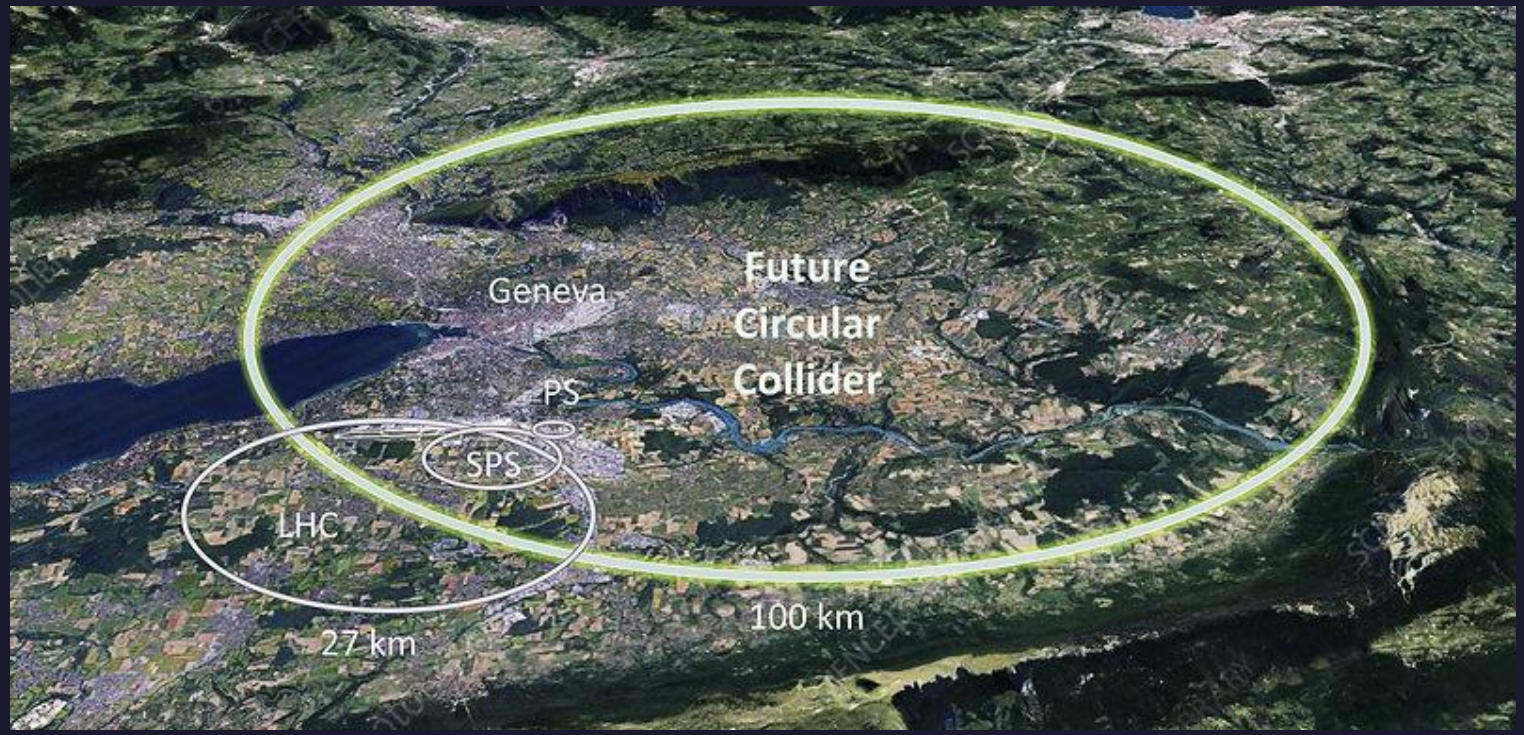
Long-lived axion-like particles at the FCC-ee

Weekly meeting with Juliette



Elnura Bakhishova

HELMHOLTZ

27.11.24

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Question 1

Effective coupling constant of ALP to gluons

- **Is used to determine f_alp**
- **But is set to 0 in MadGraph**

Finally, the global symmetry breaking scale Λ can be defined in terms of f_a, a parameter used in the event simulations to specify the new physics scale (in this case, $f_a = \frac{1000}{16\pi^2}\,GeV \approx 6.33\,GeV$) [7]:

$$\Lambda = 32\pi^2 f_a \left|C_{GG}^{\text{eff}}\right|, \tag{6}$$

where C_{GG}^{eff} is the effective coupling constant of the ALP to gluons and is set to 0.5 in the model.

mg5_proc_card_ALP_aa_1GeV_0p5CYY.dat ● .keep

MG5_aMC_v3_5_6 > mg5_proc_card_ALP_aa_1GeV_0p5CYY.dat

```
#*********************************************************************
#*                     MadGraph5_aMC@NLO                             *
#*                                                                   *
#*                *                       *                          *
#*                  *        * *        *                            *
#*                    * * * * 5 * * * *                              *
#*                  *        * *        *                            *
#*                *                       *                          *
#*                                                                   *
#*                                                                   *
#*         VERSION 3.2.0                 2021-08-22                  *
#*                                                                   *
#*    The MadGraph5_aMC@NLO Development Team - Find us at            *
#*    https://server06.fynu.ucl.ac.be/projects/madgraph              *
#*                                                                   *
#*********************************************************************
#*                                                                   *
#*               Command File for MadGraph5_aMC@NLO                  *
#*                                                                   *
#*     run as ./bin/mg5_aMC  filename                                *
#*                                                                   *
#*********************************************************************
set group_subprocesses Auto
set ignore_six_quark_processes False
set low_mem_multicore_nlo_generation False
set complex_mass_scheme False
set include_lepton_initiated_processes False
set gauge unitary
set loop_optimized_output True
set loop_color_flows False
set max_npoint_for_channel 0
set default_unset_couplings 99
set max_t_for_channel 99
set zerowidth_tchannel True
set nlo_mixed_expansion True
set auto_convert_model T
import model sm
define p = g u c d s u~ c~ d~ s~
define j = g u c d s u~ c~ d~ s~
define l+ = e+ mu+
define l- = e- mu-
define vl = ve vm vt
define vl~ = ve~ vm~ vt~
import model ALP_NLO_UFO
generate e+ e- > Z, (Z > a ALP, (ALP > a a))
output ALP_Z_aa_1GeV_cYY_0p1
launch ALP_Z_aa_1GeV_cYY_0p1
done
# set to electron beams (0 for ele, 1 for proton)
set lpp1 0
set lpp2 0
set ebeam1 45.594
set ebeam2 45.594
# set ALP mass
set Ma 5.
# set ALP couplings
set cWW = 0.0
set CYY = 1.
set cGG = 0.
set cuu = 0.
set cdd = 0.
set ccc = 0.
set css = 0.
set ctt = 0.
set cbb = 0.
set cee = 0.
set cmumu = 0.
set ctautau = 0.
set cah = 0.
set cZh5 = 0.
# set supression scale in the effective operators coupling the ALP to SM particles: 1000/(16*pi**2)
set falp = 6.33

# set the decay width of the ALP to auto
set WALP auto
set time_of_flight 0
set nevents 1000
done
```

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Question 2

Cross-section should depend on mass AND coupling, needs to be adjusted in code

- **Run MadGraph for 1000 events to attain correct cross-sections [pb]**

analysis_stage1_new.py M | analysis_final.py M ● | analysis_plots.py M | n_RecoPhotons_ALP_nostack_log.png | n_GenALP_ALP_nostack_log.png | All_n_GenALP_ALP_nostack_log.png

amples > FCCee > bsm > LLPs > ALPs > analysis_final.py > procDictAdd

```
61  procDictAdd={
92
93      # "ALP_Z_aa_0.6.GeV_cYY_1.0": {"numberOfEvents": 100000, "sumOfWeights": 100000, "crossSection": 0.027, "kfactor": 1.0, "matchingEfficiency": 1.0},
94      # "ALP_Z_aa_0.8.GeV_cYY_1.0": {"numberOfEvents": 100000, "sumOfWeights": 100000, "crossSection": 0.027, "kfactor": 1.0, "matchingEfficiency": 1.0},
95      # "ALP_Z_aa_1.GeV_cYY_1.0": {"numberOfEvents": 100000, "sumOfWeights": 100000, "crossSection": 0.027, "kfactor": 1.0, "matchingEfficiency": 1.0},
96      # "ALP_Z_aa_1.2.GeV_cYY_1.0": {"numberOfEvents": 100000, "sumOfWeights": 100000, "crossSection": 0.027, "kfactor": 1.0, "matchingEfficiency": 1.0},
97      # "ALP_Z_aa_1.4.GeV_cYY_1.0": {"numberOfEvents": 100000, "sumOfWeights": 100000, "crossSection": 0.027, "kfactor": 1.0, "matchingEfficiency": 1.0},
98
99      # 'ALP_Z_aa_3.GeV_cYY_0.1':{"numberOfEvents": 100000, "sumOfWeights": 100000, "crossSection": 2.744e-05, "kfactor": 1.0, "matchingEfficiency": 1.0},
00      # 'ALP_Z_aa_3.GeV_cYY_0.3':{"numberOfEvents": 100000, "sumOfWeights": 100000, "crossSection": 2.744e-05, "kfactor": 1.0, "matchingEfficiency": 1.0},
01      # 'ALP_Z_aa_3.GeV_cYY_0.5':{"numberOfEvents": 100000, "sumOfWeights": 100000, "crossSection": 2.744e-05, "kfactor": 1.0, "matchingEfficiency": 1.0},
02      # 'ALP_Z_aa_3.GeV_cYY_0.7':{"numberOfEvents": 100000, "sumOfWeights": 100000, "crossSection": 2.744e-05, "kfactor": 1.0, "matchingEfficiency": 1.0},
03      # 'ALP_Z_aa_3.GeV_cYY_0.9':{"numberOfEvents": 100000, "sumOfWeights": 100000, "crossSection": 2.744e-05, "kfactor": 1.0, "matchingEfficiency": 1.0},
```

Question 2

Cross-section should depend on mass AND coupling, needs to be adjusted in code

- **Run MadGraph for 1000 events to attain correct cross-sections [pb]**

```
###different masses###

#ALP_Z_aa_0p1GeV_cYY_1:  2.733 +- 0.00428 pb
ALP_Z_aa_0p5GeV_cYY_1:  2.733 +- 0.00428 pb
ALP_Z_aa_0p8GeV_cYY_1:  2.733 +- 0.00428 pb
ALP_Z_aa_1GeV_cYY_1:    2.733 +- 0.00428 pb
ALP_Z_aa_1p2GeV_cYY_1:  2.733 +- 0.00428 pb
ALP_Z_aa_2GeV_cYY_1:    2.73 +- 0.004275 pb
ALP_Z_aa_5GeV_cYY_1:    2.709 +- 0.004242 pb
ALP_Z_aa_8GeV_cYY_1:   2.671 +- 0.004183 pb


#Alp_Z_aa_10GeV_cYY_1:   2.636 +- 0.004128 pb
#Alp_Z_aa_20GeV_cYY_1:   2.358 +- 0.003692 pb
#Alp_Z_aa_50GeV_cYY_1:   0.9351 +- 0.001464 pb


###different couplings###

#ALP_Z_aa_5GeV_cYY_1p2:  5.31 +- 0.008315 pb
#ALP_Z_aa_5GeV_cYY_2:    10.84 +- 0.01697 pb
```

- **No big change despite different masses, would expect a more drastic change**
- **Cross section gets smaller for bigger masses**

- **For different coupling strength significant change in cross-section**

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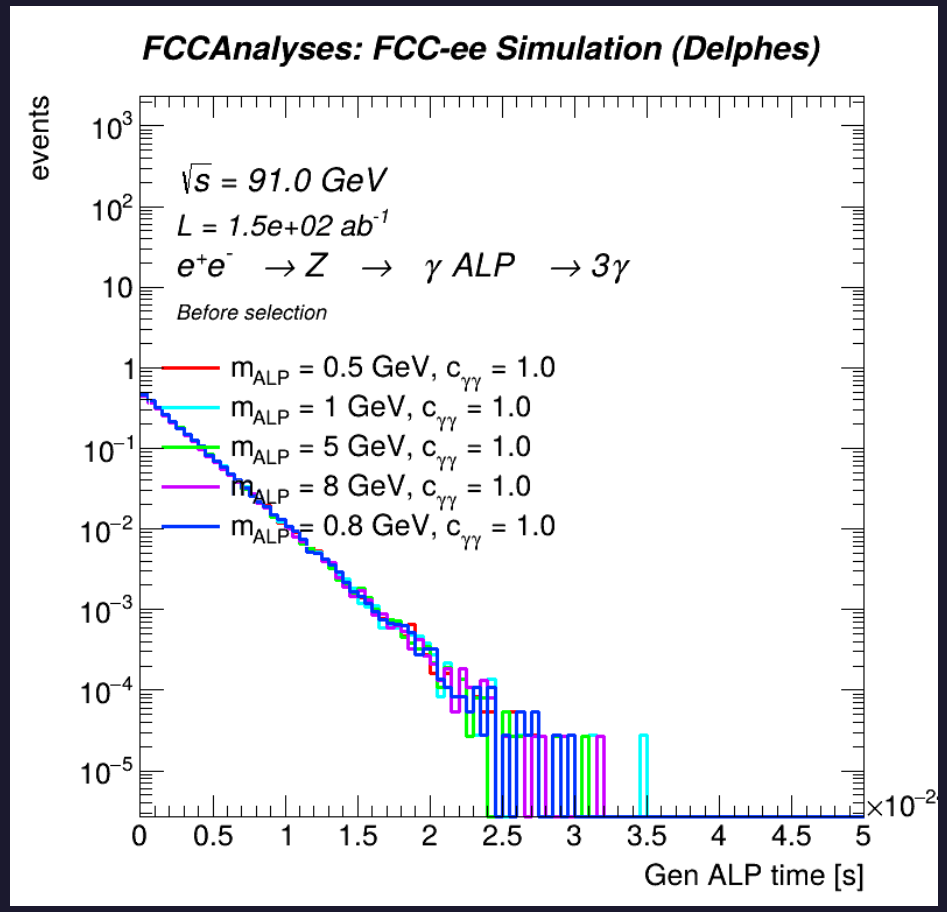
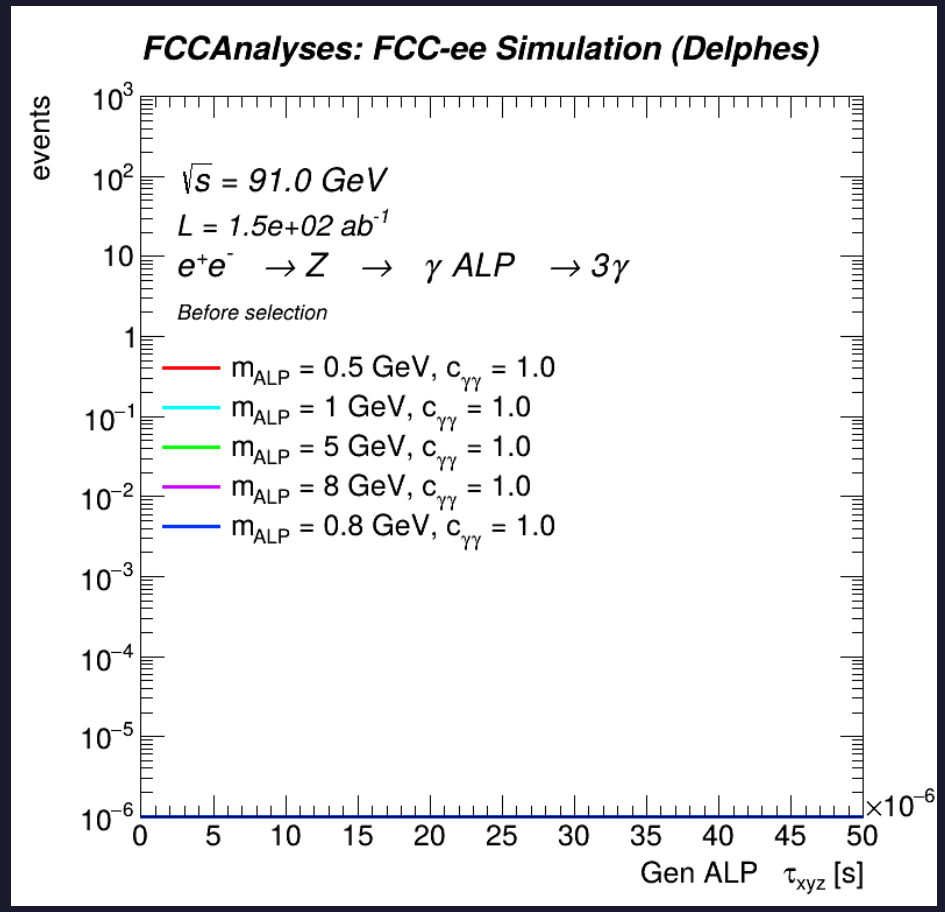
Results





Where are all the values for ALP lifetime

Change Luminosity display

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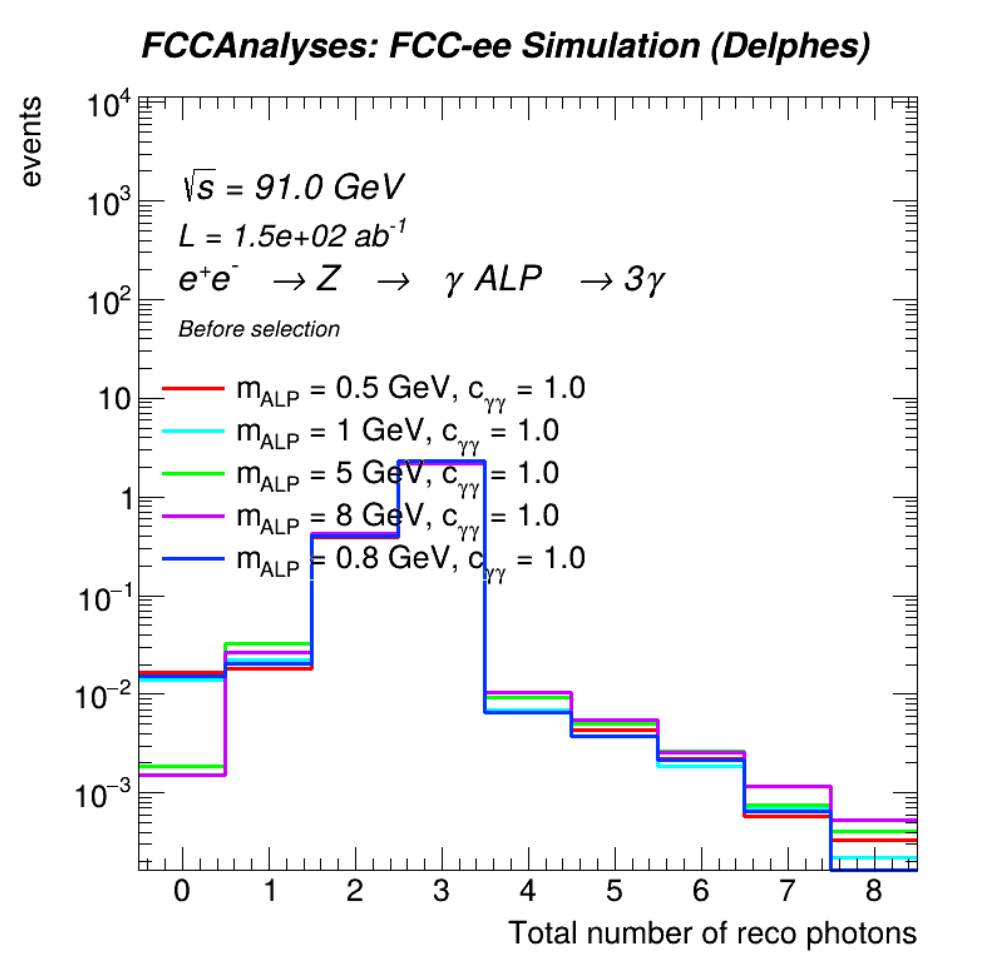
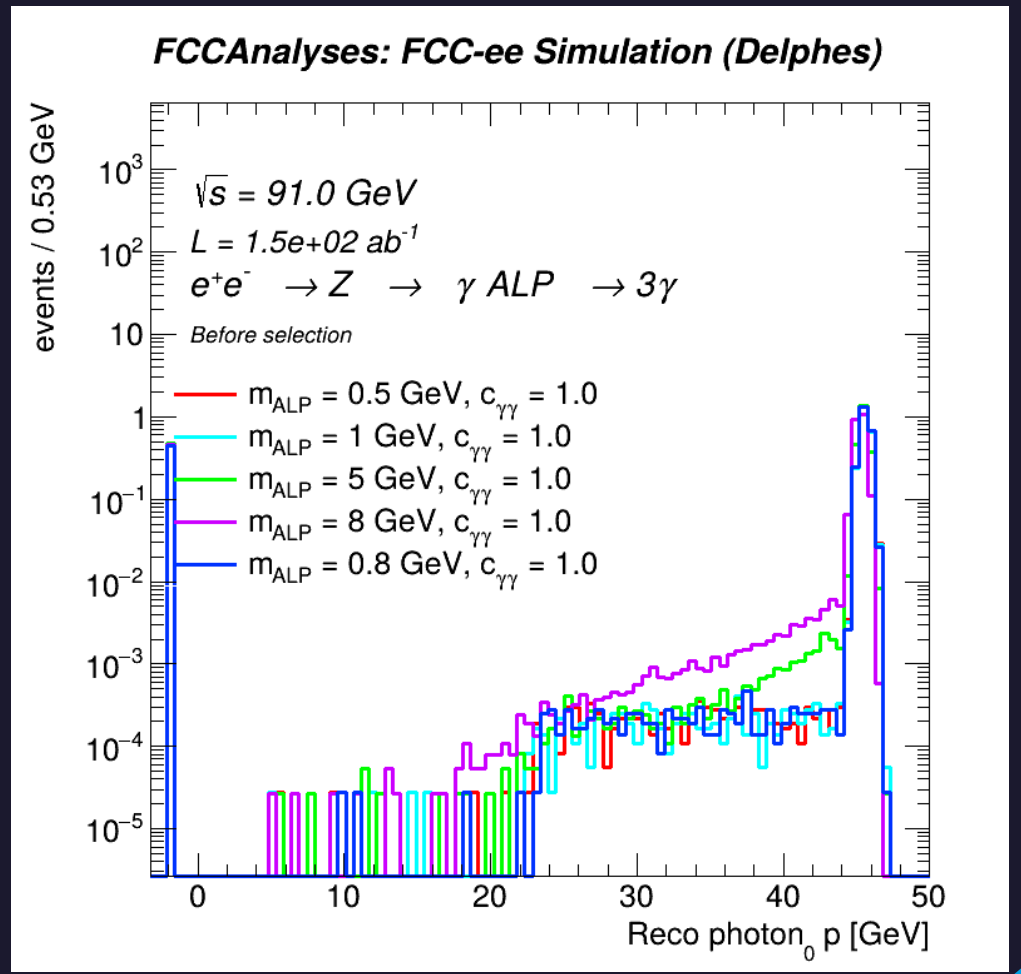
Results





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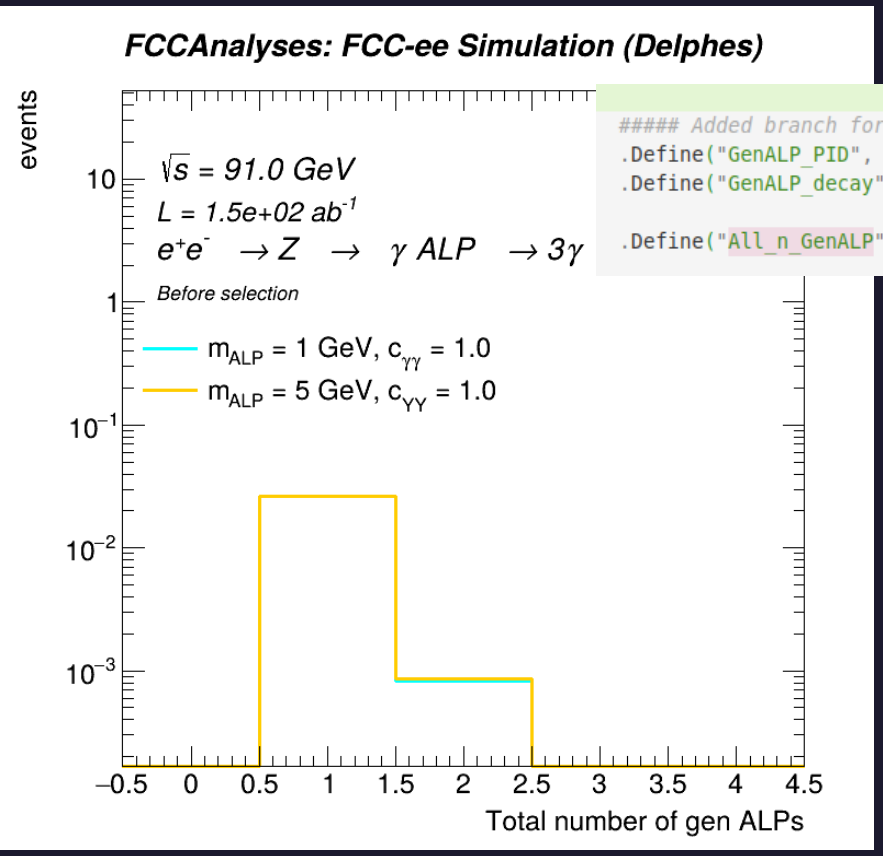
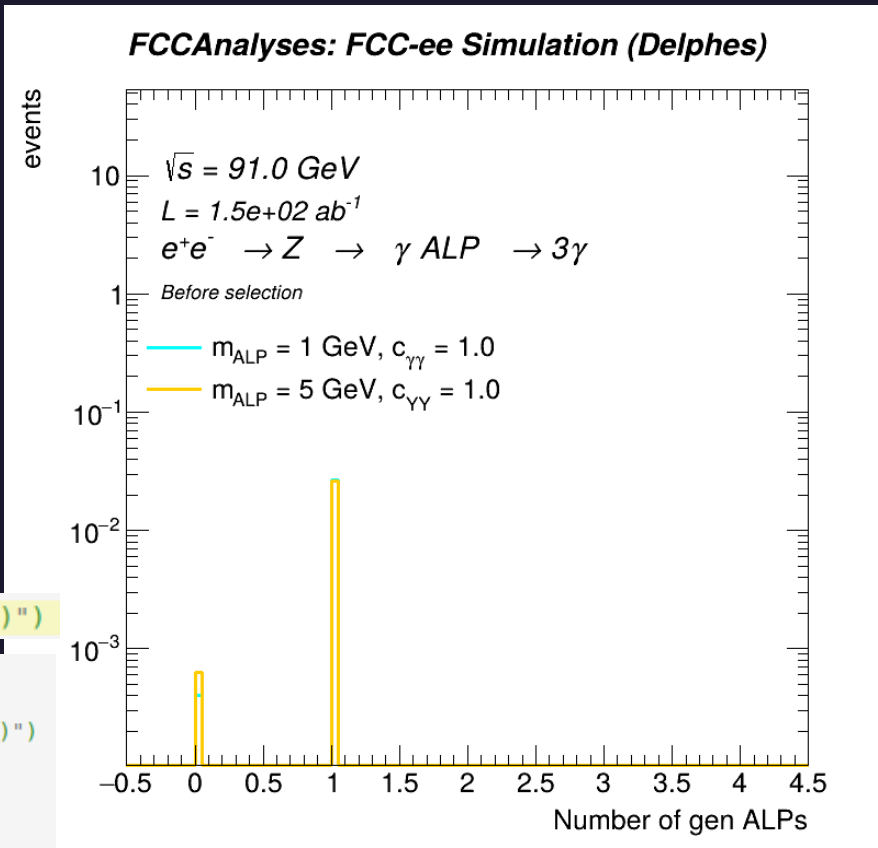
Question 3

Difference between these 2 plots? Why 0?




```
##### Added branch for MCParticle; finding PID of the MC particle for ALP
.Define("GenALP_PID", "MCParticle::sel_pdgID(9000005, false)(Particle)")
.Define("GenALP_decay", "MCParticle::get_list_of_particles_from_decay(0, GenALP_PID, Particle1)")

.Define("All_n_GenALP", "MCParticle::get_n(GenALP_PID)")
```

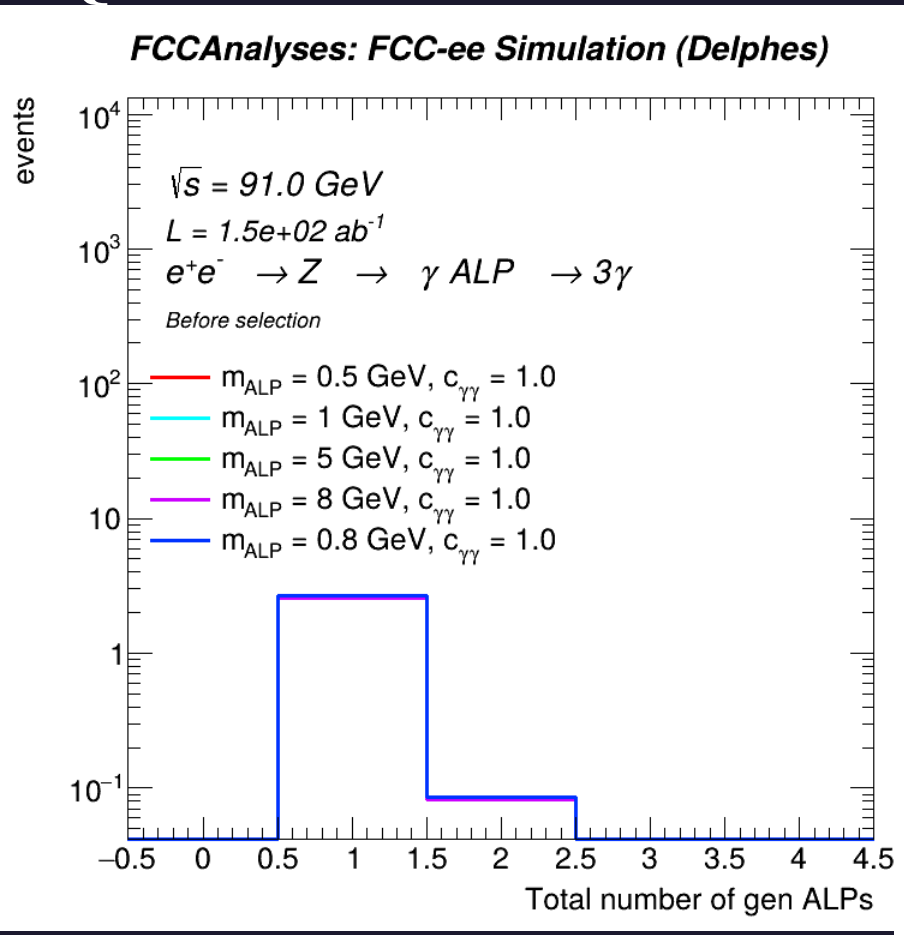


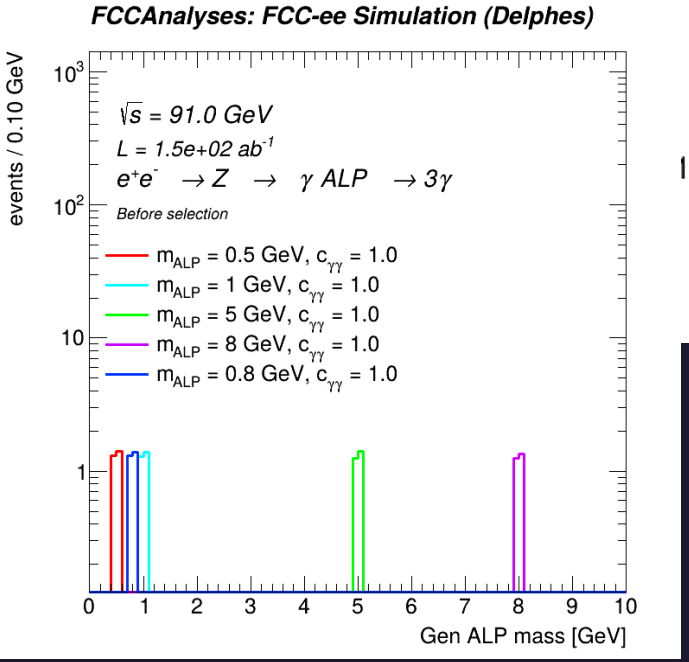

```
.Define("n_GenALP", "MCParticle::get_n( GenALP )")
```

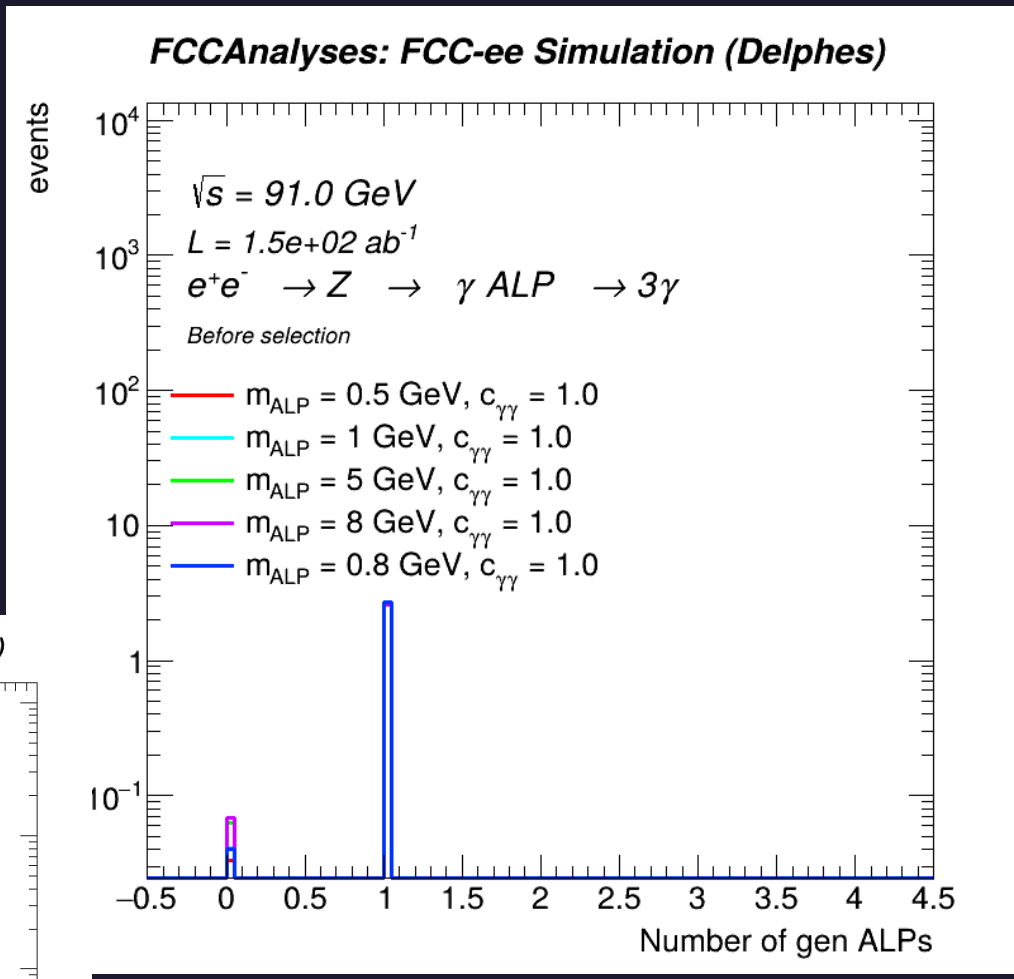
```
# Defining a vector containing the ALP and its daughters in order written
# Name of vector is ALP_indices
.Define("GenALP_indices", "MCParticle::get_indices(9000005, {22, 22}, true, false, false, true)(Particle, Particle1)")

# Defining the individual particles from the vector
.Define("GenALP", "myUtils::selMC_leg(0)(GenALP_indices, Particle)")
.Define("GenALPPhoton1", "myUtils::selMC_leg(1)(GenALP_indices, Particle)")
.Define("GenALPPhoton2", "myUtils::selMC_leg(2)(GenALP_indices, Particle)")
```

Question 3

What happened to normalization to unit area?







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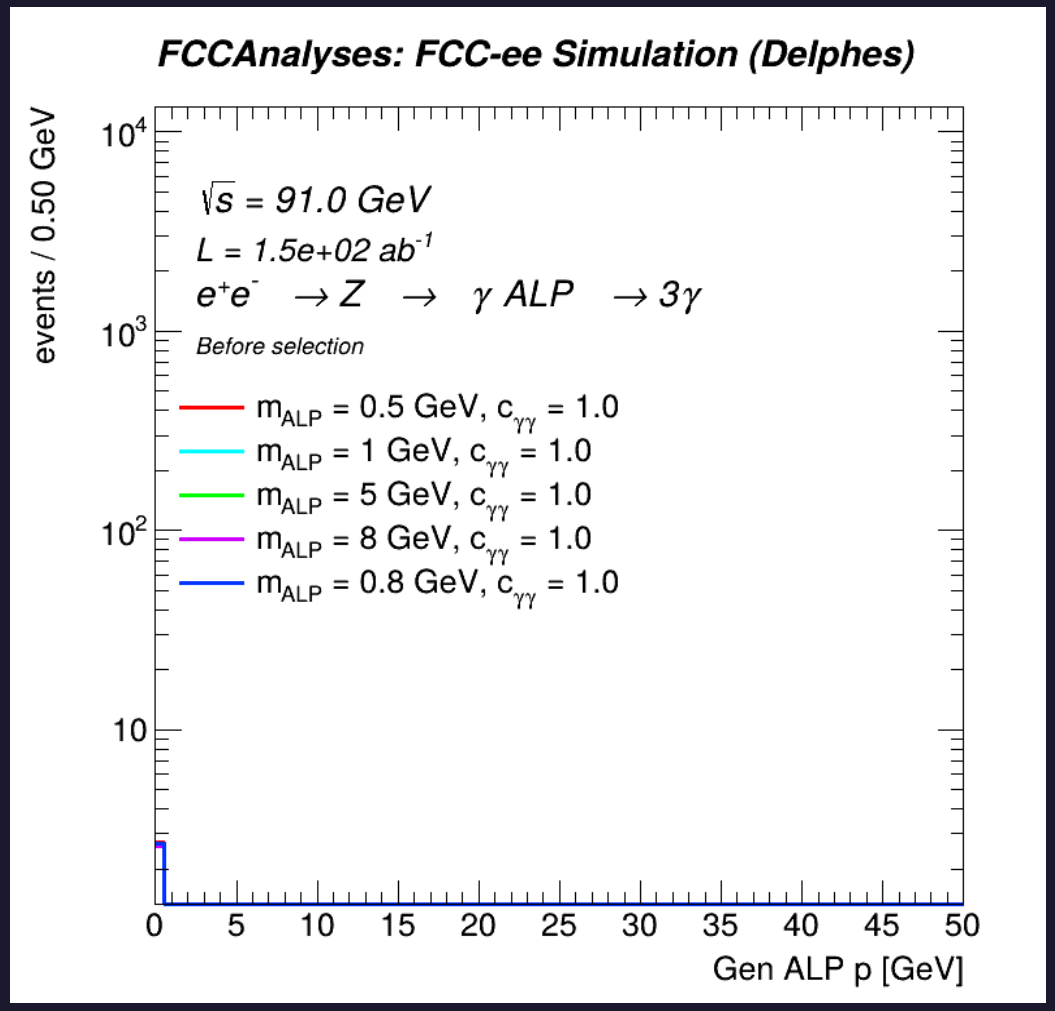
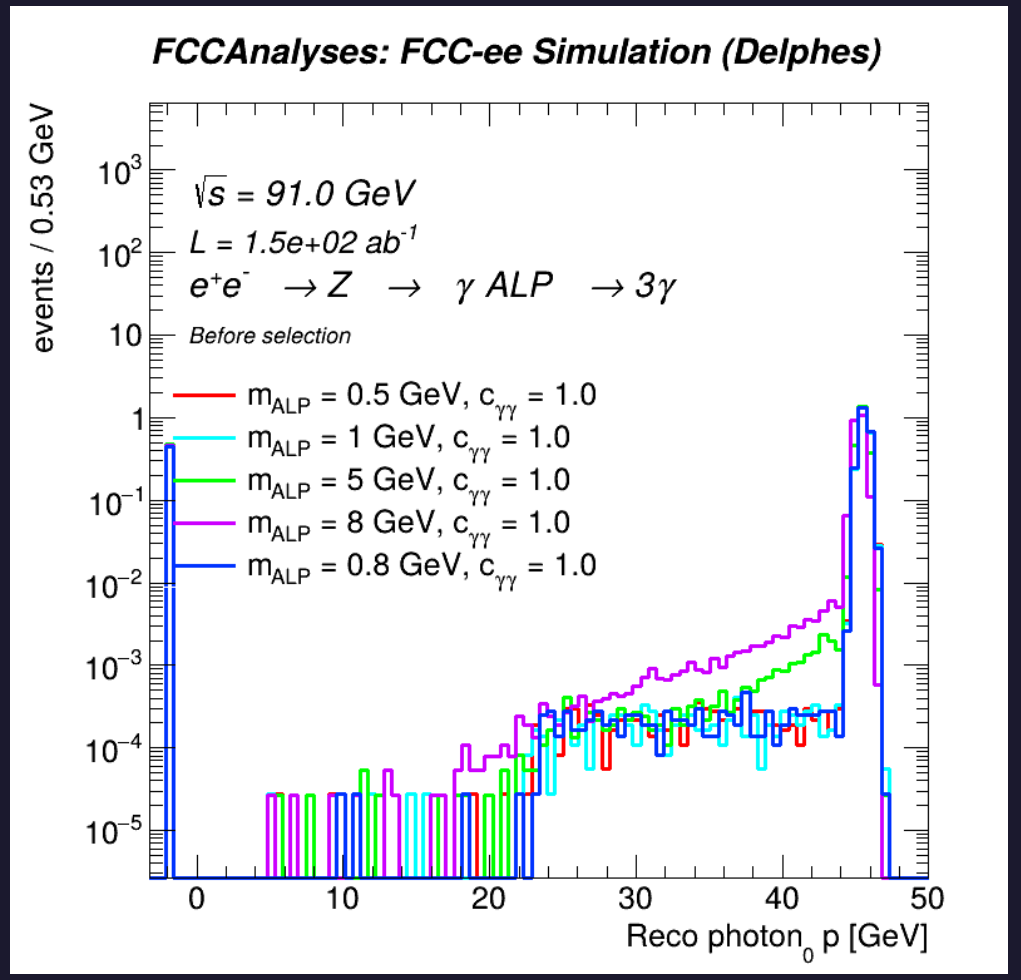
Question 4

GenALP momentum





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