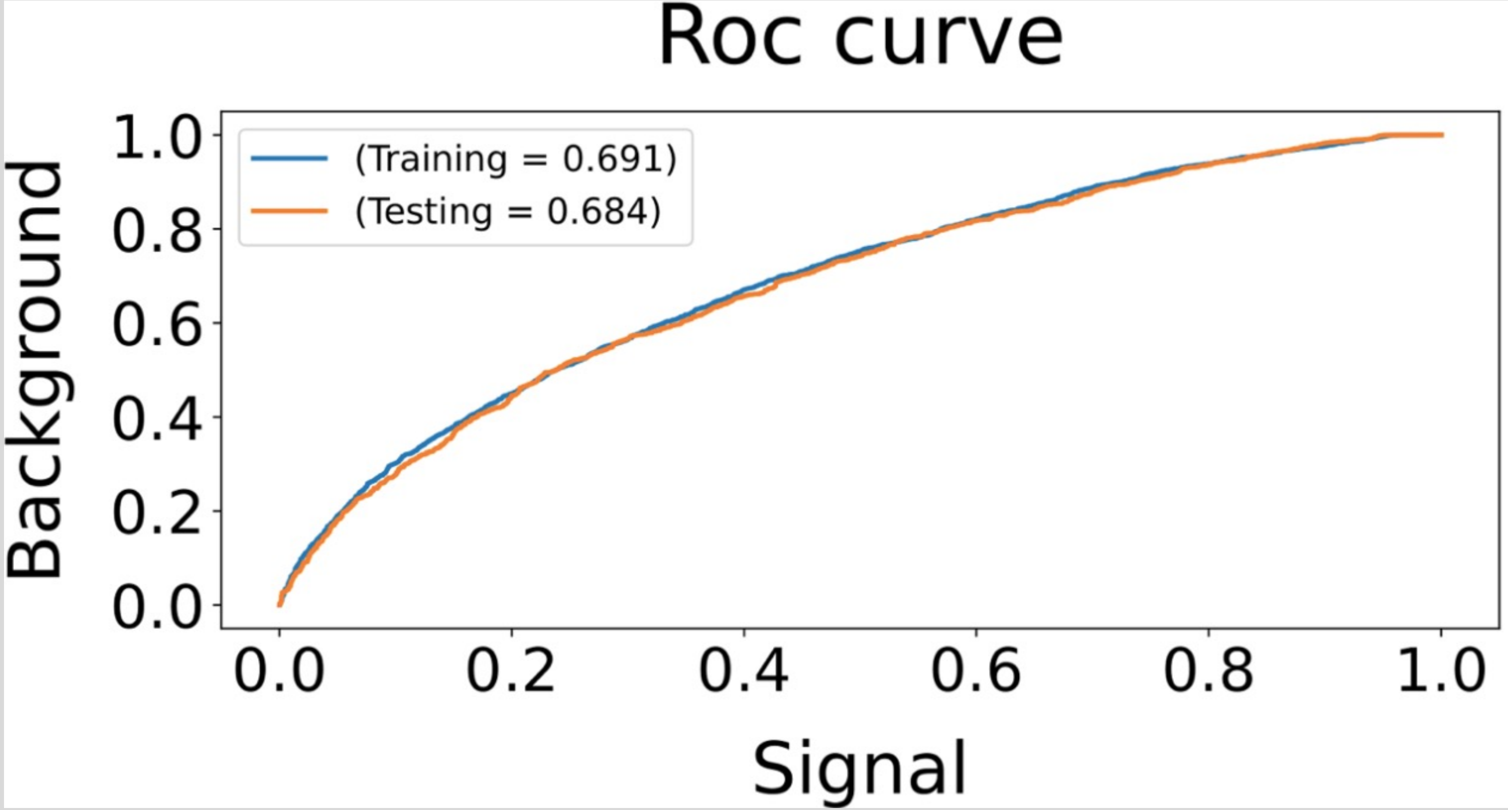

Outlook

- Excess around 95 GeV seems to be growing at the LHC and can be taken further in e^+e^- collider environment.
- At LHC, reached 3.8σ global significance just over 95 GeV, fitting well in a simplified model to explain the multi-lepton anomalies at the LHC.
- Overall the 95 GeV excess can be explained within errors with a $2HDM + S$ model, where predictions for e^+e^- can be made.
- Given the proximity of the Z peak, it is essential to use Machine Learning techniques to disentangle signal from background. → **going into deep learning** (entire final state).

Short Note - $2HDM + S$ Capabilities at Future e^+e^- Collider

- Simple extensions of the Standard Model (SM) are the two-Higgs doublet models (2HDMs) .

- Phenomenology and constraints on 2HDM using the experimental data from different collider environments can be explored.

- Set of independent parameters in N2HDM :

$$\alpha_1, \alpha_2, \alpha_3, t_\beta, v, v_S, m_{H_{1,2,3}}, m_A, m_H^\pm, m_{12}^2$$

- We can give optimised values of mixing angles which gives largest BR for $S \rightarrow W^+W^-$ – channel.

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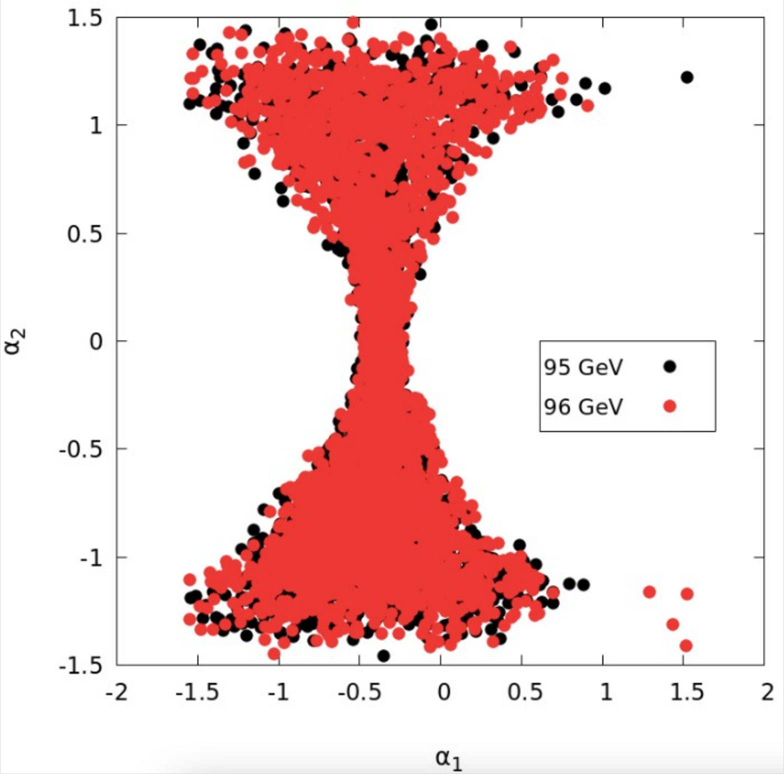

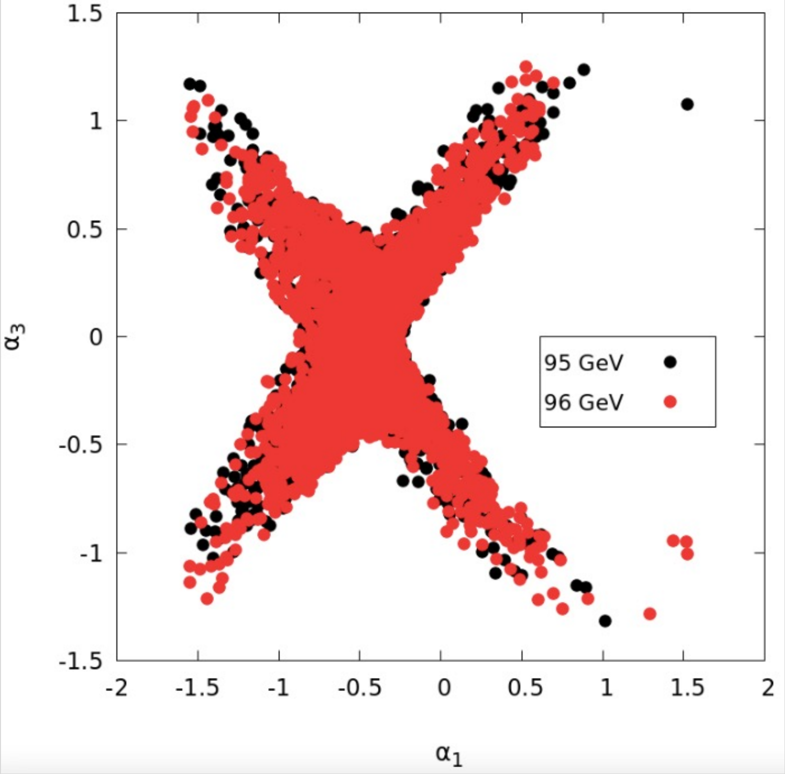

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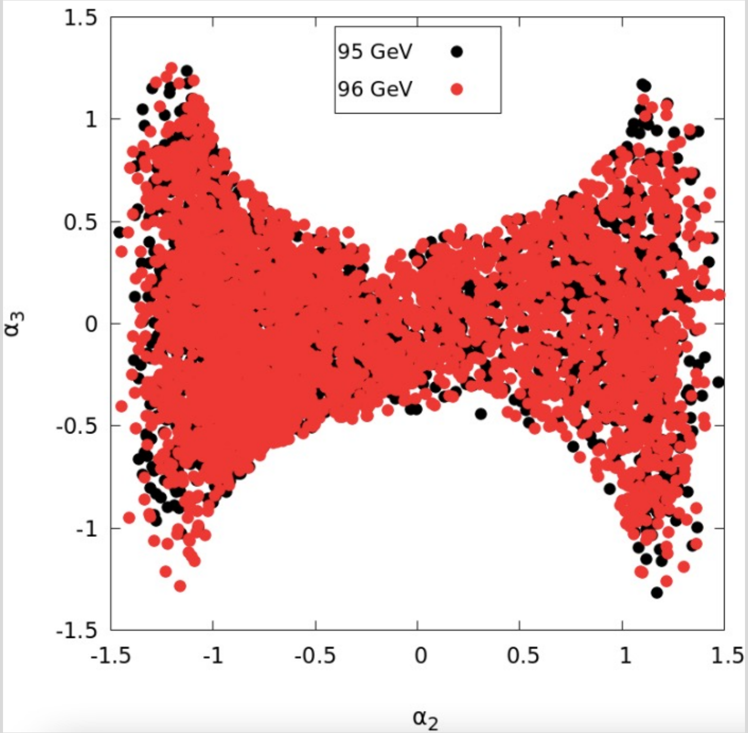

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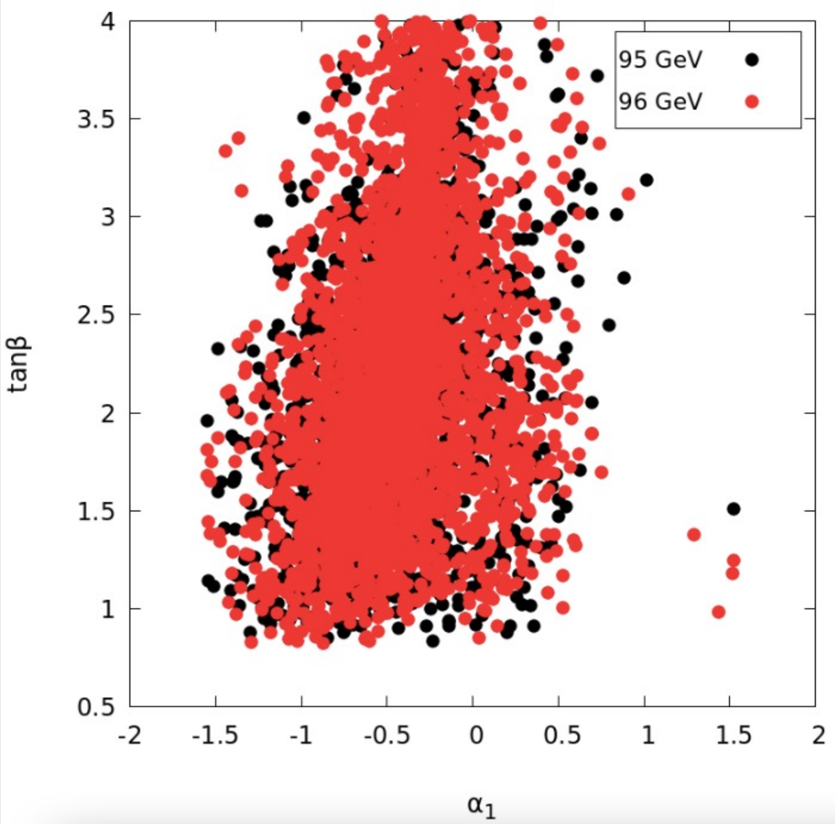

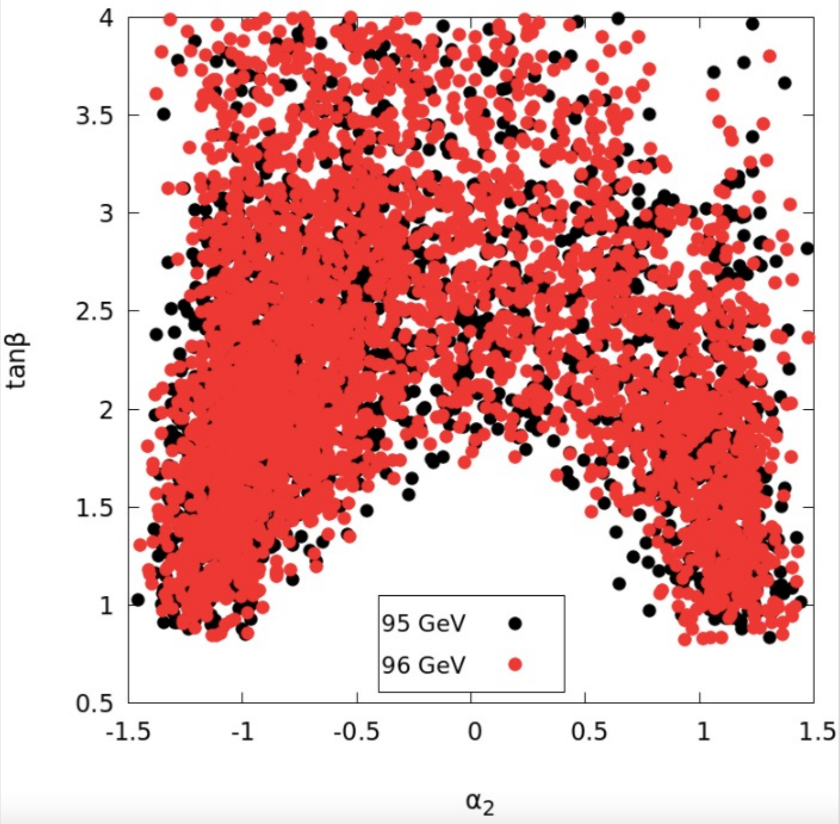

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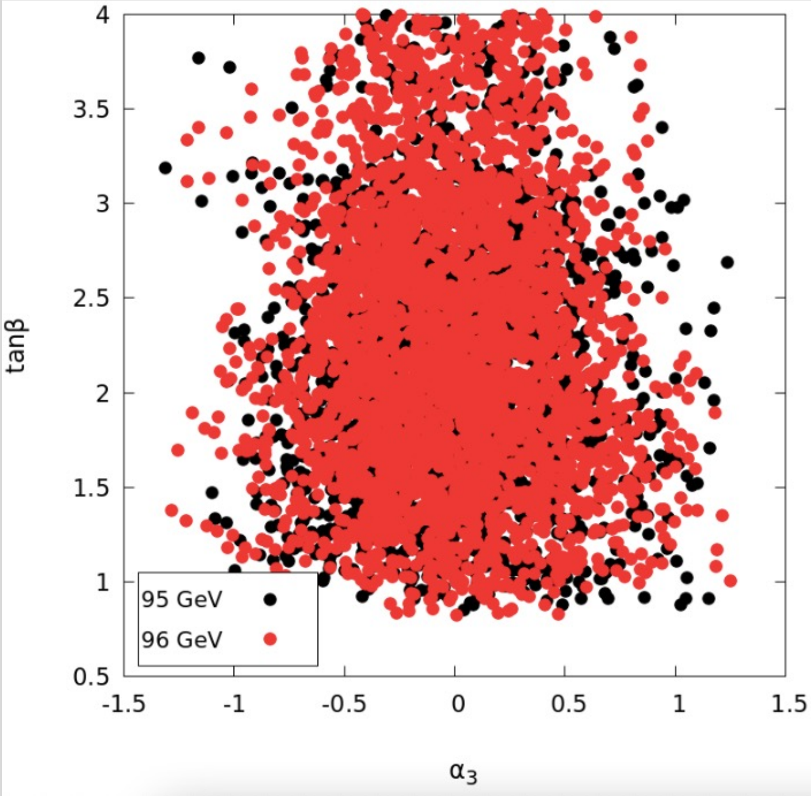

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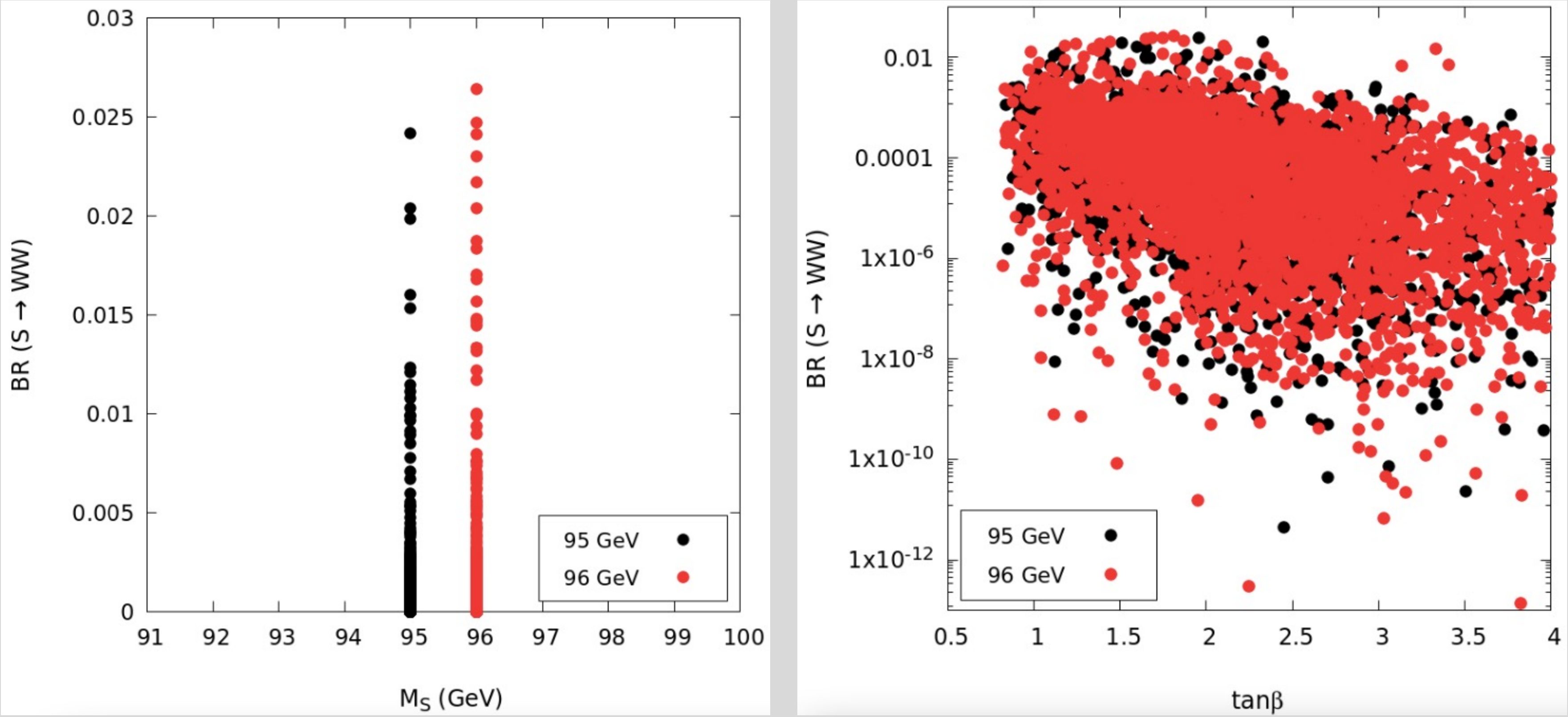

Short Note - $2HDM + S$ Capabilities at Future e^+e^- Collider

General consideration:

- Scalar Higgs S is produced through

$$e^+e^- \rightarrow e^+e^-S$$

$$e^+e^- \rightarrow v_e v_e \sim S$$

$$e^+e^- \rightarrow ZS$$

- The expected cross-sections are

  95 GeV are 0.001372, 0.01715, and 0.3566 pb, respectively.

  96 GeV are 0.00134, 0.01678, 0.353 pb, respectively.