# Signatures of light scalars particles with long lifetimes at the LHC and FCC

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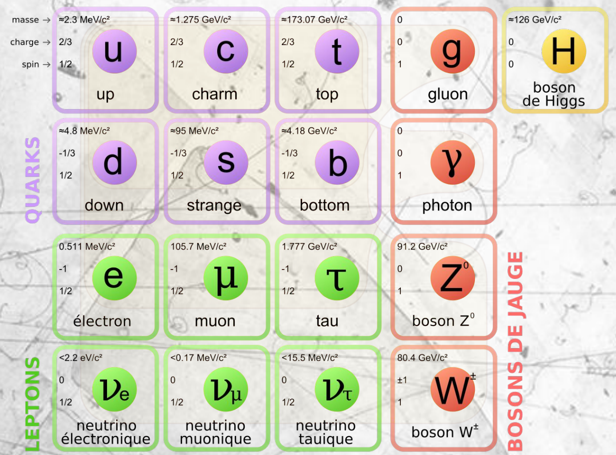
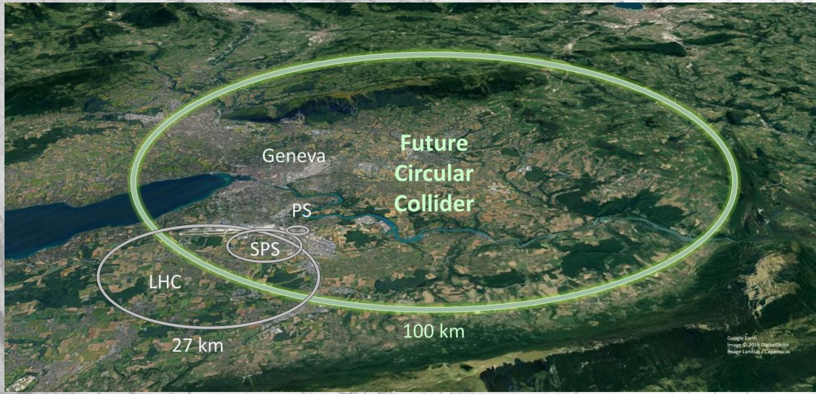
# Introduction

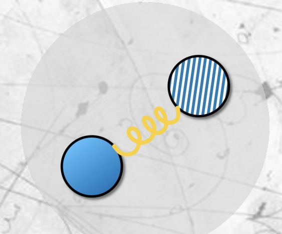
- The standard model is an effective theorie : (neutrino masses, dark matter, matter-antimatter asymmetry)
- Active area of research in search of a model beyond the standard model
- Colliders are tools in order to test these models in particular the LHC
- Future colliders like the FCC will improve the precision : ee phase, and the energy scale reached : hh phase



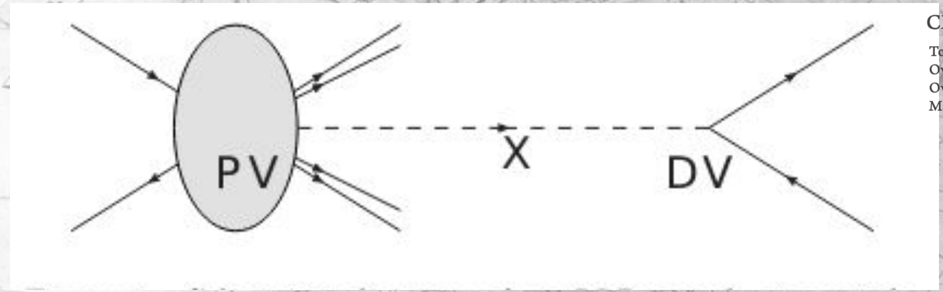



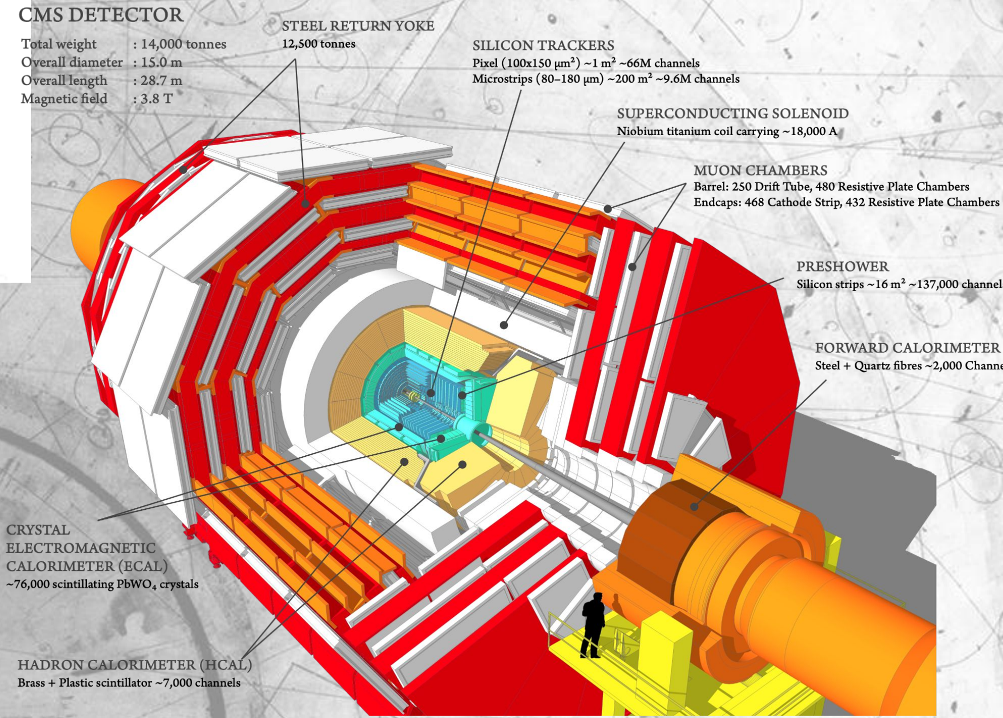
# Higgs composite model

- <u>Main idea :</u> the Higgs boson **is not** an elementary particle
- Scalar particles in the standard model are composite particles (hadrons : pion, sigma, kaon). → what if the Higgs boson is a composite particle too?
- Advantages :
  - The hierarchy problem can be solve by this consideration
- Some important physical concepts used in this model :
  - Higgs is a pNGB ( pseudo-Nambu Goldstone boson)
  - Partial compositeness to fermions (interaction between fermions of the SM to the composite sector)



# Long lived particles (LLP)

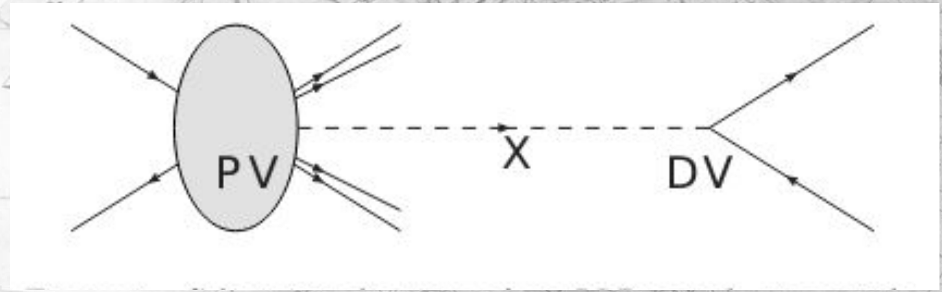



PV : primary vertex
DV : decay vertex

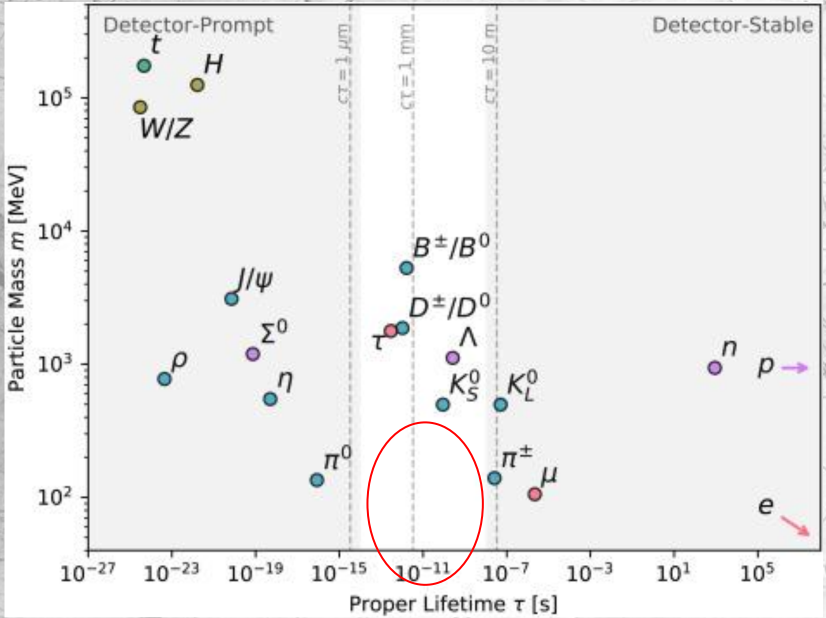
- They are present in many models beyond the standard model who could answer open questions → Probes for new physics

# Long lived particles (LLP)



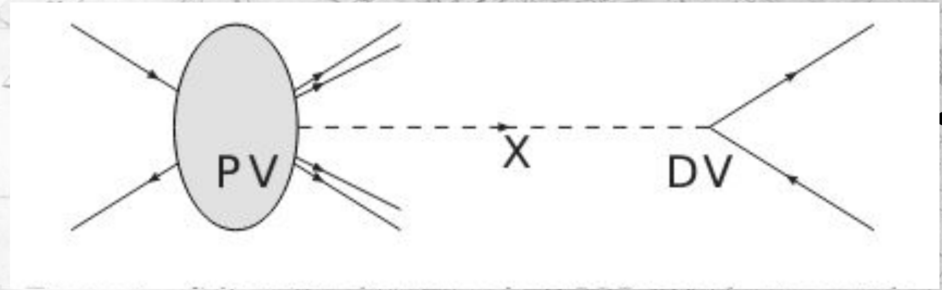

- LLP have special signatures → negligible background

PV : primary vertex
DV : decay vertex




**Efficient search by means of LLP**

# Long lived particles (LLP)




PV : primary vertex
DV : decay vertex

- Test of the model by means of the following lagrangian of interaction between a pseudo-scalar particle (here an axion) and the electroweak gauge bosons of the SU(2)U(1).

$$\mathcal{L}_{int} = a\left(g^2 \frac{C_W}{\Lambda} W_{\mu\nu}\tilde{W}^{\mu\nu} + g'^2 \frac{C_B}{\Lambda} B_{\mu\nu}\tilde{B}^{\mu\nu}\right)$$

- 2 different scenarios depending on the interaction between the scalar particle and photons (C = Cw + Cb):
  - **Photophilic** : Cw=Cb
  - **Photophobic** : Cw=-Cb

# Recasting of the LHC analysis : ATLAS-SUSY-2017-04

- Recasting : reproduction of the logic of an analysis in a simulation considering a different process/phase space
- ATLAS-SUSY-2017-04 : very developed analysis and adapted to the search of LLP who decay into oppositely charged leptons (ee,mu mu, e mu)

$$pp \rightarrow Z'$$

- 2 bodies

$$Z' \rightarrow ee$$
$$Z' \rightarrow e\mu$$
$$Z' \rightarrow \mu\mu$$

Case studied :

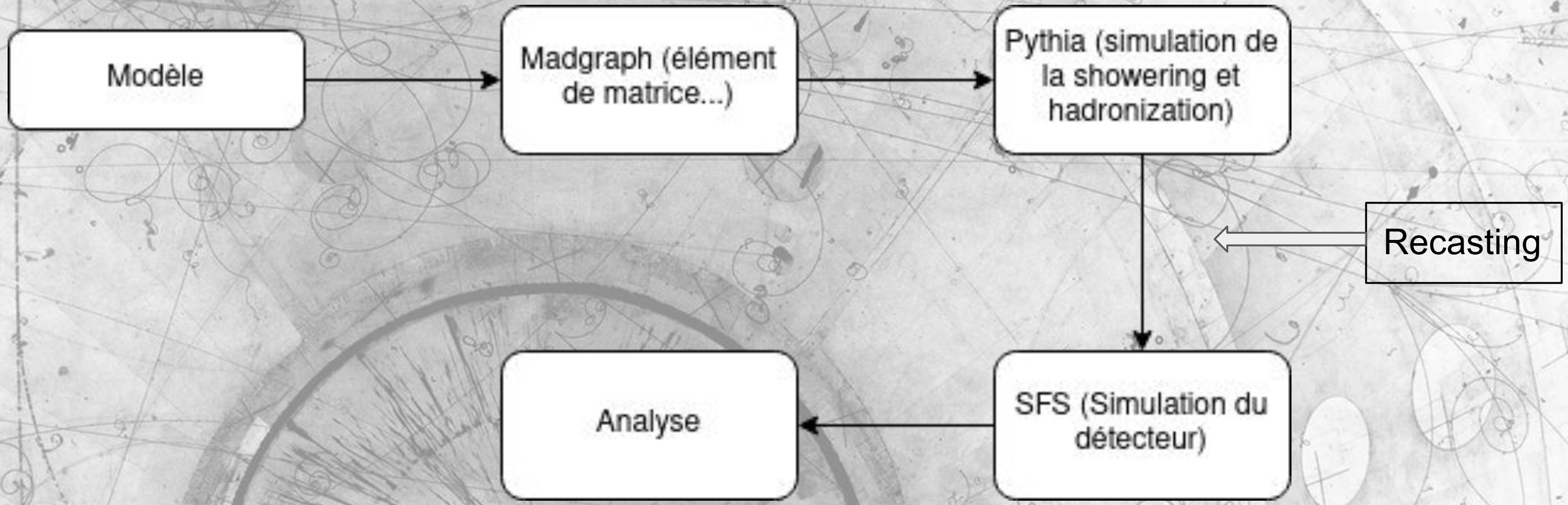
$$\Gamma(a \rightarrow \gamma\gamma) = \frac{(\frac{C_W}{\Lambda})^2 ma^6}{4\pi ma^3}$$

$$\Gamma(a \rightarrow b\tilde{b}) = \frac{3(\frac{C_W}{\Lambda})^2 \sqrt{ma^4 - 4ma^2 * m_b^2}}{2\pi ma^3}$$

$$\Gamma(a \rightarrow \tau\tilde{\tau}) = \frac{(\frac{C_W}{\Lambda})^2 ma^2 mt^2 \sqrt{ma^4 - 4ma^2 mt^2}}{2\pi ma^3}$$

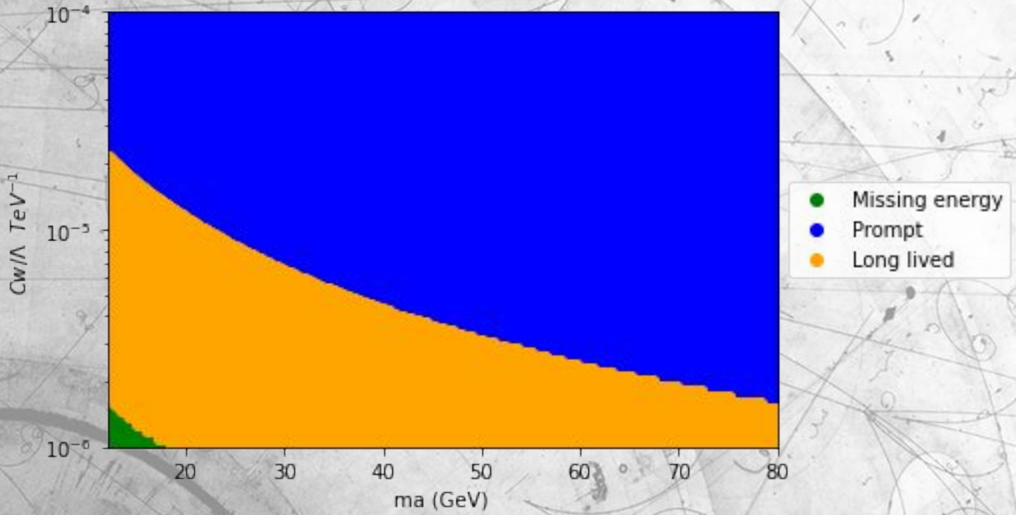
$$\Gamma(a \rightarrow \mu\tilde{\mu}) = \frac{(\frac{C_W}{\Lambda})^2 ma^2 mu^2 \sqrt{ma^4 - 4ma^2 mu^2}}{2\pi ma^3}$$

# Numerical implementation



# Simulations : strategies

- Simulations and analysis can be very heavy → we need to implement strategies
- Lifetime depends on the coupling Cw and the mass)




→ Yellow region is the region that must be analyzed in order to get the limits on the cross section and therefore to test the model

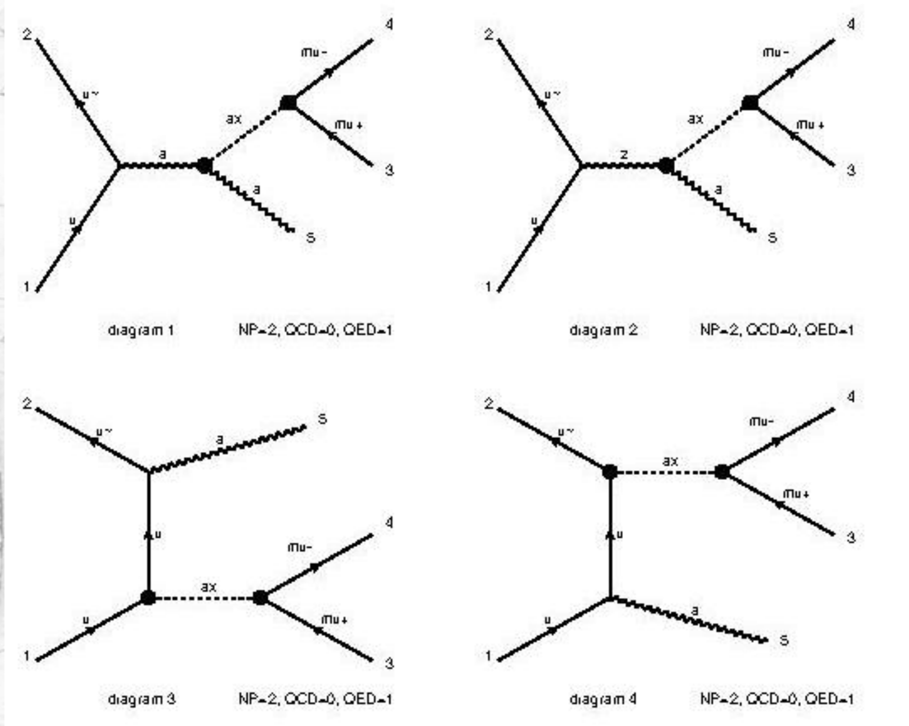
# Simulation : details

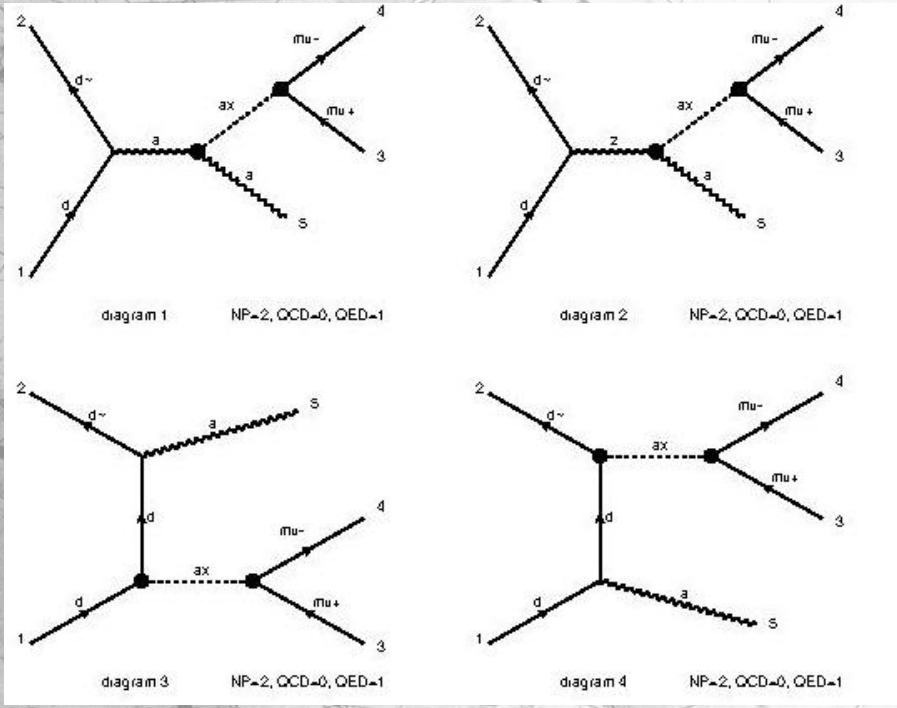
- We tested the analysis generating events of the process $pp \to a\gamma$ et $a \to \mu\mu$

because the analysis is sensitive only to oppositely charged leptons. Center of mass energy = 13 TeV, Lint = 32.8 fb^-1

- Explored region : mass between 20 and 80 GeV, c**τ** between 50 and 300 mm

# Simulations : Feynman diagrams



# Exclusion limits (phenomenology of the model)

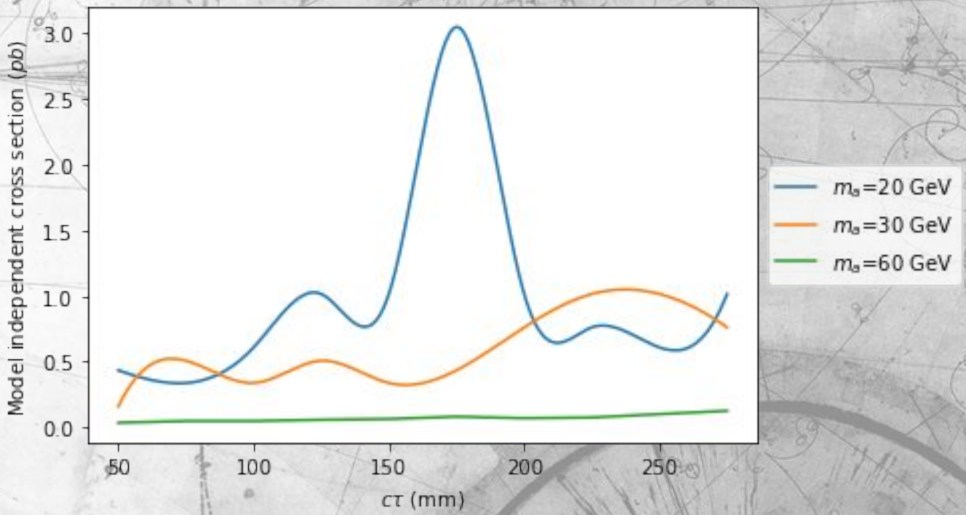
- Determination of the exclusion limit is essential from a phenomenological point of view
- Exclusion criteria :

$$\sigma_{IM} \times \mathcal{L} \times S = 10$$

$$N_{obs} = \sigma_{IM} \times \mathcal{L}$$

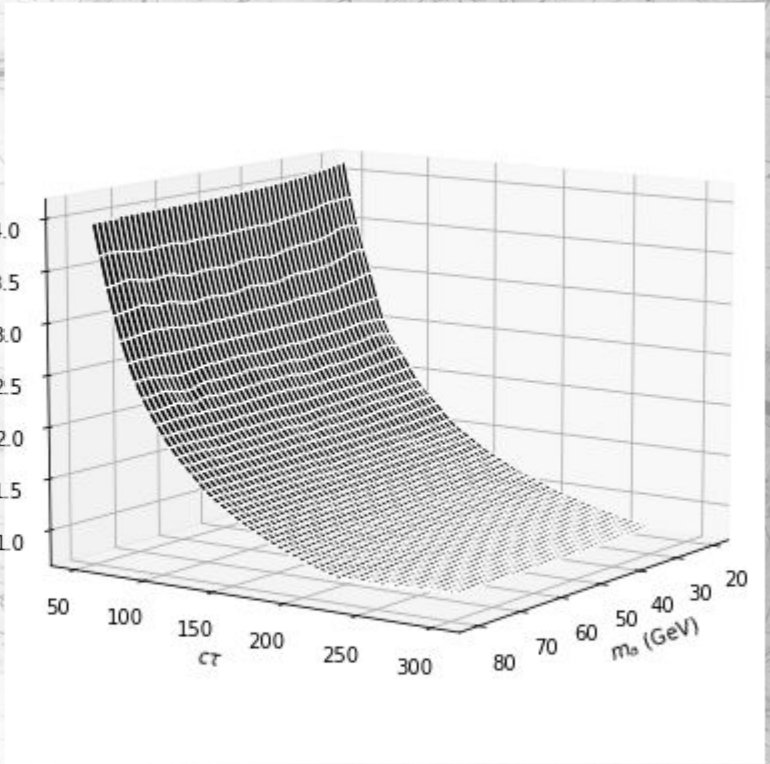
$$\sigma_M > \sigma_{IM} = \frac{10}{\mathcal{L} \times S}$$

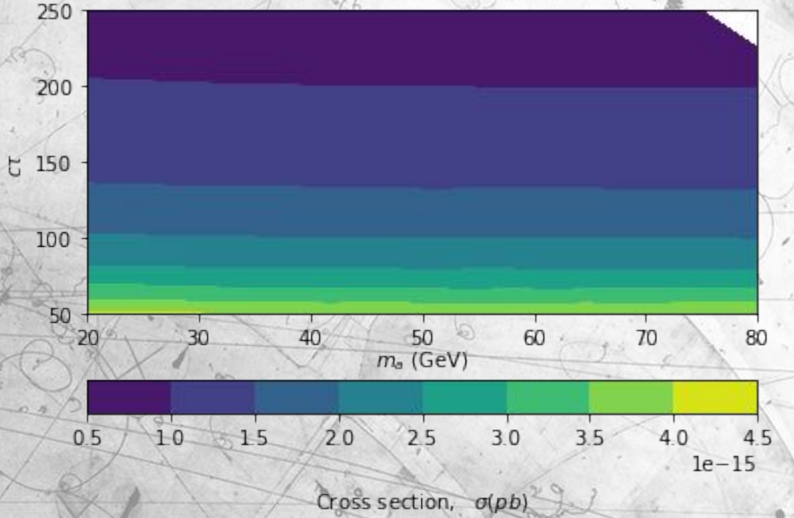
# Selection efficiency

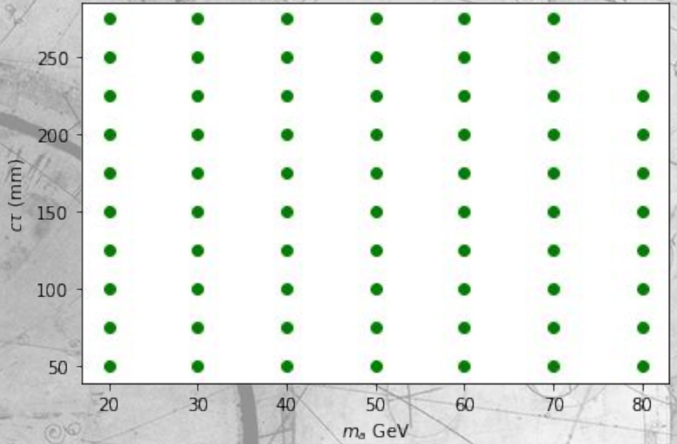



- Search for this type of particle is best when :
  - when the mass increase
  - for a given mass when the lifetime decrease

# Exclusion limits




In work ! The local server is being used in order to get a better plot of the exclusion limit

# Perspectives

- Development of new analysis adapted to composite models both using cuts and using machine learning methods.
- Construction of new composite models (exploration of symmetry of composite models and particle content using the restrictions imposed by the analysis)