Search for dark matter in Higgs decays to two Taus + P_T^{miss} channel using full Run-2 data

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On behalf of the CMS collaborations

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Introduction:

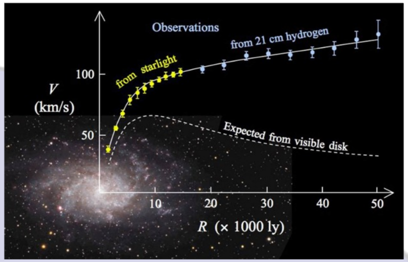
Dark Matter:

Electrically Neutral

Interact only through gravity

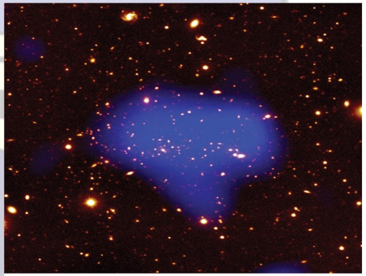
Weakly Interacting Massive Particles (WIMPs)

Rotation Curve Galaxy

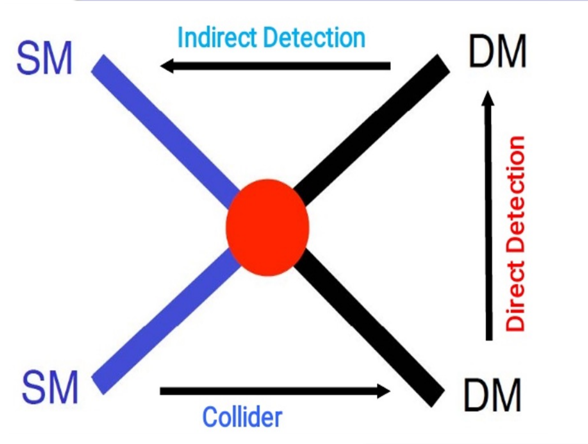


Bullet Cluster

Hot gas in clusters of galaxies

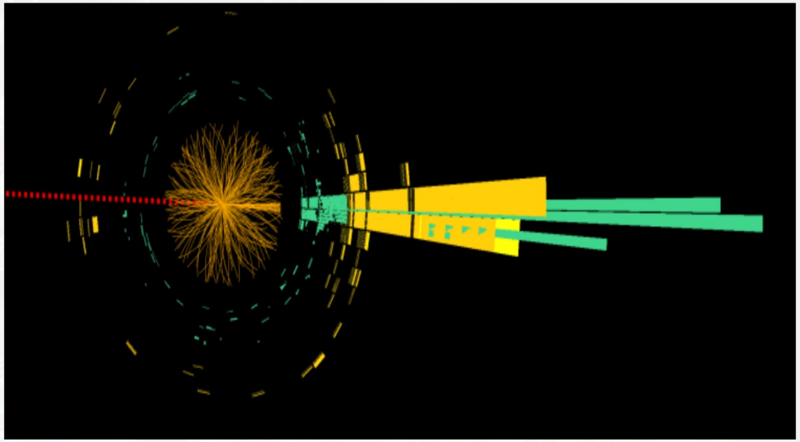


How to Detect Dark matter?



Colliders: Collision of SM particles (p-p at LHC) DM may produce, appear as **Missing Transverse Momentum**

Why Mono-Higgs Search?

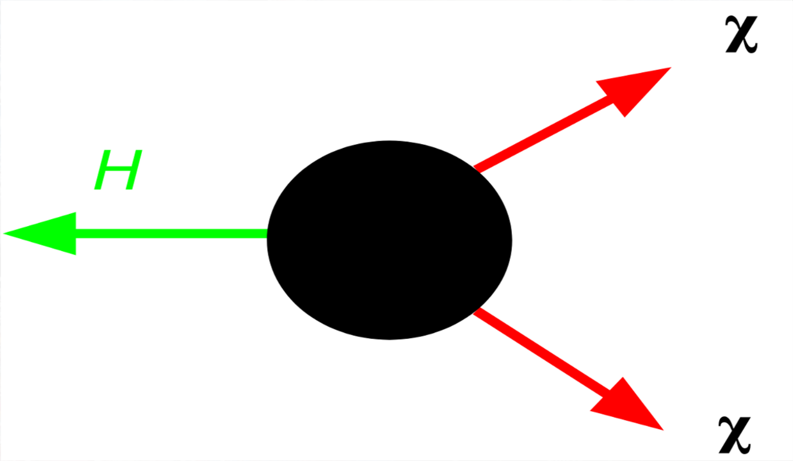


Canonical mono-jet/photon/W/Z from initial state radiation (ISR)

Mono-Higgs (Mono-h)

-“h” produced in ISR is highly suppressed

-The FSR of DM particles or the Beyond SM (BSM) interaction of DM particles with “h”, typically via a mediator particle

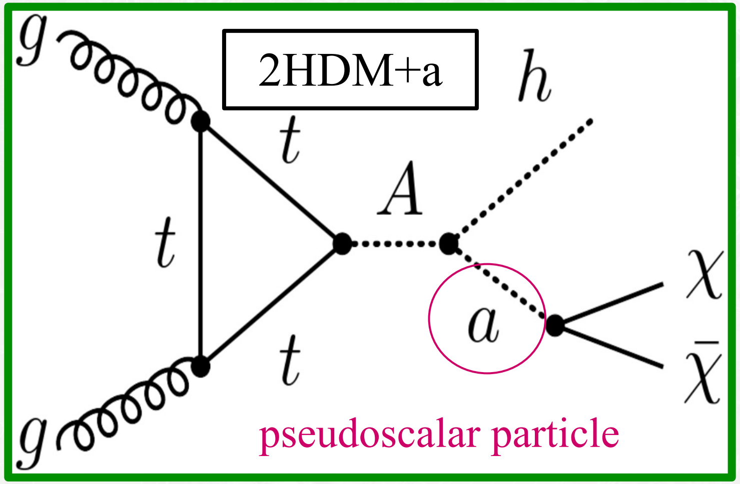


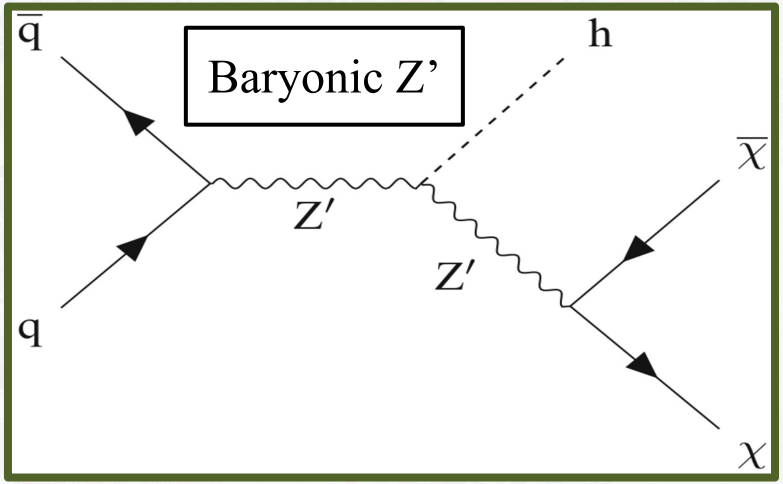
Signature:

-Reconstruct Higgs and search for excess of events with high p_T^{miss}

Analysis:

- Signature of mono-Higgs: Higgs (τ+τ) + missing transverse momentum (p_T^{miss})
- Benchmark models:
  - 2HDM+a
  - Baryonic Z'

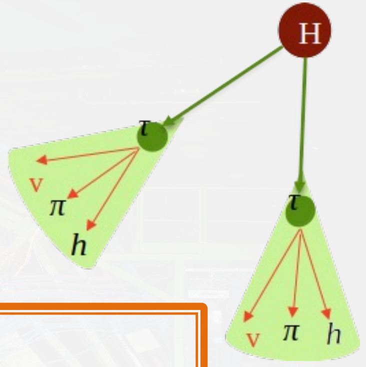




SM Backgrounds:

- $Z \rightarrow \ell\ell \Rightarrow$ Two real taus coming from Z boson, major background (ℓ-lepton)
- Jet misidentified as taus:
  - QCD, W+jets and ttbar contribution
- TTbar : TT $\Rightarrow 2\ell+2\nu$ (ν-neutrino)
- Diboson:
  - WW $\Rightarrow 2\ell+2\nu$
  - ZZ $\Rightarrow 2\ell+2\nu$
- SM Higgs

Event Selection:



Analysis is divided into 3 channels depending on decay mode of leading τ

$e\tau_h$ channel

Electron :
$p_T > 25$, $|\eta| < 2.1$
Tau :
$p_T > 30$, $|\eta| < 2.3$

$\mu\tau_h$ channel

Muon:
$p_T > 29$, $|\eta| < 2.4$
Tau :
$p_T > 30$, $|\eta| < 2.3$

b-jet veto: Reduce ttbar an single top backgrounds
Third lepton veto: Reduce multilepton backgrounds

$\tau_h\tau_h$ channel

Leading Tau:
$p_T > 55$, $|\eta| < 2.1$
Sub-leading Tau :
$p_T > 45$, $|\eta| < 2.1$

Common selections in all the three channels →

- ✓ Opposite charge
- ✓ $\Delta R > 0.5$
- ✓ Higgs $p_T > 65$ GeV
- ✓ Visible mass of the system < 125 GeV
- ✓ MET > 105 GeV
- ✓ $M_T^{Tot} > 100$ GeV

Background Estimation: Jet to tau fake background

- Jet → τ events estimated with data-driven fake factor (FF) method
- Wjets CR definition is modified to be orthogonal to our SR
    - Higgs PT < 65 GeV
- Jet→ τ background include events from the following processes:
    - QCD multijet (large majority of jet→ τ fake events in the $\tau_h\tau_h$ final state).
    - W+jets (mostly in the $e\tau_h$ and $\mu\tau_h$ final states).
    - tt events with fully-hadronic or semi-leptonic decays.
- To estimate the fake background in signal region, anti-isolated tau region is selected, and events are weighted with fake factors.
- Anti-isolated τ : pass Loose isolation and fail nominal isolation criteria

$$\left(FF = \frac{N_{iso}}{N_{anti\text{-}iso}}\right) \times \text{shape from anti-isolated data}$$

$$= \text{fakes backgrounds in isolated region (signal region)}$$

Signal Extraction Strategy:

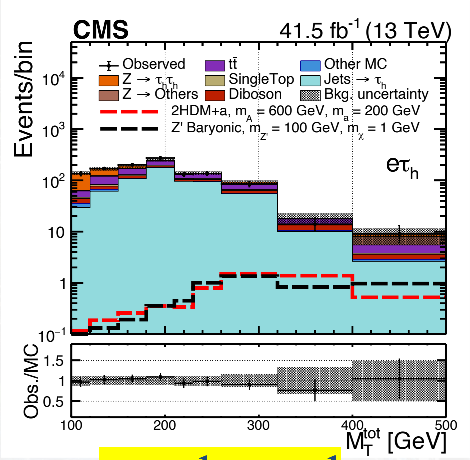
- ✓ Select eτ, μτ, ττ pairs with opposite sign, third lepton-veto, bjet veto
- ✓ $\Delta R > 0.5$
- ✓ Higgs $p_T > 65$ GeV
- ✓ Visible mass of the system < 125 GeV
- ✓ MET > 105 GeV
- ✓ $M_T^{Tot} > 100$ GeV

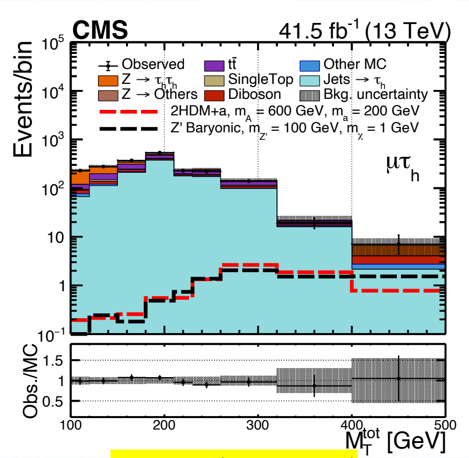
Signal is extracted based on the likelihood fit on the total transverse mass variable in the signal region

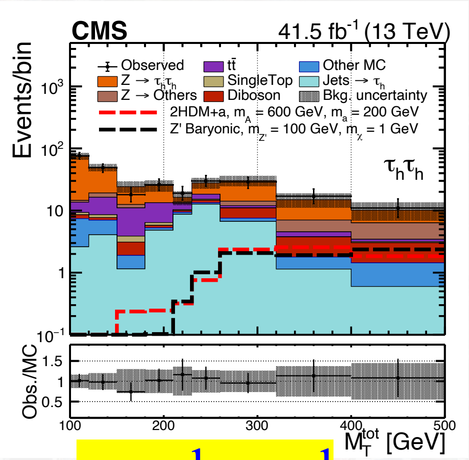
$$M_T^{tot} = \sqrt{(E_T^{\tau_1} + E_T^{\tau_2} + p_T^{miss})^2 - (p_x^{\tau_1} + p_x^{\tau_2} + p_x^{miss})^2 - (p_y^{\tau_1} + p_y^{\tau_2} + p_y^{miss})^2}$$

Total transverse Mass:

2017





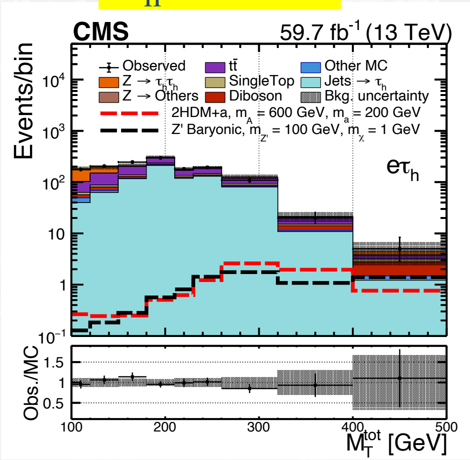


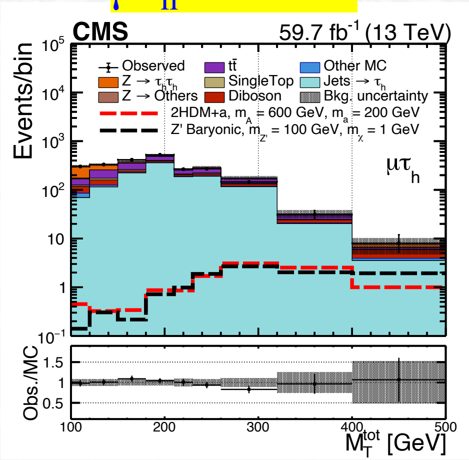
$e\tau_h$ channel

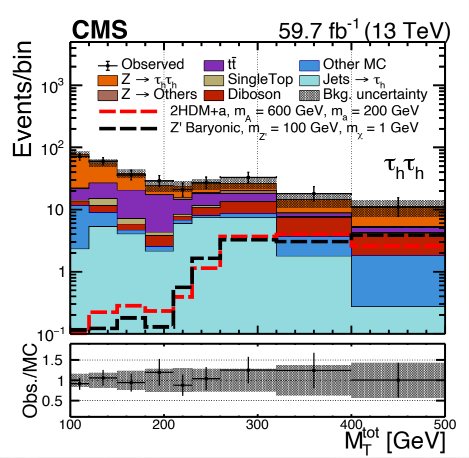
$\mu\tau_h$ channel

$\tau_h\tau_h$ channel

2018







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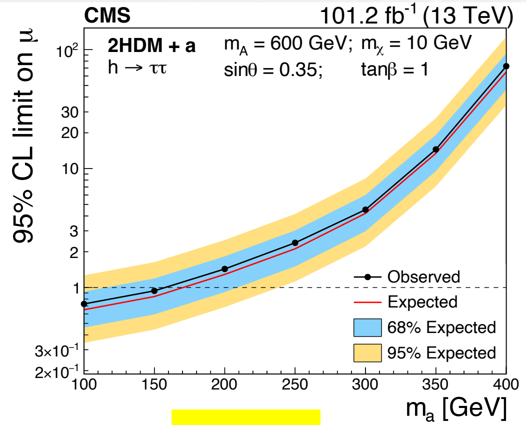
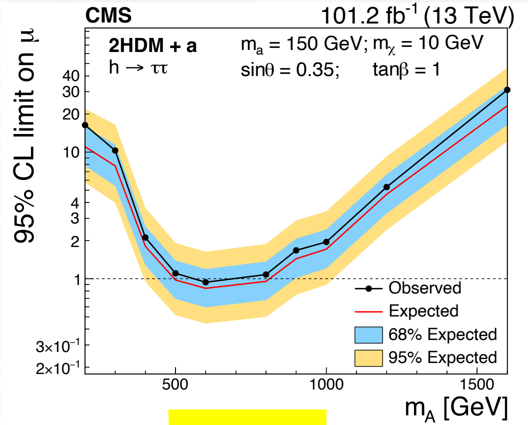
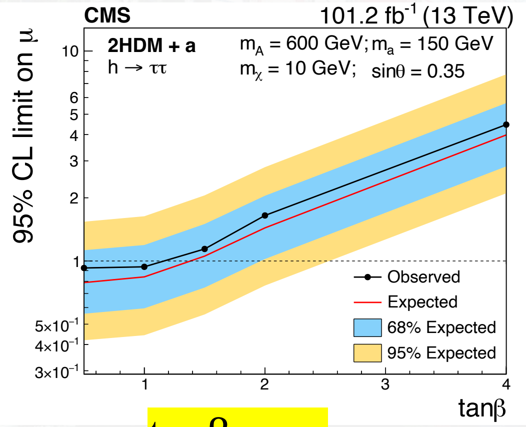
2HDM+a Model Limits 1d scans: combined 2017 and 2018



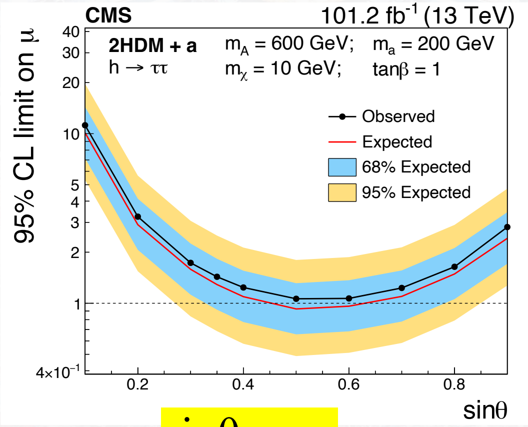
m_a scan



m_A scan



tanβ scan



sinθ scan

- m_a scan: Excluding m_a up to 160 GeV at m_A 600 GeV
- m_A scan: m_A 500 GeV and 700 GeV for m_a = 150 GeV
- tanβ scan: Exclusion region for tanβ ~ 1.2
- sinθ scan: No Exclusion is observed for sinθ scan
  Expected exclusion ~ 0.45 - 0.7

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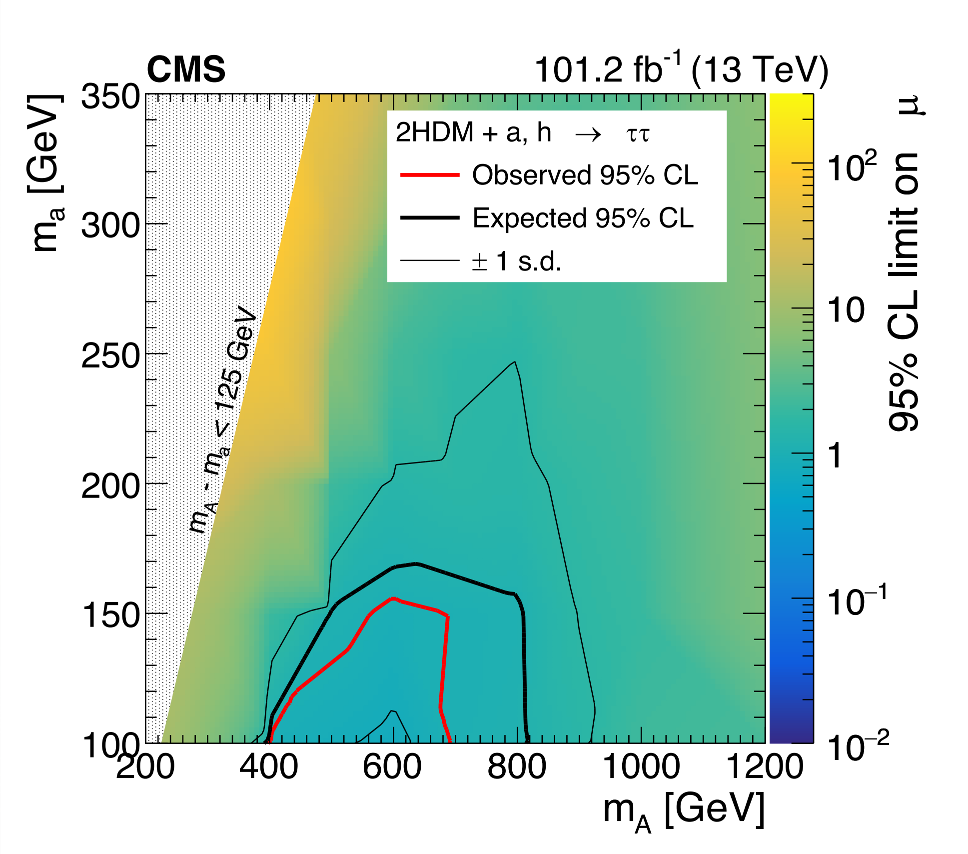
2HDM+a Model Limits 2d scans: combined 2017 and 2018



Varying m_A vs m_a

For the $m_a \sim 100$ GeV, the observed (expected) exclusion region for $m_A \sim 400$-700 (400-800) GeV

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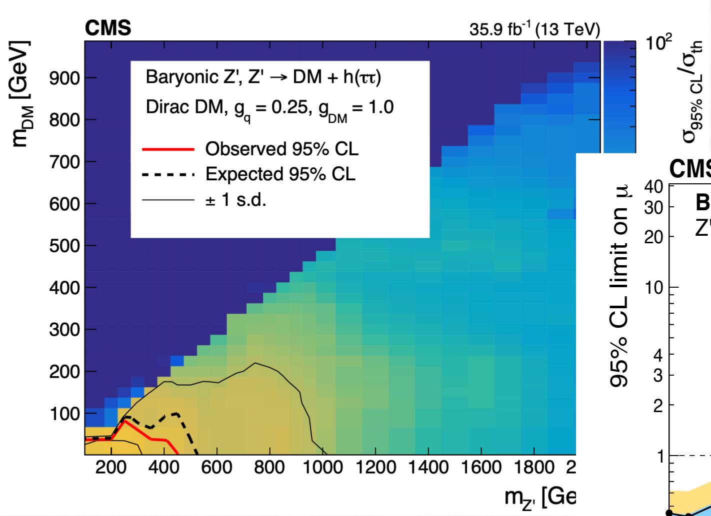
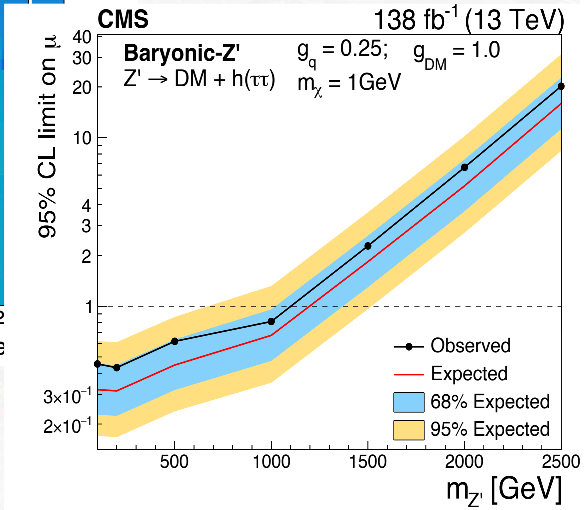
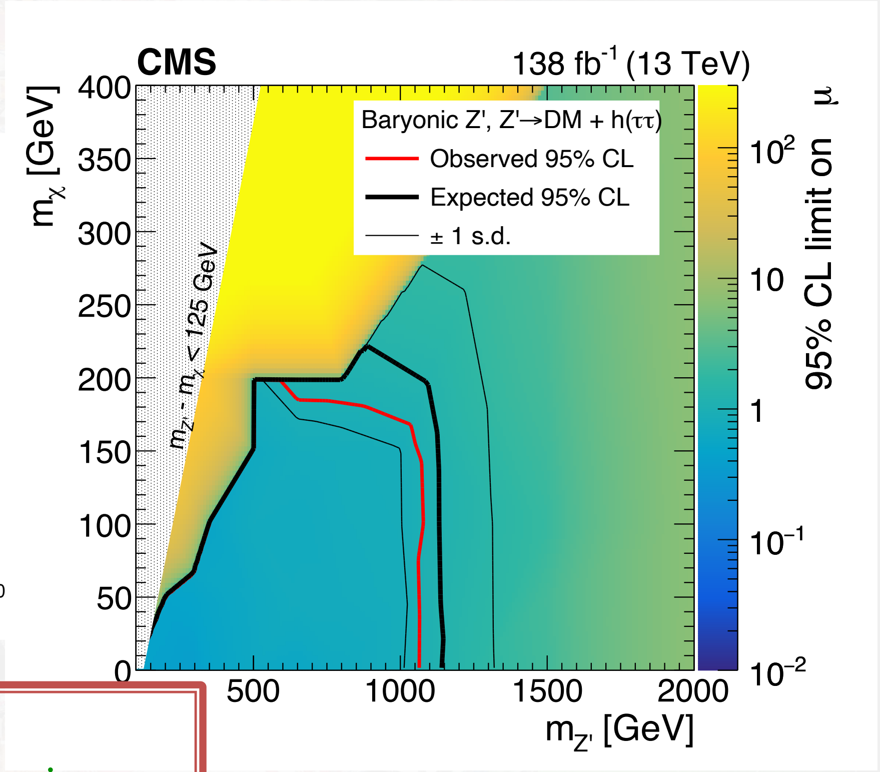
Baryonic-Z' Model Limits: Full Run 2







2016:
Z' mass excluded up to 450 GeV

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Full Run-2:
The observed (expected) exclusion regions for the Z' mass up to 1050 (1150) GeV, *for low m_χ*

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Summary

- Search for dark matter produced in association with a Higgs boson decaying to taus is presented using full Run-2 data
- Results are interpreted using 2HDM+a and Z' Baryonic models
- No significant deviation is observed from the SM predictions
- Upper limits are set on the model parameters at 95% CL
- The exclusion regions are shown for both models
  - For 2HDM+a
    - First time interpretation for this model using 2017+2018 data
    - For ma ~ 100 GeV, the observed (expected) exclusion for the mA ~ 400-700 (400-800) GeV for ma ~100 GeV
  - Z' Baryonic model
    - Full Run-2 combination is presented
    - For m_χ=1 GeV, the observed (expected) exclusion for the Z' mass is 1050 (1150) GeV

Thank you for your attention…

Backup

Background estimation: *Jet to taus fake background*

- Step: 1. Fake rate are determined as ratio of isolated to non-isolated $\boldsymbol{\tau_h}$ candidates, measured as a function of the $\boldsymbol{\tau_h}$ p_{T}, separately for QCD, W+jets, and ttbar CRs

- Step: 2. A visible mass corrections derived by comparing the distributions of isolated events in the control region with anti-isolated events in the control region reweighted with the raw fake rates of step 1.

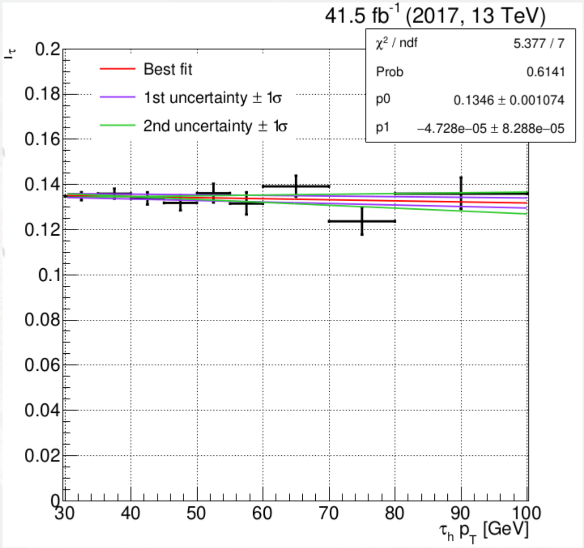
- Step: 3. Additional corrections derived for the selection criteria that differ between the signal region and the control regions

- Step: 4. Computation of the relative fraction of QCD, W+jets, and ttbar events for a given category (depending on number of jets) and $\boldsymbol{\tau_h}$ p_{T} to compute a fake rate as a weighted average of the individual fake rates.

$$\boldsymbol{FF(\text{category}) = fracW \times FFW + fracQCD \times FFQCD + fractt \times FFt}$$

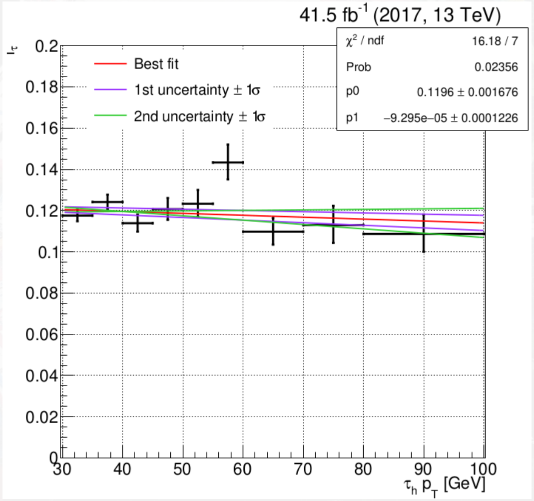
- Step: 5. Events that pass the signal region selection except that the τ_h candidate fails the isolation are reweighted with the global fake rate of step 4.

Fakerates for 2017 $\mathbf{e}\boldsymbol{\tau_h}$ 0jet



Wjets CR

Fakerates for 2017 $\mathbf{e}\boldsymbol{\tau_h}$ 1jet



Sources of Systematics:

Uncertainty	Magnitude	Correlation years	Correlation final states
τ_h identification	p_T	0%	100 (0)% for $\ell\tau_h$ ($\tau_h\tau_h$)
τ_h ID, for high $p_T^{\tau_h}$	Event-dependent	100%	100%
τ_h energy scale	0.7–1.2%	0%	100%
Electron misidentified as τ_h	Event-dependent	0%	0%
Muon misidentified as τ_h	Event-dependent	0%	0%
Electron/muon identification	2%	0%	0%
Energy scale for lepton misidentified as τ_h	1%	0%	0%
Trigger	Event-dependent	no	no
Electron energy scale	Event-dependent	100%	100%
Muon energy scale	0.4–2.7%	100%	100%
b jet veto	Event-dependent	partial	100%
Luminosity	2–3%	partial	100%
$t\bar{t}$ cross section	4.2%	100%	100%
Diboson cross section	5%	100%	100%
Single top quark cross section	5%	100%	100%
Drell–Yan cross section	2%	100%	100%
L1 prefiring	Event-dependent	0%	100%
Z boson p_T reweighting	Event-dependent	100%	100%
Top quark p_T reweighting	Event-dependent	100%	100%
Jet energy scale	Event-dependent	100%	100%
Jet energy resolution	Event-dependent	100%	100%
p_T^{miss} unclustered ES	Event-dependent	no	100%
p_T^{miss} recoil corrections	Event-dependent	no	100%
FF in $\ell\tau_h$	Event-dependent	partial	0%
FF in $\tau_h\tau_h$	Event-dependent	partial	0%
FF in $\tau_h\tau_h$, for $p_T^{\tau_h} > 100\,GeV$	Event-dependent	0%	0%

Event selection: (2017+2018)

Final state	Observable	First lepton	Second lepton
$e\tau_h$	$p_T >$	25	30
	$\|\eta\| <$	2.1	2.3
	$I^{e}_{rel} <$	0.15	—
$\mu\tau_h$	$p_T >$	29	30
	$\|\eta\| <$	2.4	2.3
	$I^{\mu}_{rel} <$	0.15	—
$\tau_h\tau_h$	$p_T >$	55	45
	$\|\eta\| <$	2.1	2.1

Mono- Higgs searches:2. h→ tautau (2016)

Final state	Trigger type	Lepton selection p_T [GeV]	η	Isolation
$e\tau_h$	$e(25\,GeV)$	$p_T^e > 26$	$\lvert\eta^e\rvert < 2.1$	$I_{rel}^e < 0.1$
		$p_T^{\tau_h} > 20$	$\lvert\eta^{\tau_h}\rvert < 2.3$	Tight MVA τ_h
$\mu\tau_h$	$\mu(24\,GeV)$	$p_T^\mu > 26$	$\lvert\eta^\mu\rvert < 2.4$	$I_{rel}^\mu < 0.15$
		$p_T^{\tau_h} > 20$	$\lvert\eta^{\tau_h}\rvert < 2.3$	Tight MVA τ_h
$\tau_h\tau_h$	τ_h (35 GeV) & τ_h (35 GeV)	$p_T^{\tau_h} > 55\,\&\,40$	$\lvert\eta^{\tau_h}\rvert < 2.1$	Loose MVA τ_h

Table 2. Selection requirements for the three $\tau\tau$ decay channels. The p_T thresholds for the triggers are given in the second column in parentheses.

Total trmass plots: (2016)