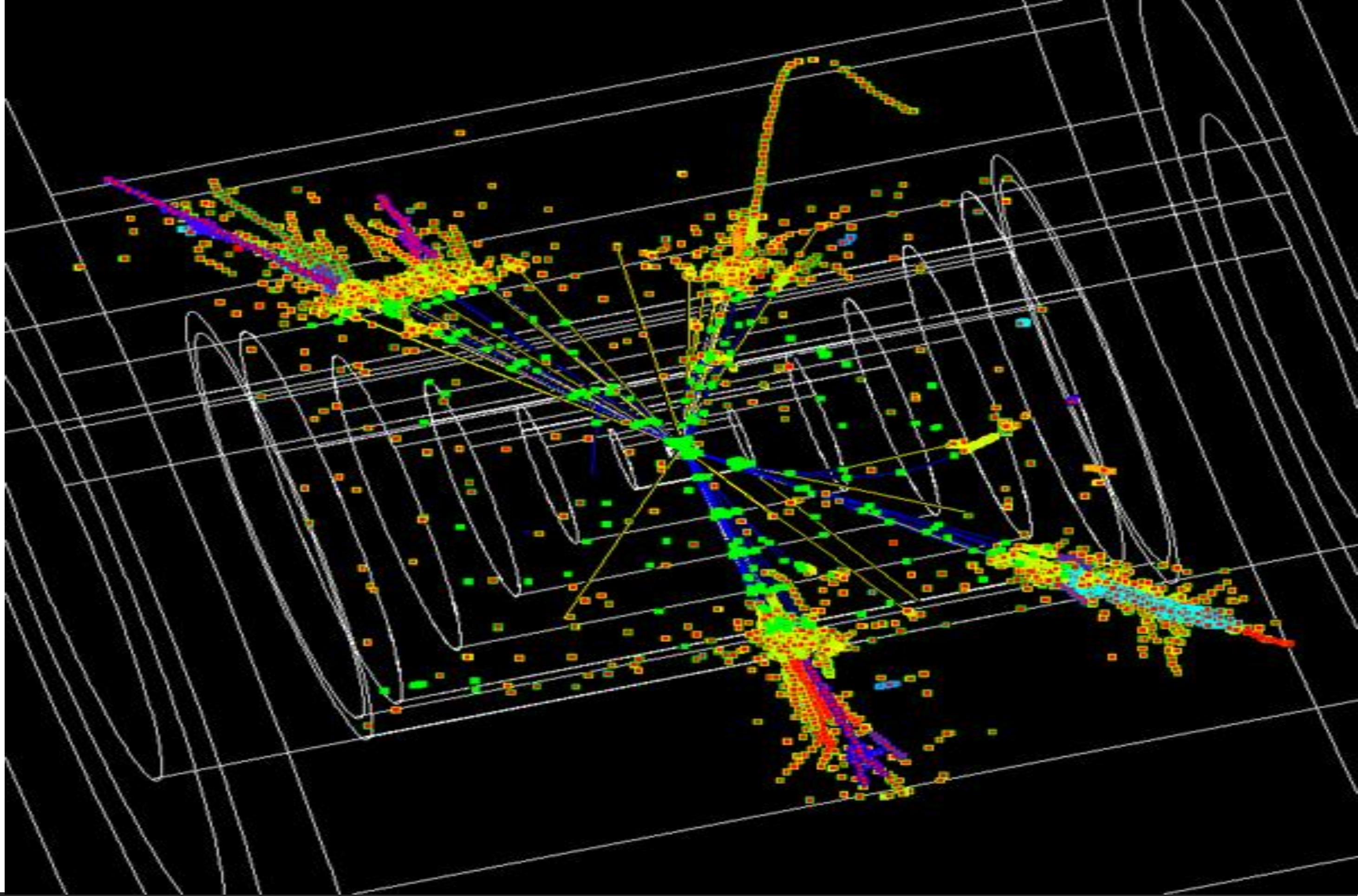

Studying the Production of a Singlet Scalar at Future $e^+ e^-$ Colliders with Deep Neural Networks

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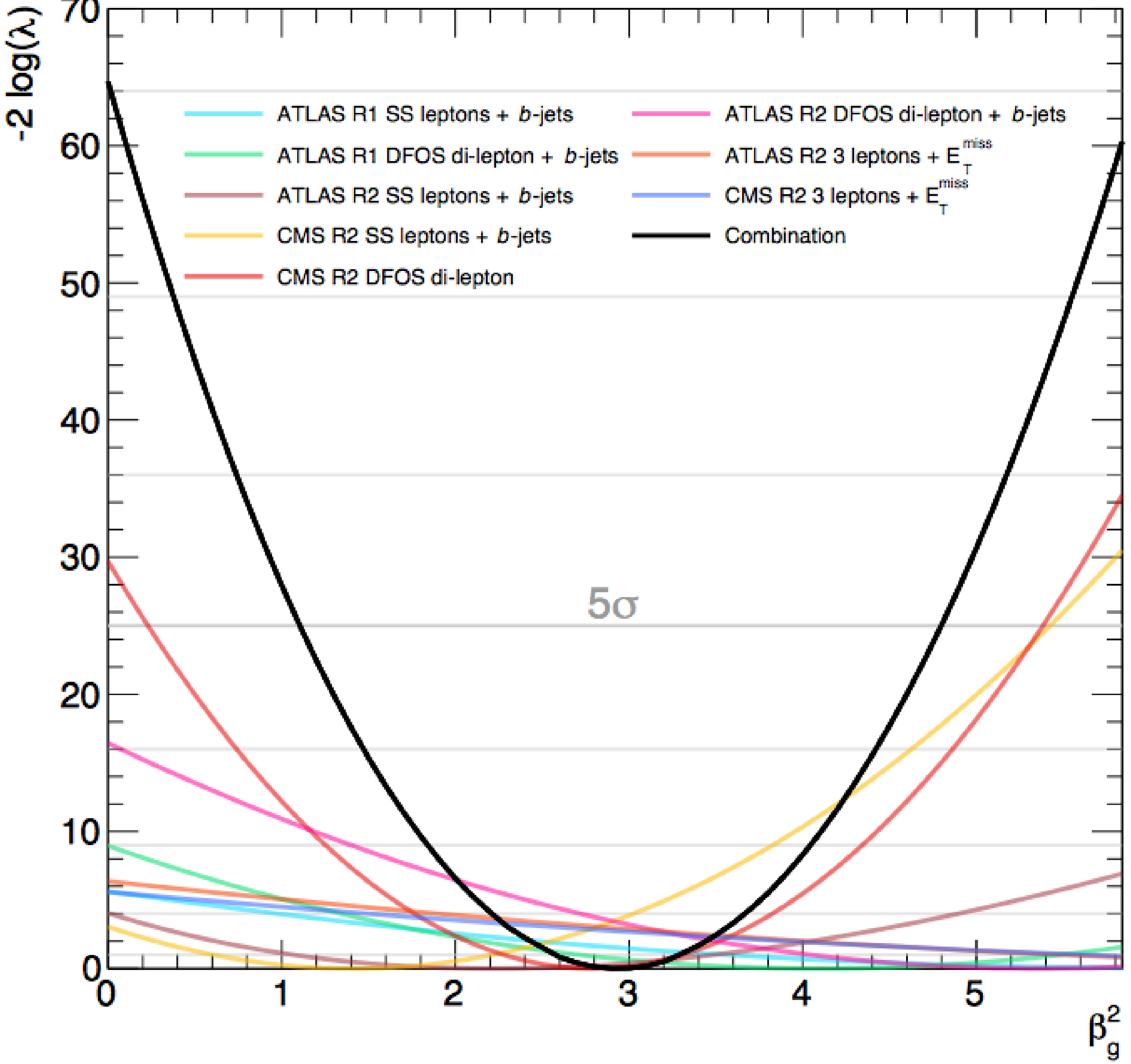
Contents

- Evidence of multi-lepton anomalies at the LHC
- Candidate of a new scalar boson at $m_S = 151.5$ GeV
- Electroweak properties of the new scalar resonance
- Monte Carlo Simulations
- Optimization of the channels
- Summary and conclusion

Evidence of Multi-lepton anomalies at the LHC

- The multi-lepton anomalies at the LHC are explained by the production of $H \to SS$ where H and S are new scalar bosons. It turns out that S has been found in association with DM, indicating that $H \to S(\to \gamma\gamma, Z\gamma)S \to \chi\chi$.
- The combined results correspond to a 8.04σ significance.
- Data consistent with new bosons: one with a mass around 270 GeV and another around 151.5 GeV.

Wits **ICPP**



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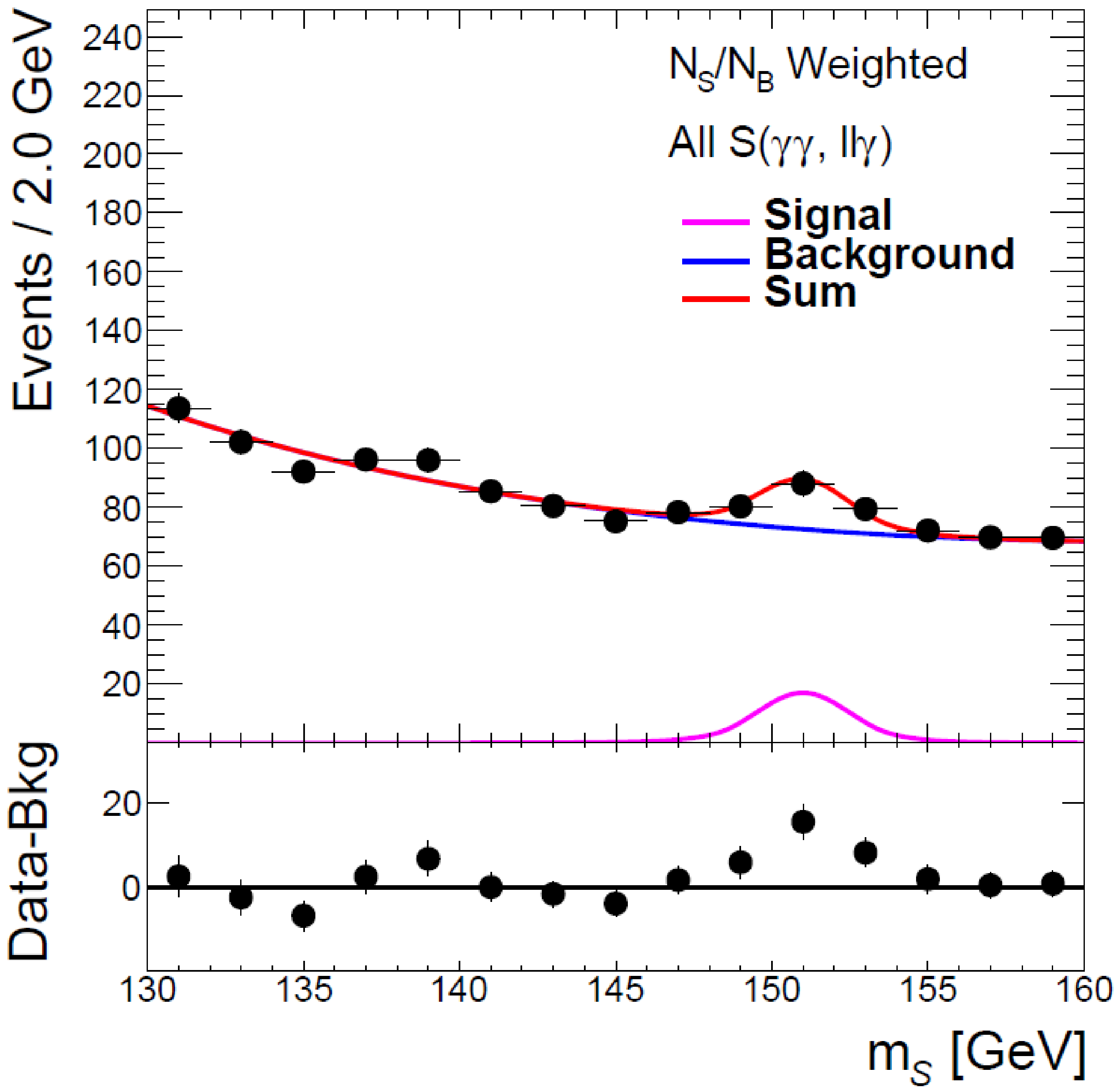
Candidate of the new boson at $m_S = 150$ GeV

- Candidate for a new boson with a mass of 150 GeV has been reported by Wits and collaborators in 2021.
- The existence was confirmed from the kinematic regions of the $\gamma\gamma$ and $Z\gamma$ channels and corresponding missing energy, di-jets and lepton, with a significance of 5.1σ.



arXiv:2109.02650

Electroweak Properties of the new scalar resonance

The Lagrangian for the model is presented as:

$$\mathcal{L} = \kappa_2 \frac{S}{2m_S} W^+_{\mu\nu} W^{-\mu\nu} + (\kappa_2 c_w^2 + \kappa_1 s_w^2) \frac{S}{4m_S} Z_{\mu\nu} Z^{\mu\nu} + 2c_w s_w \frac{S}{4m_S} (\kappa_2 - \kappa_1) Z_\nu F^{\mu\nu} + (\kappa_2 s_w^2 + \kappa_1 c_w^2) \frac{S}{4m_S} F_{\mu\nu} F^{\mu\nu}$$

$g_{SWW} = \kappa_2$, $g_{SZZ} = (\kappa_2 c_w^2 + \kappa_1 s_w^2)$, $g_{SZ\gamma} = c_w s_w (\kappa_2 - \kappa_1)$, and $g_{S\gamma\gamma} = \kappa_2 s_w^2 + \kappa_1 c_w^2$

The Electroweak singlet will have the following partial decay widths into two on-shell electroweak bosons ($m_S = 151.5$ GeV):

$$\Gamma(s \to WW) = \frac{1}{32\pi} g_{sWW}^2 m_s \sqrt{1 - 4x}(1 - 4x + 6x^2)$$

$$\Gamma(s \to ZZ) = \frac{1}{64\pi} g_{sZZ}^2 m_s \sqrt{1 - 4x}(1 - 4x + 6x^2)$$

$$\Gamma(s \to Z\gamma) = \frac{1}{32\pi} g_{sZ\gamma}^2 m_s (1 - x^2)^3$$

$$\Gamma(s \to \gamma\gamma) = \frac{1}{64\pi} g_{s\gamma\gamma}^2 m_s$$

where $x = \frac{m_V^2}{m_S^2}$

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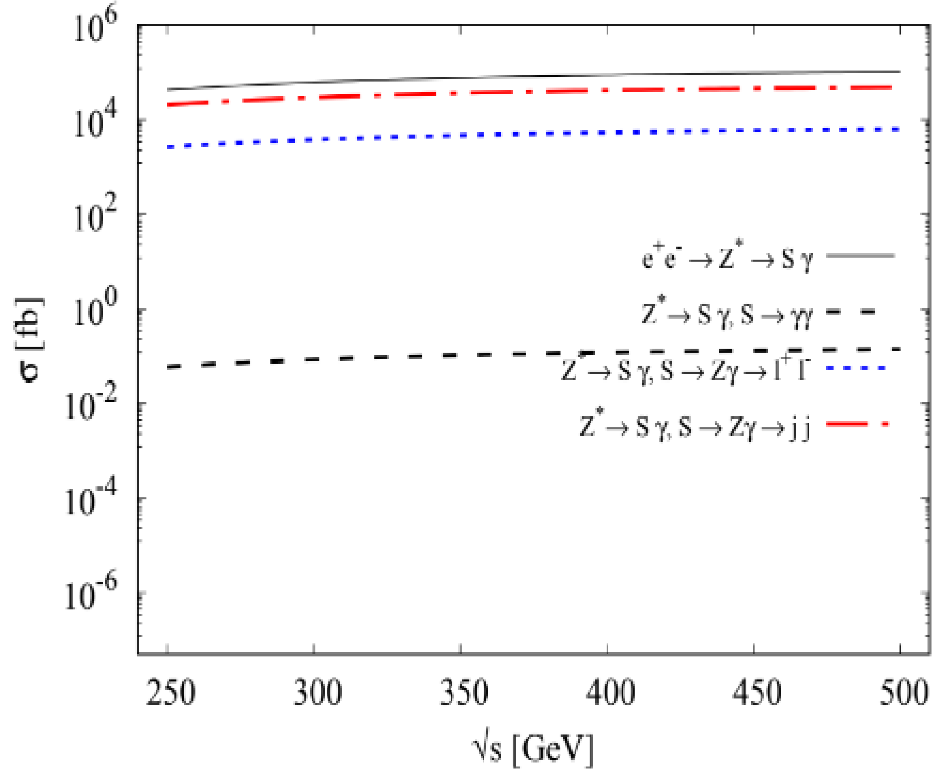
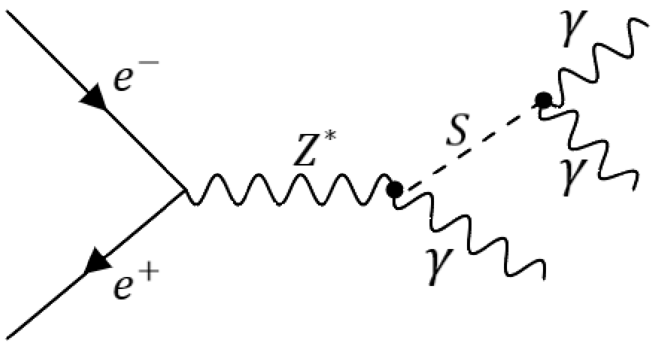
Monte Carlo Simulations

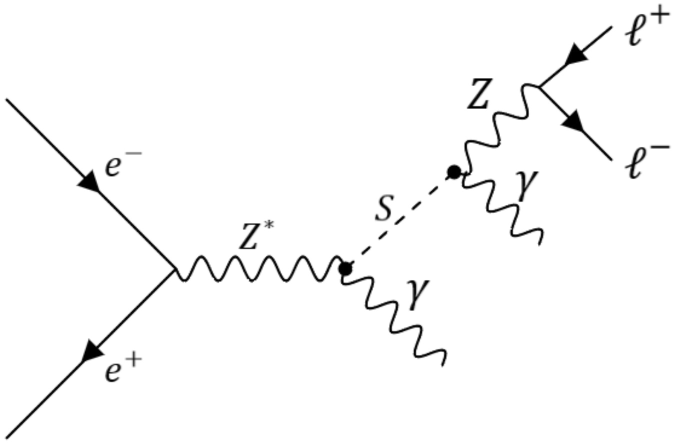
- The production of S was simulated using MG5@NLO.
- 500 000 signal and background events were simulated.



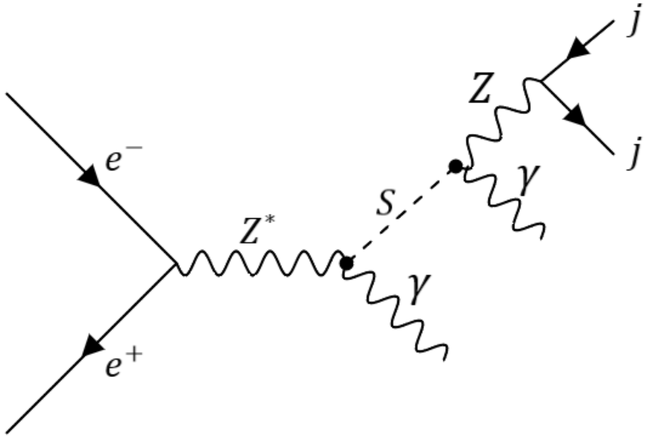
$\gamma\gamma$ channel:



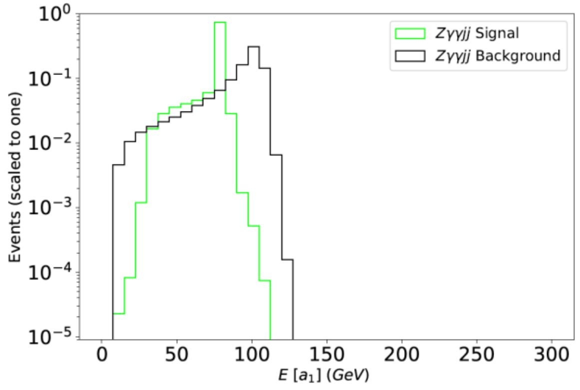
$Z\gamma\, l^+\, l^-$ channel:

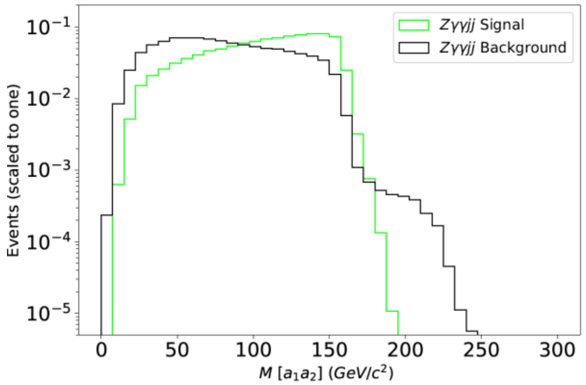


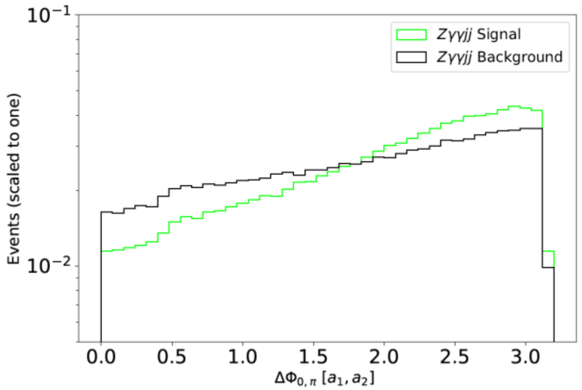
$Z\gamma\, j\, j$ channel:

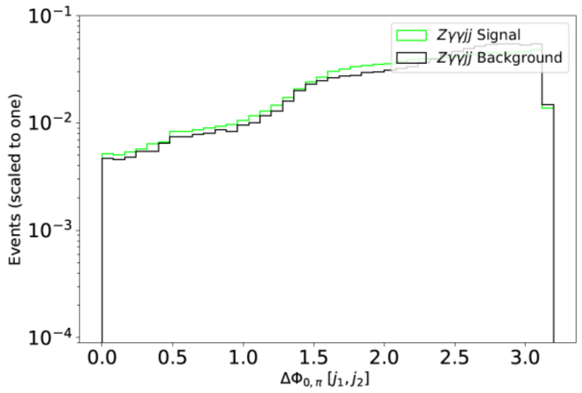


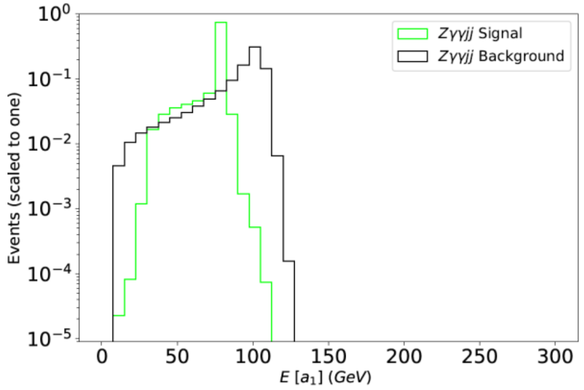
Kinematic distributions: $Z\gamma\, jj$ final state

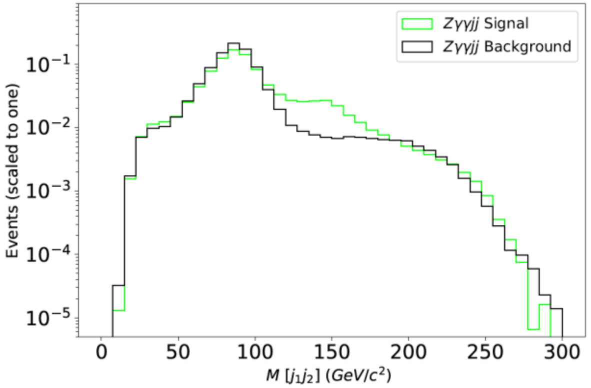






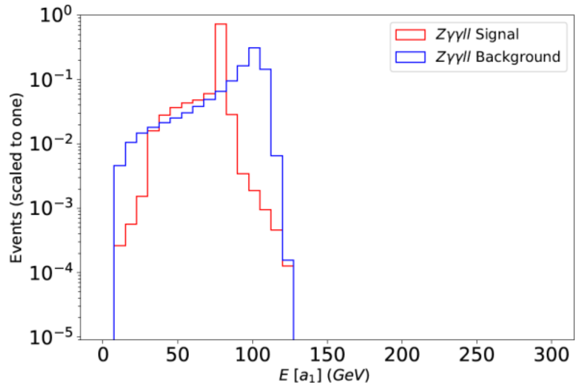


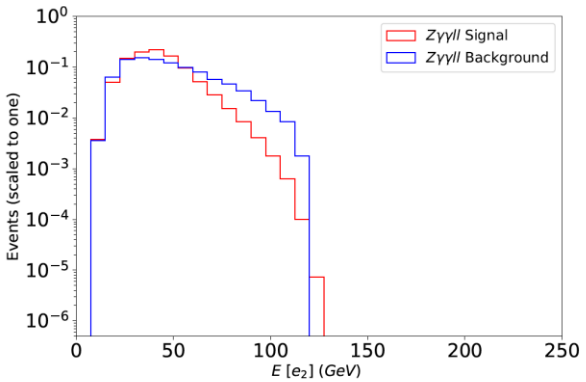


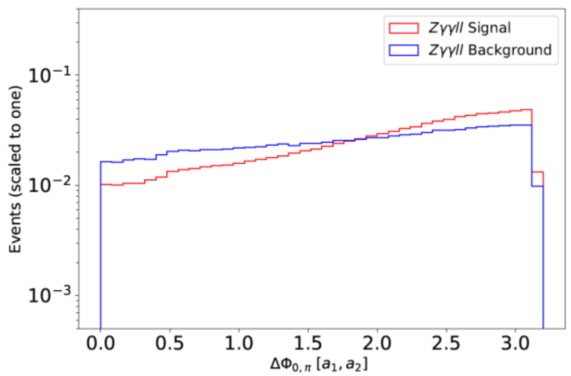


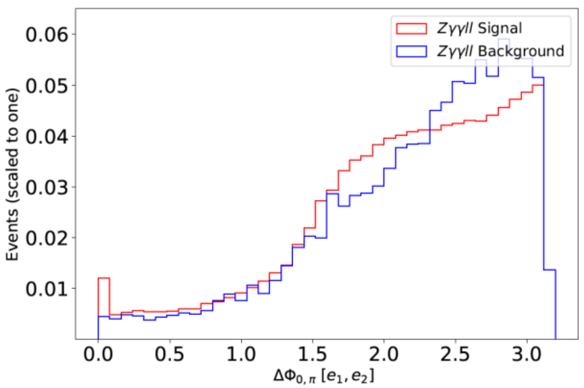
Cuts	Signal (S)	Background (B)	S vs B
Initial (no cut)	10258	300875	18.7
SEL: THT > 140.0	8463.1 +/- 38.5	101870 +/- 259	26.515729 +/- 0.000369
SEL: 30.0 > E < 90.0	8177.4 +/- 40.7	34920 +/- 175	43.75982 +/- 0.00109
SEL: 30.0 > E < 90.0	6220.4 +/- 49.5	22888 +/- 145	41.11579 +/- 0.00171
SEL: 40.0 > PT < 80.0	5806.6 +/- 50.2	18226 +/- 130	43.00988 +/- 0.00206
SEL: 25.0 > PT < 80.0	5087.1 +/- 50.6	11170 +/- 103	48.13267 +/- 0.00293
SEL: -1.1 > ETA < 1.1	4858.5 +/- 50.6	10267.7 +/- 99.6	47.9471 +/- 0.0031
SEL: -1.4 > ETA < 1.4	4592.6 +/- 50.4	9127.9 +/- 94.1	48.07023 +/- 0.00335
SEL: 90.0 > M < 170.0	3334.4 +/- 47.4	4613.0 +/- 67.4	49.09348 +/- 0.00497

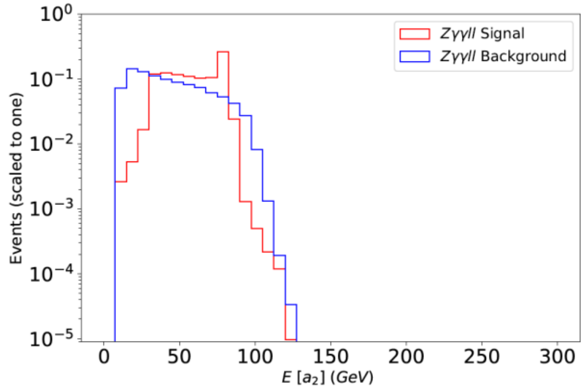
Kinematic distributions: $Z\gamma\, l^{+}\, l^{-}$ final state

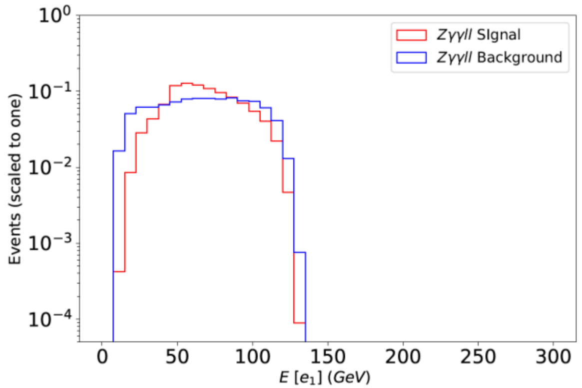






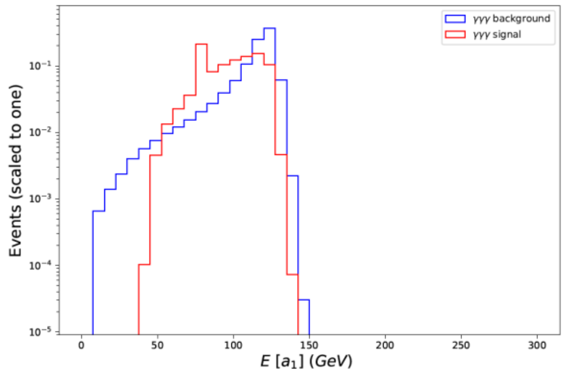


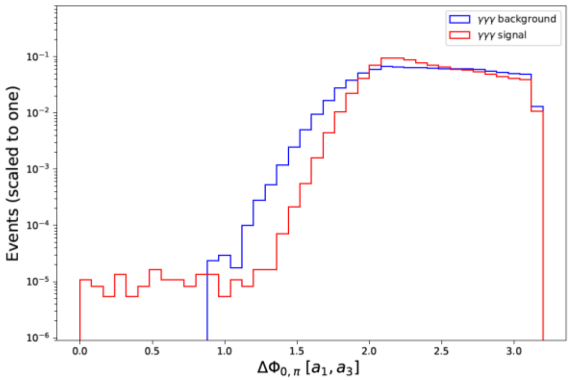


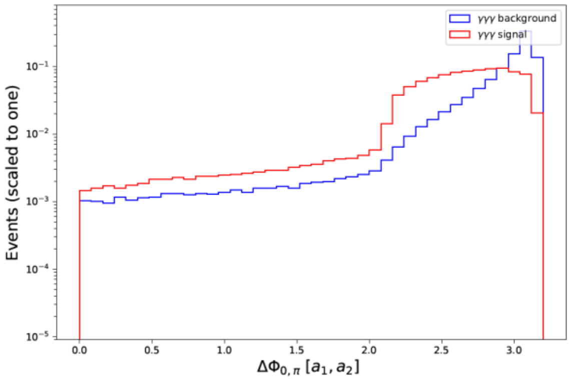


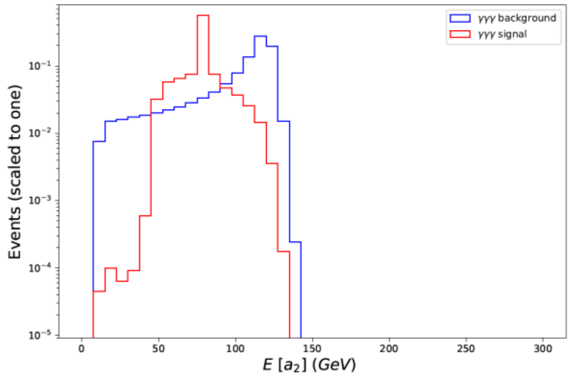
Cuts	Signal (S)	Background (B)	S vs B
Initial (no cut)	1317	300875	2.4
SEL: THT > 150.0	1109.3 +/- 13.2	86163 +/- 247	3.779210 +/- 0.000154
SEL: 30.0 > E < 95.0	1082.4 +/- 13.9	37808 +/- 181	5.566398 +/- 0.000371
SEL: 30.0 > E < 95.0	918.5 +/- 16.7	21904 +/- 142	6.206159 +/- 0.000745
SEL: 40.0 > PT < 80.0	857.0 +/- 17.3	17397 +/- 128	6.497286 +/- 0.000962
SEL: 25.0 > PT < 85.0	760.9 +/- 17.9	10997 +/- 102	7.25531 +/- 0.00153
SEL: -1.0 > ETA < 1.0	701.8 +/- 18.1	9446.3 +/- 95.7	7.22083 +/- 0.00178
SEL: -1.2 > ETA < 1.2	617.8 +/- 18.1	7415.4 +/- 85.0	7.17398 +/- 0.00223
SEL: 90.0 > M < 190.0	464.8 +/- 17.3	3753.7 +/- 60.9	7.58653 +/- 0.00399

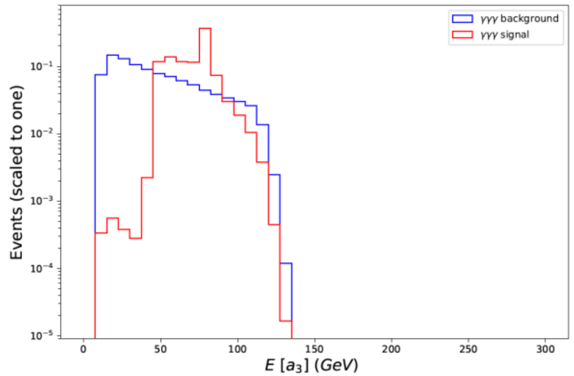
Kinematic distributions: $\gamma\gamma$ final state







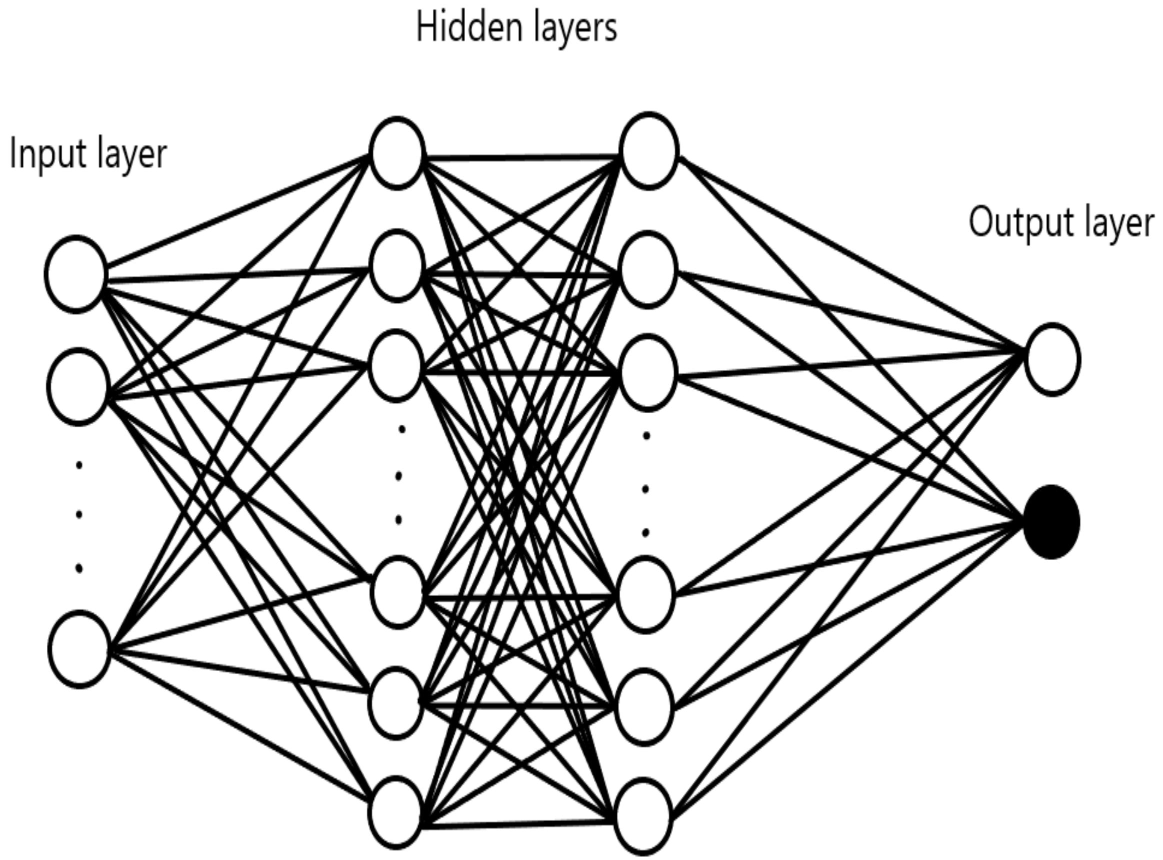




Cuts	Signal (S)	Background (B)	S vs B
Initial (no cut)	0.0294	301410	5.36e-05
SEL: THT > 140.0	0.0262 +/- 0.0533	120535 +/- 268	7.55e-05 +/- 4.43e-07
SEL: 40.0 > E < 110.0	0.018 +/- 0.084	29685 +/- 163	1.04e-04 +/- 2.82e-06
SEL: 50.0 > E < 90.0	0.0148 +/- 0.0858	9215.3 +/- 94.5	1.54e-04 +/- 9.31e-06
SEL: 50.0 > E < 90.0	0.0103 +/- 0.0819	5297.0 +/- 72.1	1.42e-04 +/- 1.55e-05
SEL: 65.0 > PT < 115.0	0.0102 +/- 0.0817	5162.6 +/- 71.2	1.43e-04 +/- 1.58e-05
SEL: 45.0 > PT < 80.0	0.00977 +/- 0.08079	4401.2 +/- 65.9	1.47e-04 +/- 1.84e-05
SEL: 30.0 > PT < 85.0	0.00841 +/- 0.07748	2684.4 +/- 51.6	1.62e-04 +/- 2.89e-05
SEL: -0.8 > ETA < 0.8	0.00803 +/- 0.07641	2397.4 +/- 48.8	1.64e-04 +/- 3.19e-05
SEL: -1.0 > ETA < 1.0	0.00772 +/- 0.07545	2225.0 +/- 47.0	1.64e-04 +/- 3.39e-05
SEL: _-1.5 > ETA < 1.5	0.00739 +/- 0.07440	2029.7 +/- 44.9	1.64e-04 +/- 3.67e-05
SEL: _90.0 > M < 210.0	0.00739 +/- 0.07440	2029.7 +/- 44.9	1.64e-04 +/- 3.67e-05
SEL: _80.0 > M < 170.0	0.00736 +/- 0.07429	2014.0 +/- 44.7	1.64e-04 +/- 3.69e-05

Optimisation of the channels

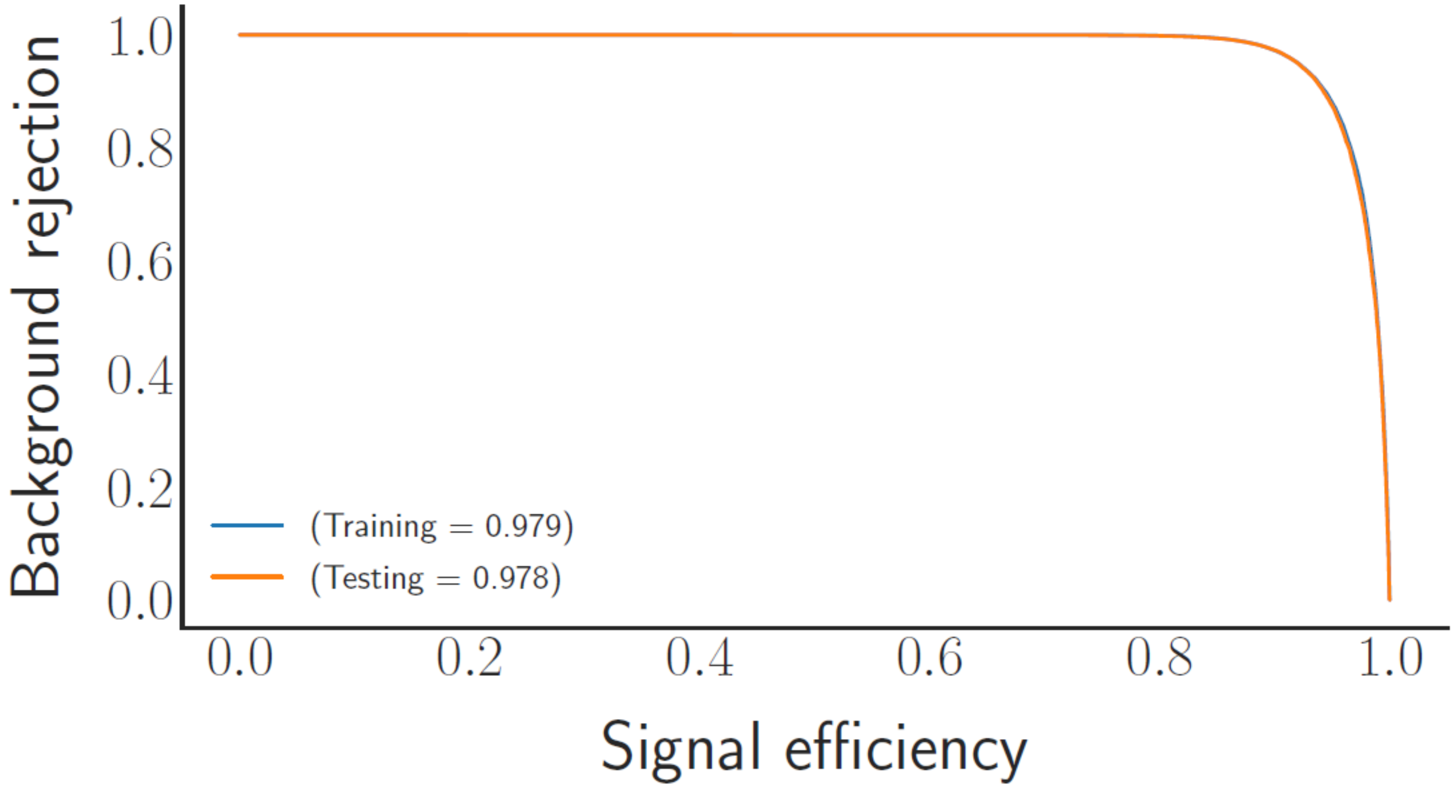
- This is the motivation to introduce Machine Learning (ML) in this study.
- It makes use of a Deep Neural Network (DNN) to distinguish between signal and background processes through a Sequential Model.
- Parameters:
  - Optimiser, learning rate, neurons, batch size and epochs.



Results (preliminary):

$\gamma\gamma$ final state:

Batch size	23
Learning rate	0.000743
Neurons	48
Optimizer	Adamax
Epochs	273
Accuracy	97.8%



Conclusion and summary:

- The multi-lepton anomalies at the LHC are explained by the production of $H \rightarrow SS$ where H and S are new scalar bosons. It turns out that S has been found in association with DM, indicating that $H \rightarrow S(\rightarrow \gamma\gamma, Z\gamma)S \rightarrow \chi\chi$.
- The results show that the cross-section of these scalar resonances are large enough to be detected at future $e^+ e^-$ colliders.
- The use of machine learning helps us to distinguish between the signal and the background events and using hyperparameter optimisation, we were able to get a considerable accuracy for our models.
- This motivates the search for the scalar resonances at future $e^+ e^-$ colliders.

Thank you!