ALPs @ FCC-ee

Sensitivity of the FCC-ee to ALPs decaying to two photons

FUTURE CIRCULAR COLLIDER

Indico: https://indico.desy.de/event/50381/
18 August 2025

Uncertainty Calculations

$$N_{\text{exp}} = \sigma \mathcal{L}_{\text{int}} \frac{N_{\text{sel}}}{N_{\text{tot}}}$$

expected number of events
cross section
integrated luminosity
remaining events after selections
total number of events before selections

The number of expected events is given by:

$$N_{\text{exp}} = \sigma \mathcal{L}_{\text{int}} \frac{N_{\text{sel}}}{N_{\text{tot}}} \tag{1}$$

where N_{exp} corresponds to the number of expected events, σ to the cross section, $\mathcal{L}_{\text{int}}$ to the integrated luminosity, N_{sel} to the remaining events after selections, and N_{tot} to the total number of events before selections, respectively.

We assume Poissonian statistics for N_{sel}. Uncertainty propagation gives:

$$\Delta N_{\text{exp}} = \sigma \mathcal{L}_{\text{int}} \frac{\Delta N_{\text{sel}}}{N_{\text{tot}}} \tag{2}$$

For a Poisson-distributed count N, the standard deviation (statistical uncertainty) is $\sqrt{N}$. Substitute $\Delta N_{\text{sel}} = \sqrt{N_{\text{sel}}}$

$$\Delta N_{\text{exp}} = \sigma \mathcal{L}_{\text{int}} \frac{\sqrt{N_{\text{sel}}}}{N_{\text{tot}}} \tag{3}$$

Uncertainty Calculations

Using Elnura's results from the Z-Pole study. Given statistics are from Z-Pole centre-of-mass energy, thus integrated luminosity corresponds to $\mathcal{L} = 205\ \text{ab}^{-1}$. Results for two signal points summarized below:

m_a [GeV]	$c_{\gamma\gamma}$	σ [pb]	N_{exp}	%
10.0	1.6	6.764	4.25e+0.8	63
1.0	1.0	2.739	2.26e+0.8	82

Table 1: Summary of results from Elnura's thesis and slides. Table displays ALP mass, photon coupling strength, rounded cross section from MadGraph, number of expected events after selections, and remaining percent of initial number of events after selections. For each sample, 10^6 events were produced.

Uncertainty Calculations

Will calculate uncertainty for $m_a = 1.0$ GeV and $c_{\gamma\gamma} = 1.0$ sample. First need to determine N_{sel}. Rearranging Equation 1 gives:

$$N_{sel} = \frac{N_{exp} N_{tot}}{\sigma \mathcal{L}_{int}}$$

Substituting this into Equation 3 results in:

$$\Delta N_{exp} = \sigma \mathcal{L}_{int} \frac{\sqrt{\frac{N_{exp} N_{tot}}{\sigma \mathcal{L}_{int}}}}{N_{tot}} = \sqrt{\frac{\sigma \mathcal{L}_{int} N_{exp}}{N_{tot}}}$$

Substituting values and evaluating:

$$\Delta N_{exp} = \sqrt{\frac{2.74 \text{ pb} \times 205 \text{ ab}^{-1} \times 10^6 \text{ ab pb}^{-1} \times 2.26 \times 10^8}{10^6}} = 3.56 \times 10^5$$

Hence

$$\frac{\Delta N_{exp}}{N_{exp}} = 0.0016$$

This uncertainty is small, so generating 10^6 signal events is reasonably sufficient for the analysis.

Uncertainty Calculations

Now we show the calculations for uncertainty on the expected number of **background** events.

Once again using Elnura's results from the Z-Pole study. Given statistics are from Z-Pole centre-of-mass energy, thus integrated luminosity corresponds to $\mathcal{L} = 205\ \text{ab}^{-1}$. Results for three background processes summarized below:

Process	σ [pb]	N_{exp}	%
$e^+e^- \to \gamma\gamma$	67.25	0	0
$e^+e^- \to \gamma\gamma\gamma$	2.995	9.16e+0.7	15
$e^+e^- \to \gamma\gamma\gamma\gamma$	0.06271	2.16e+04	0.17

Table 2: Summary of results from Elnura's thesis and slides. Table displays background process, rounded cross section from MadGraph, number of expected events after selections, and remaining percent of initial number of events after selections. For each sample, 10^6 events were produced.

Uncertainty Calculations

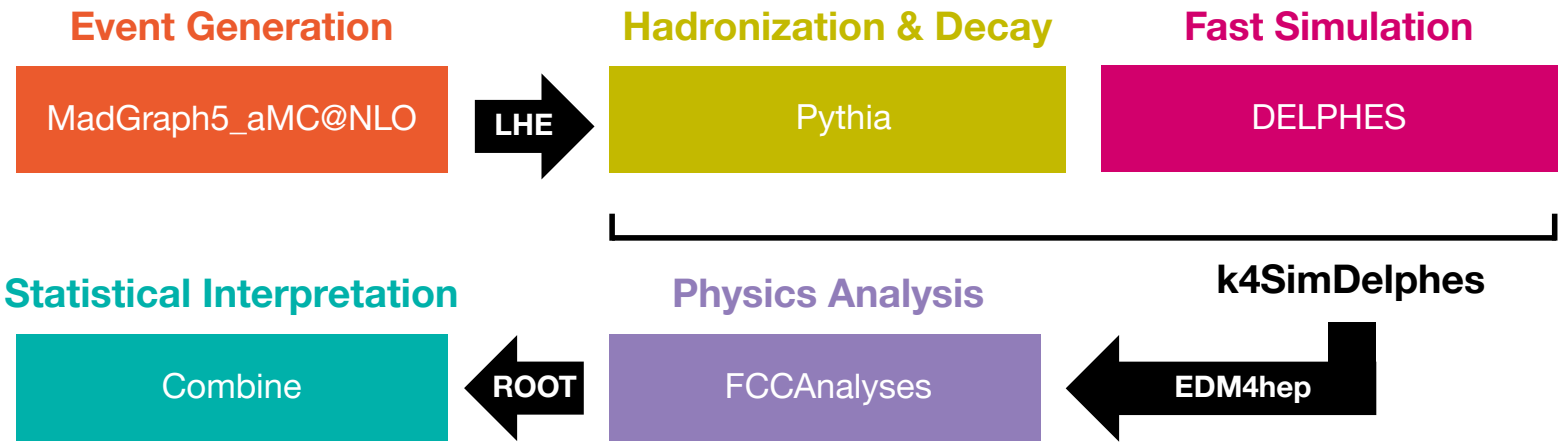
We observe zero expected events for the background process $e^+e^- \to \gamma\gamma$. Will calculate expected number of events given the conservative estimate that 10 events remain after selections.

Using Equation 1:

$$N_{\text{exp}} = \sigma \mathcal{L}_{\text{int}} \frac{N_{\text{sel}}}{N_{\text{tot}}} = 67.25 \text{ pb} \times 205 \text{ ab}^{-1} \times 10^6 \text{ ab pb}^{-1} \times \frac{10}{10^6} = 1.38 \times 10^5$$

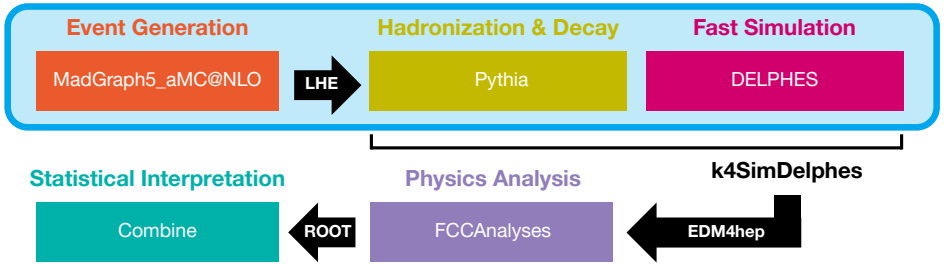
This is approximately three orders of magnitude lower than the expected number of events for the dominant background process $e^+e^- \to \gamma\gamma\gamma$. Hence, we can disregard this background with negligible effect. We also see that the background process $e^+e^- \to \gamma\gamma\gamma\gamma$ yields an expected number of events that is also three/four orders of magnitude smaller than the dominant background, so the same conclusion holds.

Technical workflow

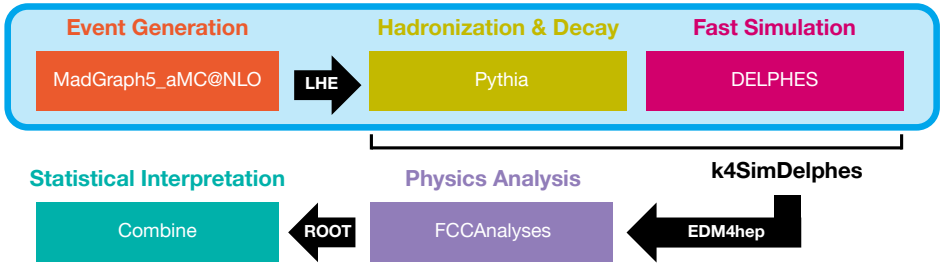


Samples

- Small “test” dataset already produced
  - Samples generated with MadGraph, passed through Pythia + DELPHES
  - Ready to analyze with FCCAnalyses



Samples



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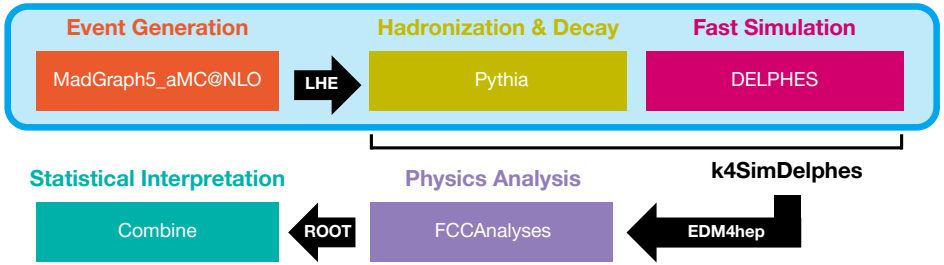
- *'signal_Z_malp1_events10k_edm4hep'*
- *'signal_Z_malp50_events10k_edm4hep'*
- *'signal_WW_malp1_events10k_edm4hep*
- *'signal_WW_malp50_events10k_edm4hep'*
- *'signal_ZH_malp1_events10k_edm4hep'*
- *'signal_ZH_malp50_events10k_edm4hep'*
- *'signal_tt_malp1_events10k_edm4hep'*
- *'signal_tt_malp50_events10k_edm4hep'*
- *'background_Z_events10k_edm4hep'*
- *'background_WW_events10k_edm4hep'*
- *'background_ZH_events10k_edm4hep'*
- *'background_tt_events10k_edm4hep'*

Samples



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- *'signal_ZH_malp50_events10k_edm4hep'*
- *'signal_tt_malp1_events10k_edm4hep'*
- *'signal_tt_malp50_events10k_edm4hep'*
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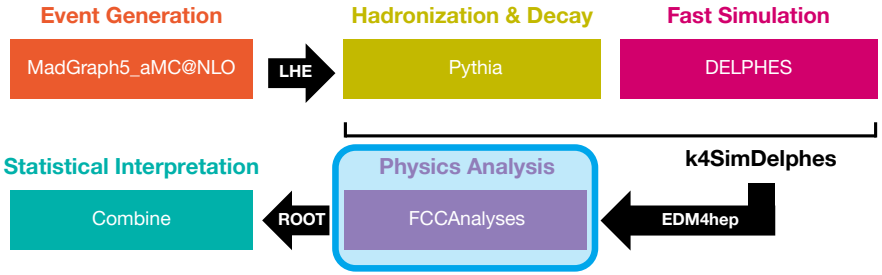
- *'background_WW_events10k_edm4hep'*
- *'background_ZH_events10k_edm4hep'*
- *'background_tt_events10k_edm4hep'*

- Set up MadGraph to run on Condor
- Currently producing full samples (1M events per signal point)

√s [GeV]	m_a [GeV]
91.2	0.01, 0.1, 1.0, 10, 50
160	0.01, 0.1, 1.0, 10, 50, 91.2, 100, 150
240	0.01, 0.1, 1.0, 10, 50, 91.2, 100, 150, 160, 200
365	0.01, 0.1, 1.0, 10, 50, 91.2, 100, 150, 160, 200, 240, 250, 300, 350

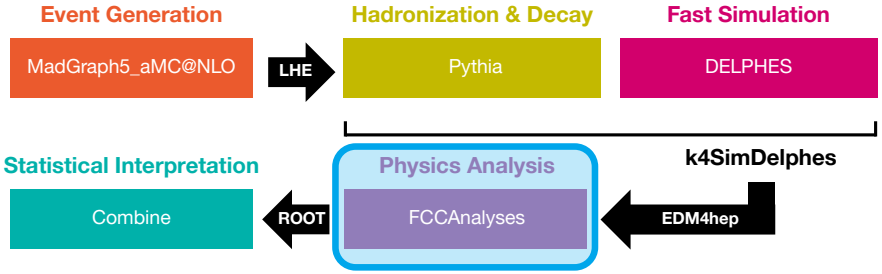
Analysis framework

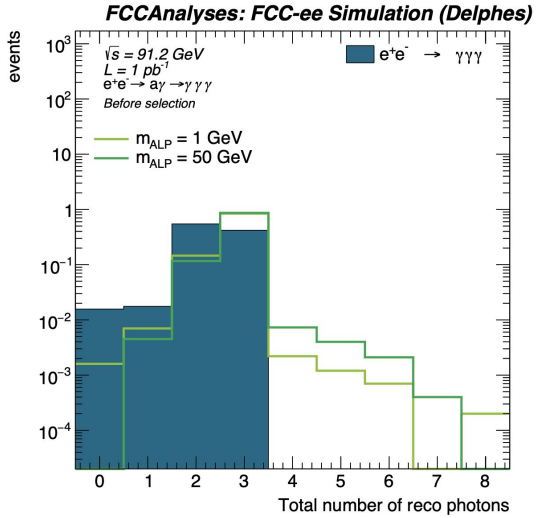
- Tested and ran over two signal points and one background (new samples)

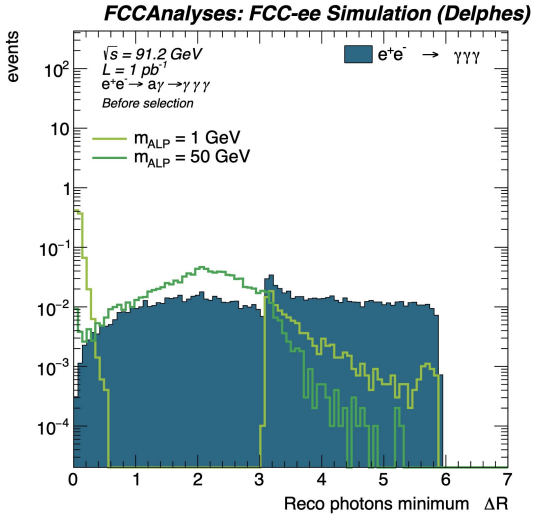


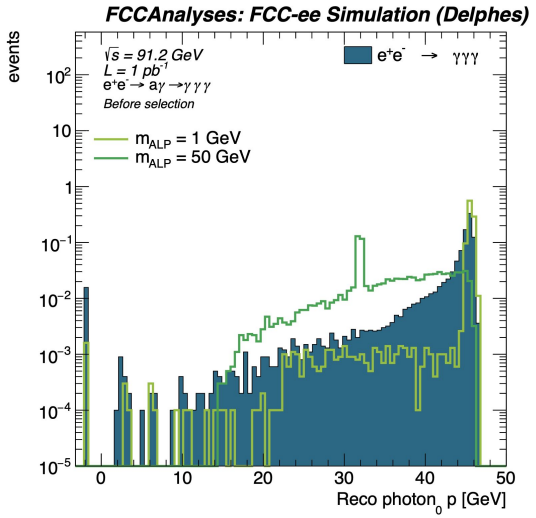
Analysis framework

- Tested and ran over two signal points and one background (new samples)
- No cuts applied at the moment, will need to include background and selections



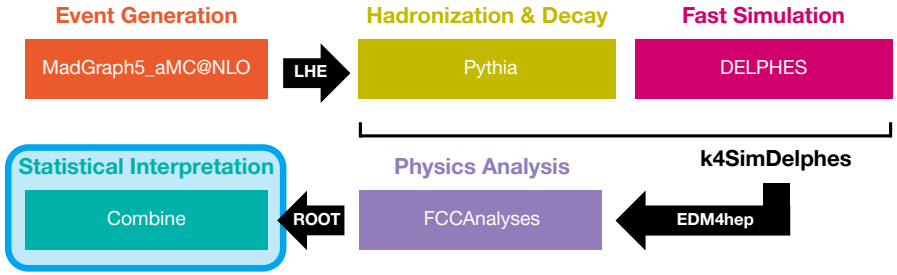




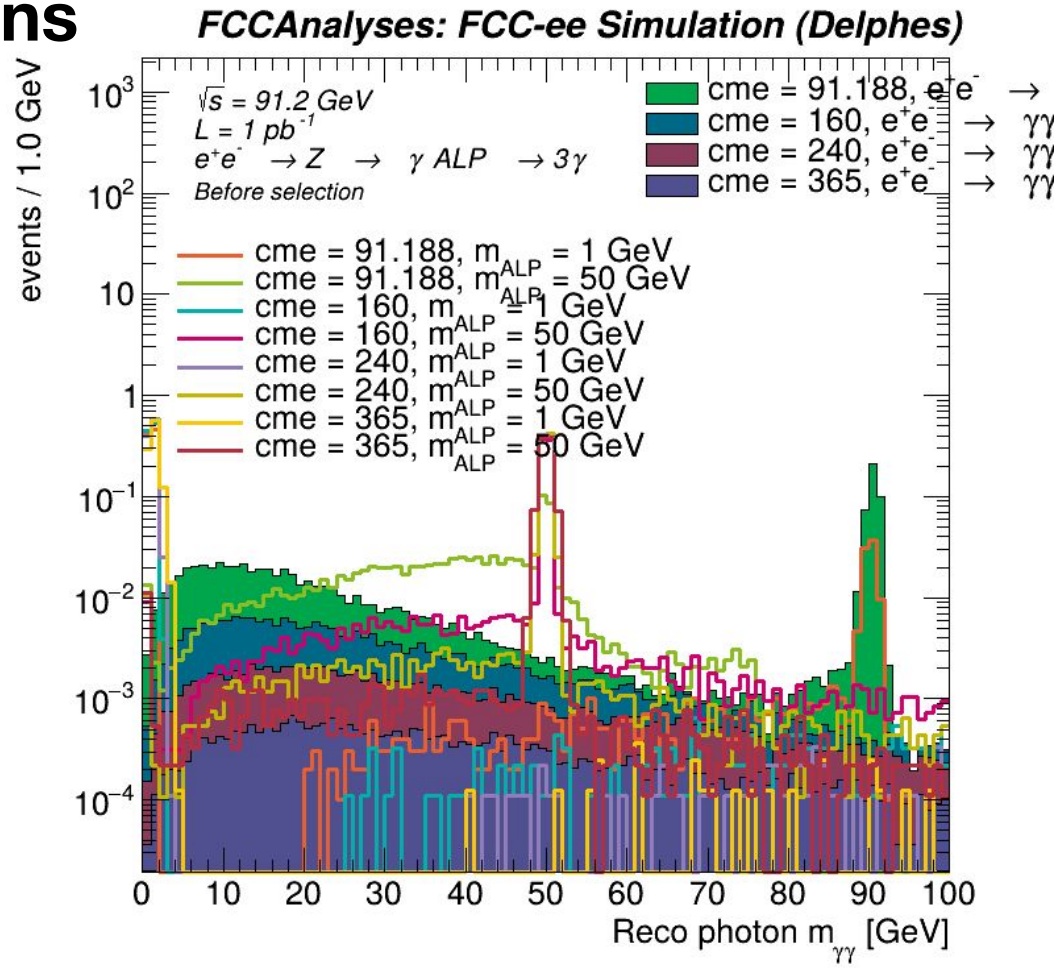


Combine

- Working on limit plot for three signal points and one background (using Elnura's samples with all selections applied)
- Using diphoton invariant mass
- Still some debugging/testing needed…



Distributions



Distributions