BF2023: Brookhaven Forum 2023: Advancing Searches for New Physics

# Recent BSM results from ATLAS and CMS

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On behalf of the ATLAS and CMS Collaborations

04 - 10 - 2023

# To put things in context …

Several SM limitations and possible solutions

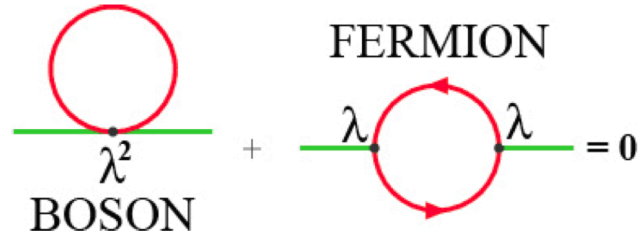
Problem 1: The mass of the Higgs boson is significantly lighter than expected when compared to the Planck Scale, creating a hierarchy problem.

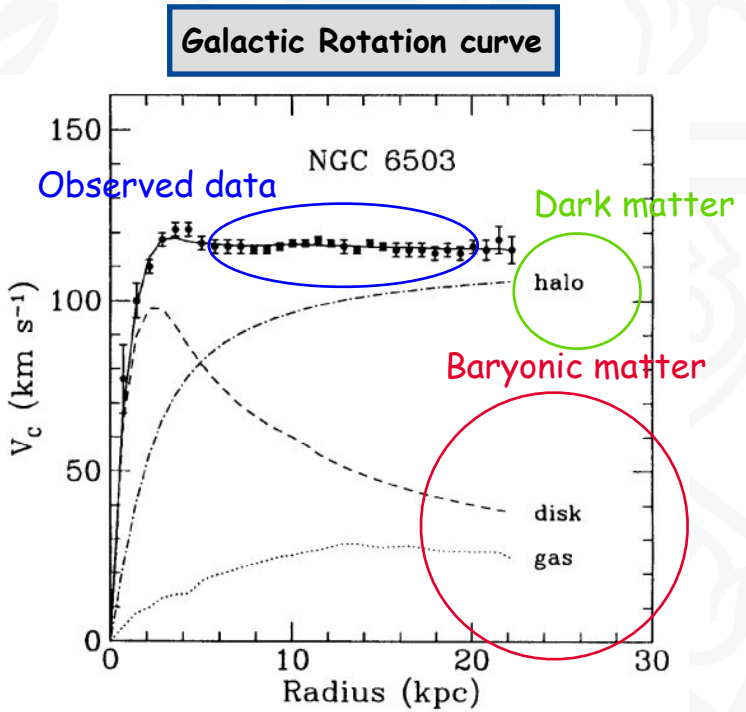
Solution 1: SuperSymmetry (Susy) and Very Heavy Quarks (VLQs), i.e., particles, cancel out quantum loop corrections → Stability of the Higgs boson mass.

Problem 2: Dark Matter: the rotation velocity of the outer layers of the galaxies does not match the observed Baryonic matter. Not only…

Solution 2: Susy, i.e., neutralinos as dark matter candidate

and Dark Sector



# To put things in context …

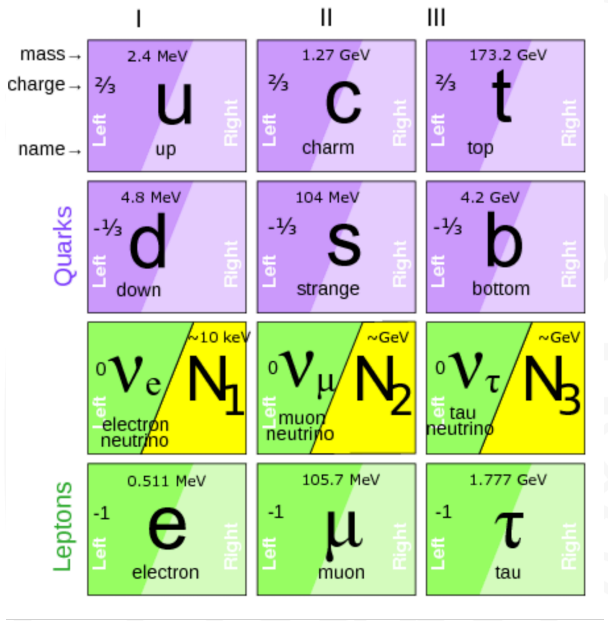
Several SM limitations and possible solutions

Problem 3: Origin of Neutrino mass: SM neutrinos are LH, believed to be massless until the discovery of neutrino's oscillation.

Solution 3: Extension of the SM by RH neutrinos simple SM extension uses type-I seesaw mechanism i.e. Heavy Neutral Leptons (HNLs) or Left-Right Symmetric Models (LRSM) to incorporate mass to neutrinos.

Problem 4: Baryon assymetry in the universe, matter is much more abondant than anti matter.

Solution 4: HNLs, Axion like particles (ALPs), etc …



# Overview: recent results

| Analysis | Topology | Experiment |
|---|---|---|
| ATLAS-CONF-2023-058 | Stop pair production in MSSM | ATLAS |
| CMS-PAS-EXO-21-008 | LLPs decay in the muon system | CMS |
| CMS-PAS-SUS-21-006 | Charged LLPs susy with disappearing tracks | CMS |
| CMS-PAS-EXO-22-020 | LLPs within split susy | CMS |
| ATLAS-CONF-2023-046 | Ewk susy combination | ATLAS |
| CMS-PAS-SUS-21-008 | Ewk susy combination | CMS |
| EXO-23-014 | Run 3 LLPs results | CMS |
| ATLAS-CONF-2023-070 | Search for double VLQ pair production | ATLAS |
| ATLAS-CONF-2023-047 | Search for dark jets | ATLAS |
| EXOT-2019-39 | Search for $W_R$ bosons and heavy neutrino | ATLAS |
| EXO-21-013 | Search for LL HNLs in 2 leptons + jets | CMS |
| CMS-PAS-EXO-22-017 | Search for LL HNLs in the muon system | CMS |
| 2307.14944 | Tetrajets generic resonance | ATLAS |
| 2308.04835 | Search for monopoles | ATLAS |
| ATLAS-CONF-2023-040 | Search for short and longlived ALPs | ATLAS |

CMS and ATLAS results with full Run 2 dataset corresponding to ~138 $fb^{-1}$ and 140 $fb^{-1}$ respectively.

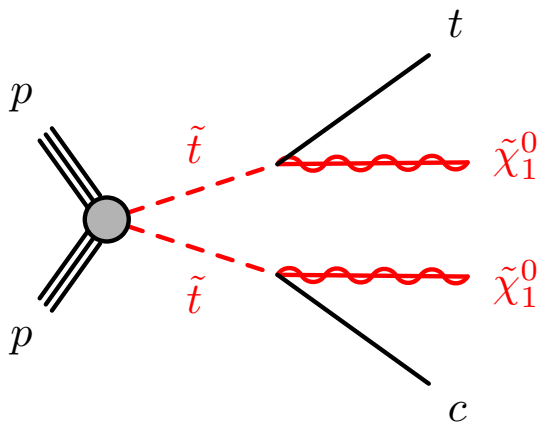
One CMS result using the Run 3 dataset corresponding to 36.7 $fb^{-1}$

All results can be found:

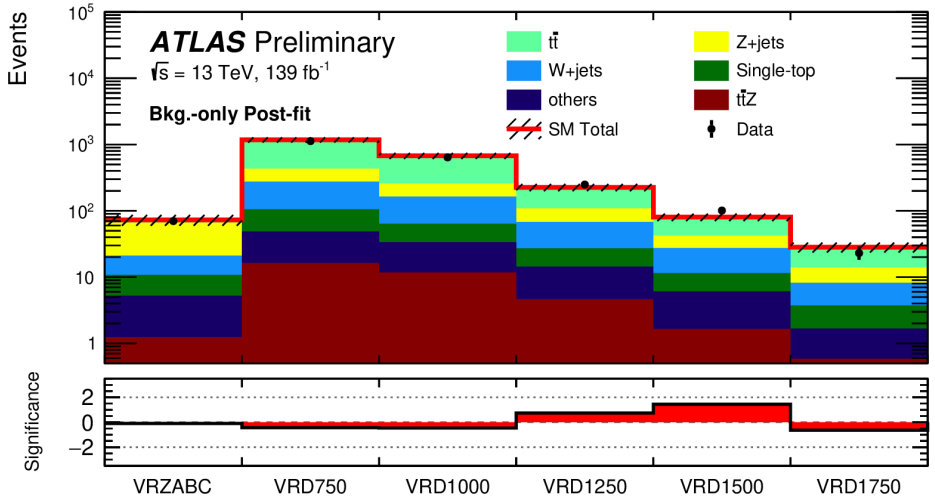
- ATLAS: Exotics Physics Searches Publications
- CMS: Beyond $2^{nd}$ Generation : Preliminary , Publications , Exotica : Preliminary , Publications

# stop pair production search

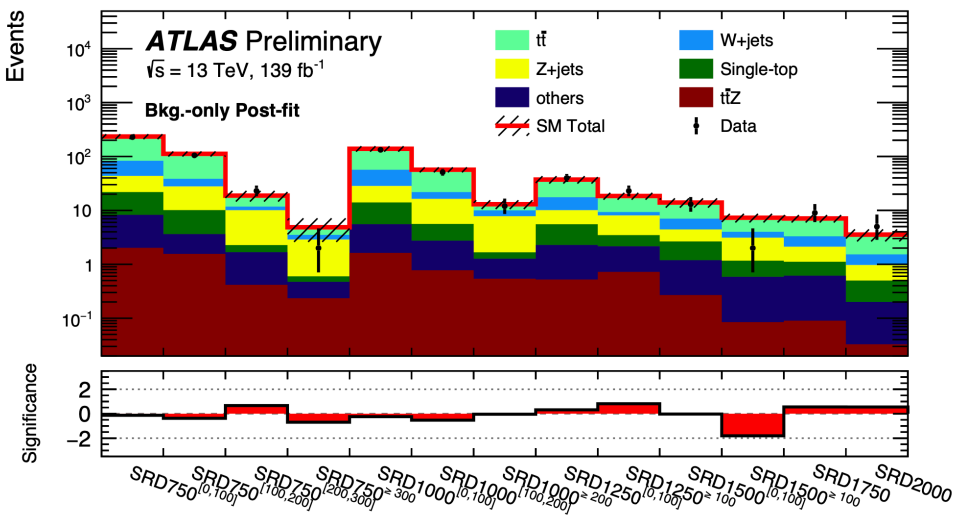
MSSM model




Validation regions




Signal regions 3




VRZABC: VR for 1 and 2 SRs

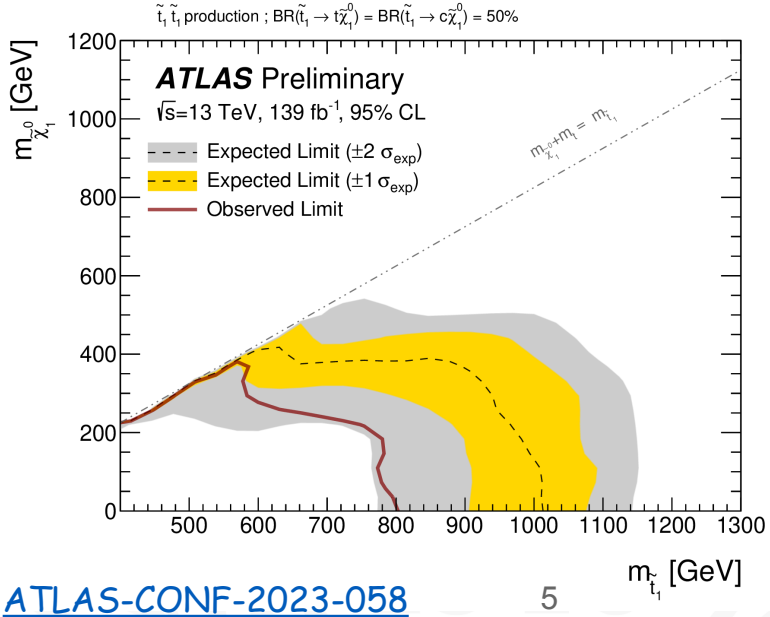
3 regions: based on mass splitting $\Delta m(\tilde{t}, \tilde{\chi}_1^0)$

Bulk region: large $\Delta m(\tilde{t}, \tilde{\chi}_1^0)$ (1)

Intermediate region: $m_{\tilde{t}} \approx m_{\chi_1^0}$ (2)

Compressed region: $\Delta m(\tilde{t}, \tilde{\chi}_1^0) \approx m_t$ (3)

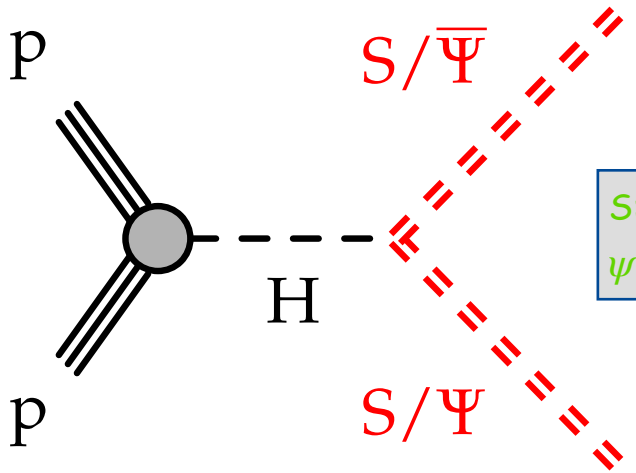
Several SRs are defined to maximize sensitivity to different scenarios.




ATLAS-CONF-2023-058

# Higgs decays to neutral LLPs in the muon system

Twin Higgs and Dark shower models




S: LLP scalars
ψ: dark sector quarks

A broad range of LLP decay modes: decays to a pair of quarks, $K^{\pm}$, $\pi^{\pm}$, $e^{\pm}$, $\gamma$, or $\tau$ leptons.

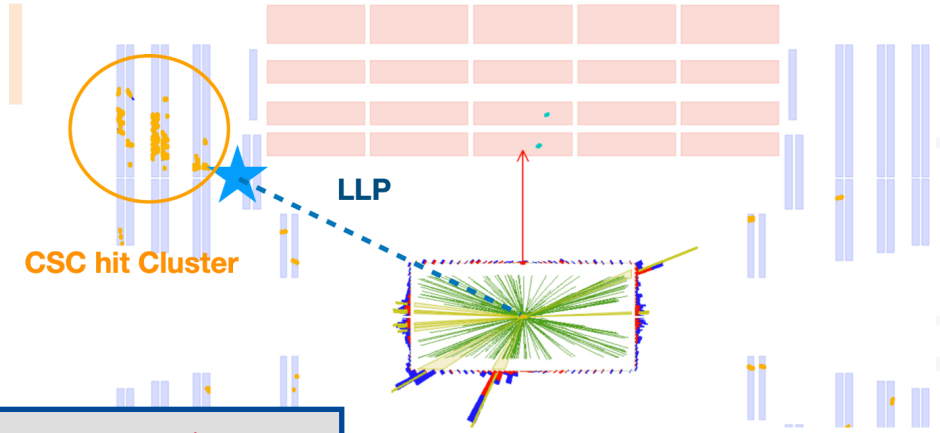
LLP decays in the muon system:

Clusters reconstructed in the CSC and DT

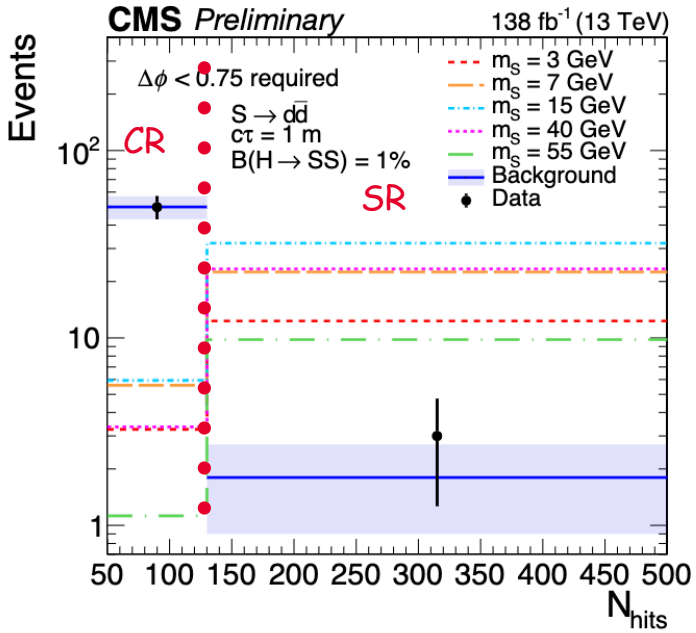
→3 main categories :

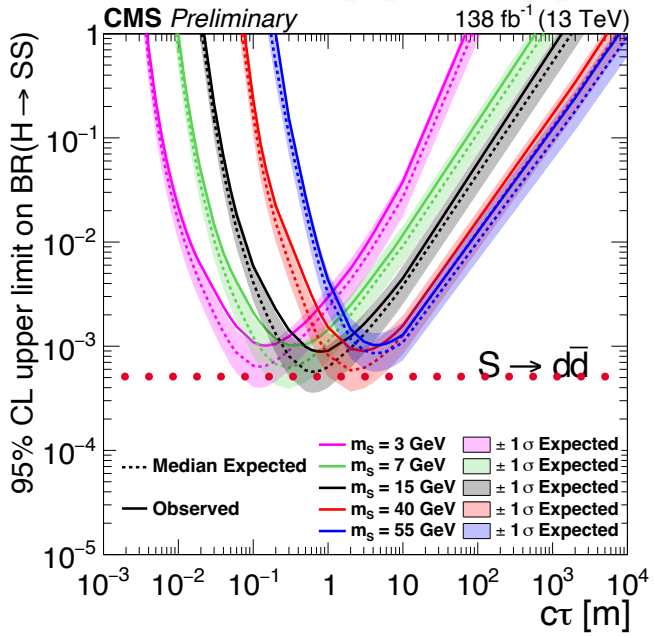
2 clusters, exactly 1 CSC, exactly 1 DT

→2 clusters: 2 CSC clusters, 2 DT clusters, and 1 CSC and 1 DT cluster




CSC cluster Search Region

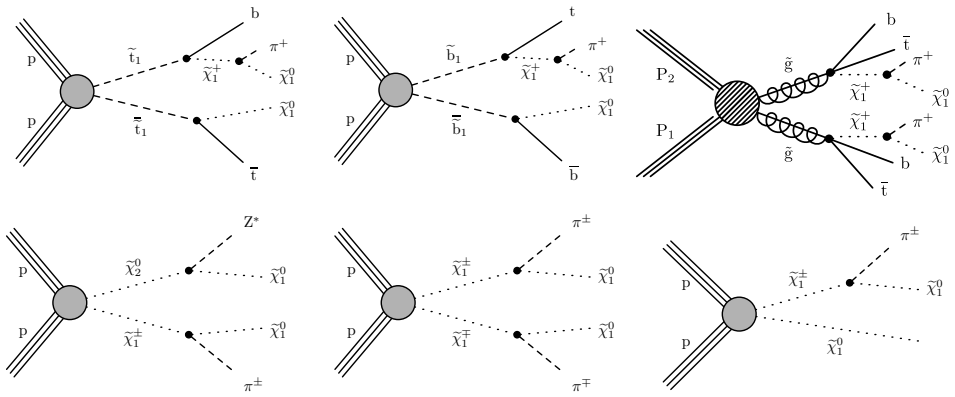



CMS-PAS-EXO-21-008

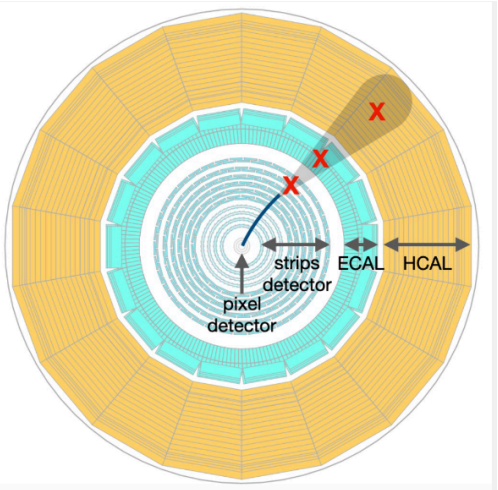
# Charged LLPs with disappearing tracks

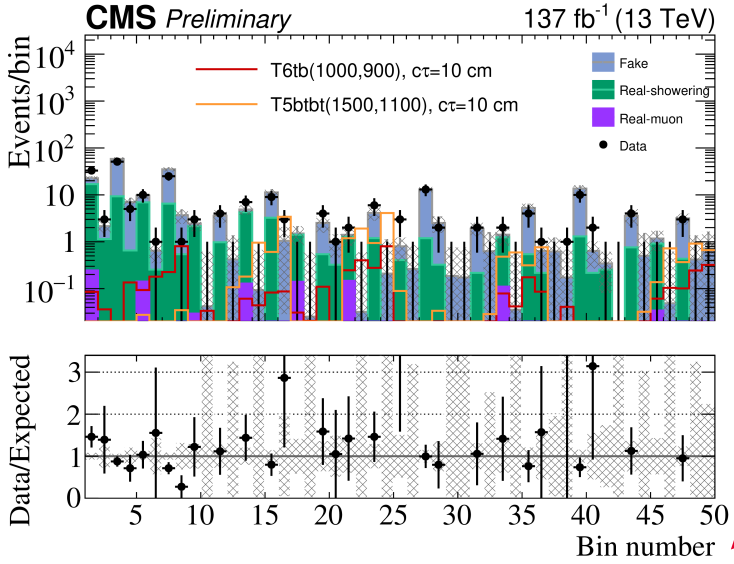
R-parity conserving MSSM



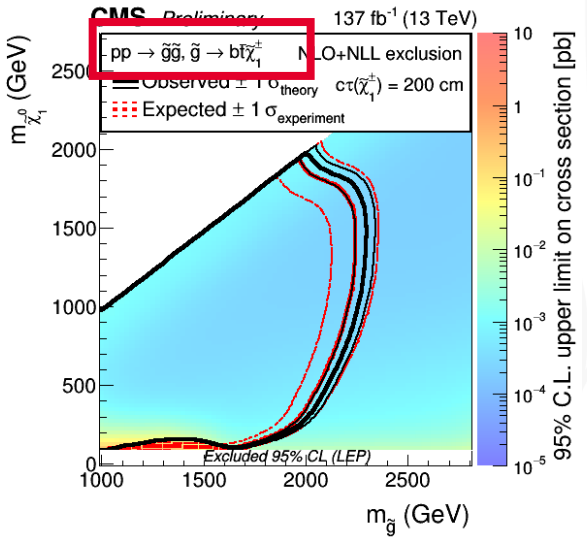
Different final states based on:

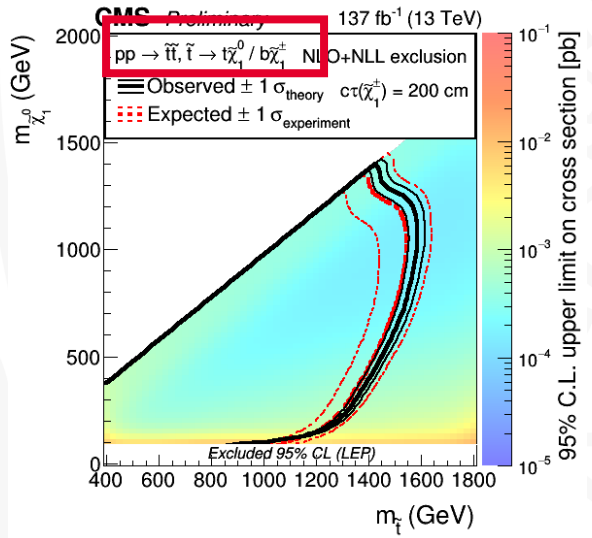
Number of jets, b-jets, leptons, and disappearing tracks.




49 SRs

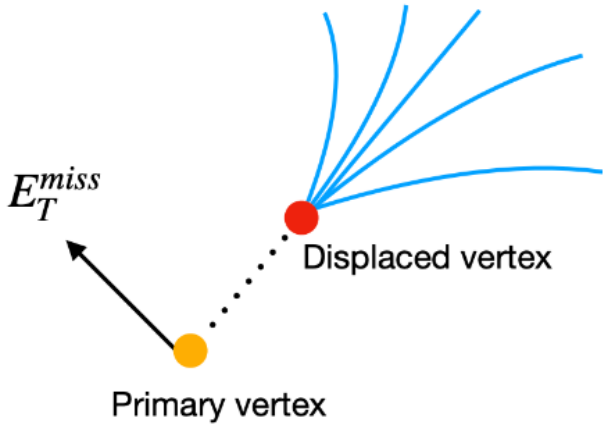


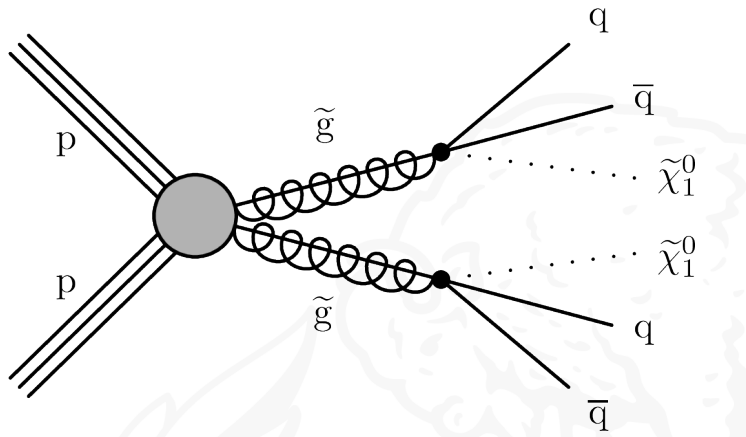




CMS-PAS-SUS-21-006

# LLPs with displaced vertex and missing energy

Split susy model, search for longlived gluinos



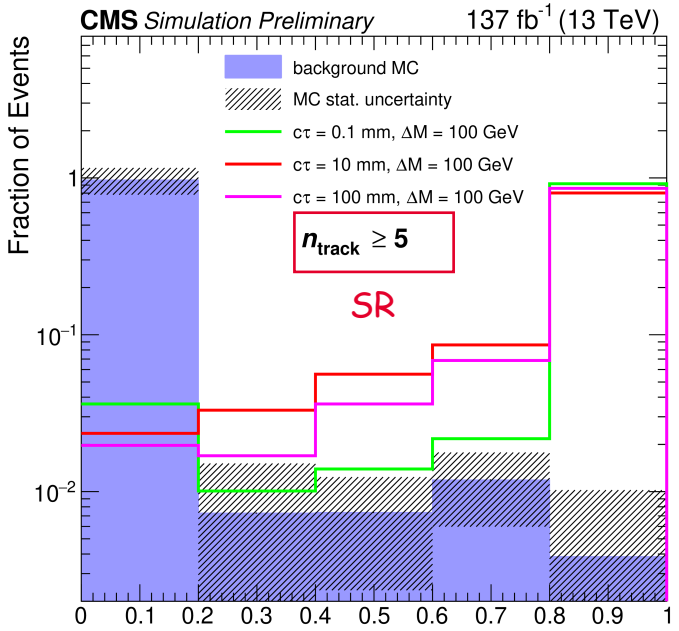



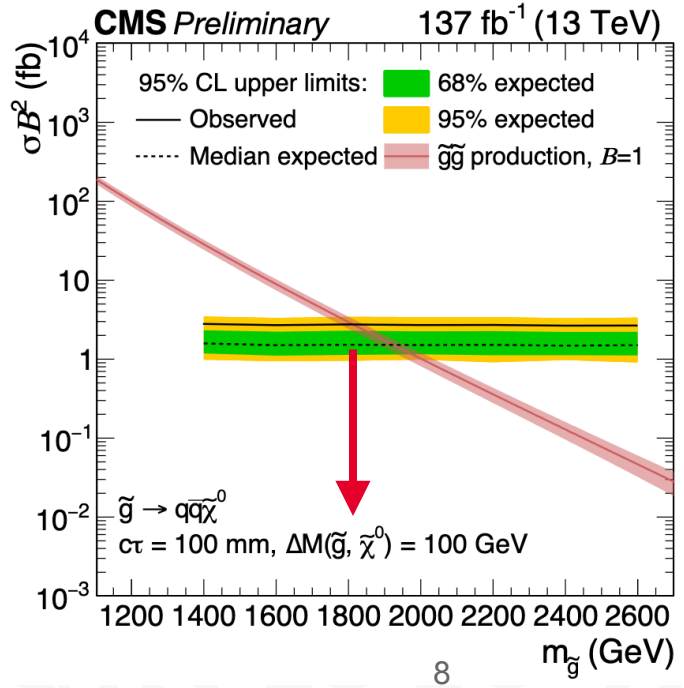

Excl. $\tilde{g}$ mass Up to 1.8 TeV

1 displaced vertex + MET to increase sensitivity to high lifetimes

Interaction network based on graph NN to further suppress background from randomly reconstructed vertices.

High tracks multiplicity for SR



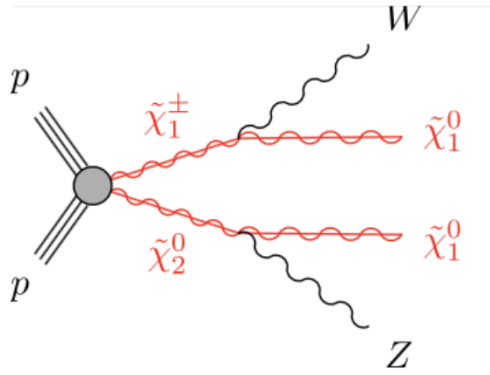



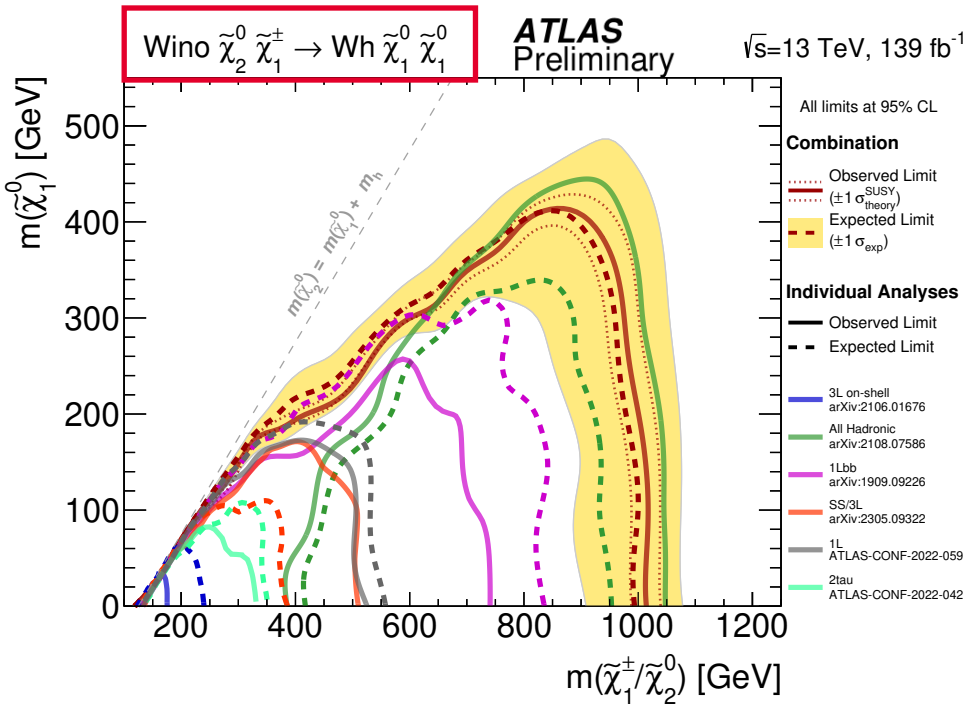

CMS-PAS-EXO-22-020

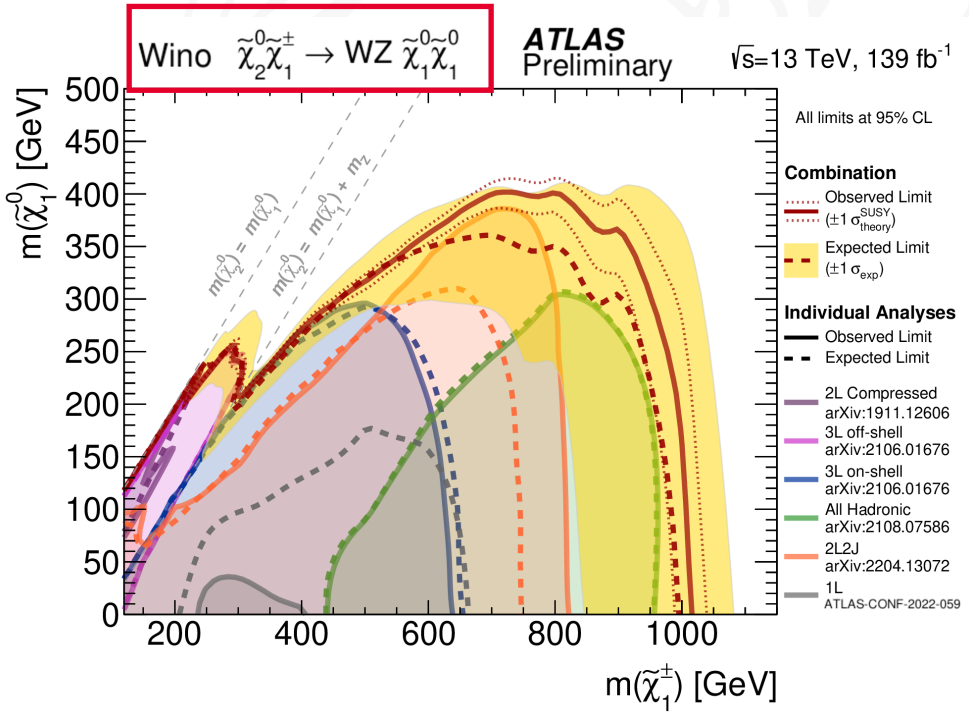
# Susy: EWK combination results

Combined EWK SUSY ATLAS 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** | $\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$ | $\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$<br>$\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0$ | $\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$<br>$\tilde{\chi}_2^0 \to h\tilde{\chi}_1^0$ | $\tilde{\chi}_1^0 \to Z/h\tilde{G}$ |



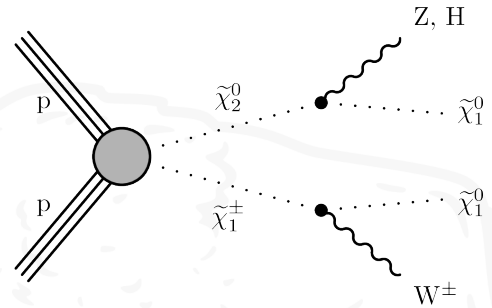




ATLAS-CONF-2023-046

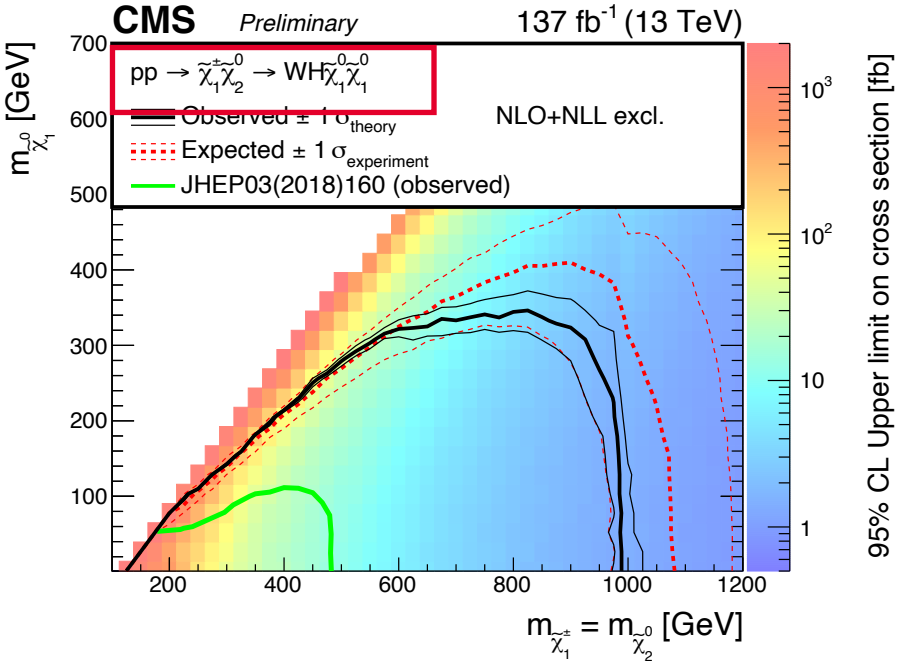
# Susy: EWK combination results

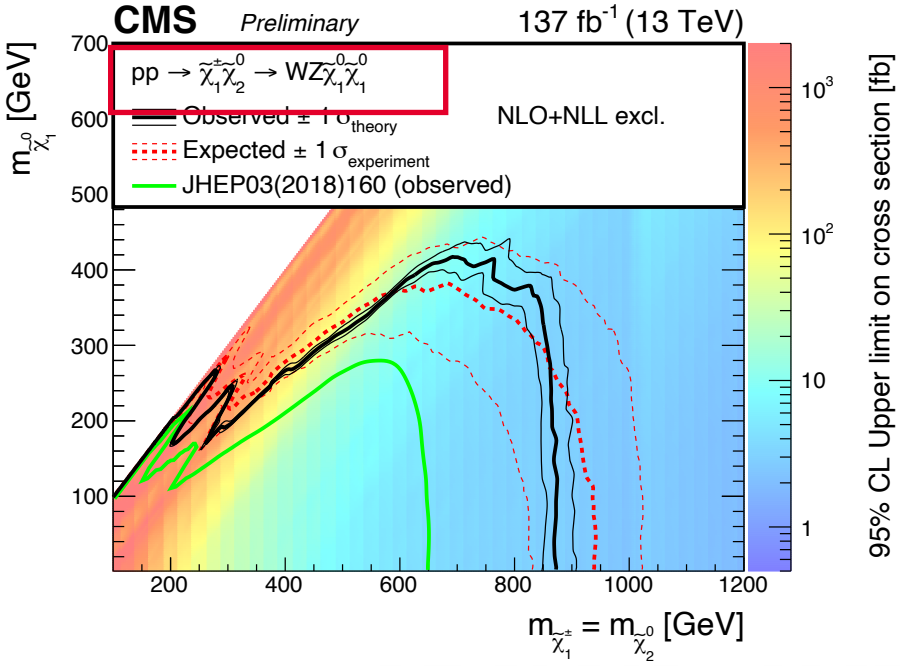
**Combined EWK SUSY CMS analyses. Considered processes**

| **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** | $\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$ | $\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$<br>$\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0$ | $\tilde{\chi}_1^\pm \to W^\pm\tilde{\chi}_1^0$<br>$\tilde{\chi}_2^0 \to h\tilde{\chi}_1^0$ | $\tilde{\chi}_1^0 \to Z/h\tilde{G}$ |




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



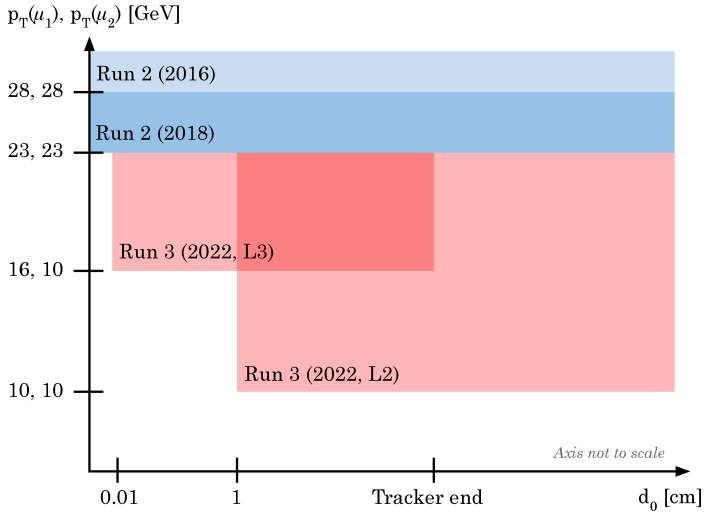




CMS-PAS-SUS-21-008

# Displaced dimuon

Run3

## New triggers in Run3 dedicated to LLPs




Two types of muon reconstruction :

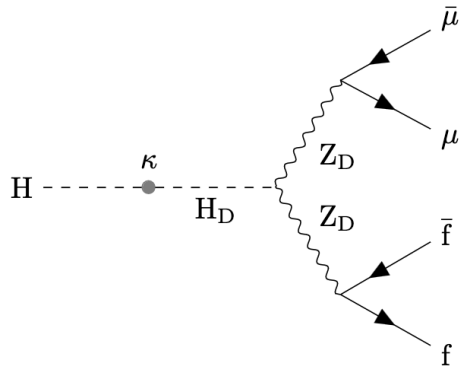
Tracker + muon system (TMS)

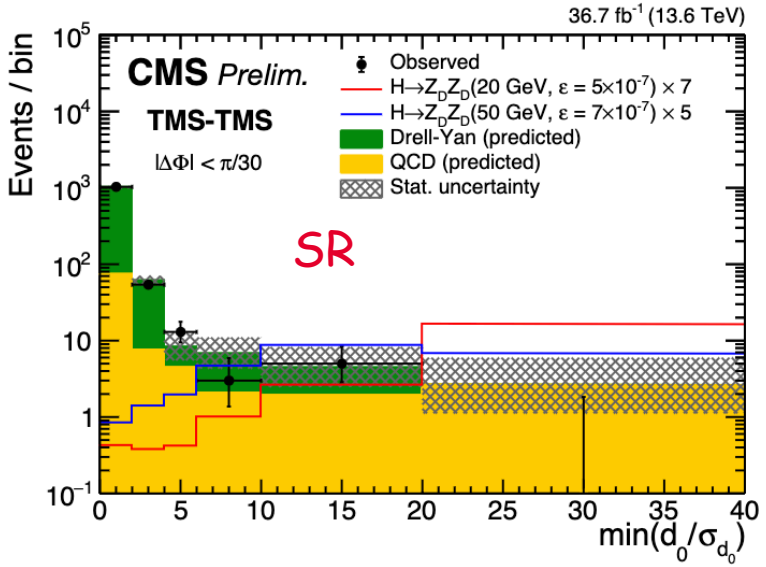
Muon system only (STA)

→ 3 categories: TMS-TMS , STA-STA, TMS-STA

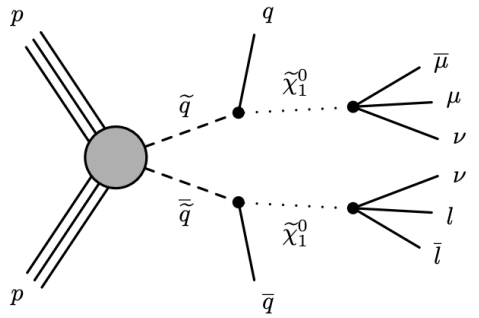
Reconstruction of the dimuon system secondary vertex

## Dark photon in hidden Abelian Higgs model

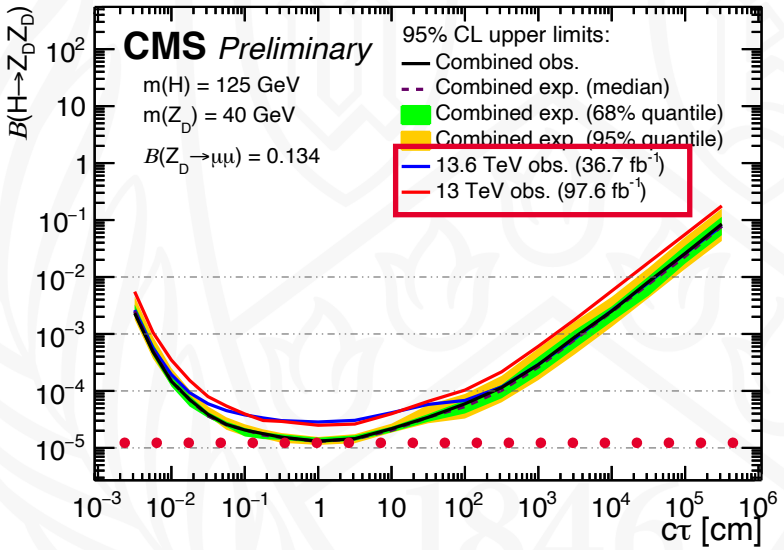



## LL neutralinos in RPV SUSY




Limits on given HAHM signal scenario $m(Z_D) = 40$ GeV



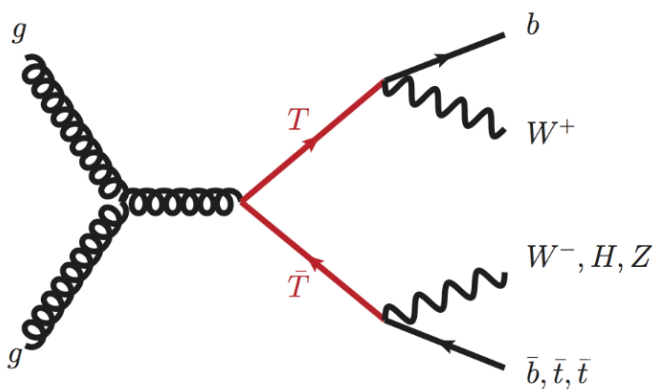

EXO-23-014

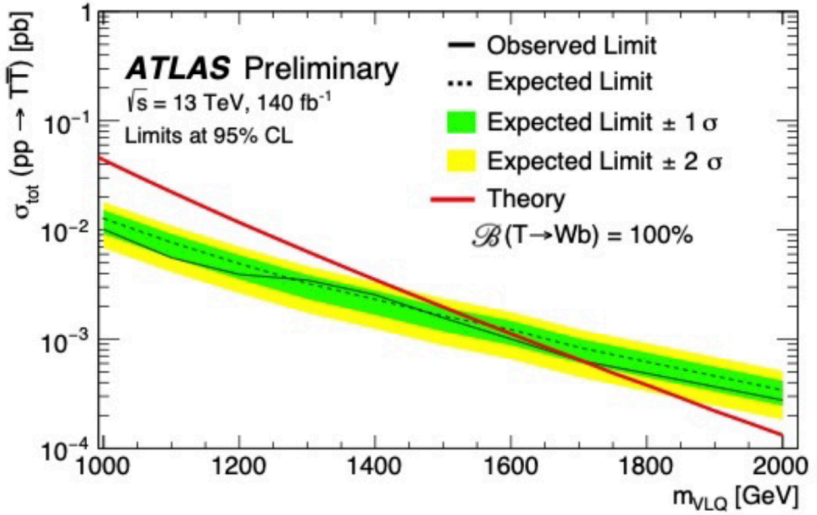
# Search for VLQs pair production

Optimised for $T\bar{T} \rightarrow WbW\bar{b}$ but sensitive to different channels

- One hadronic W decay
- One leptonic W decay

Events with one electron or muon, met and jet are analyzed

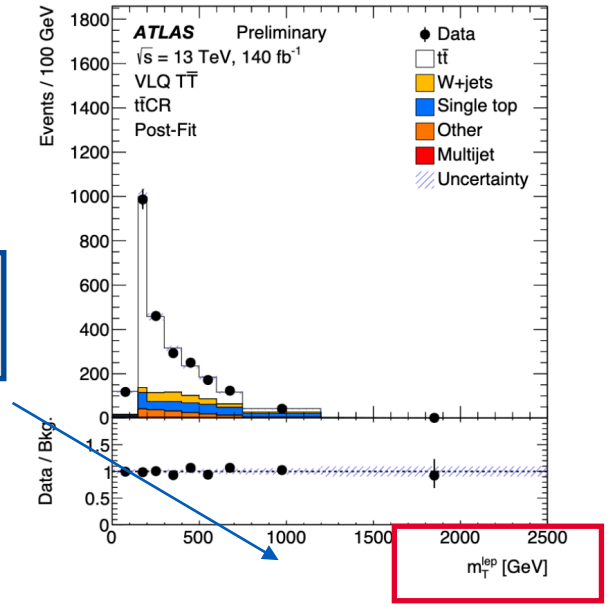


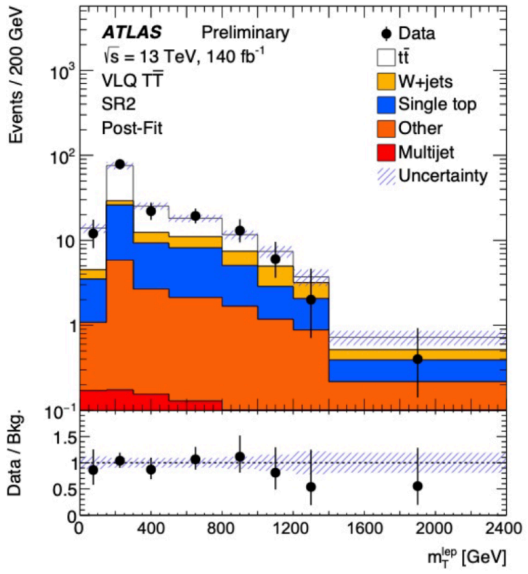



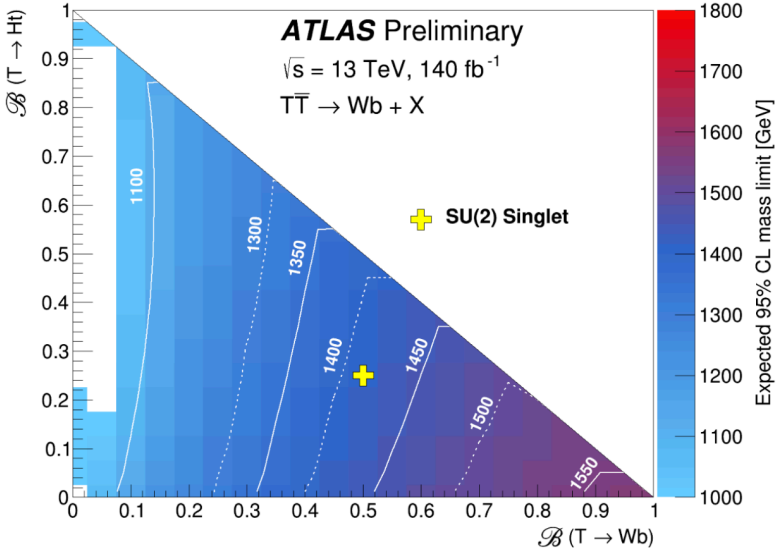

## $t\bar{t}$ CR

## Signal region

Reco. Mass T decays Leptonically




ATLAS-CONF-2023-070

# Search for Dark Jets

A bump hunter in the dijet mass spectrum

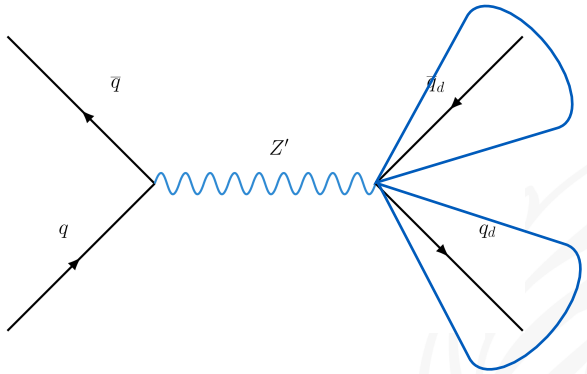
Dark hadrons decay promptly to SM particles

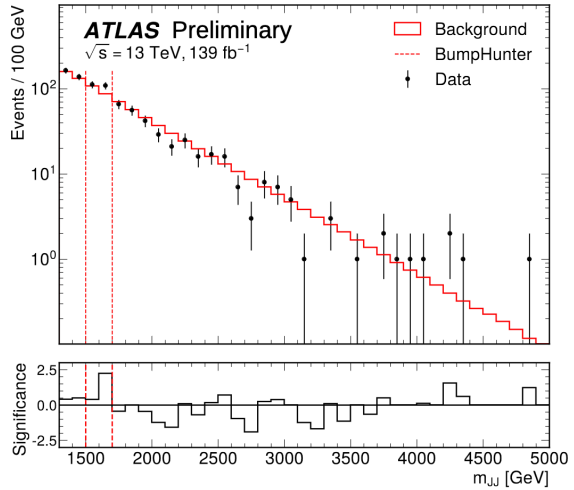
-> Visible large-radius jets + high track multiplicity

-> Complimentary search to semi-visible

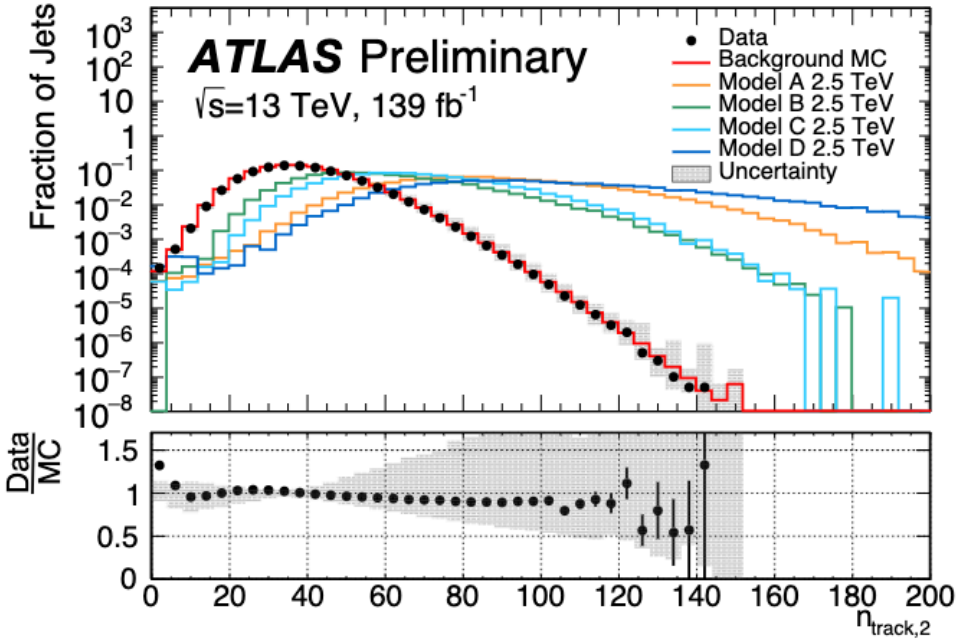
No excess beyond the expected background

Large radius jets

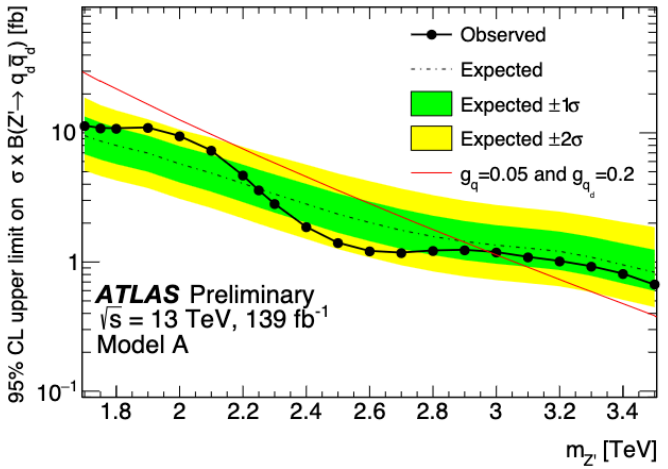


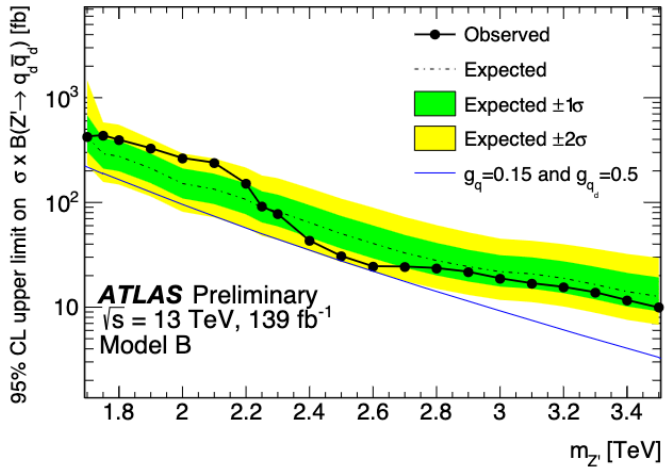

#tracks Subleading jet




$\pi_d \to c\bar{c}$




$\pi_d \to s\bar{s}$

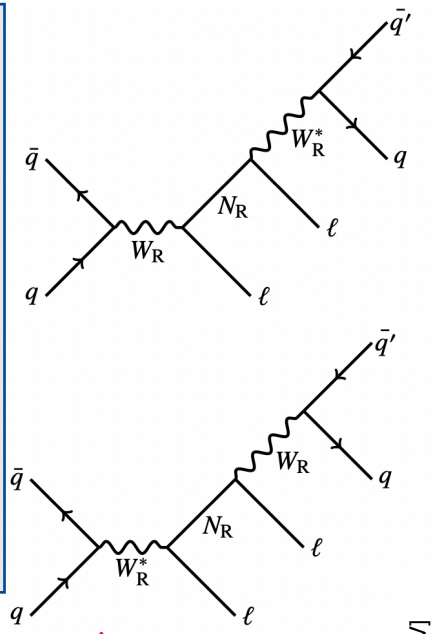



ATLAS-CONF-2023-047

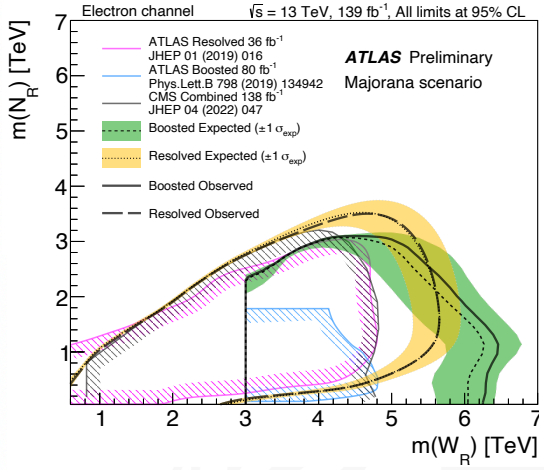
# Search for right-handed $W_R$ bosons and heavy neutrino $N_\ell$

- Left-Right symmetry model (LRSM) : Extension to the SM by an $SU(2)_R$.
- Majorana and Dirac $N_\ell$ nature and exclusive coupling to 3 $\ell$ generation.
  - SF $2\ell$ : 2 $\mu$, 2 $e$ + jets events also events $1\ell$: $1e$ + jets.
  - 2 $\ell$ OS(OS + SS ) for Dirac(Majorana).
  - 2 event topology : boosted and resolved

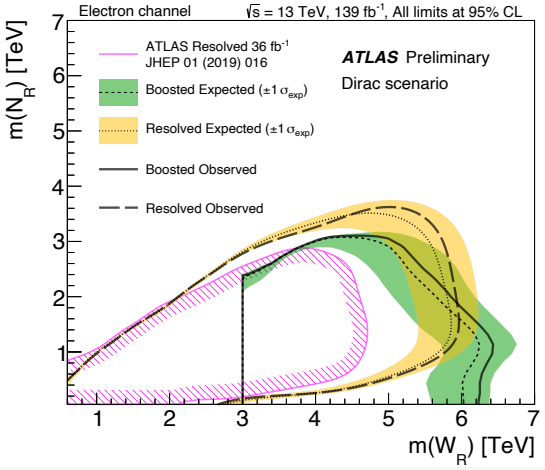
$$\Delta M = m_{W_R} - m_{N_R} > 4(<4)\ \text{TeV respectively.}$$



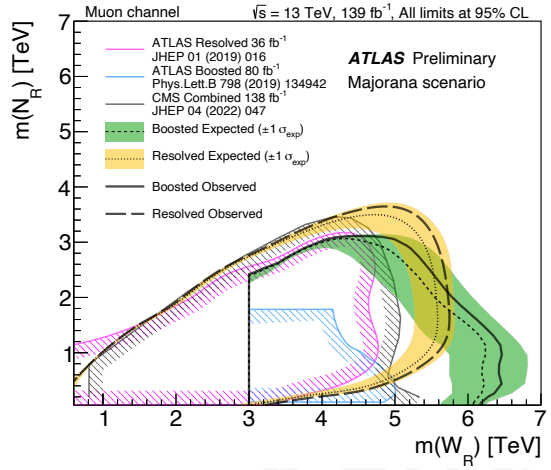

## Majorana: electron channel



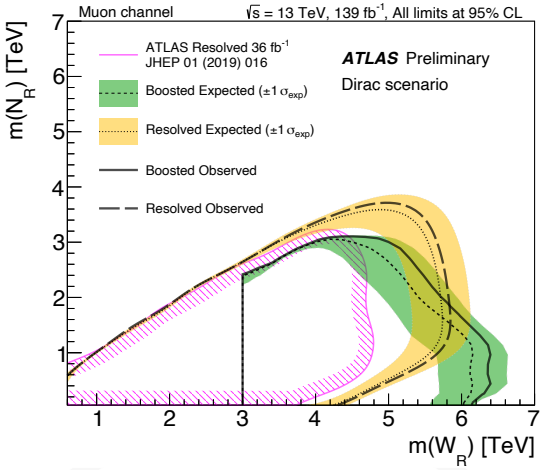

## Dirac: electron channel



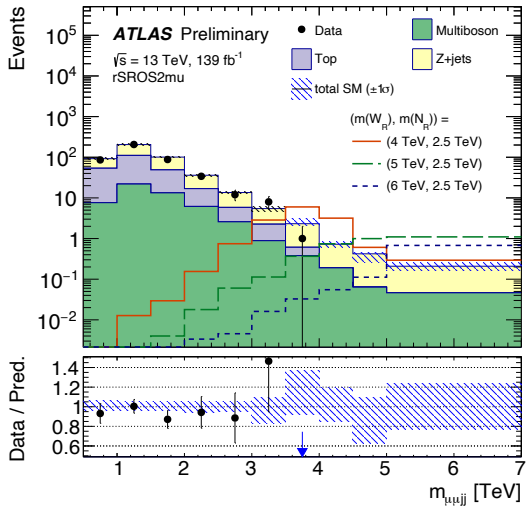

## Majorana: muon channel



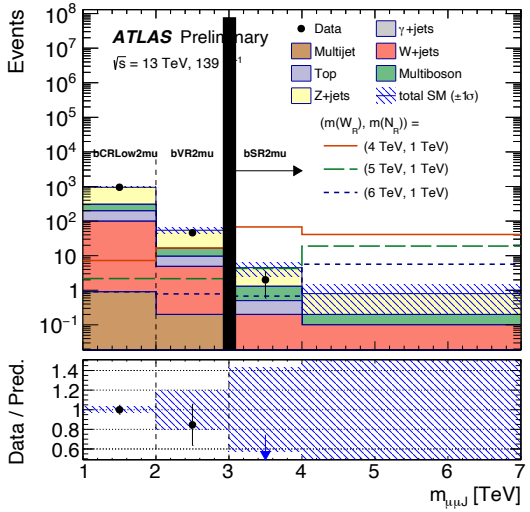

## Dirac: muon channel




## SR: 2$\mu$ OS resolved



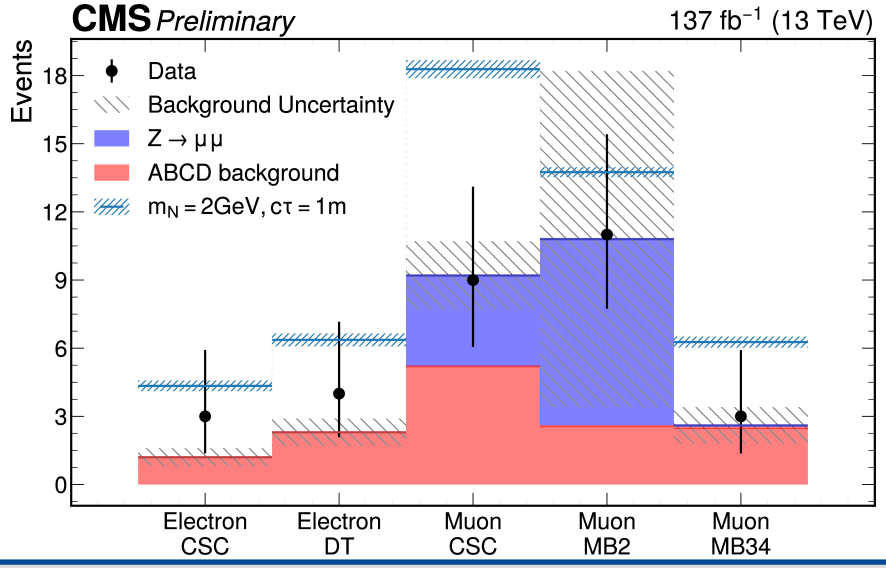

## SR: 2$\mu$ OS boosted



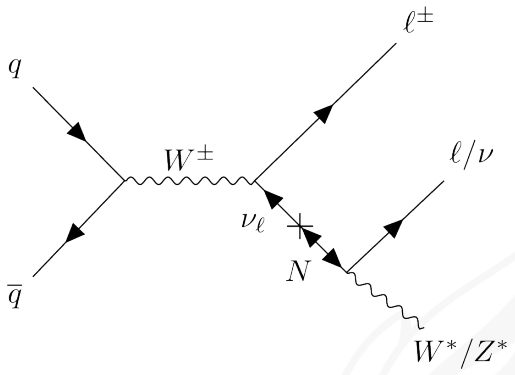

EXOT-2019-39

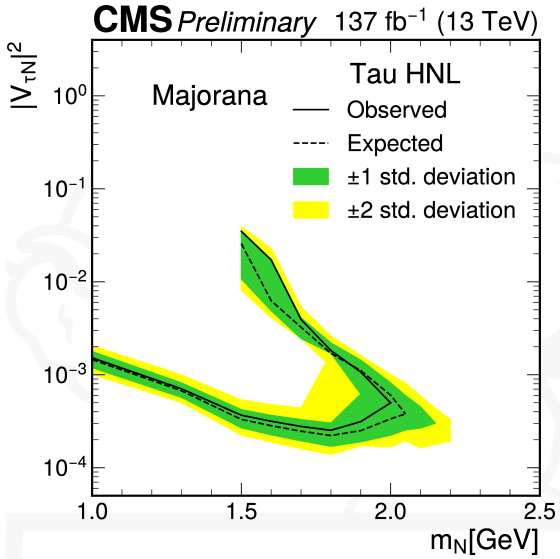
# Long-lived HNLs in the muon system

- Dirac and Majorana HNLs with inclusive coupling to the 3lepton generations.
- Inclusive HNL decay search
- Low mass region → displaced decays
- HNL decay in the muon system (MS)
- 1 prompt lepton + hit clusters in the MS
- Event categorised based on lepton flavor and the muon subsystem

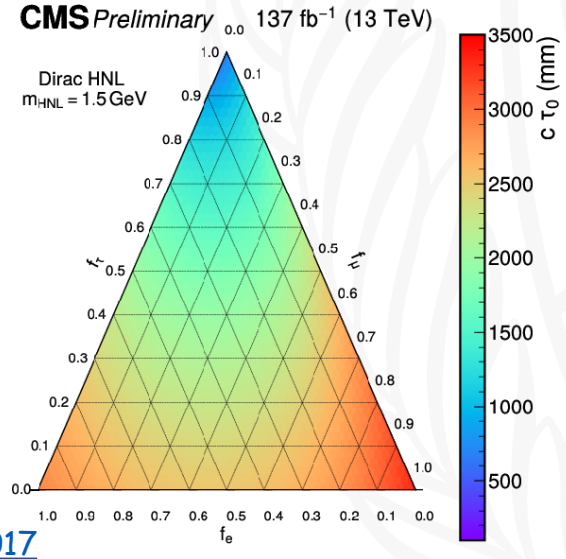


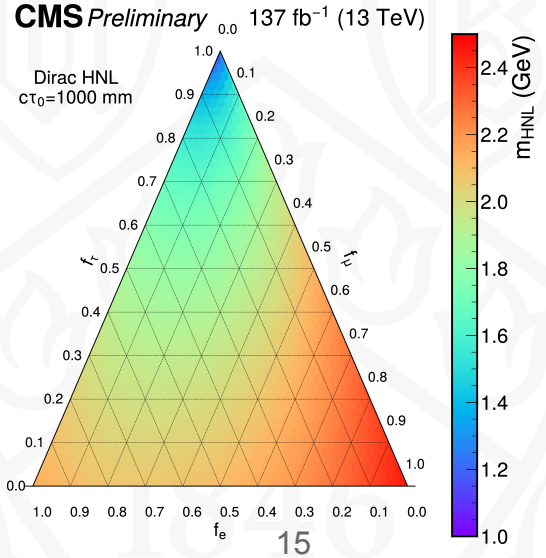

No excess is observed beyond the expected background




Relative coupling to the 3 lepton generation



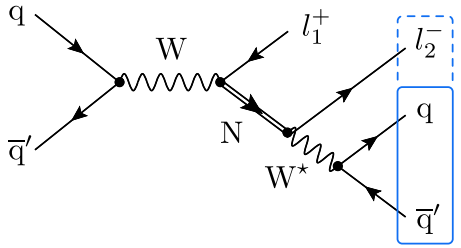

CMS-PAS-EXO-22-017

# Long-lived HNLs in 2 $\ell$ + jet final state

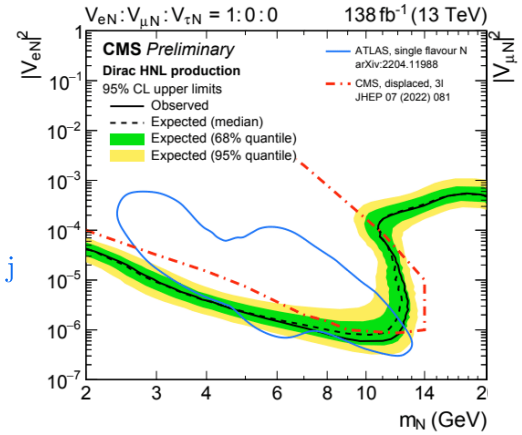
- Dirac and Majorana HNLs /Incl. coupling to the 3 generation
- Prompt $\ell_1$ + displaced $\ell_2$ and $j^\star$
- $\ell_2, j^\star$ topology : boosted or resolved
- $\ell_1\ell_2$ flavour(charge) combination i.e SF/OF(OS/SS)
- The 2D displacement sign. from PV:
- $d_{xy}^{sig}(\ell_2) = d_{xy}(\ell_2)/d_{xy}^{err}(\ell_2)$

A displaced jet tagger to maximize sensitivity to a broad $c\tau_0$.

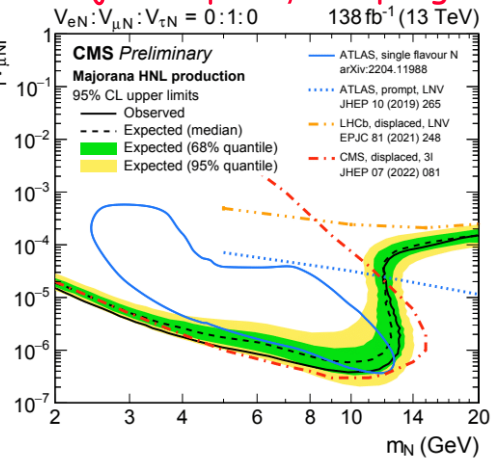
EXO-21-013




Dirac pure e coupling

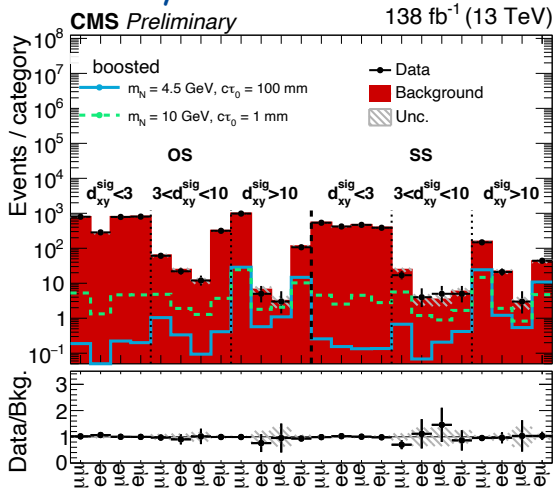



Majorana pure $\mu$ coupling

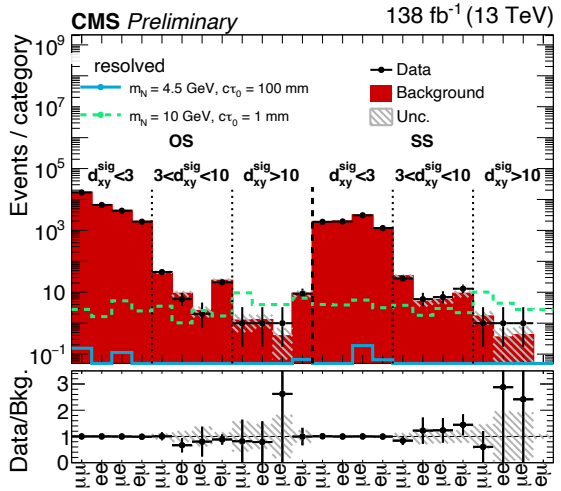



Broad categorisation (48 category):

#yields SR:boosted

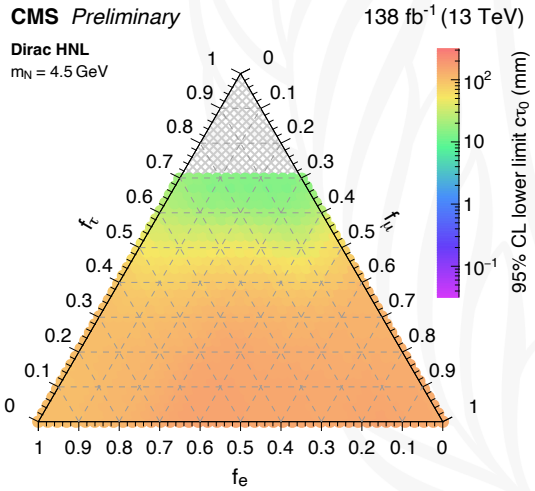



#yields SR:resolved

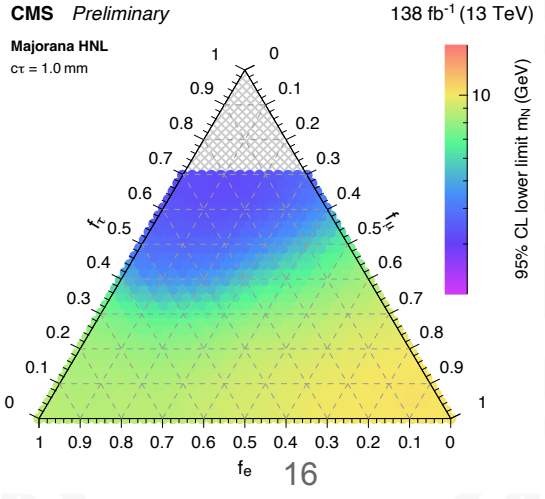



Relative coupling to the 3 lepton generation

Max excl. $c\tau_0$ for fixed $m_N$



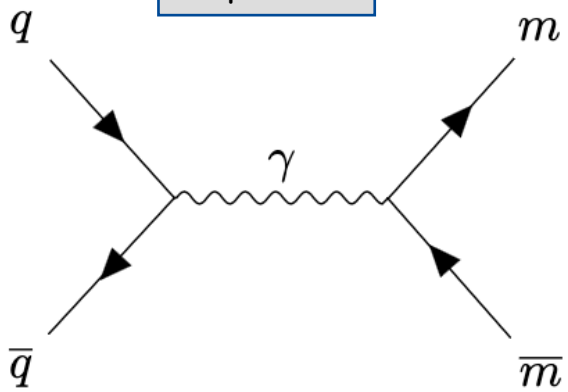

Max excl. $m_N$ for fixed $c\tau_0$



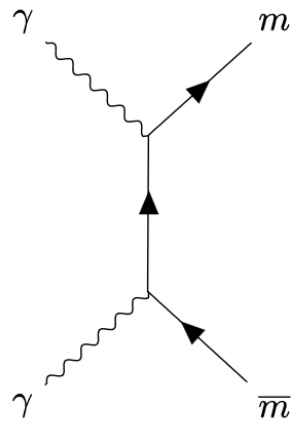
# Search for monopoles

- Search for highly ionizing and stable particles with spin zero and half
- first results on photon fusion pair production
- Main characteristics:
  - Many HT hits in the transition radiation tracker (TRT) → high $f_{HT}$
  - a narrow high-energy deposit in EM calorimeter → low lateral dispersion (w)

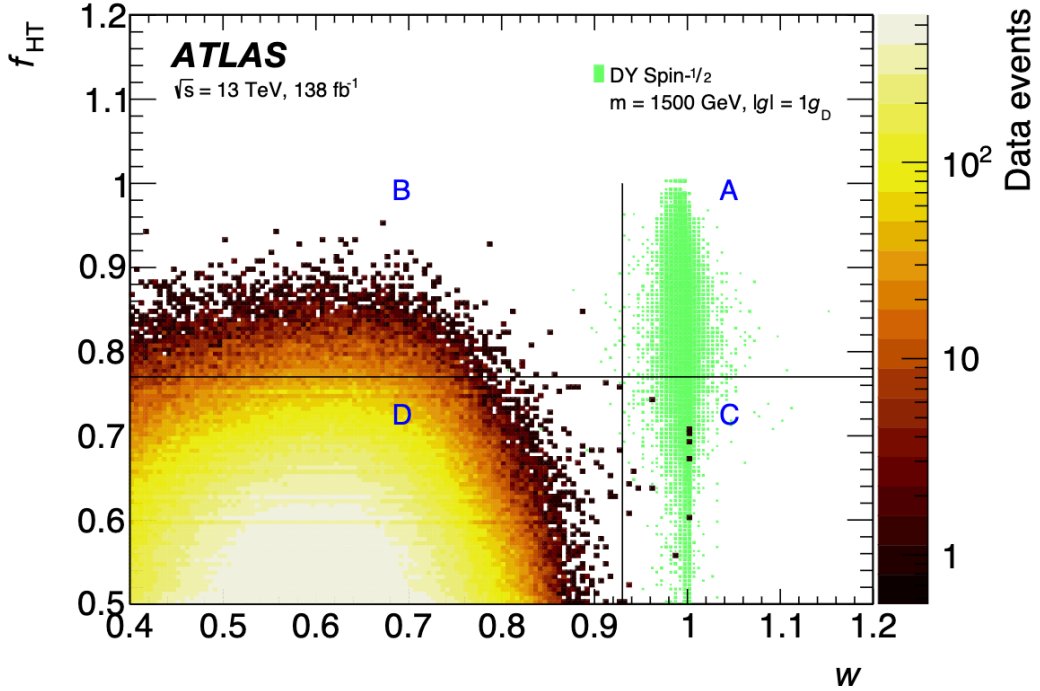
DY process

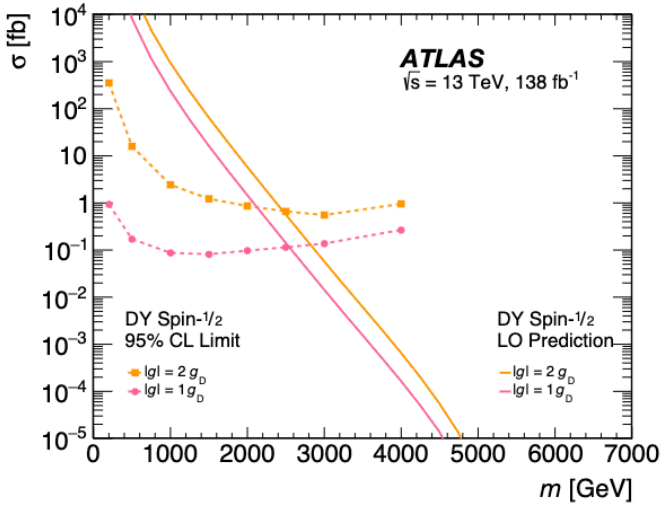



Photon fusion pair production

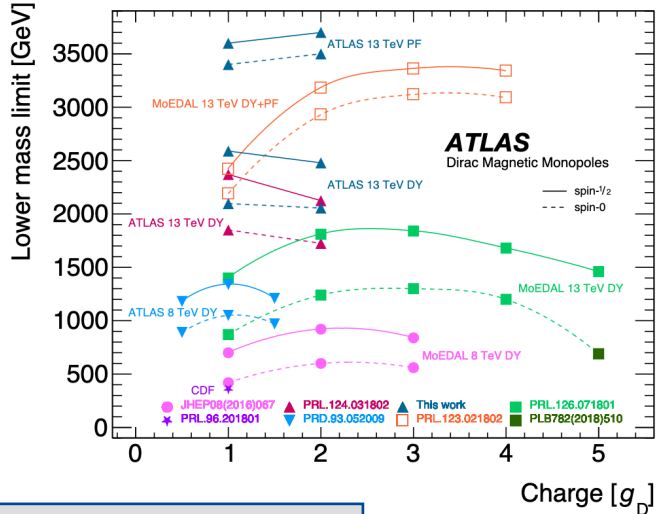



A : signal region




Comparison of the lower mass limits




2308.04835

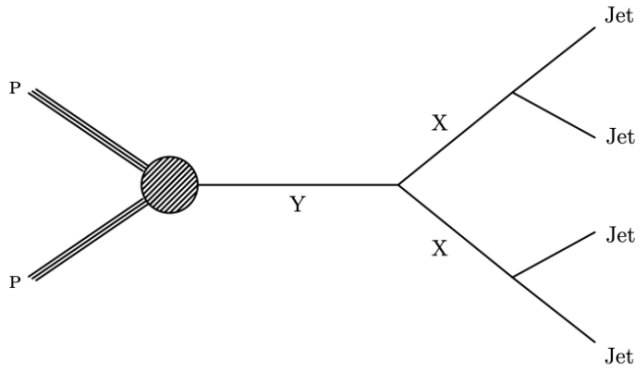
$|g| = 1$ or 2 fundamental magnetic $g_D$ charge

# Tetrajets generic resonance

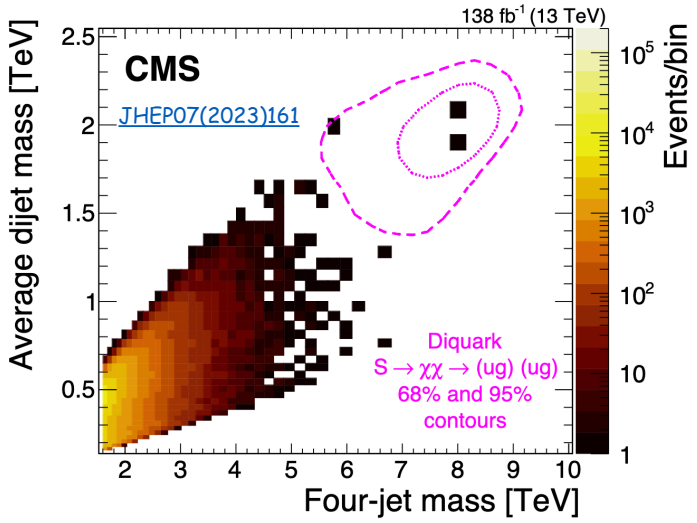
Search for a new resonance in $< m_{4j} >$ and $< m_{2j} >$ inv. mass

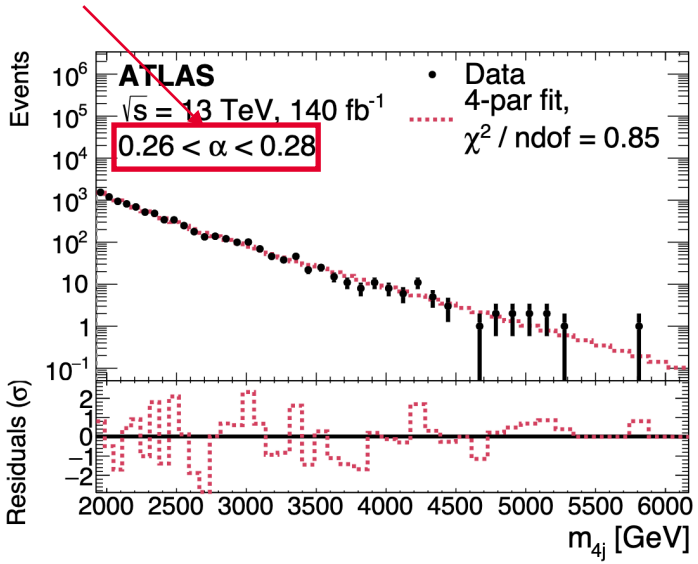
A massive resonance Y decaying to intermediate resonances X

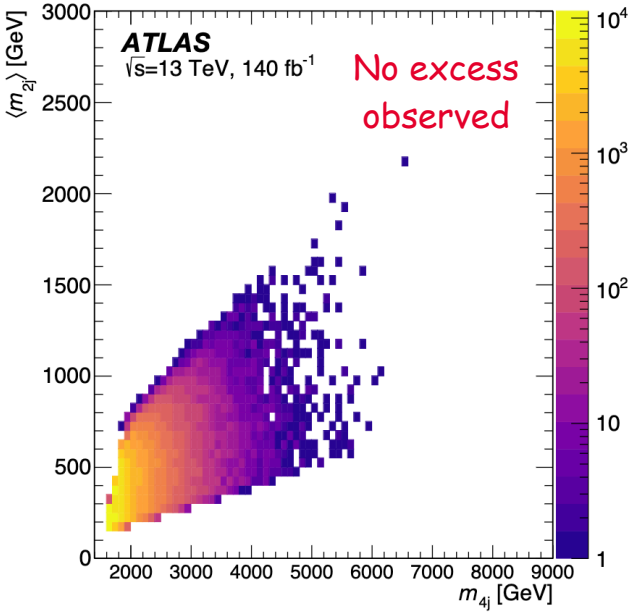
$$\alpha = \frac{< m_{2j} >}{< m_{4j} >}$$

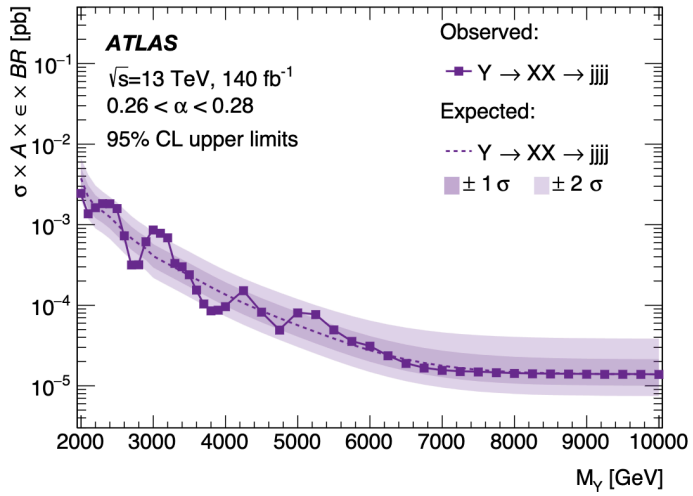



3.6$\sigma$ excess




2307.14944

# Search for ALPs

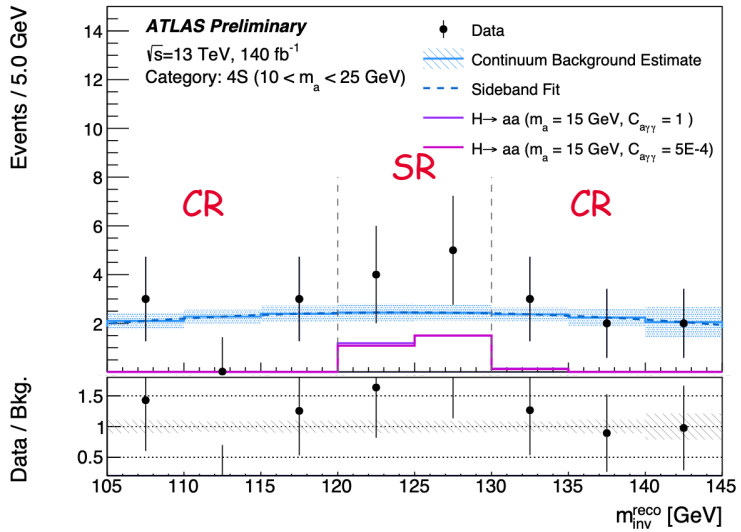
Search for a pseudo scalar denoted $a$

short and longlived depends on $C_{a\gamma\gamma}$, for prompt a $\rightarrow C_{a\gamma\gamma} > 0.1$

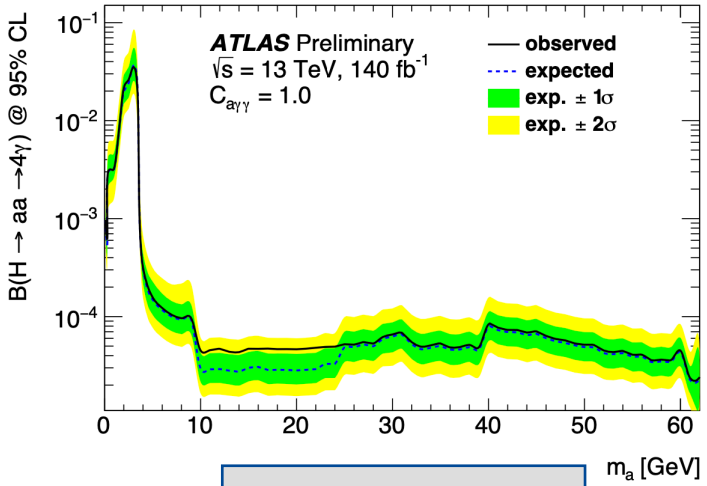
In $H \rightarrow aa \rightarrow 4\gamma$

Five main categories based on photons candidates reco:

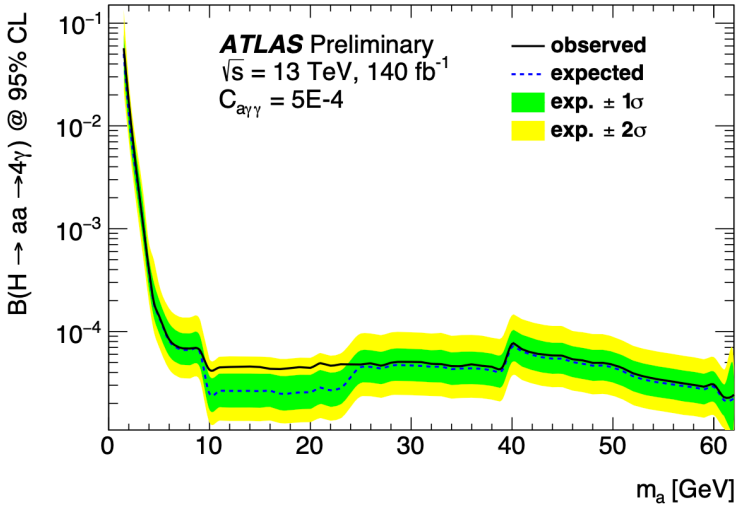
4S, 3S, 2S, 2M and 1S1M




Prompt ALPs




Displaced ALPs




ATLAS-CONF-2023-040

# Summary

- Recent results from ATLAS and CMS using Run 2 Dataset and Run3 as well!

- Several techniques used to maximise sensitivities.

- 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 started with ~ 67 $fb^{-1}$ for ATLAS and CMS of collected data

The best is yet to come!