The dark matter candidates in 2HDM+a model

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on behalf of CMS collaboration

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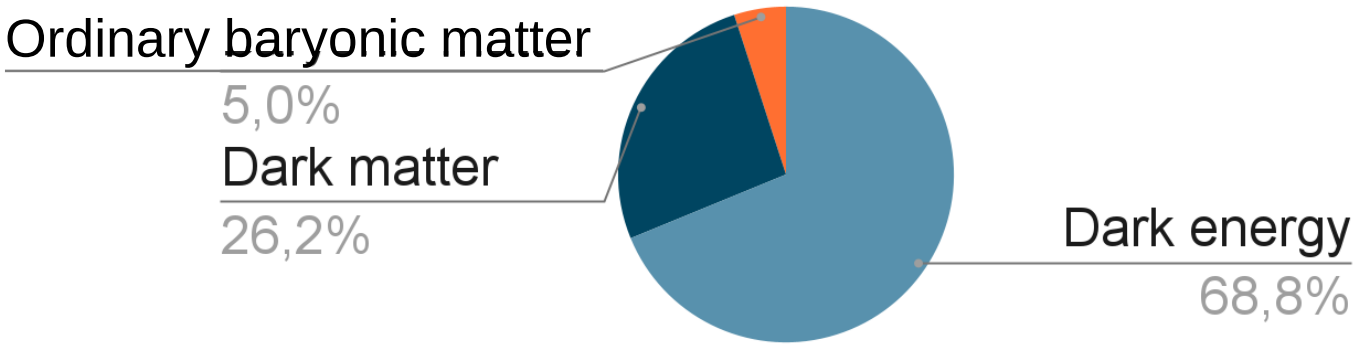
Dark matter



Dark matter (DM) makes up ~26% of the Universe's matter, but its particles have not been detected.

Main search strategies: collider experiments and underground experiments

Dark matter portals

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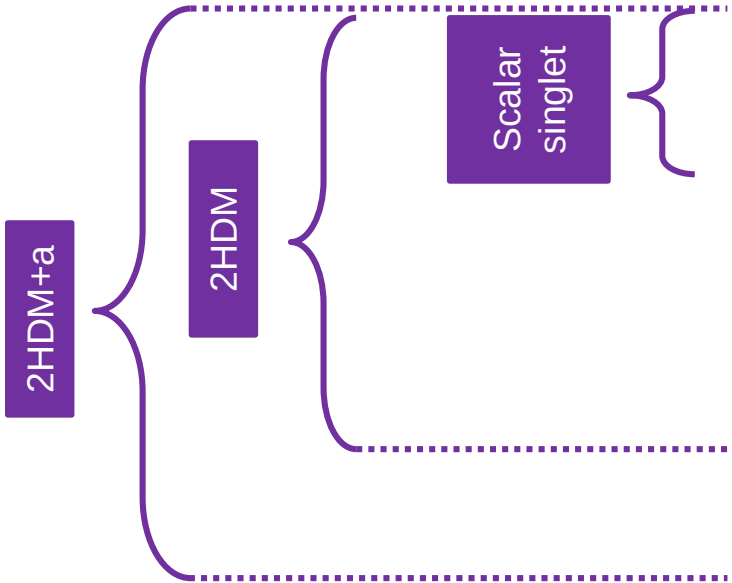
h_{125} can't decay into dark matter particles itself, that's why we need extra particles as mediators between Standard Model and Dark Sector



- **h** (~125 GeV) – Standard Model Higgs boson
- **H** – Neutral CP-even heavy boson
- **A** – Heavy CP-odd pseudoscalar
- **H^+**, **H^-** – Charged Higgs bosons
- **a** – Light pseudoscalar

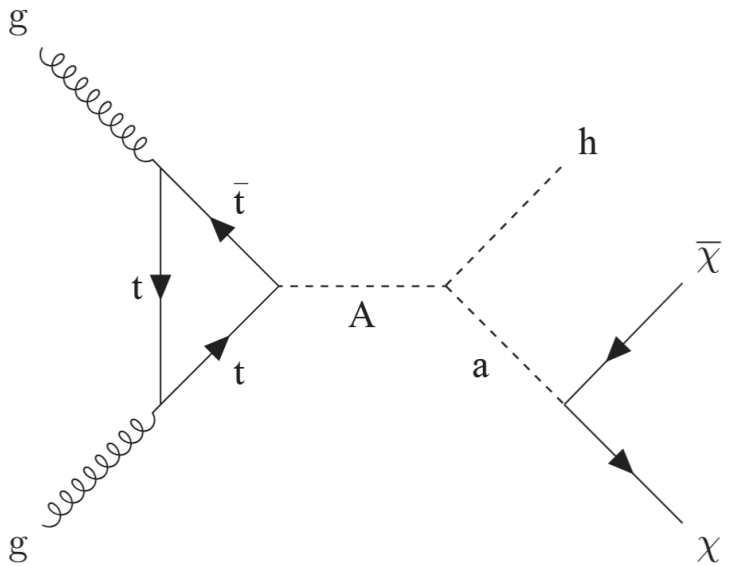
Target Model: 2HDM+a

J. High Energ. Phys. **2017**, 138 (2017)

An extension of the Type-II Two-Higgs-Doublet Model (2HDM) with an additional light pseudoscalar boson ***a***

Signal production/decay chain: $pp \rightarrow A \rightarrow (h \rightarrow b\,\bar{b}) + (a \rightarrow \chi\,\chi)$

- **A** – Heavy CP-odd pseudoscalar
- **a** – Light pseudoscalar
- **H** – Neutral CP-even heavy boson
- **h** (~125 GeV) – Standard Model Higgs boson.
- **H^+**, **H^-** – Charged Higgs bosons
- χ – Fermionic Dark Matter candidate

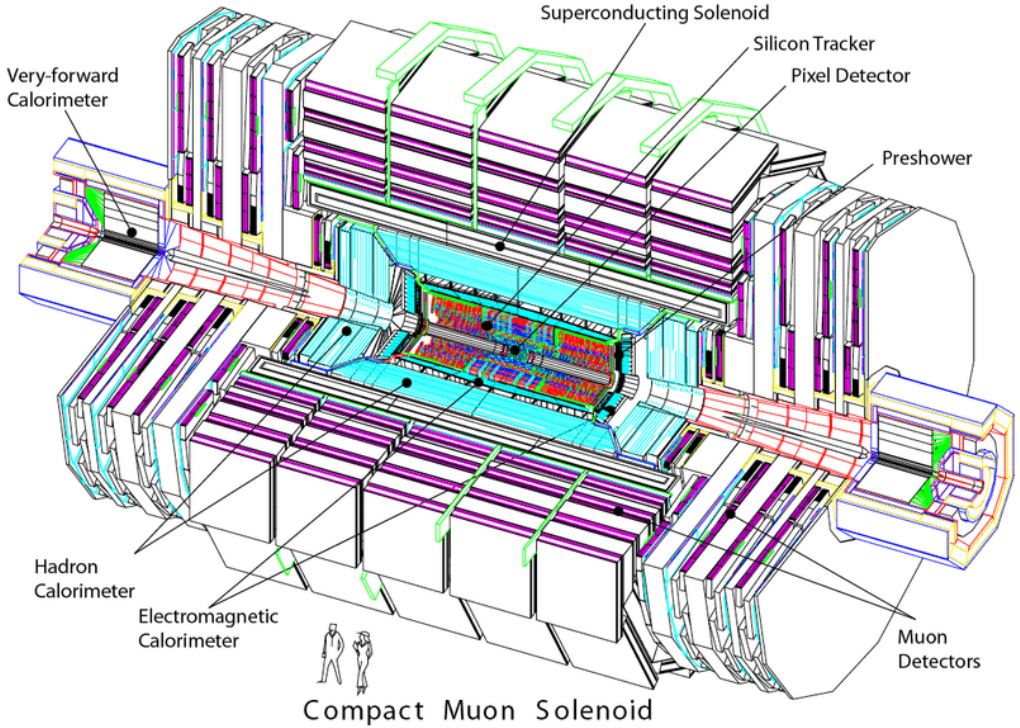


Key parameters: *masses of* $H, A, H^{\pm}, a, m_{\chi}$*, mixing angles,* $tan\,\beta = \frac{v_1}{v_2}$

$v_1^2 + v_2^2 \equiv v^2 = (246\,GeV)^2$

The CMS Detector

The Compact Muon Solenoid (CMS) is one of two general-purpose experiments at CERN's Large Hadron Collider (LHC). The CMS physics program includes studying the properties of the Higgs boson, precision testing of the Standard Model (SM) conclusions, and searching for evidence of new physics beyond the SM.



Data and Tools

Used instruments:

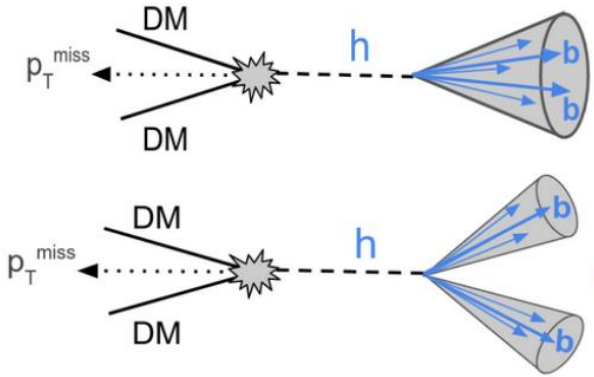
- Signal samples – MADGRAPH5 aMC@NLO ver. 2.6.5
- The parton shower, hadronization, and the underlying event simulation – PYTHIA ver. 8.202
- The response of the CMS detector – GEANT4

Event Reconstruction uses the Particle-Flow (PF) algorithm to combine information from all subdetectors.

Data: Proton-proton collisions at 13 TeV. Analyzed 101 fb^{-1} (2017-2018) + 35.9 fb^{-1} (2016) = 138 fb^{-1} total.

Event selection

Events are selected using triggers with a p_T^{miss} > 120 GeV to ensure high efficiency for signal events



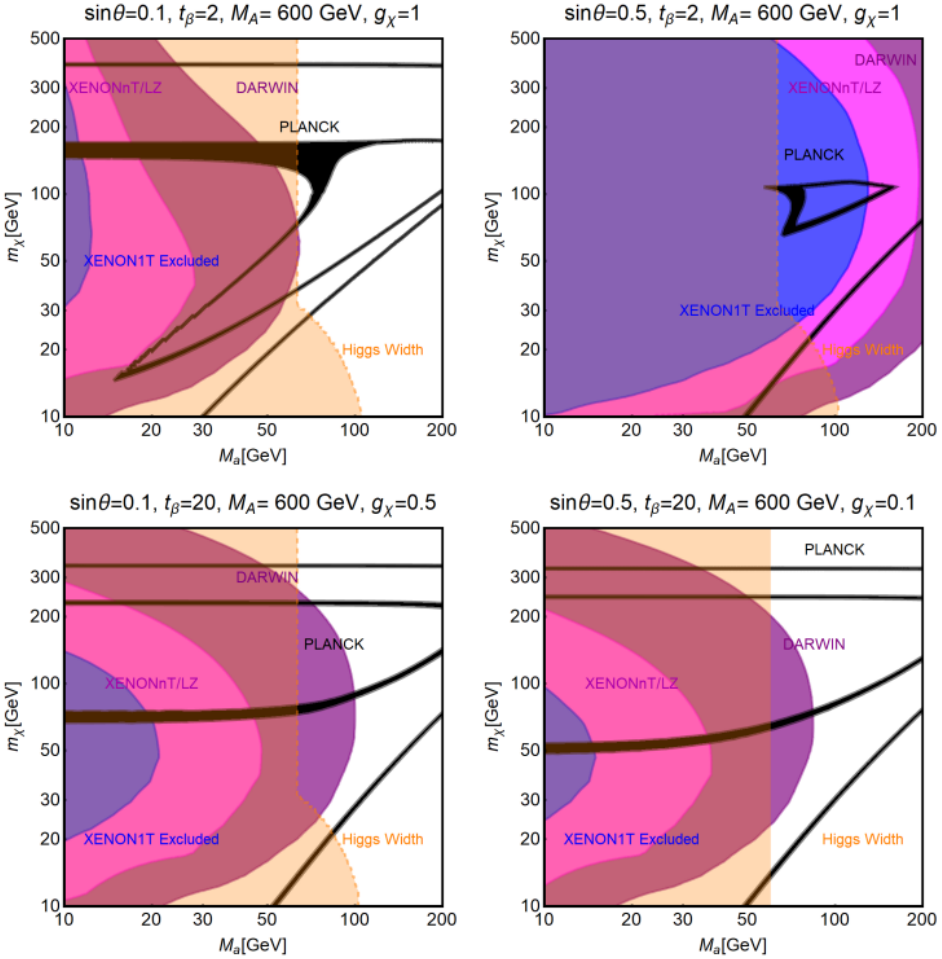
Merged – products are highly collimated (reconstructed as an AK8 jet)

Resolved – low to moderate pT with well separated decay products (AK4 jets are used)

Backgrounds

- **Dominant:**
  - Z(νν) + jets: Neutrinos create genuine p_T^{miss}.
  - $t\,\bar{t} \rightarrow (bW)\,(\bar{b}\,W) \rightarrow$ b-jets + leptons/neutrinos: Mimics the signal if leptons are missed.
- **Important:**
  - W/Z + heavy flavor (b, c) jets.
  - QCD multijet events: Large instrumental p_T^{miss} from measurement miscalibrations.
- **Minor:** Single top quark, dibosons, Standard Model Higgs production.

Results for 2HDM+a



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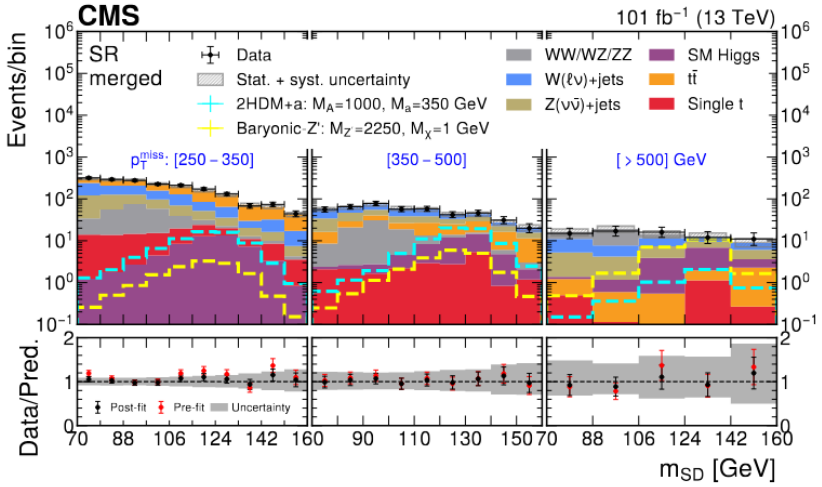
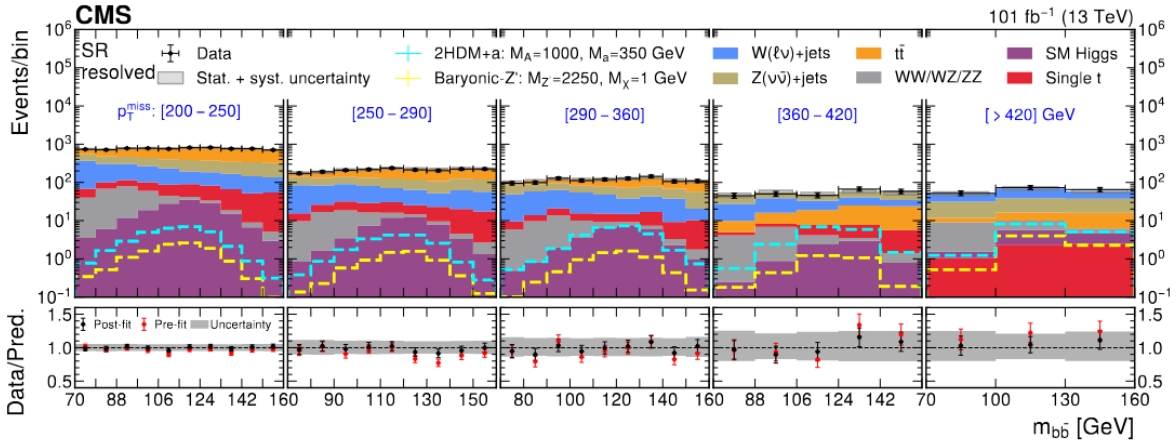
Results for 2HDM+a

CMS-SUS-24-007
https://arxiv.org/pdf/2601.11330v1





Results for 2HDM+a

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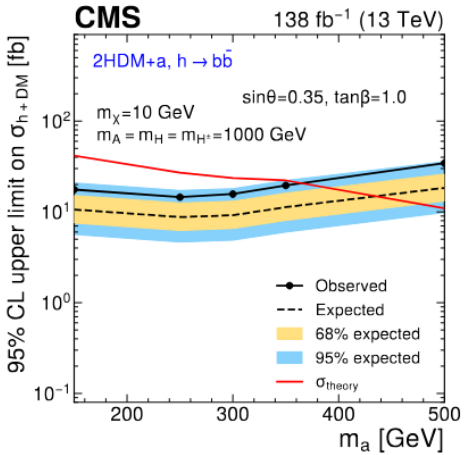
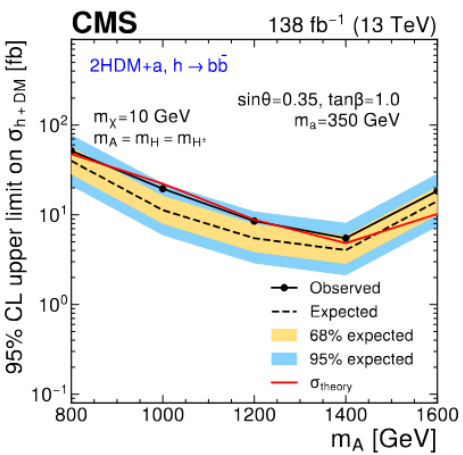
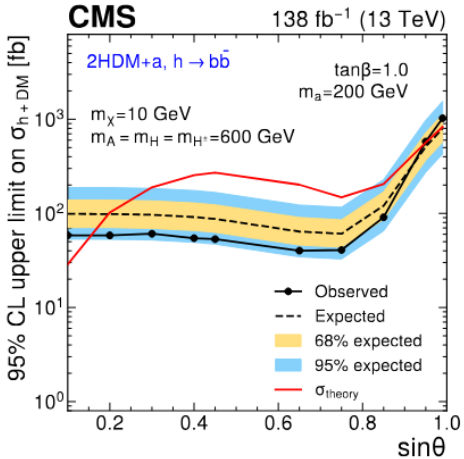
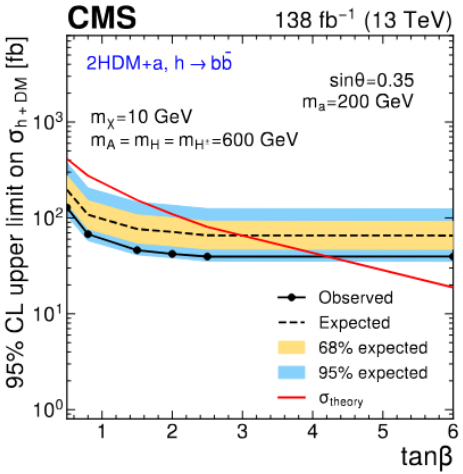








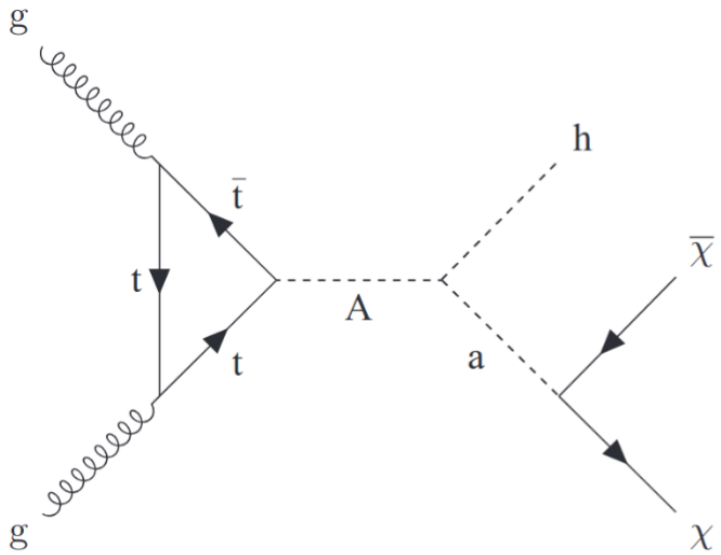
Conclusions

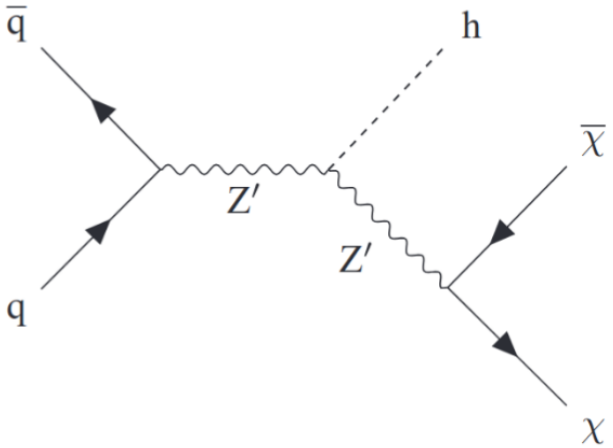
In the 2HDM+a framework, light pseudoscalar masses m_a below 360 GeV are excluded. For a heavy pseudoscalar mass m_A of 1000 GeV, and m_A masses between 850 and 1300 GeV are excluded for m_a of 350 GeV. For the other model parameters, $\sin\theta$ values between 0.15 and 0.95 are excluded, while $\tan\beta$ values less than 4.2 are excluded

Conclusion: Observed data is in excellent agreement with Standard Model background predictions and no signal of dark matter production in the 2HDM+a model was detected was detected so far in the data

Thank you for attention!

Backup





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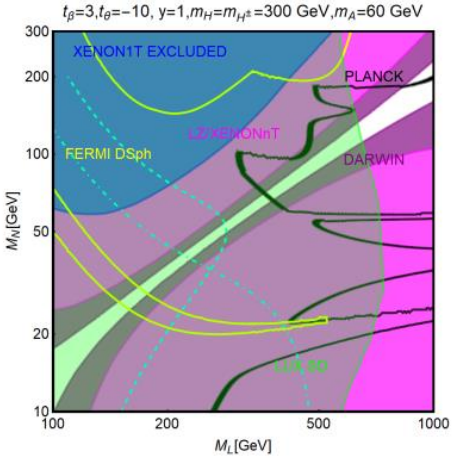
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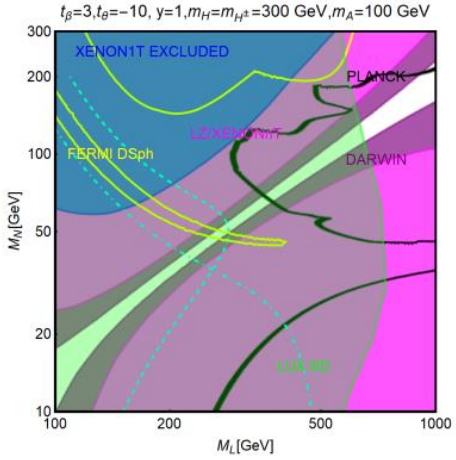
XENON1T EXCLUDED
PLANCK
LZ/XENONnT
FERMI DSph
DARWIN
LUX SD
M_N[GeV]
M_L[GeV]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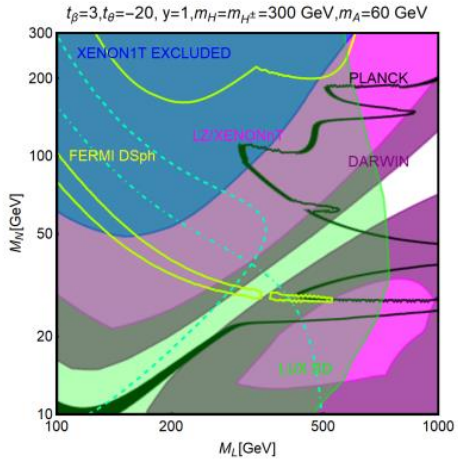
PLANCK
LZ/XENONnT
FERMI DSph
DARWIN
LUX SD
M_N[GeV]
M_L[GeV]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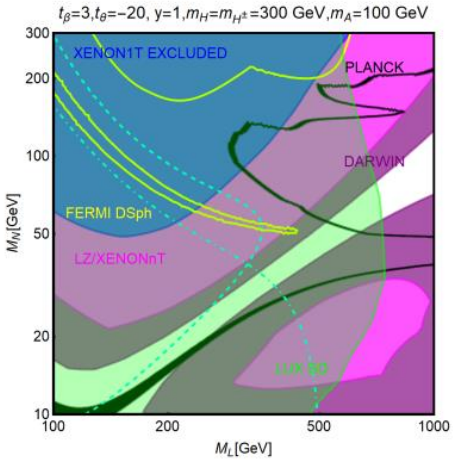
XENON1T EXCLUDED
PLANCK
LZ/XENONnT
FERMI DSph
DARWIN
LUX SD
M_N[GeV]
M_L[GeV]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PLANCK
LZ/XENONnT
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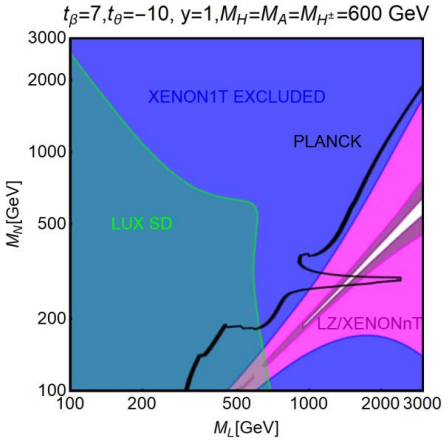
DARWIN
LUX SD
M_N[GeV]
M_L[GeV]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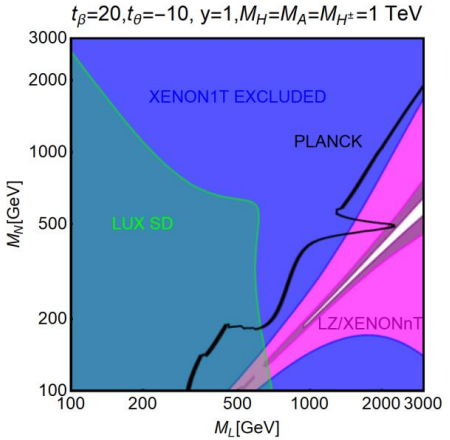
PLANCK
LUX SD
LZ/XENONnT
M_N[GeV]
M_L[GeV]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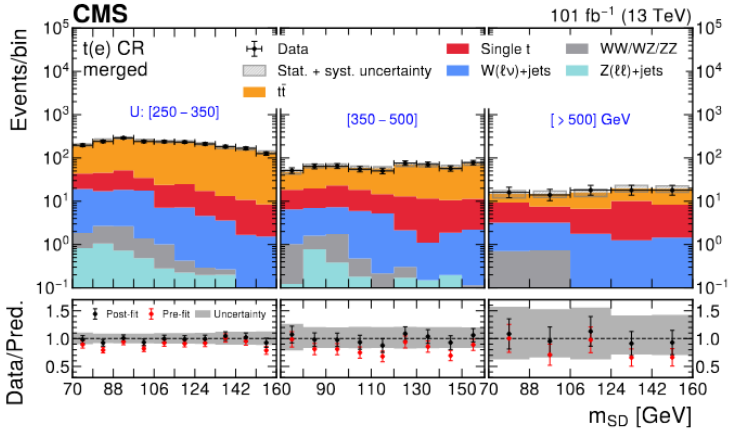
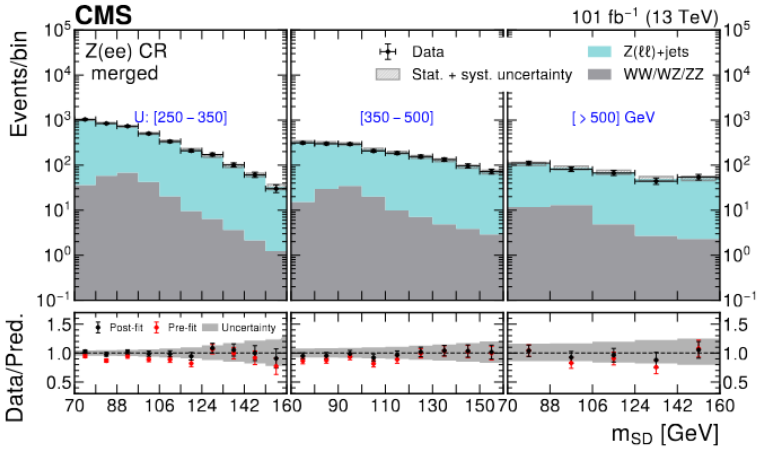
PLANCK
LUX SD
LZ/XENONnT
M_N[GeV]
M_L[GeV]

Backup


CMS
101 fb^{-1} (13 TeV)
t(e) CR
merged
Data
Stat. + syst. uncertainty
tt̄
Single t
W(ℓν)+jets
WW/WZ/ZZ
Z(ℓℓ)+jets
U: [250 – 350]
[350 – 500]
[> 500] GeV
Events/bin
Data/Pred.
Post-fit
Pre-fit
Uncertainty
m$_{SD}$ [GeV]


CMS
101 fb^{-1} (13 TeV)
Z(ee) CR
merged
Data
Stat. + syst. uncertainty
Z(ℓℓ)+jets
WW/WZ/ZZ
U: [250 – 350]
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Events/bin
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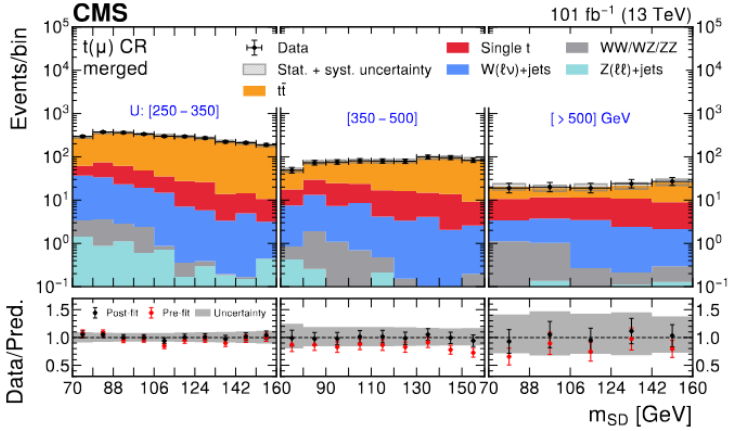
CMS
101 fb^{-1} (13 TeV)
t(μ) CR
merged
Data
Stat. + syst. uncertainty
tt̄
Single t
W(ℓν)+jets
WW/WZ/ZZ
Z(ℓℓ)+jets
U: [250 – 350]
[350 – 500]
[> 500] GeV
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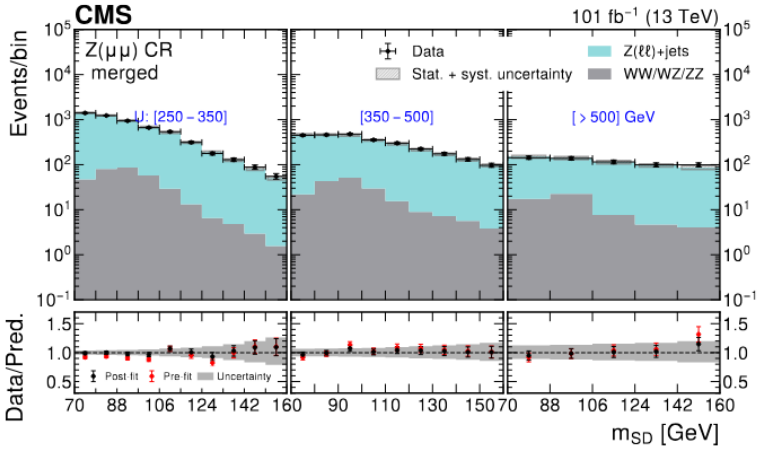
CMS
101 fb^{-1} (13 TeV)
Z(μμ) CR
merged
Data
Stat. + syst. uncertainty
Z(ℓℓ)+jets
WW/WZ/ZZ
U: [250 – 350]
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Events/bin
Data/Pred.
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Pre-fit
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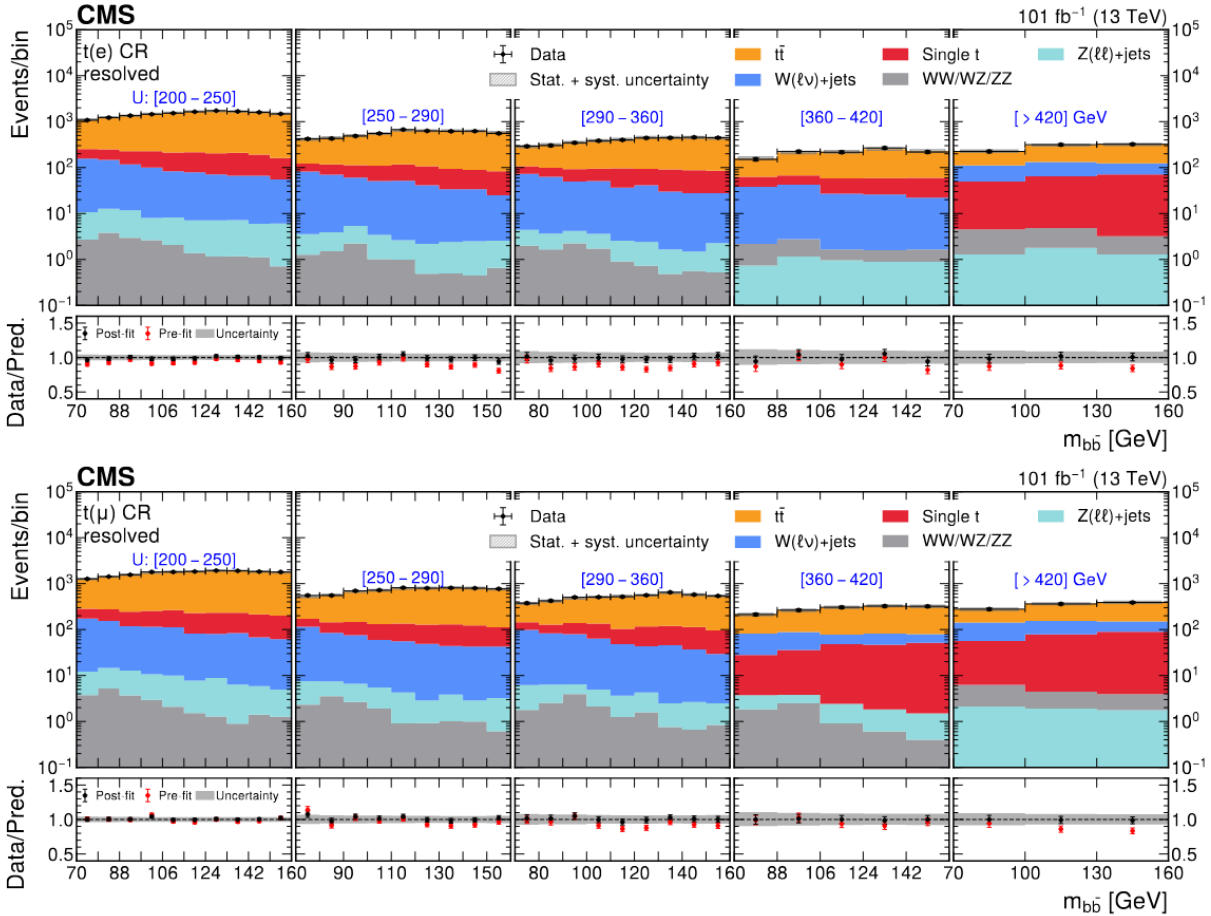
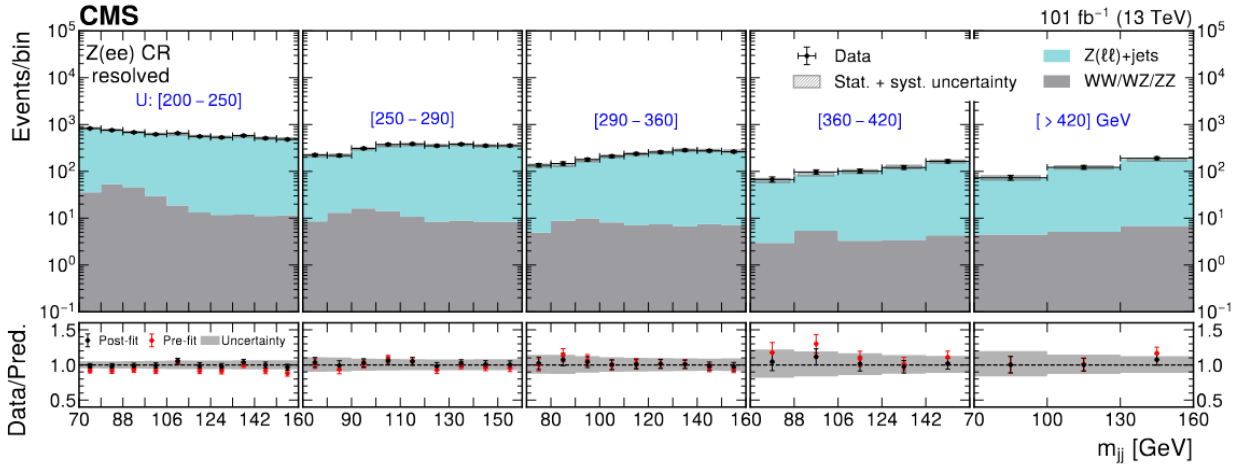
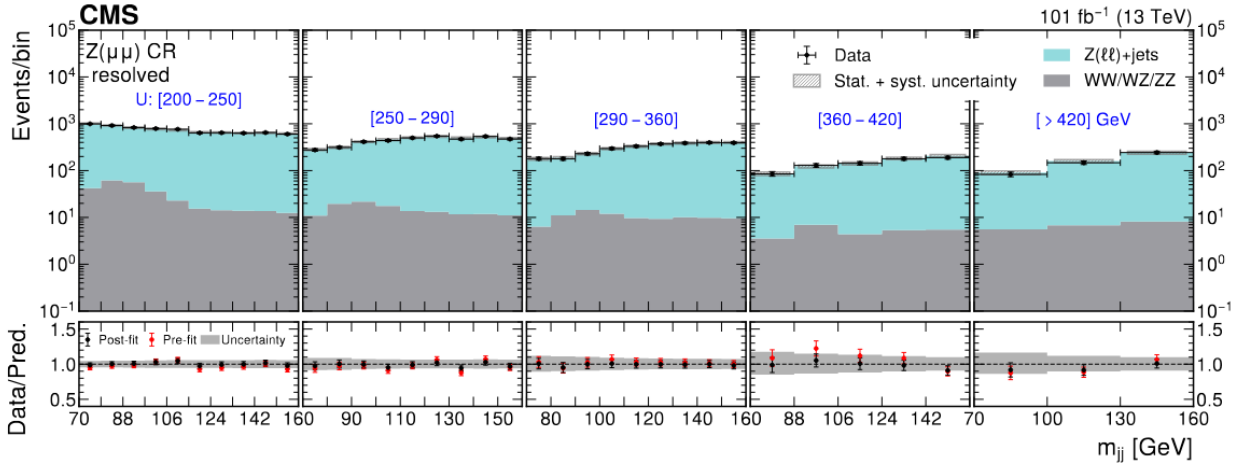
Backup


CMS
101 fb⁻¹ (13 TeV)
t(e) CR
resolved
U: [200 – 250]
[250 – 290]
[290 – 360]
[360 – 420]
[> 420] GeV
Data
Stat. + syst. uncertainty
tt̄
W(ℓν)+jets
Single t
WW/WZ/ZZ
Z(ℓℓ)+jets
Events/bin
Post-fit
Pre-fit
Uncertainty
Data/Pred.
m_bb̄ [GeV]
CMS
101 fb⁻¹ (13 TeV)
t(μ) CR
resolved
U: [200 – 250]
[250 – 290]
[290 – 360]
[360 – 420]
[> 420] GeV
Data
Stat. + syst. uncertainty
tt̄
W(ℓν)+jets
Single t
WW/WZ/ZZ
Z(ℓℓ)+jets
Events/bin
Post-fit
Pre-fit
Uncertainty
Data/Pred.
m_bb̄ [GeV]

Backup


CMS
101 fb^{-1} (13 TeV)
Z(ee) CR
resolved
U: [200 – 250]
[250 – 290]
[290 – 360]
[360 – 420]
[> 420] GeV
Data
Stat. + syst. uncertainty
Z(ℓℓ)+jets
WW/WZ/ZZ
Events/bin
Post-fit
Pre-fit
Uncertainty
Data/Pred.
m$_{jj}$ [GeV]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U: [200 – 250]
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Data
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Z(ℓℓ)+jets
WW/WZ/ZZ
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Pre-fit
Uncertainty
Data/Pred.
m$_{jj}$ [GeV]