A window to new physics through the Large Hadron Collider

3rd African conference on Fundamental and Applied Physics
On behalf of ATLAS and CMS Collaboration

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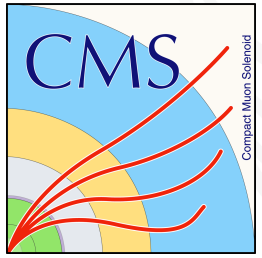
25 - 09 - 2023



Introduction : The standard model

- What is the origin of the universe?
- What are we made of?
- What is the universe made of?
- Etc …

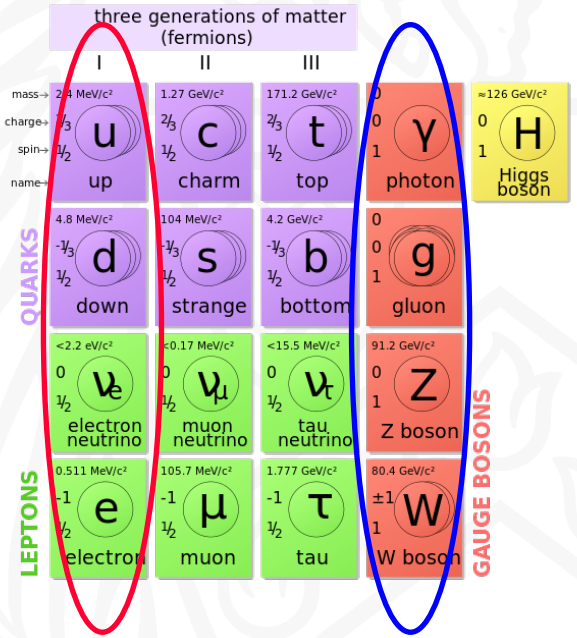
→ Physics experiments and discoveries

Mendeleev table → electrons → neutrinos →quarks, Etc…

The standard model theory

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\chi} \not{D} \chi + h.c. + \chi_i y_{ij} \chi_j \phi + h.c. + |D_\mu \phi|^2 - V(\phi)$$

→ Matter and forces Building blocks



Ordinary matter

Force messengers

The Origin of mass : The Higgs Boson

Newton: Weight proportional to Mass

Einstein: Energy-related to Mass

But what is the origin of mass? → Higgs Boson

The Higgs field = Snow Field (Same as sand field)

Higgs Boson = Snowflake

Photons γ

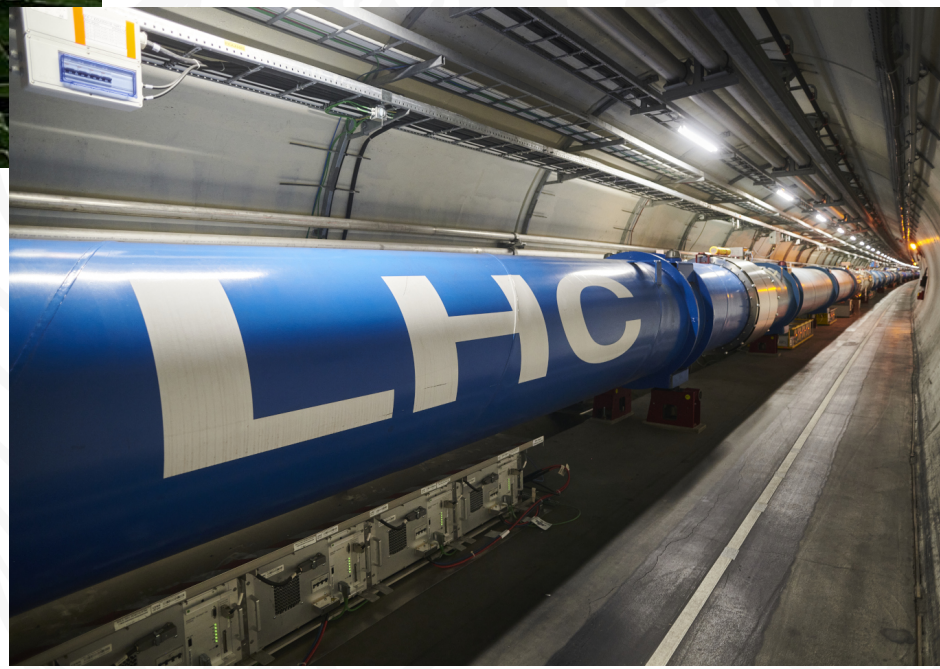
Electrons, muons …

$e^{\pm}, \mu^{\pm}$

top quark

The Large Hadron Collider

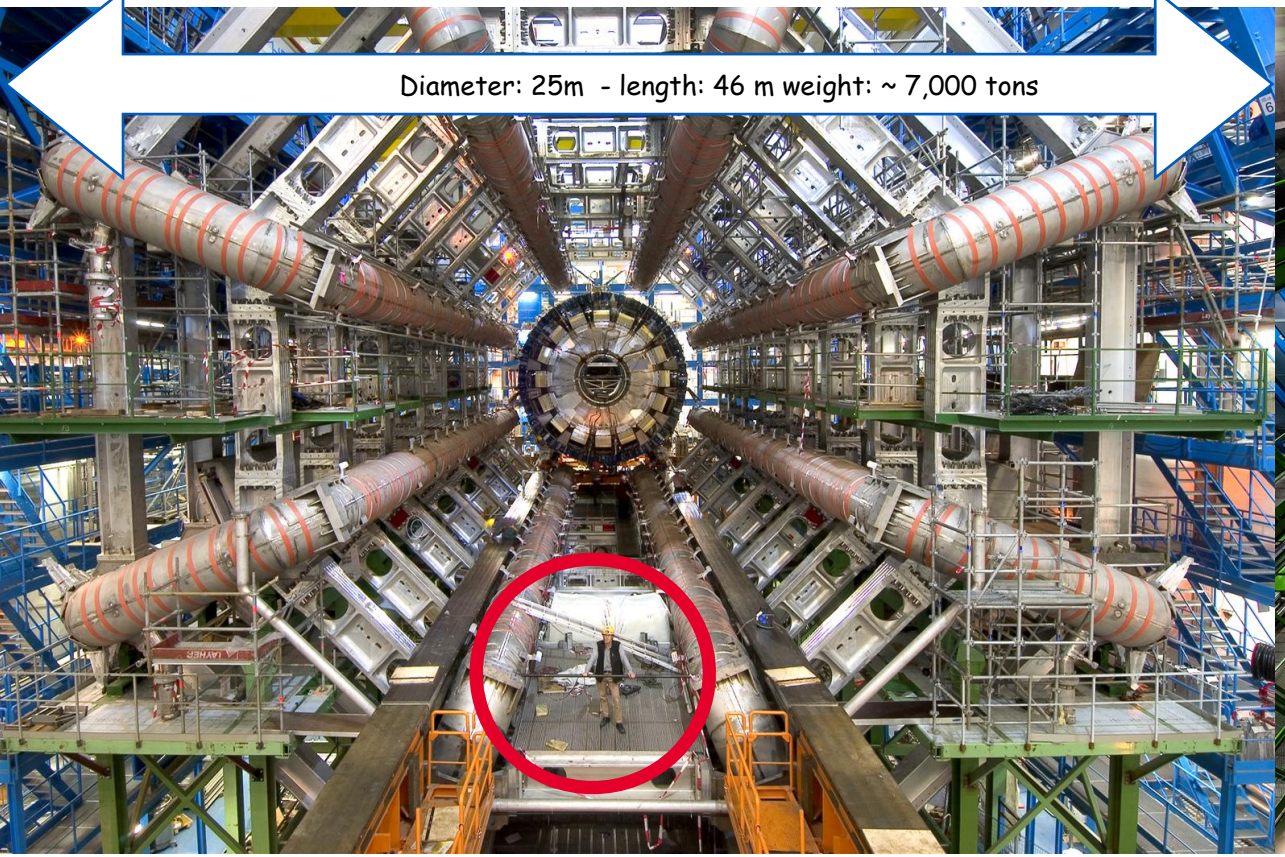
Large Hadron Collider At CERN

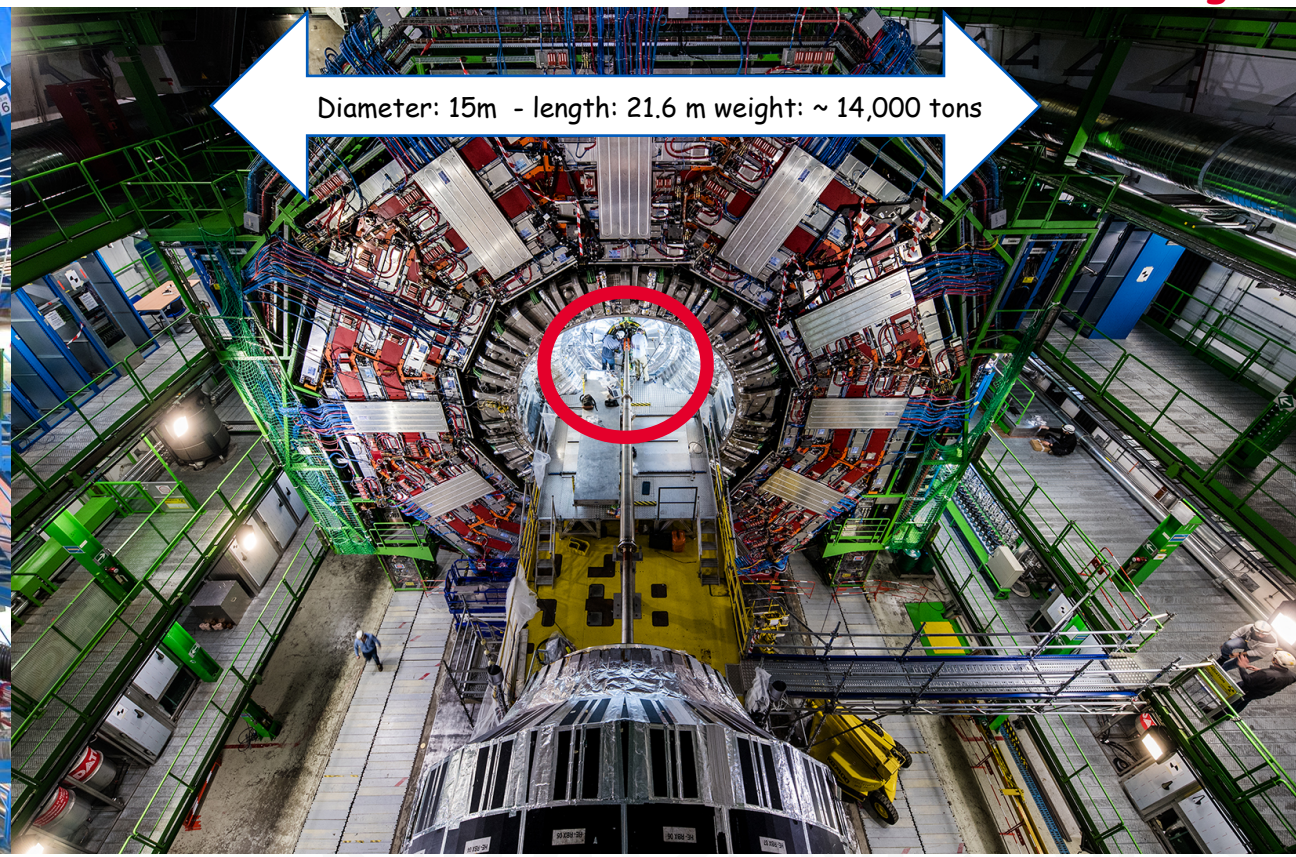


- 100 m underground, tunnel of ~27 km of circumference.
- Proton Proton collisions every 25 ns at energy 13 TeV.
- ATLAS, CMS, ALICE, and LHCb, but not only …
- Data taking period: Run 1, Run 2 concluded, Run 3 started.

ATLAS and CMS experiments : The Giant cameras

x2 ATLAS weight





ATLAS

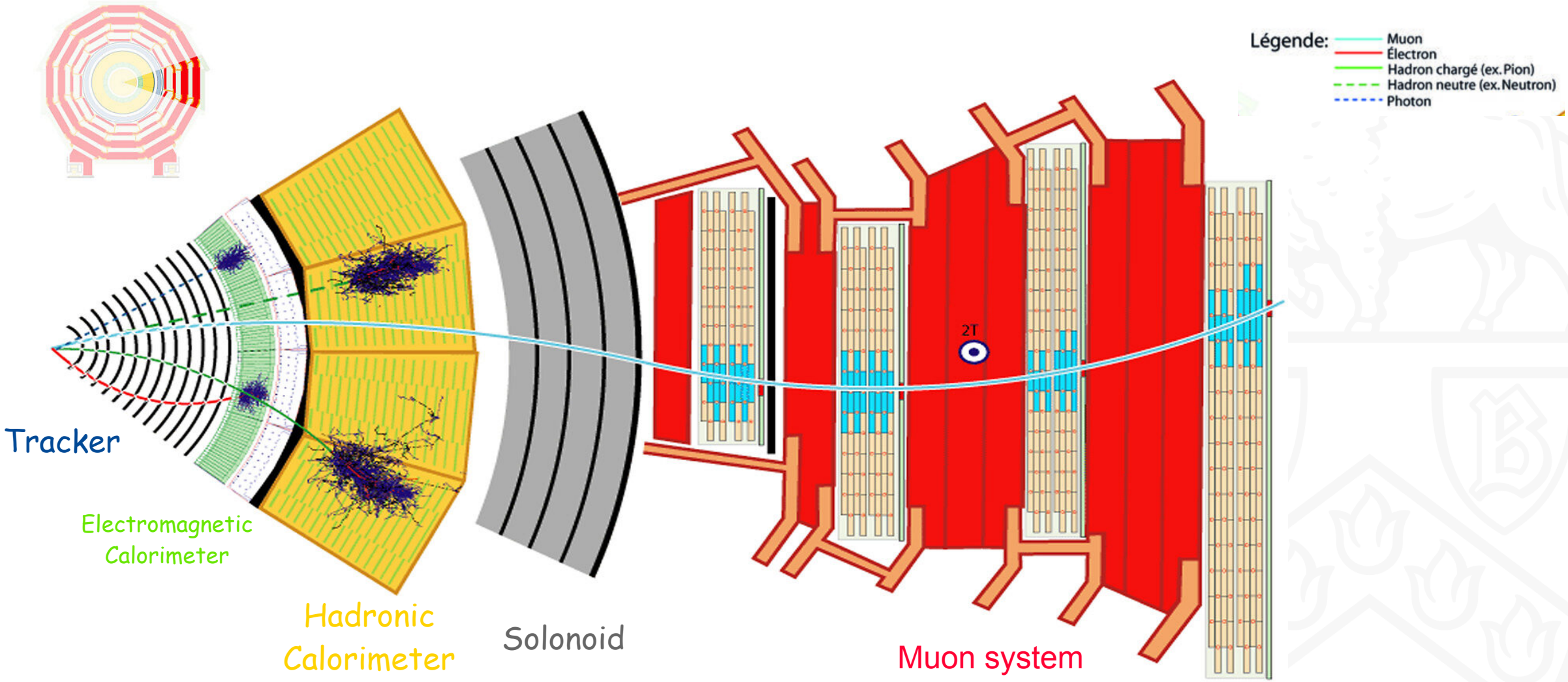
Main goal:

The origin of mass

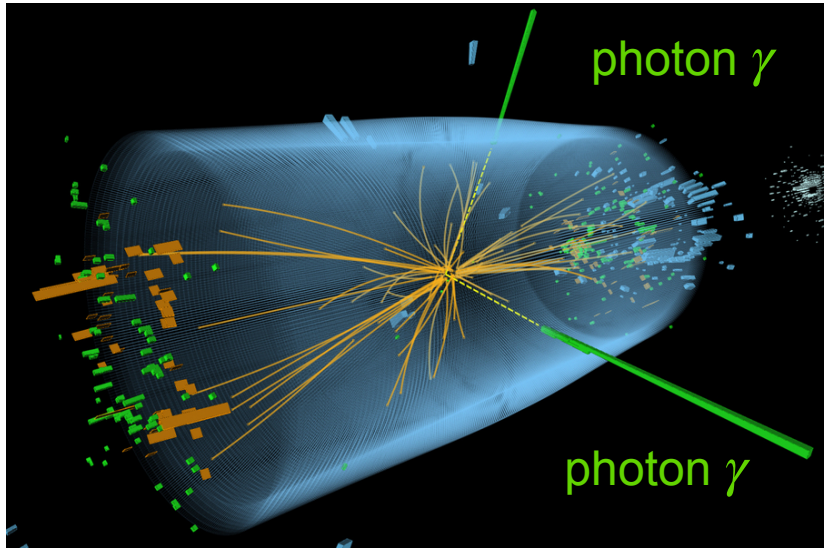
Nature of Dark Matter

CMS

CMS experiment and particles detection



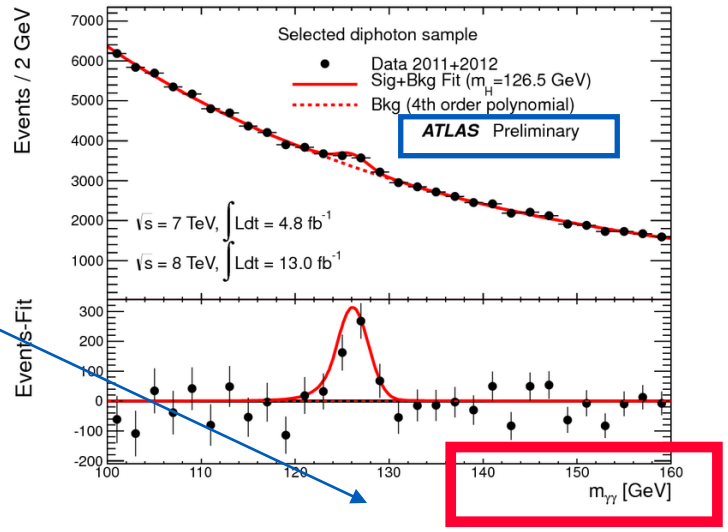
The Higgs Discovery

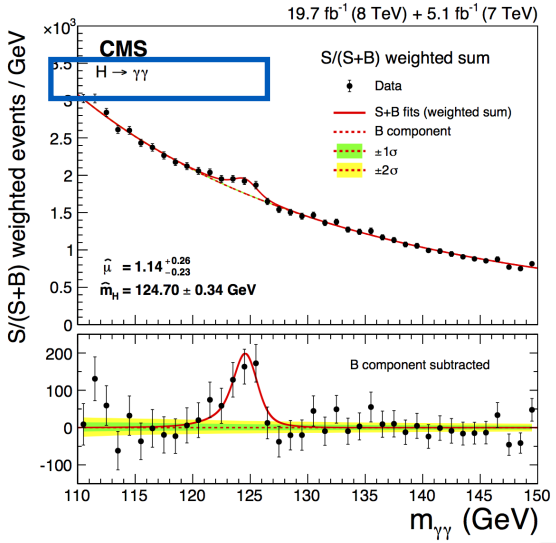


Nobel Prize in 2013

François Englert && Peter Higgs

The invariant mass of the 2γ





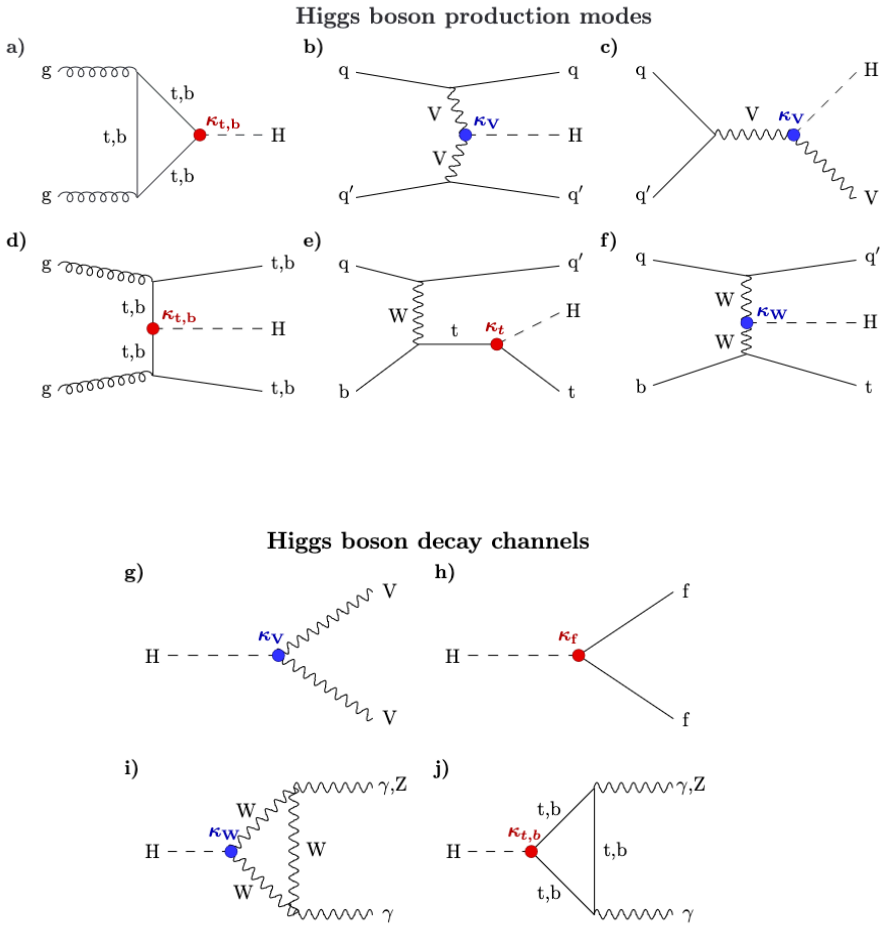
Excess observed beyond The expected background in both experiments

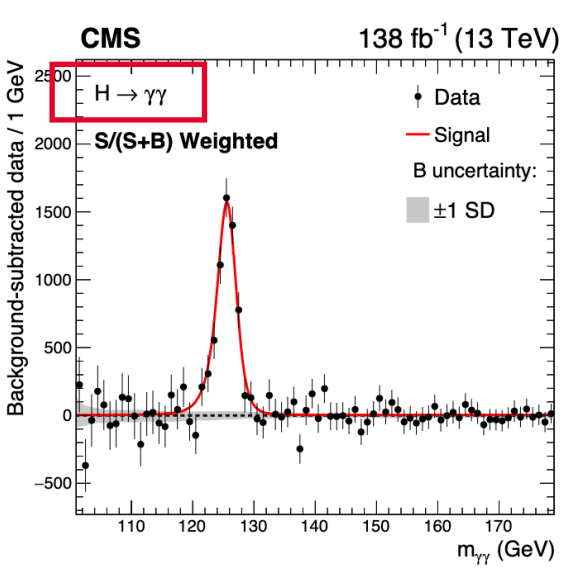
→ Discovery

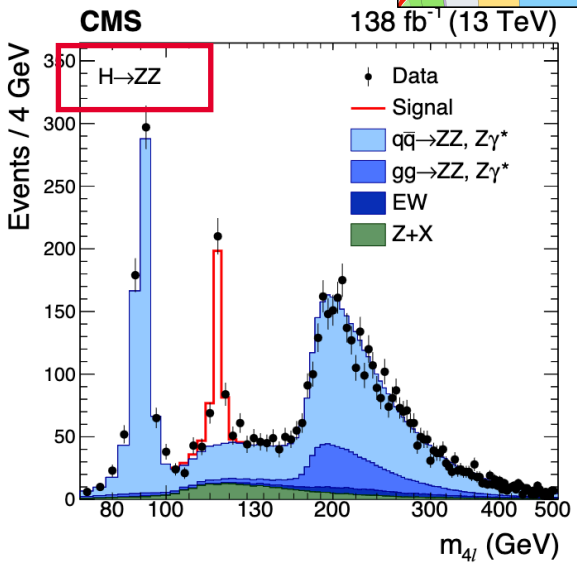
Most recent Higgs Results from CMS

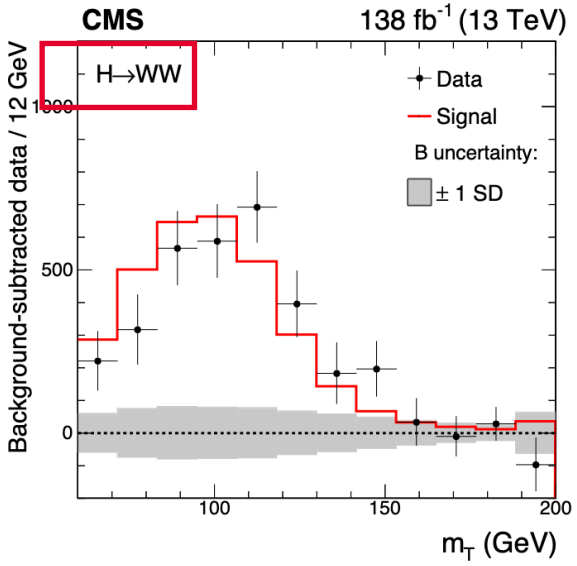
Higgs decaying to vector bosons

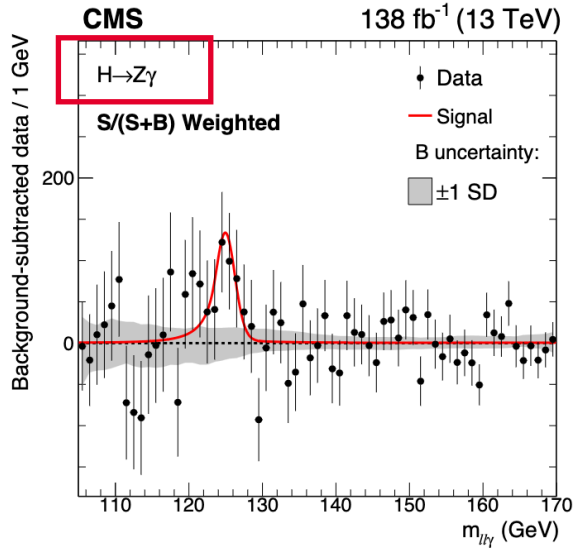
2207.00043







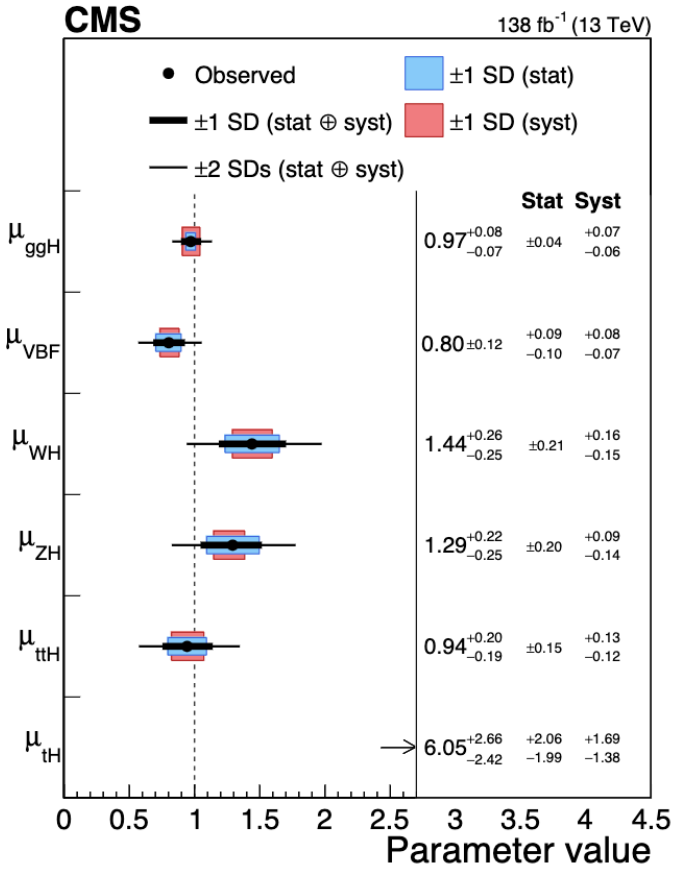




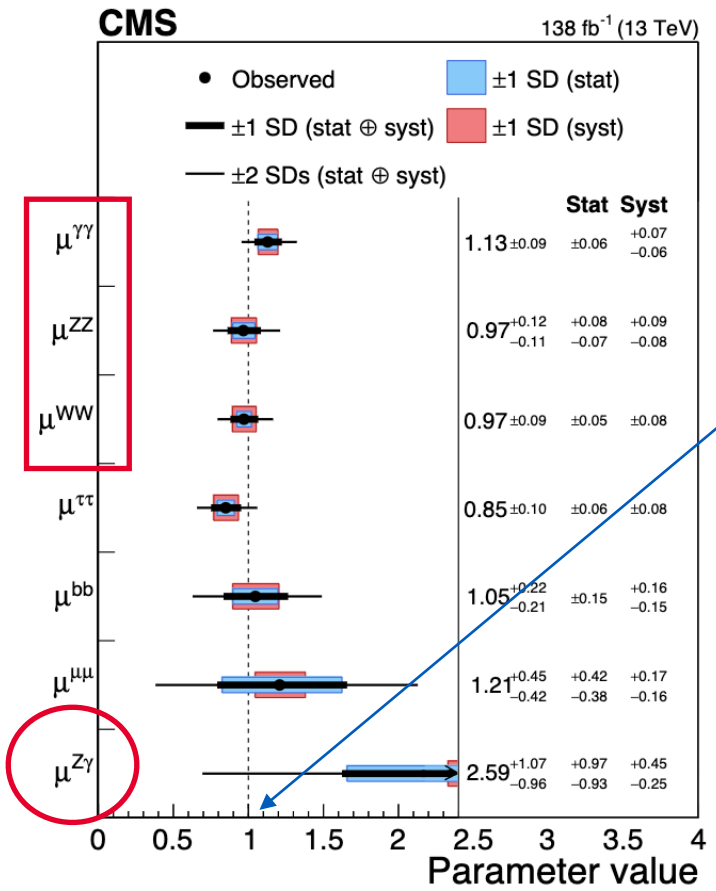
Most recent Higgs Results from CMS

2207.00043

Production modes



Decay modes



The parameter value $\mu = 1$ is the expected value from the standard model

all data from production modes and decay channels are fitted with a common signal strength parameter, μ.

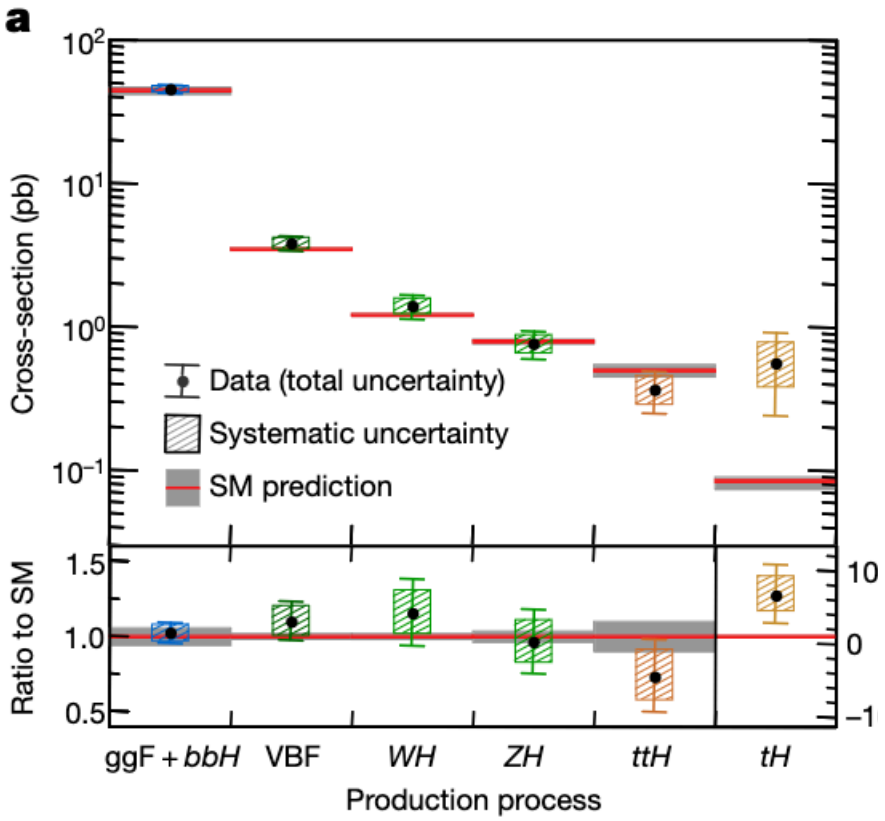
$\mu = 1.002 \pm 0.057$

Excellent agreement with the Standard model!

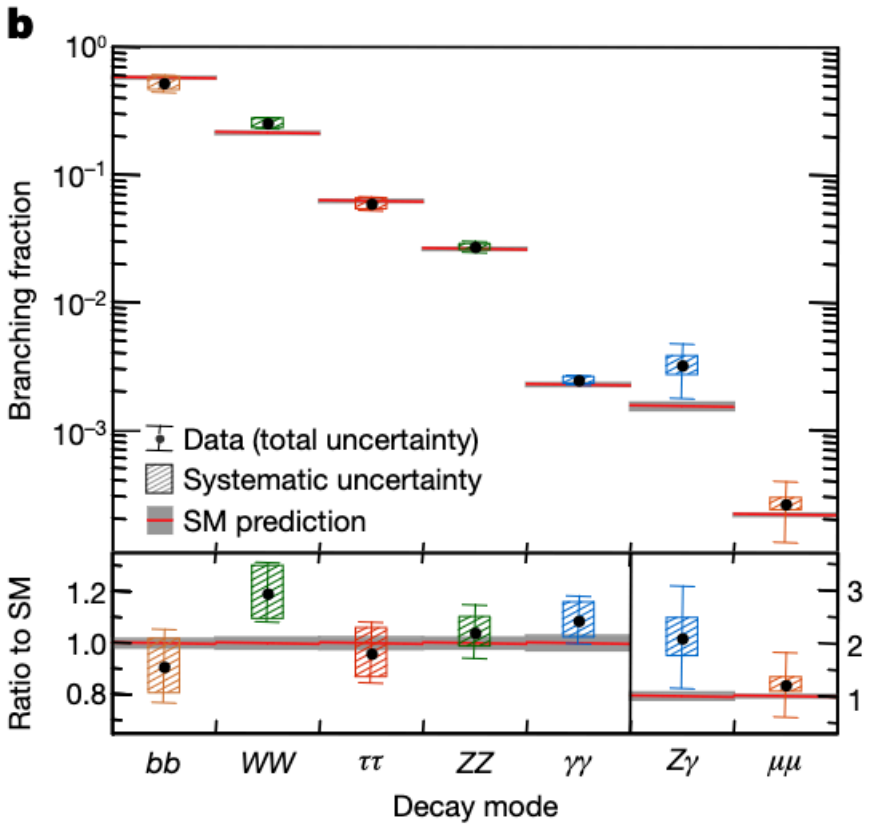
Most recent Higgs Results from ATLAS

s41586-022-04893-w

Production modes



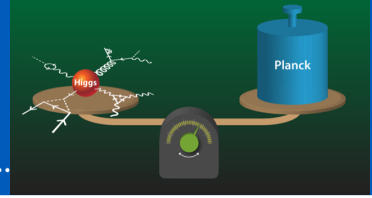
Decay modes



The combined measurements lead to $\mu = 1.05 \pm 0.06$

The SM Limitations && BSM proposals

Hierarchy Problem



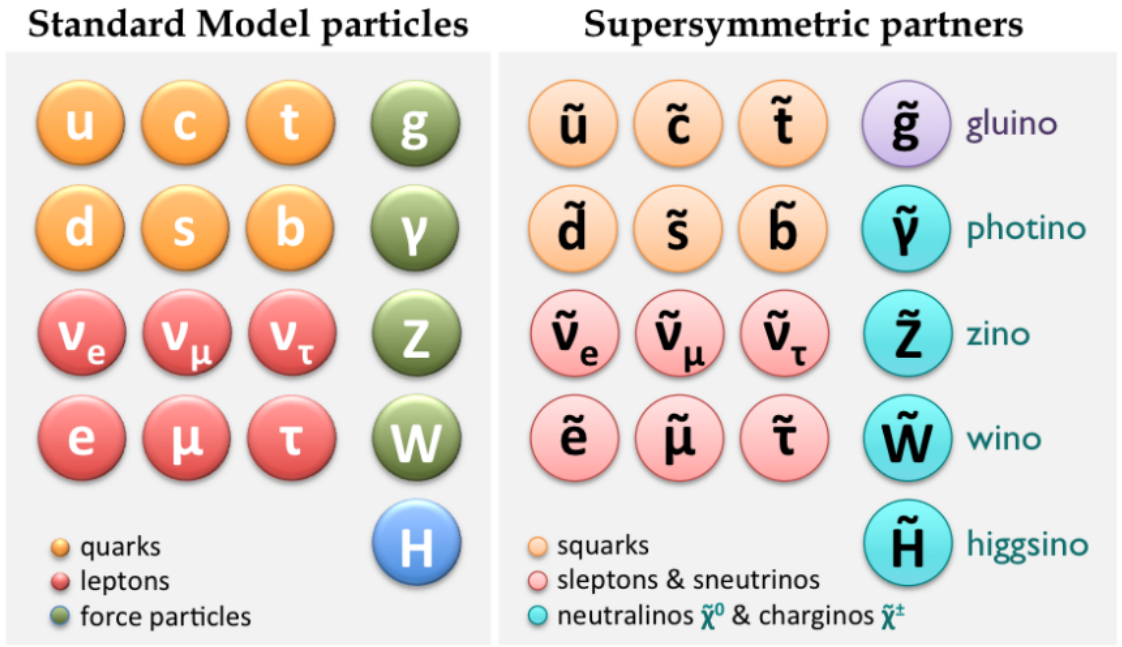
4 fundamental forces, their strength varies significantly

Gravity is 10^{38} weaker than the strong force

Quantum corrections at the Planck scale -> Higgs mass is much lighter than expected.

New physics i.e. particles cancel out quantum corrections.

Solution: Super Symmetry (SUSY).



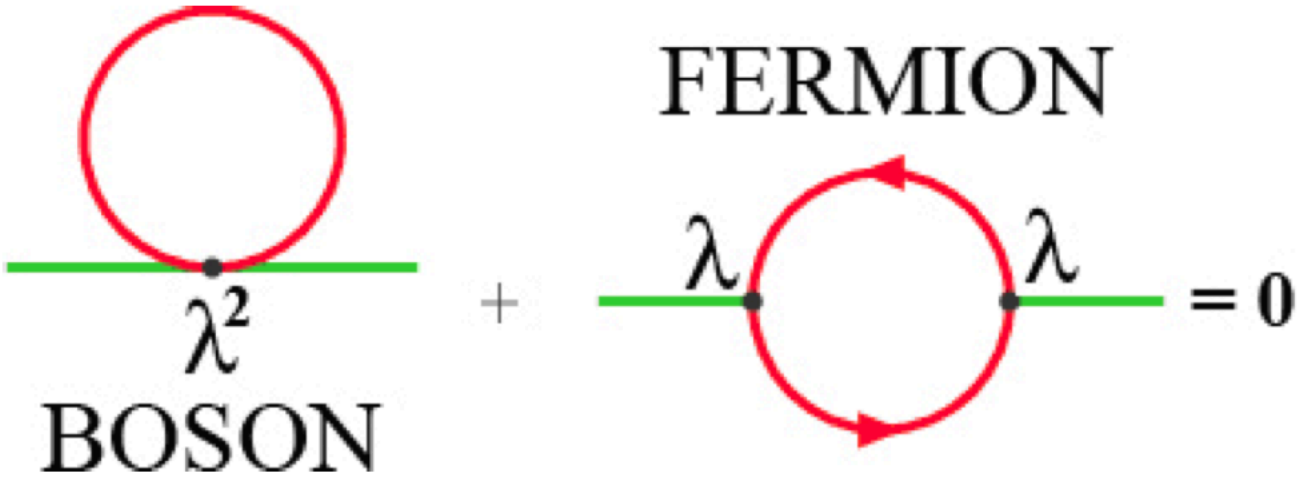
SUSY?

It is like a lemon tea after eating
It makes you feel lighter!

Supersymmetry (SUSY)

Quantum corrections at the Planck scale -> Higgs mass is much lighter than expected.

New physics i.e. particles cancel out quantum corrections.

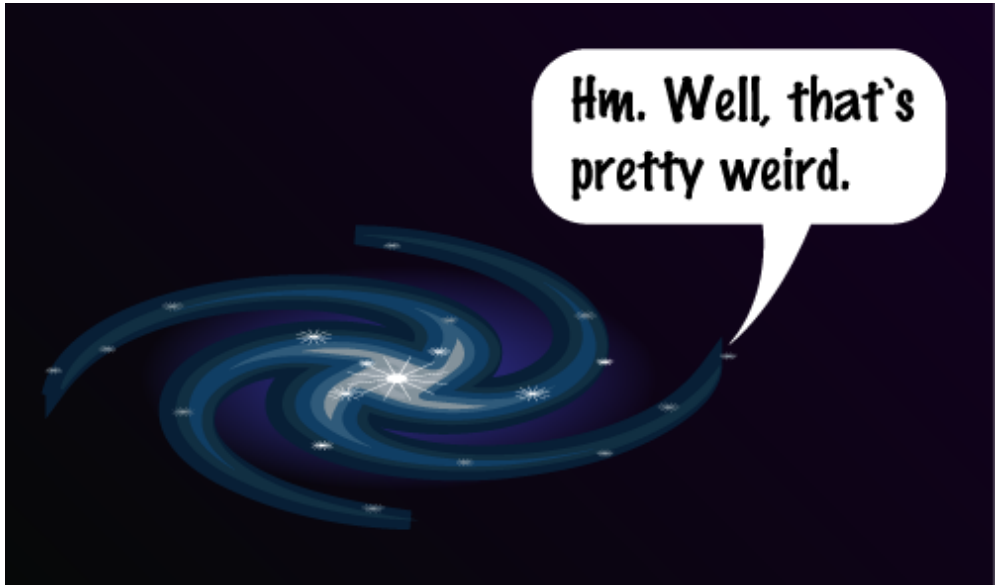


the spin differs by one-half SM vs SUSY

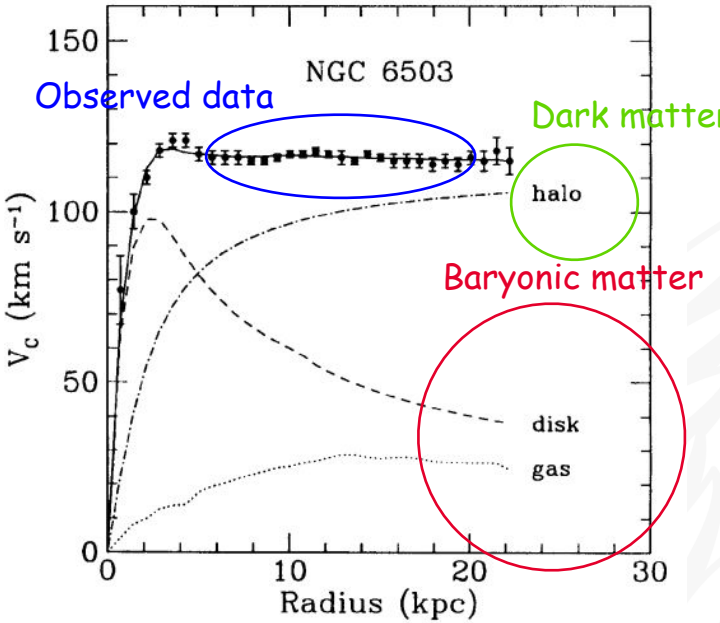
1703.09776

Dark Matter

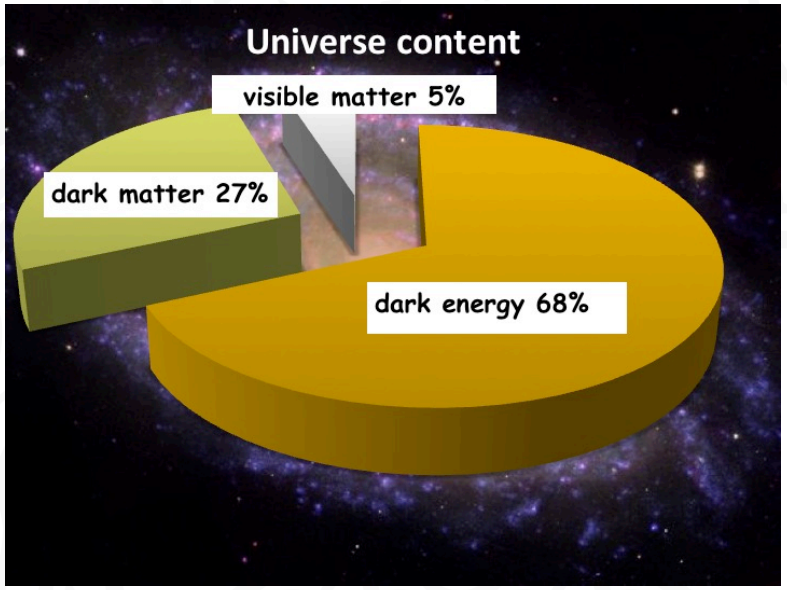
Problem



Galactic Rotation curve



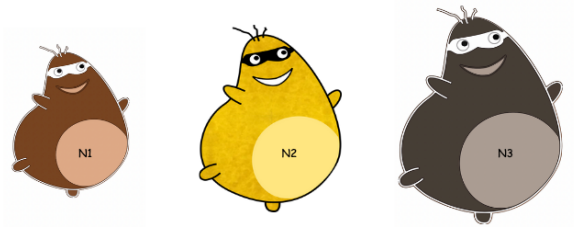
Conclusion



The outer regions of galaxies are rotating at much higher speeds than expected

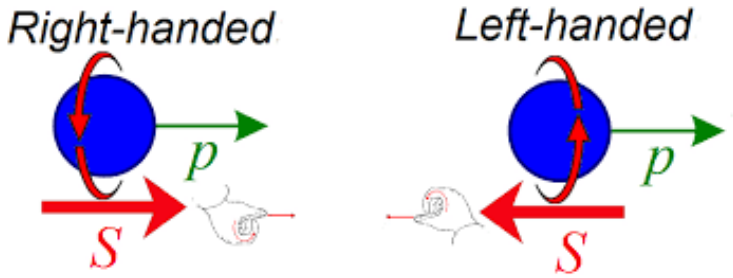
[Caltech.edu]

Neutrinos mass origin

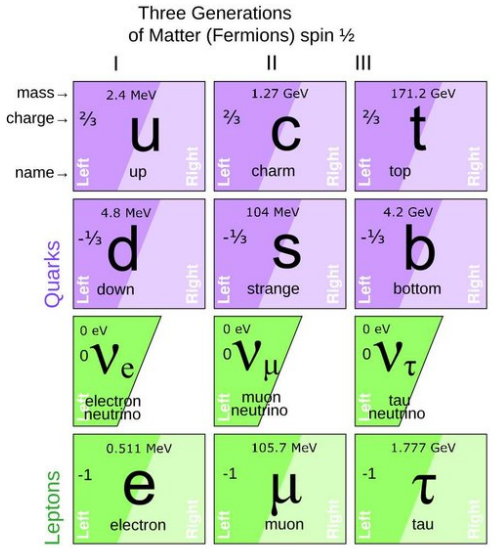


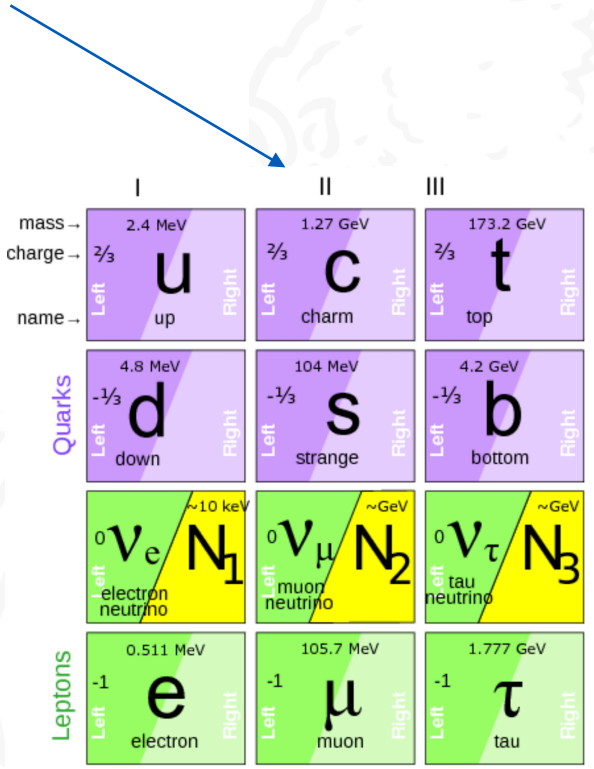
Neutrinos are left-handed particles

-> Believed to be massless

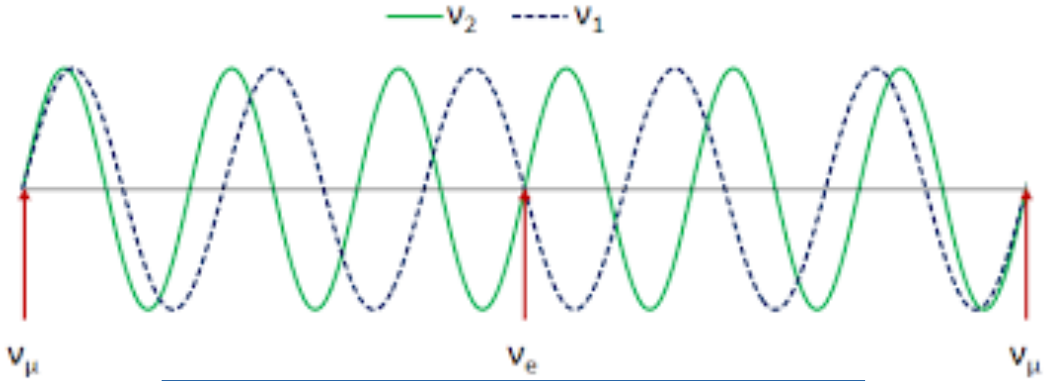


RH LH





neutrino's Oscillation: Neutrinos change flavor!



Evidence of massive neutrinos

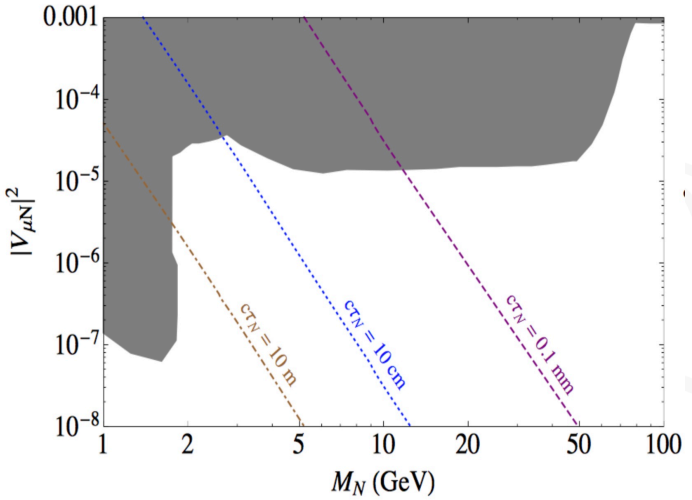
Extension of SM by RH neutrinos
i.e. Heavy Neutral Leptons (HNLs)

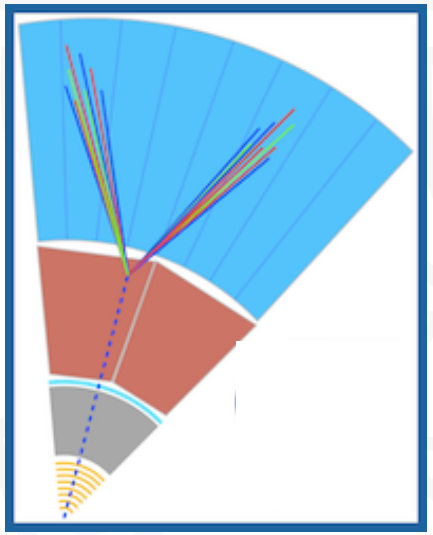
Heavy Neutral Leptons (HNLs)

- Three right-handed neutrinos as a minimal extension to the SM.
- Mass and coupling to the SM neutrinos (m_N, $V_{\ell N}$ i.e. $\ell = e, \mu, \tau$) are free parameters
- Can have Dirac(Majorana) nature process with LNC(LNC +LNV) respectively.
- Inclusive coupling to the three lepton generation i.e. LFC and LFV.
- Can be short or longlived:

$$\Gamma_N \propto G_F^2 m_N^5 \sum_{e,\mu,\tau} |V_{\ell N}|^2 \text{ and the proper lifetime } \tau \propto \frac{1}{\Gamma_N}$$

For fixed mass: The weaker the coupling the longer the lifetime is.





Manifestation at the detector Level

The LHC BSM Searches

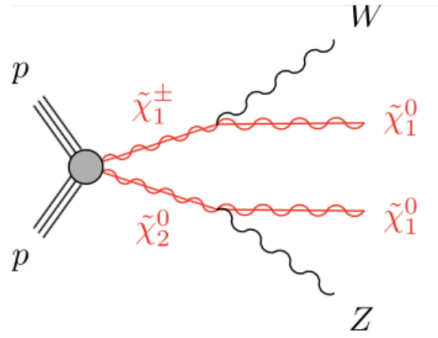
Supersymmetry: EWK results

Charginos
Super partners
Of W boson

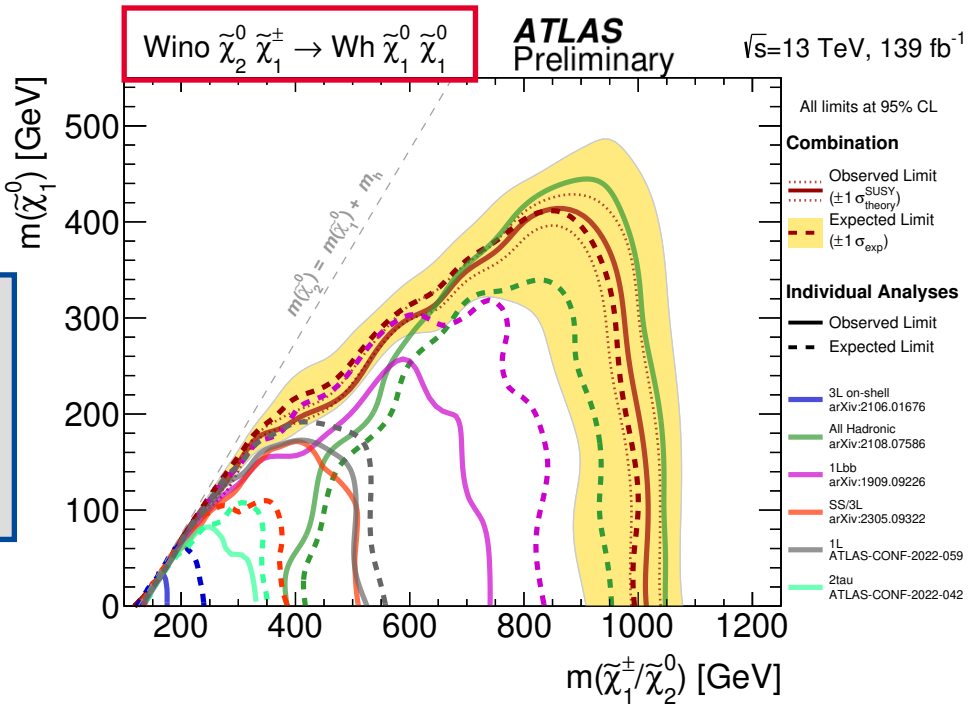
Combined EWK SUSY ATLAS analyses.
Considered processes

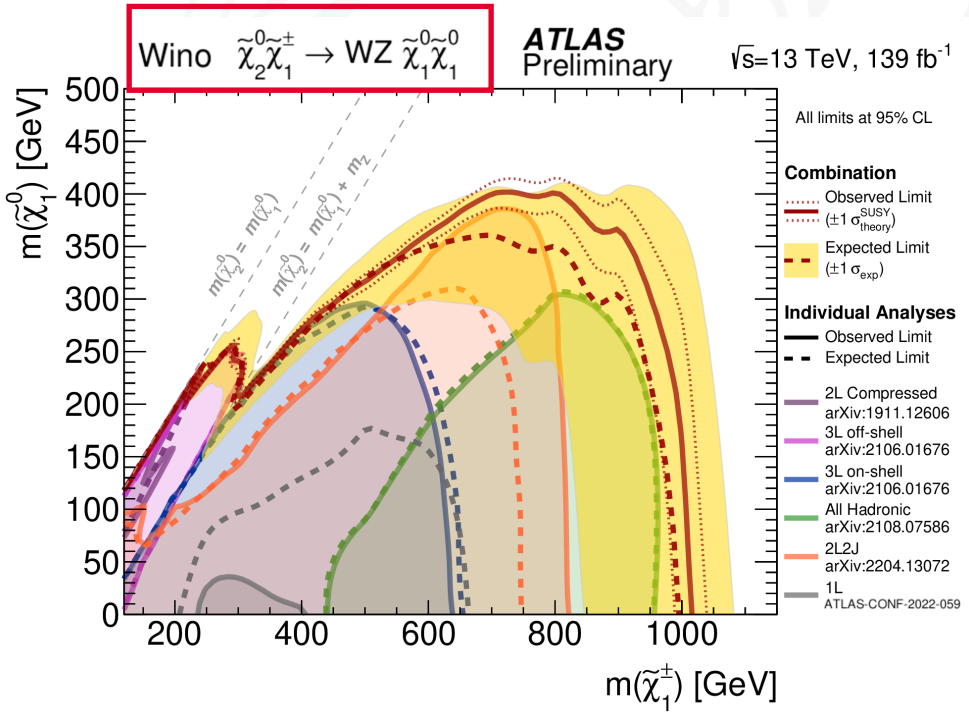
ATLAS-CONF-2023-046

Production mode	Wino $\tilde{\chi}_1^+\tilde{\chi}_1^-$	Wino $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$	Wino $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$	Higgsino GGM $\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^\pm\tilde{\chi}_{1,2}^0, \tilde{\chi}_1^0\tilde{\chi}_2^0$
Decay mode	$\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$	$\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$ $\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0$	$\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$ $\tilde{\chi}_2^0 \to h\tilde{\chi}_1^0$	$\tilde{\chi}_1^0 \to Z/h\tilde{G}$



Neutralinos
Super partners
of Z boson
Dark matter
candidate



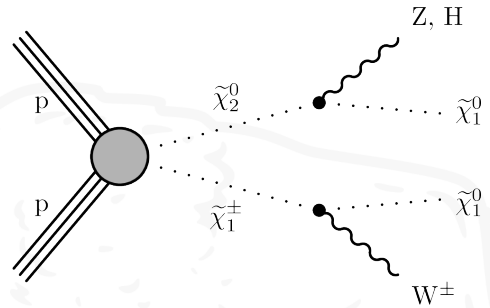


Supersymmetry: EWK results

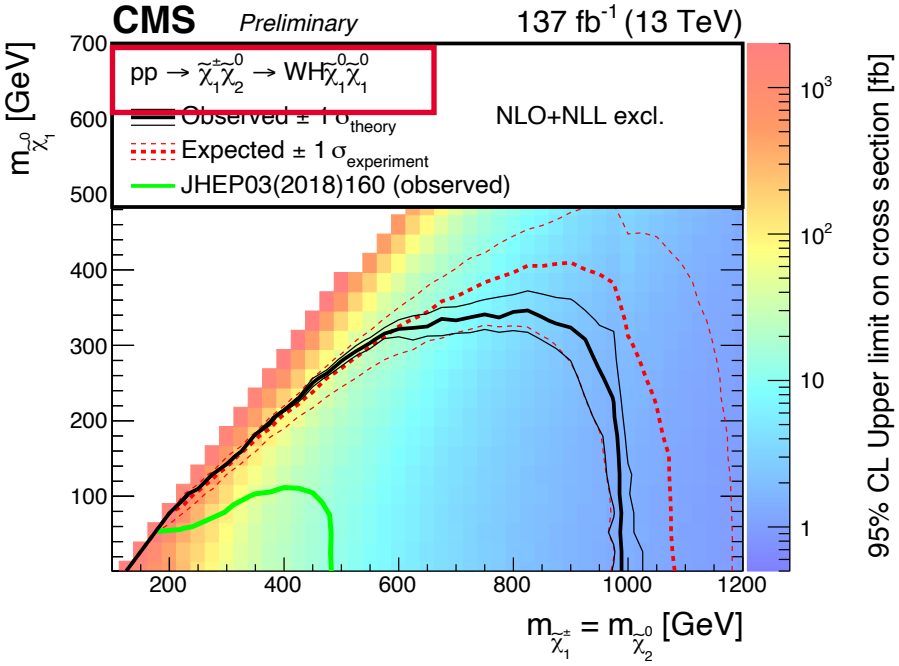
Combined EWK SUSY CMS analyses. Considered processes

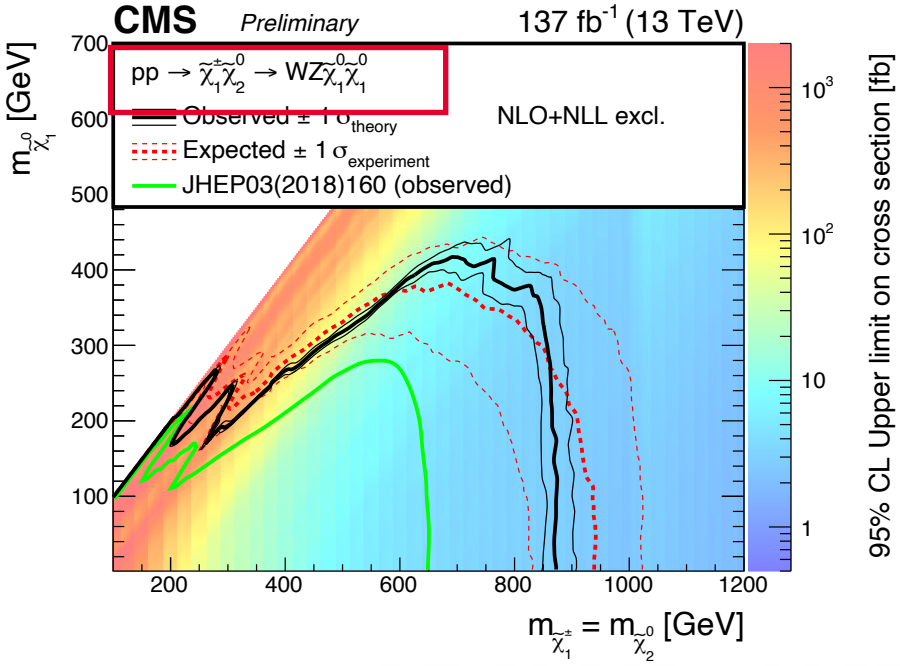
Production mode	Wino $\tilde{\chi}_1^+\tilde{\chi}_1^-$	Wino $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$	Wino $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$	Higgsino GGM $\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^\pm\tilde{\chi}_{1,2}^0, \tilde{\chi}_1^0\tilde{\chi}_2^0$
Decay mode	$\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$	$\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$ $\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0$	$\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$ $\tilde{\chi}_2^0 \to h\tilde{\chi}_1^0$	$\tilde{\chi}_1^0 \to Z/h\tilde{G}$

CMS-PAS-SUS-21-008



+ $\tilde{\chi}_3^0$ Production and decay included



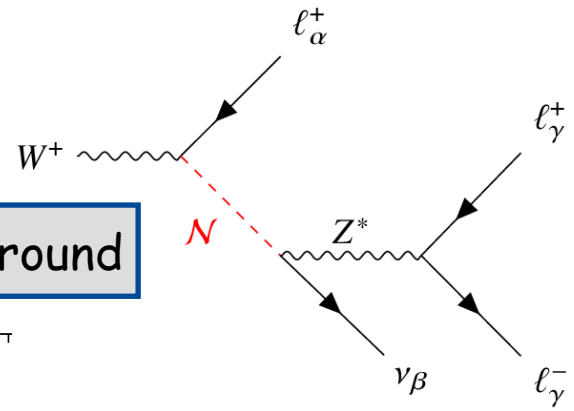


HNL search in ATLAS

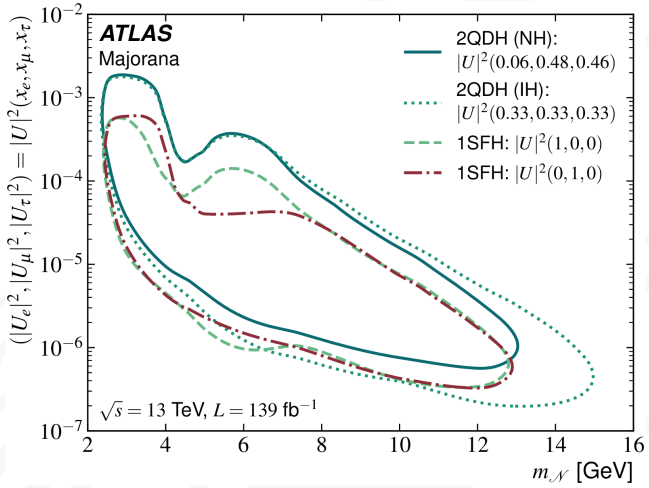
Dirac or Majorana HNLs

Incl. coupling to the 3 generation

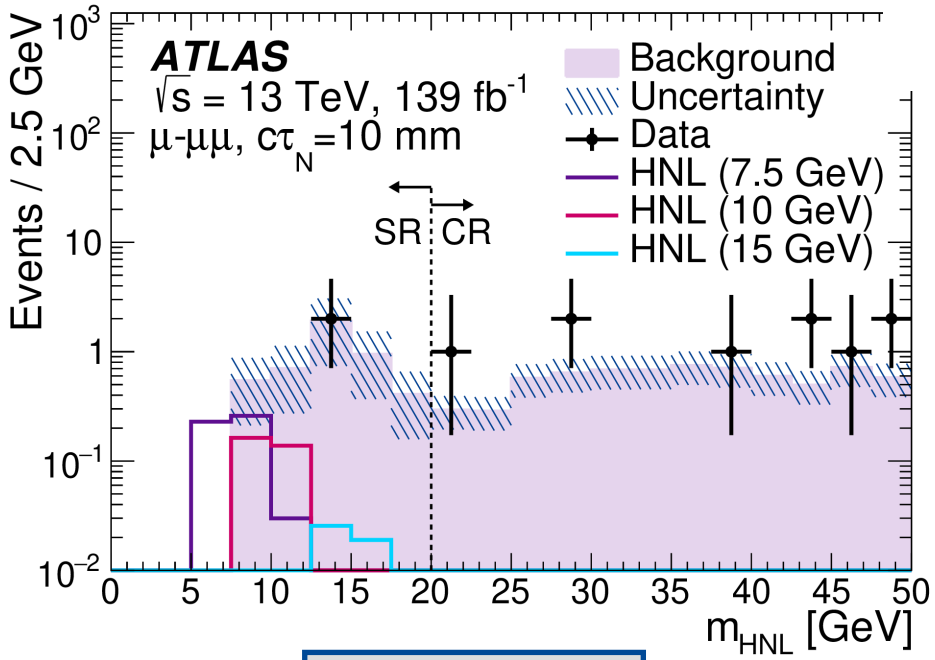
Analyzed process

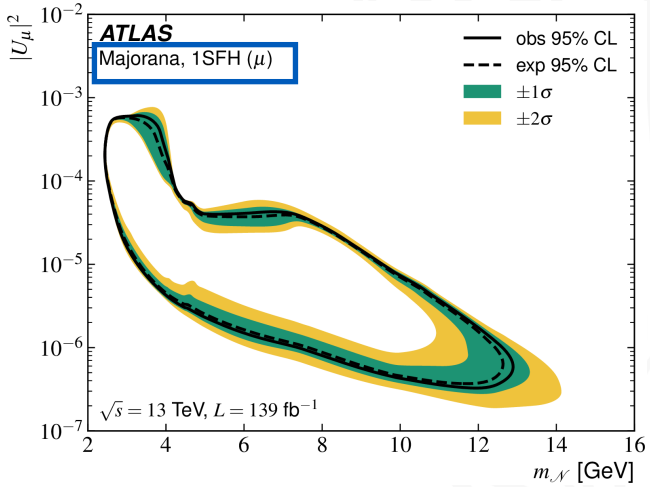


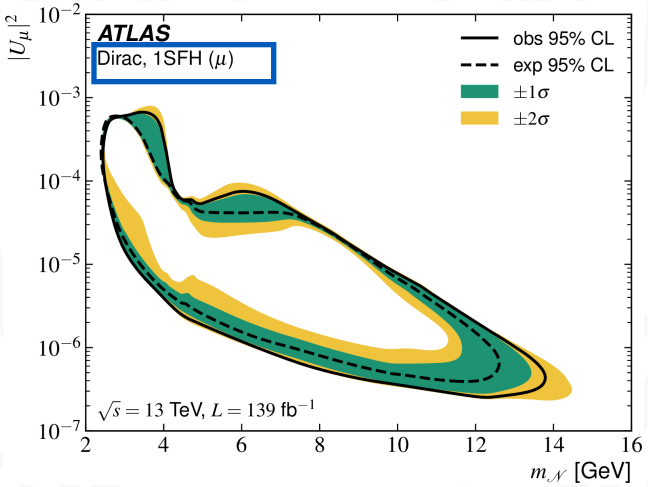
Different couplings scenarios



No Excess beyond the expected background







Signal regions

EXOT-2019-29

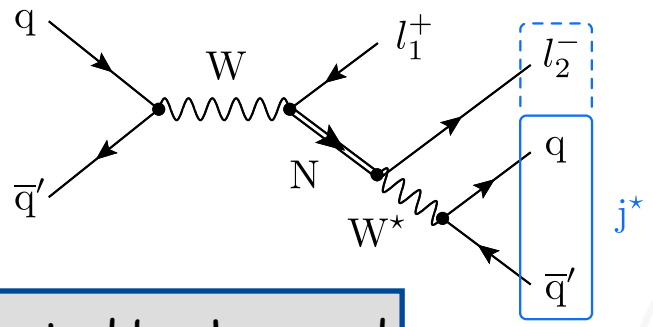
Pure coupling to muons

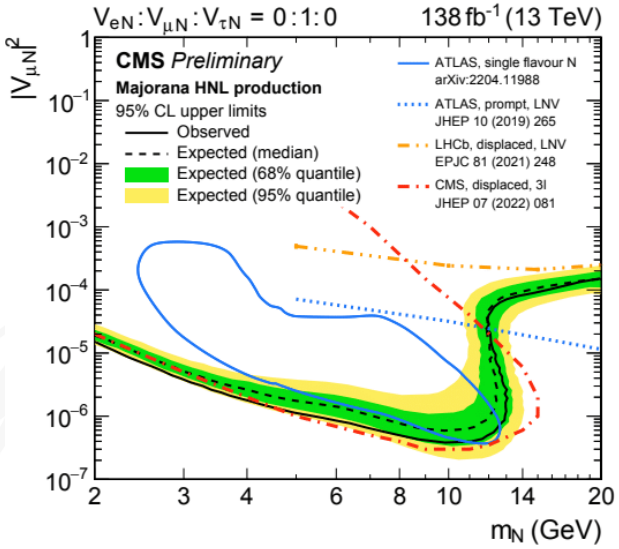
HNL search in CMS

Dirac or Majorana HNLs

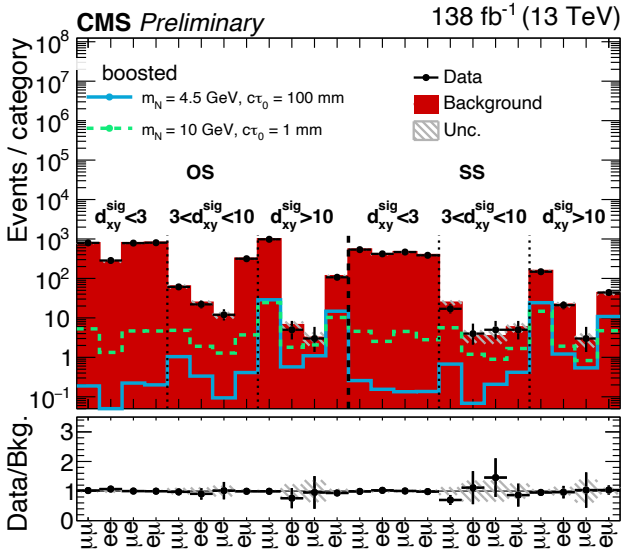
Incl. coupling to the 3 generation

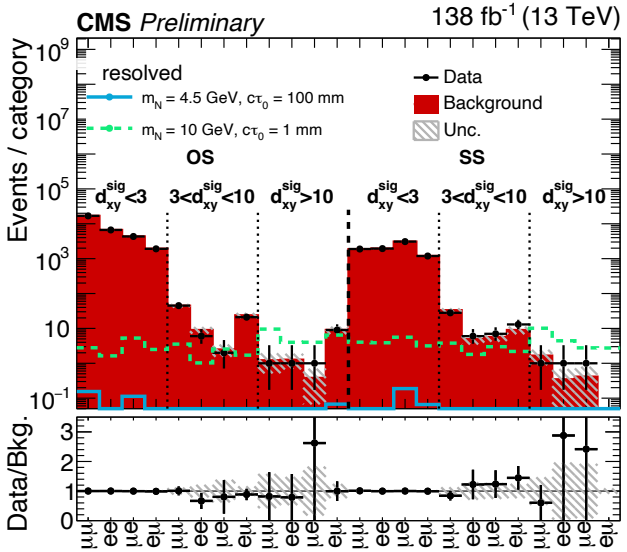
Analyzed process

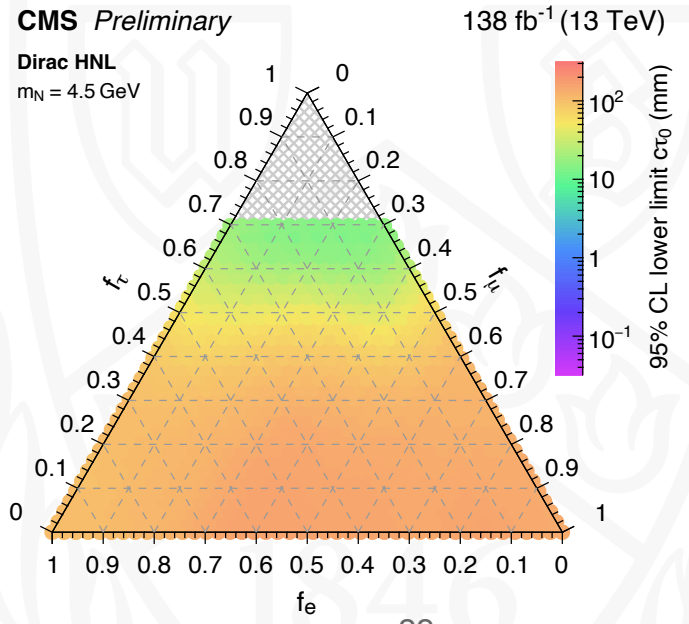




Signal region: No excess beyond the expected background





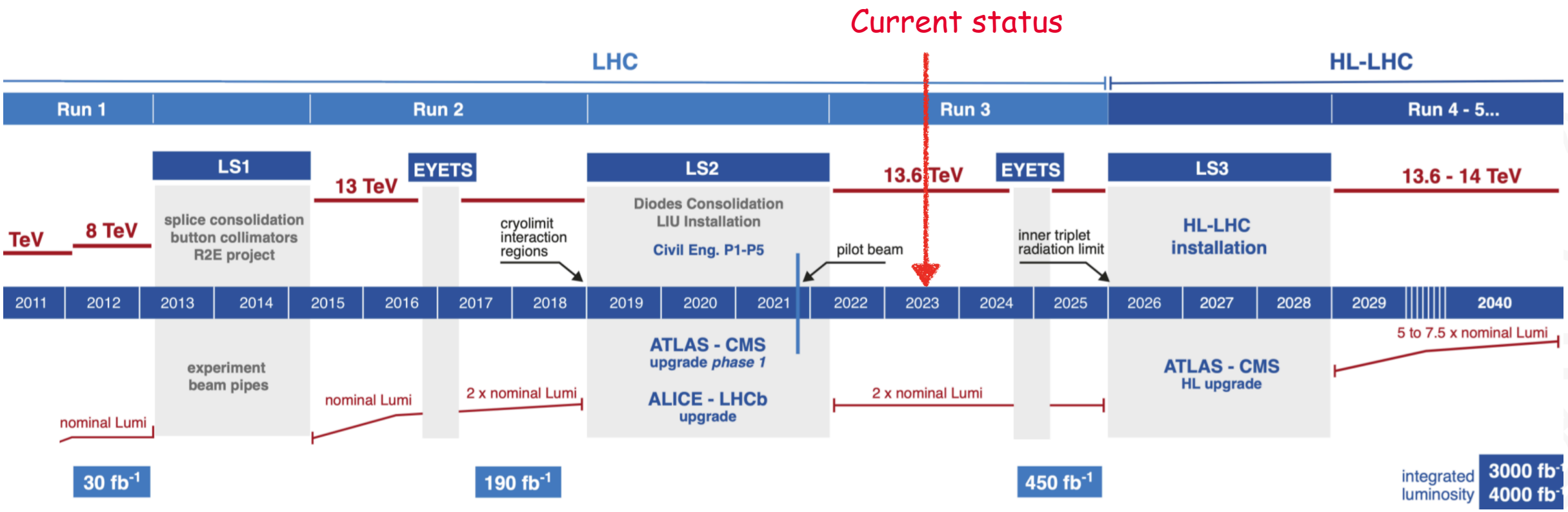


EXO-21-013

Signal regions

LHC Run 3 and HL-LHC

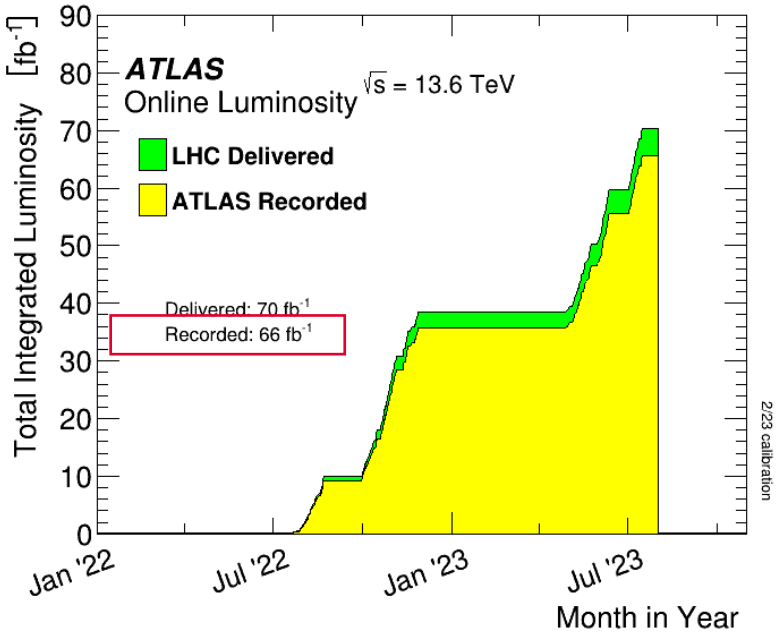
LHC status and HL-LHC plan

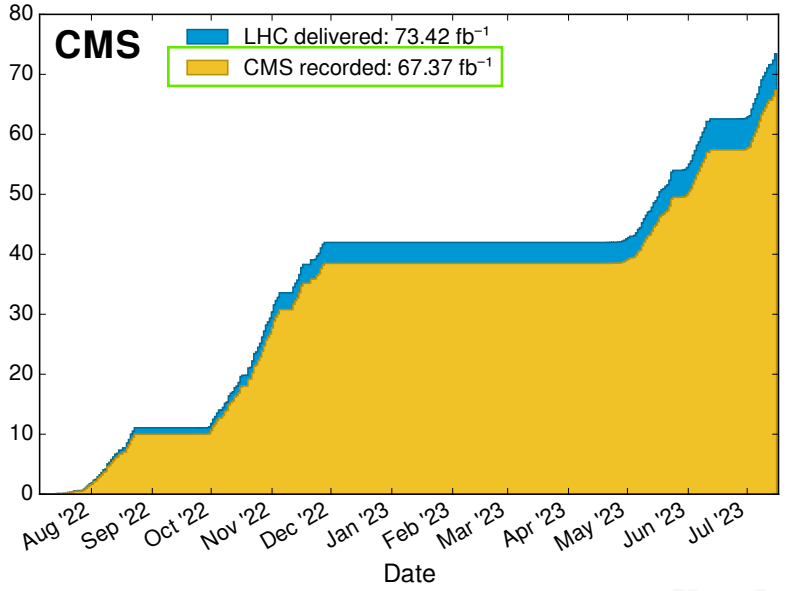


High Luminosity: Increase in the collision rate. Several ongoing upgrades work from the accelerator to the detectors level

Run3

13.6 TeV pp collision





Summer 2022 - The start of run 3

Started in 2022 with $42\ fb^{-1}$ data collected for CMS

In total ~67 and ~66 fb^{-1} for CMS and ATLAS

Aim to reach $450\ fb^{-1}$ by end of 2025

Summary

- A brief overview of the journey of particle physics and the LHC

  From the Higgs boson discovery to SUSY and HNL results

- Only a few results have been shown, but we have many more physics results

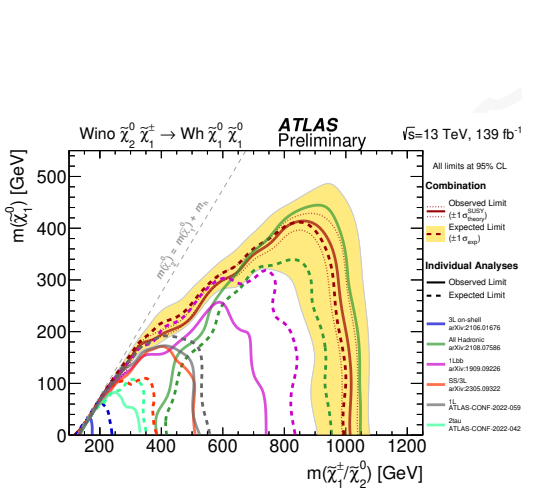
- Many other physics models are on the table - searches are ongoing.

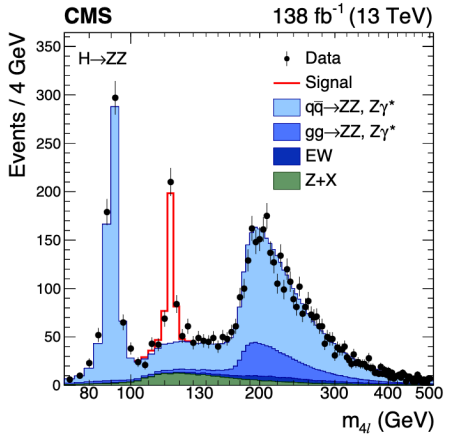
- No evidence of new physics is observed **YET !**

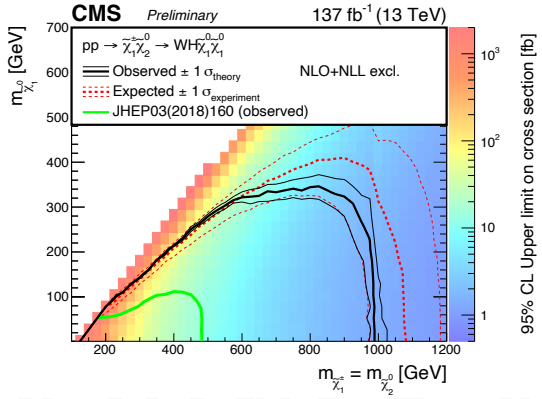
- Many phase spaces (not yet excluded) have to be explored → We need more data !

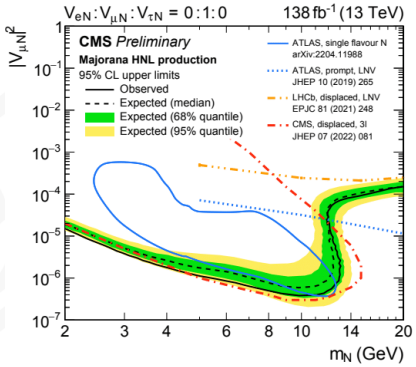
- Run 3 has just started, and even more data will be collected with the HL-LHC.

The best is yet to come!

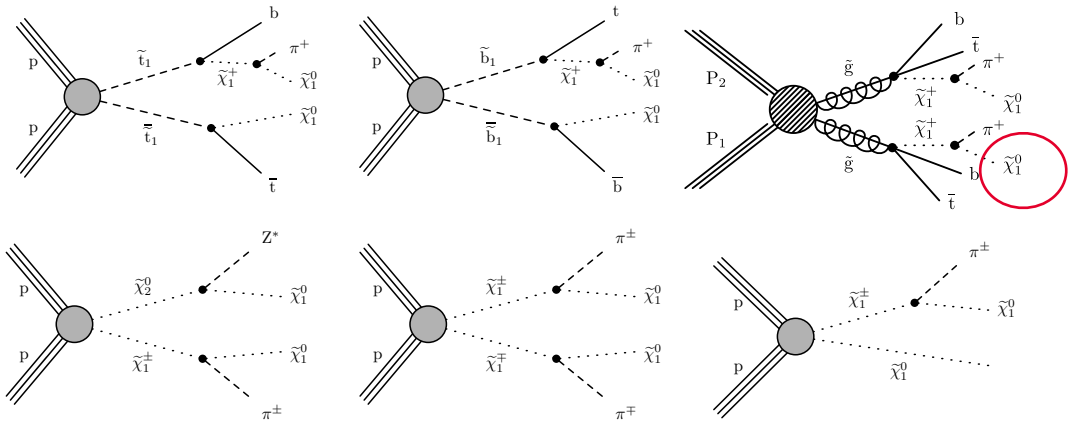




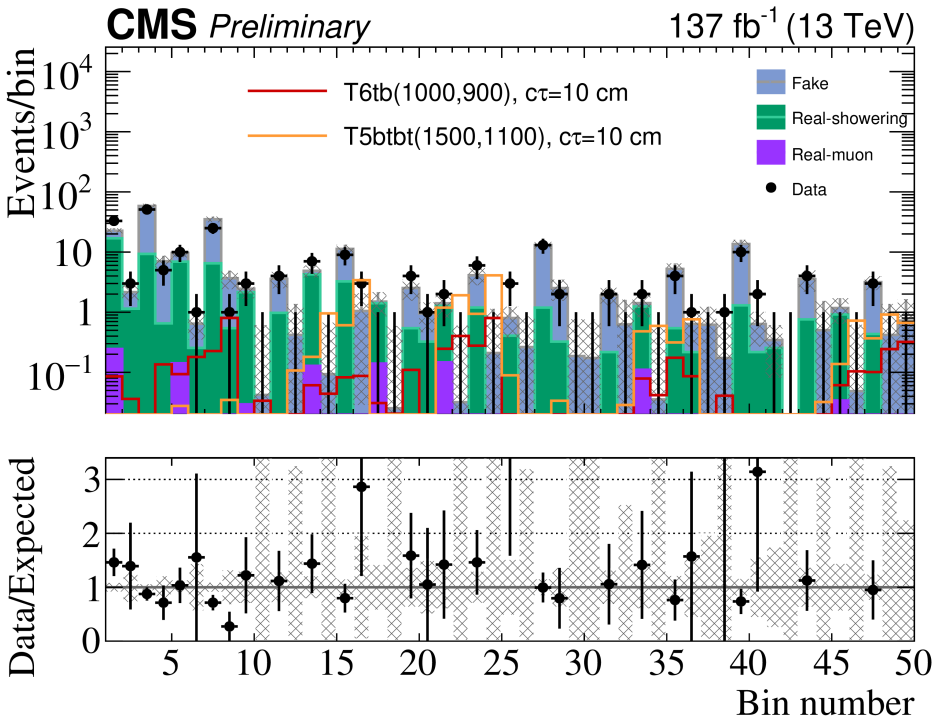


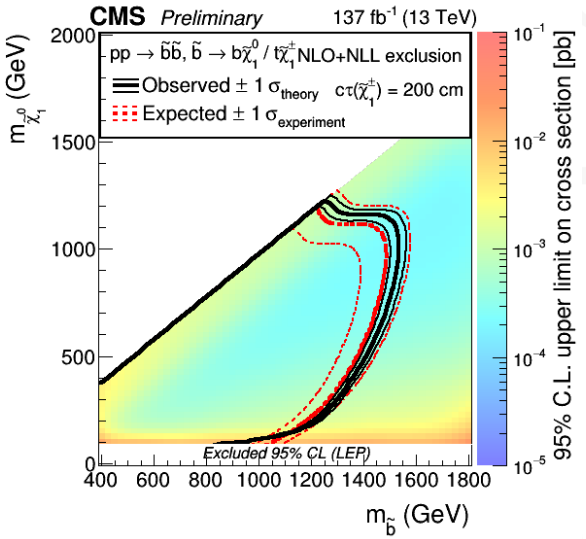


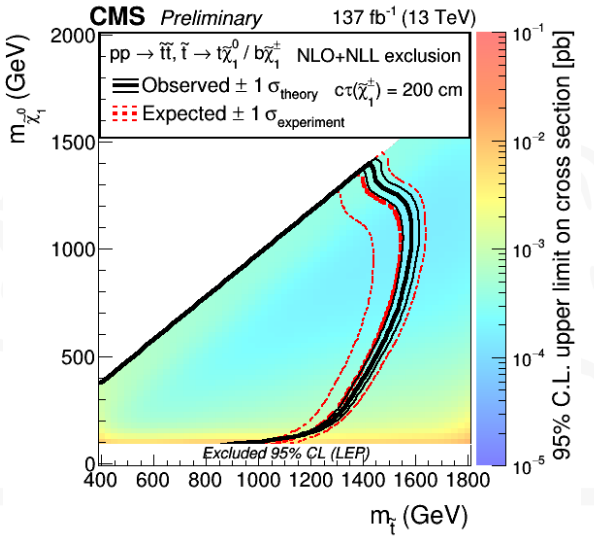
Supersymmetry Results

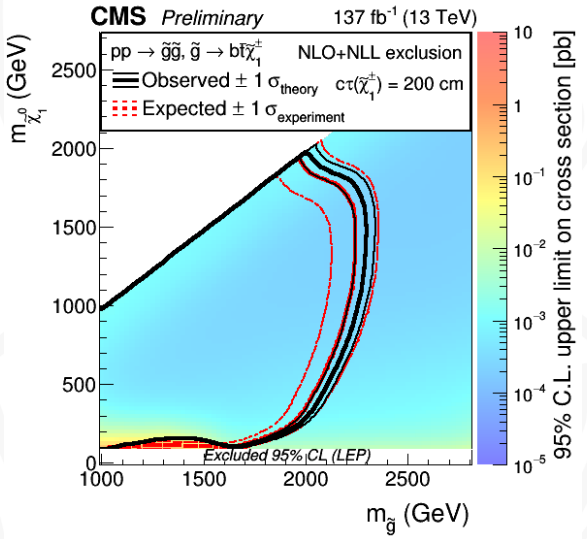


Dark matter candidates









[CMS-PAS-SUS-21-006]