Search for dark matter produced in association with a Higgs boson decaying to a pair of W bosons at CMS

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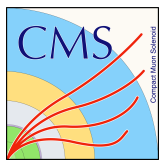
on behalf of the CMS collaboration

La Thuile 2019, 10-16 Mar 2019



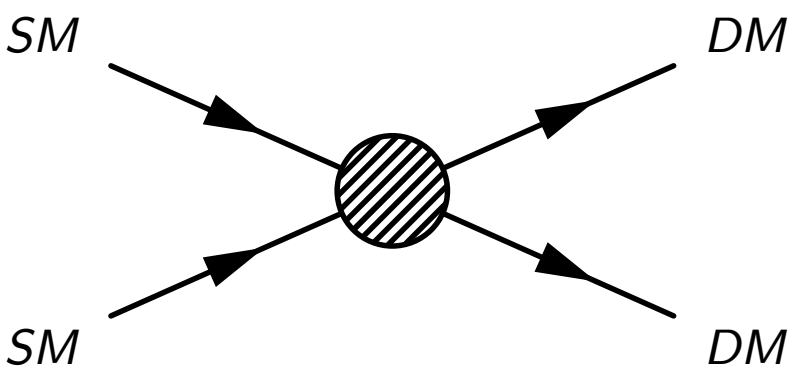

IFCA – Santander

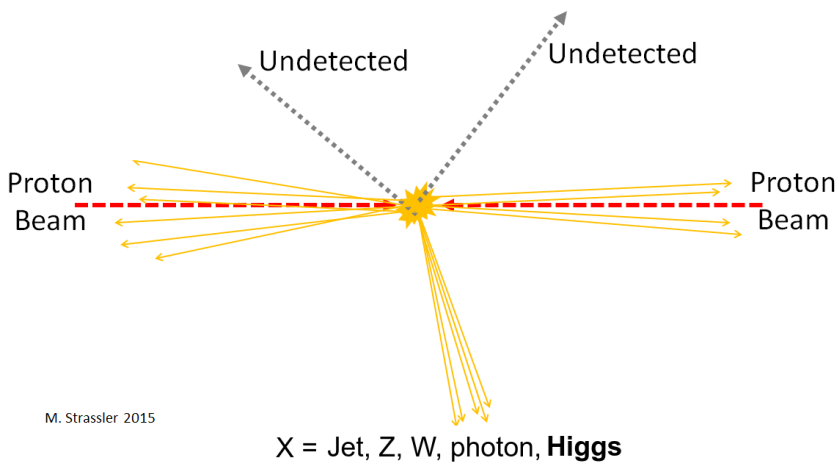
March 12, 2019

Introduction

Dark Matter particle nature is unknown and cannot be explained within Standard Model

- At a hadron collider have to assume interaction between Standard Model and Dark Matter candidate particles
- Main candidate: **Weakly Interacting Massive Particle**
  - Not expected to interact with the detector material
- Final state with two Dark Matter particles and SM particle(s)
  - Missing transverse momentum $(\mathbf{p}_T^{miss})$ + **X** signatures
  - In this case **X is a Higgs boson**





Mono-Higgs Physics Models

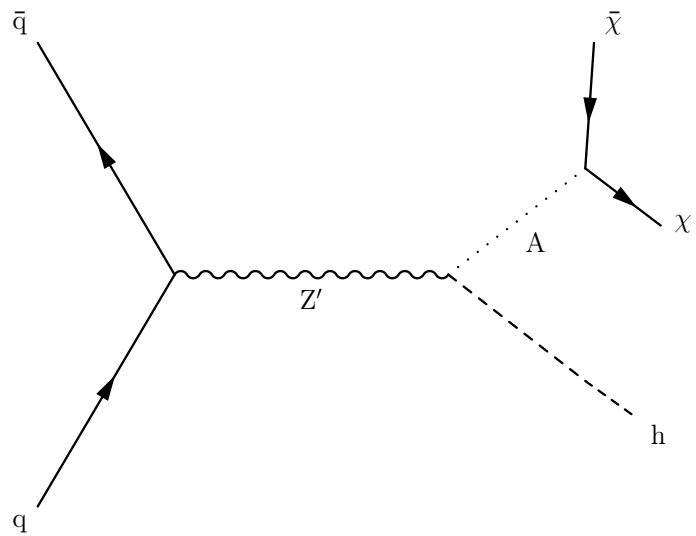
Typical p_T^{miss} + X searches are based on **initial state radiation (ISR)** of the Standard Model Particle

- ISR of a Higgs boson is strongly suppressed
- Direct **Higgs-Mediator interaction** at the vertex

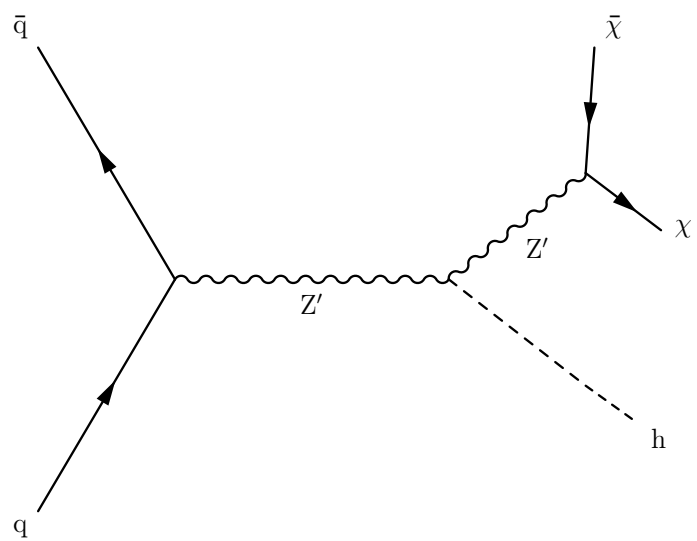
Following recommendations from **LHC DM Working Group** two simplified models have been inspected

- Z'-2HDM (left)
- Baryonic Z' (right)

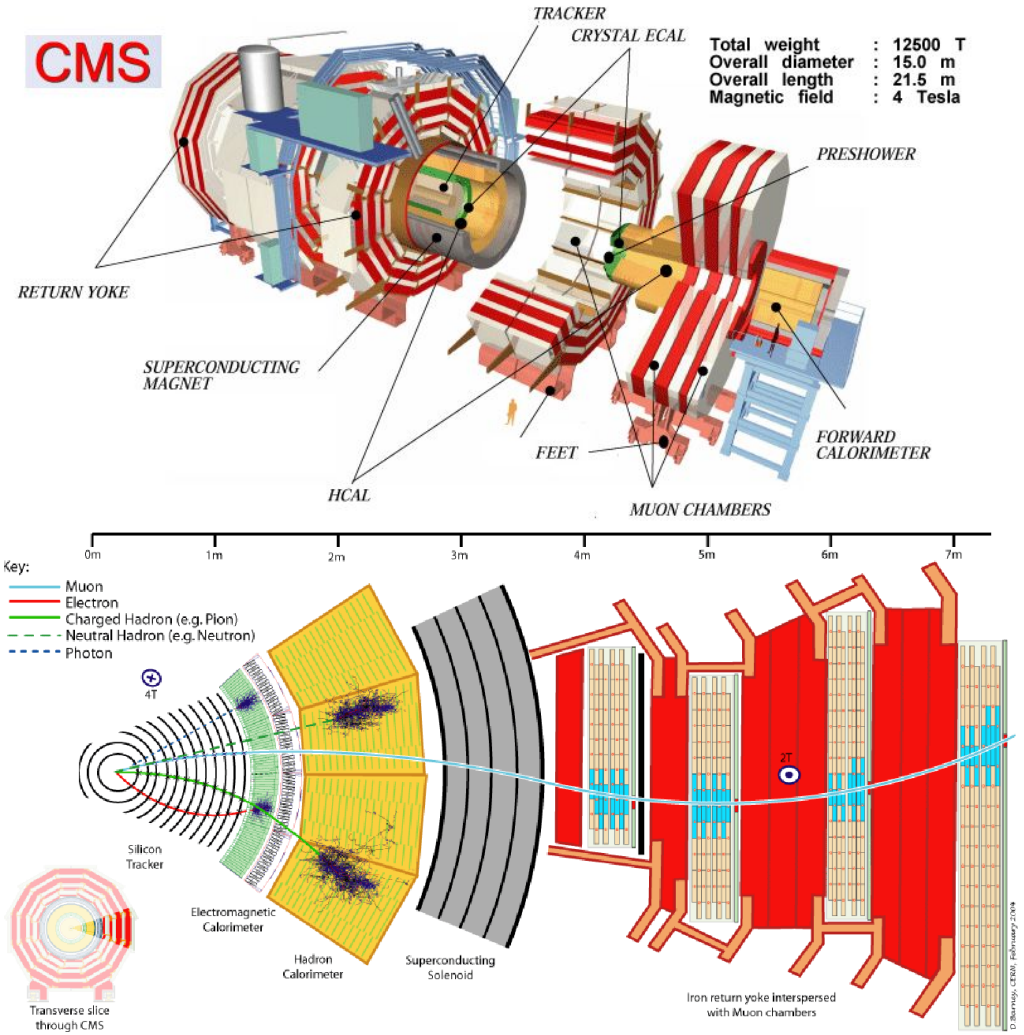
Z'-2HDM



Baryonic Z'



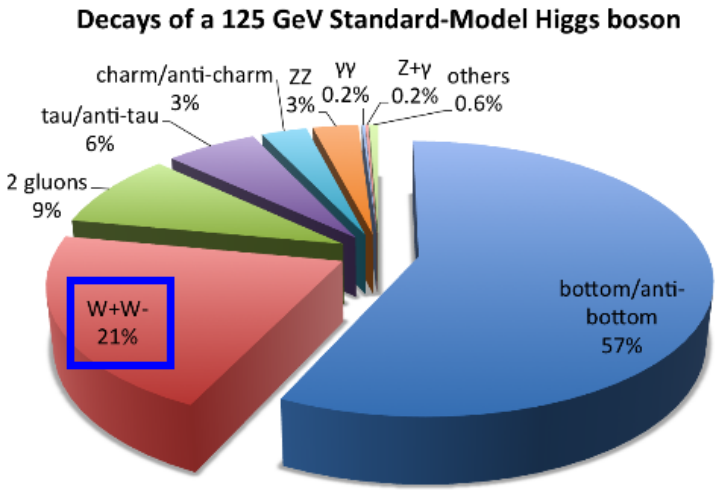
The CMS Detector at the LHC



The Fully Leptonic WW Final State

The h→WW final state

- Presents a **large branching fraction**
  - BR(h→WW) ∼ 21%
  - Second only to BR(h→bb)
- Selecting the fully leptonic WW decay
  - Significant **background reduction**
  - Good **control of systematic** uncertainties
  - Partial reduction of signal yields
- **Complements** the searches in other Higgs decay channels
  - Can confirm deviations from SM expectations observed in different final states



Event Selection

The events used in the analysis must contain two opposite sign, different flavour leptons, **one electron and one muon**:

- Leading lepton $p_T > 25$ GeV
- Trailing lepton $p_T > 20$ GeV

The signal region is then **further optimized** in order to reject background events:

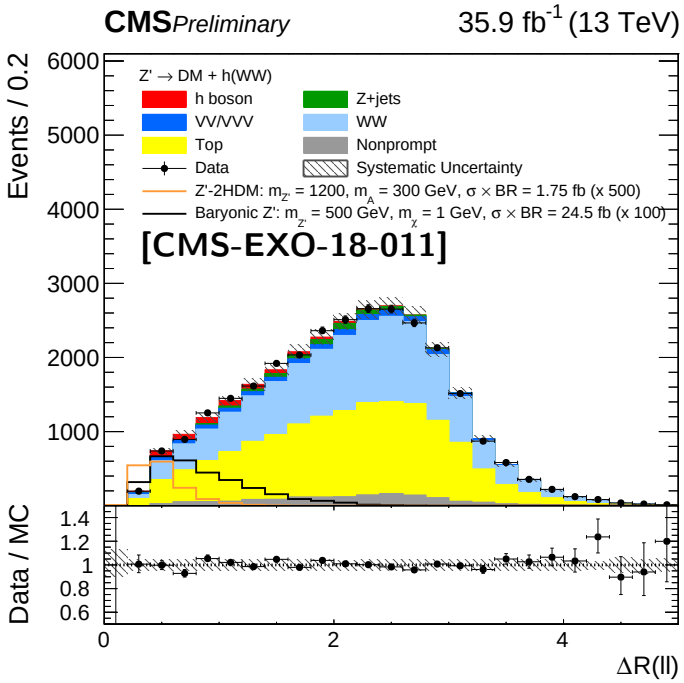
Background to reject	Selection
WZ, ZZ, VVV	Veto events with a third loose lepton with $p_T > 10$ GeV
Drell-Yan, light resonances	$m_{\ell\ell} > 12$ GeV $p_T^{miss} > 20$ GeV $m_T^H > 40$ GeV
Non-prompt leptons	$p_T^{\ell\ell} > 30$ GeV
Top quark	No b-jets with $p_T > 20$ GeV

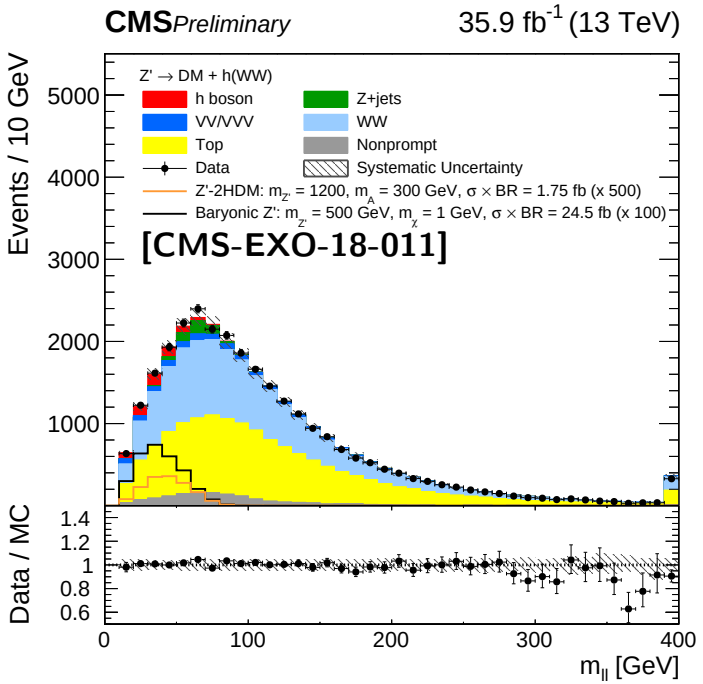
Analysis Specific Selections

On top of the previous selections, valid to define a phase space enriched in WW/HWW events, **two additional cuts** have been defined

Background to reject	Selection
Non-resonant WW	$m_{\ell\ell} < 76$ GeV
Non-boosted leptons	$\Delta R(\ell\ell) < 2.5$

- Z'-2HDM Signal: $m_{Z'} = 1200$ GeV, $m_A = 300$ GeV
- Baryonic Z' Signal: $m_{Z'} = 500$ GeV, $m_\chi = 1$ GeV





Analysis Strategy

After the basic selections are applied, the **signal significance is still low**

- This is due to the presence of neutrinos, which spoils both the $m_{\ell\ell}$ and p_T^{miss} distributions
- **To extract the signal, a multivariate analysis technique is exploited**
  - One BDT is trained for each model
- Against main backgrounds
  - Higgs, SM WW, Top
- Trained using significant kinematic variables
- In order to have a **flat response** versus the mediator mass, trained using:
  - Z'-2HDM model: all mass points with $m_A = 300$ GeV
  - Z'-Baryonic model: all mass points with $m_\chi = 1$ GeV
- The weight given to signal events is then divided by the **expected number of events** passing the pre-selections required for the training

Main Backgrounds Estimation

The estimation of the main backgrounds entering the signal region follows different approaches:

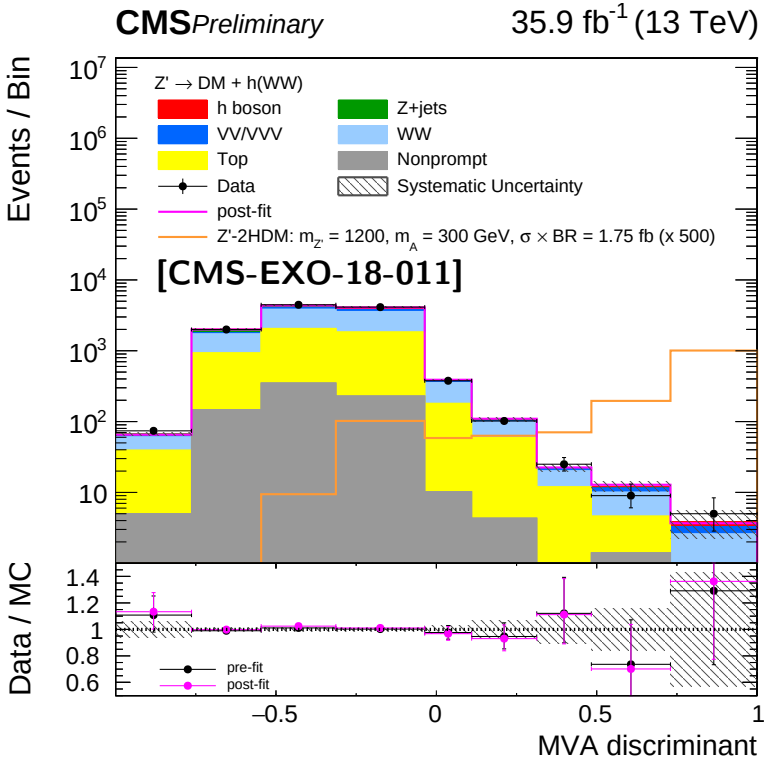
- **Jet-induced** background (non-prompt leptons): fully data-driven
  - **Tight-to-loose method**
  - Probability for a lepton inside a jet to be reconstructed as a prompt lepton measured in a jet-entiched phase space
  - Then applied to events with one tightly-identified lepton and one loosely-but-not-tightly identified lepton
- **WZ and Wγ^*** background: normalized to data in specific phase spaces with 3 leptons
  - Both the normalizations and their uncertainties are estimated in **control regions to rescale the Montecarlo** predictions
- **WW, Top, DY**: normalized in control regions that enter the fit
  - Normalizations are free to float
  - **Nominal values and uncertainties come from the fit**
- **SM Higgs** production **and** other **minor processes**: taken from MC
  - **Normalization and its uncertainty from theory**

Signal Extraction

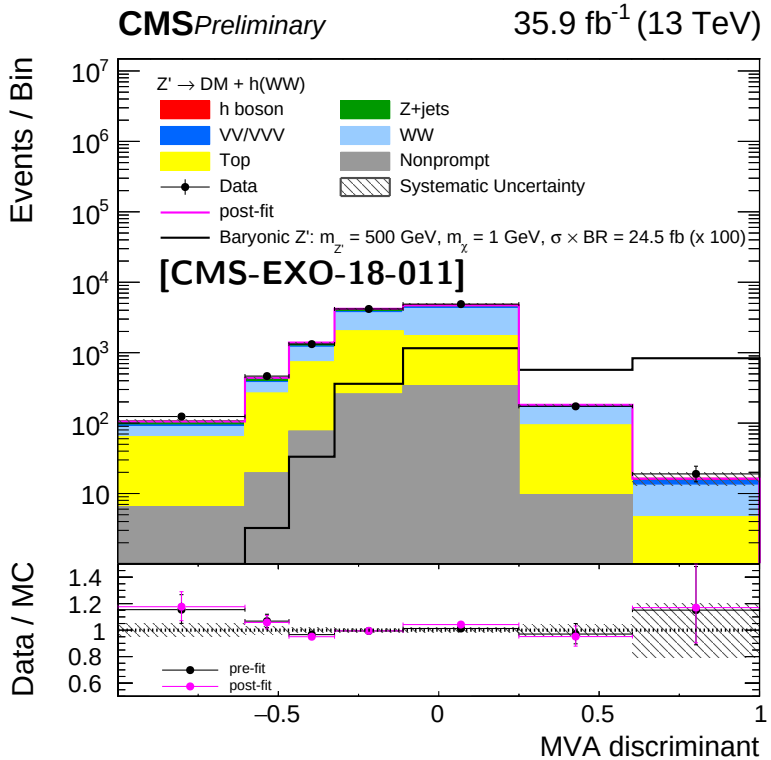
The signal and background yields are obtained through a **simultaneous fit** to the signal region and the three control regions

- **Signal region**: 1D binned shape analysis on the BDT output
- **Control regions**: just one bin for normalization

Z'-2HDM Model



Baryonic Z' Model

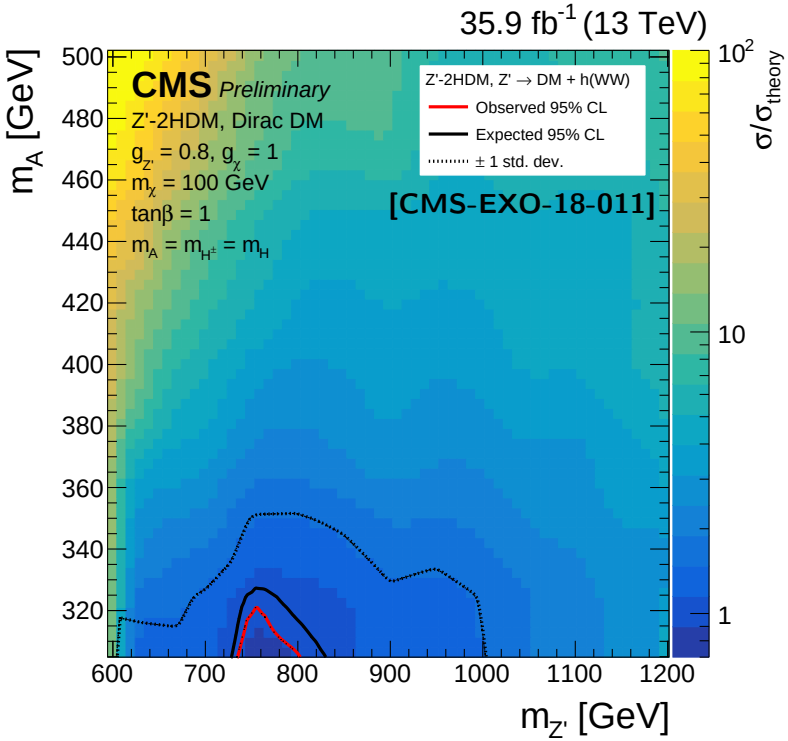


Results

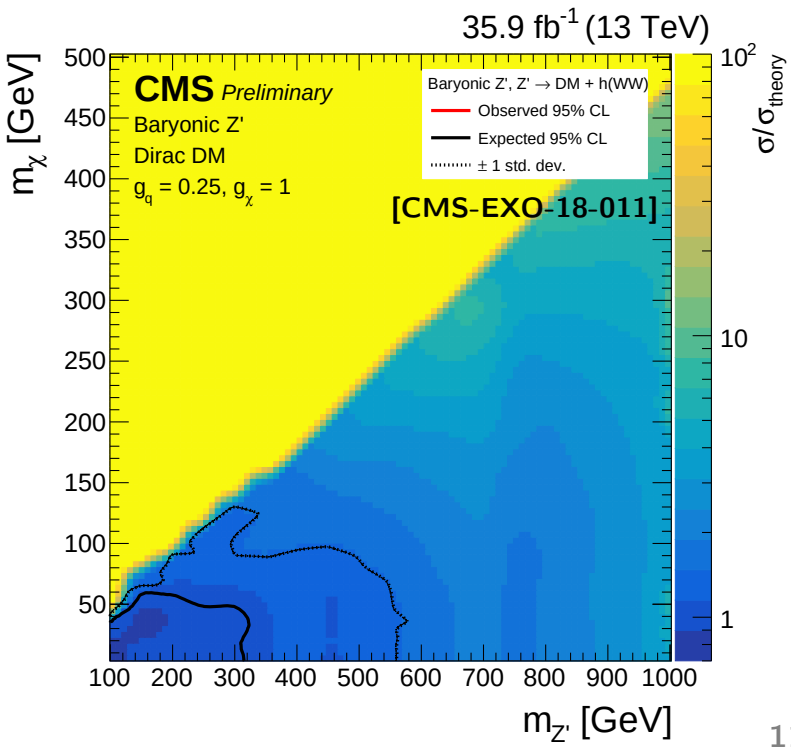
No significant discrepancies between data and the Standard Model have been found

- **Limits have been set** on the dark matter production cross section
- Results dominated by statistical uncertainty
  - **Z'-2HDM** model: 740 GeV $< m_{Z'} <$ 800 GeV and 300 GeV $< m_A <$ 320 GeV excluded
  - **Baryonic Z'** model: no sensitivity reached

Z'-2HDM Model



Baryonic Z' Model

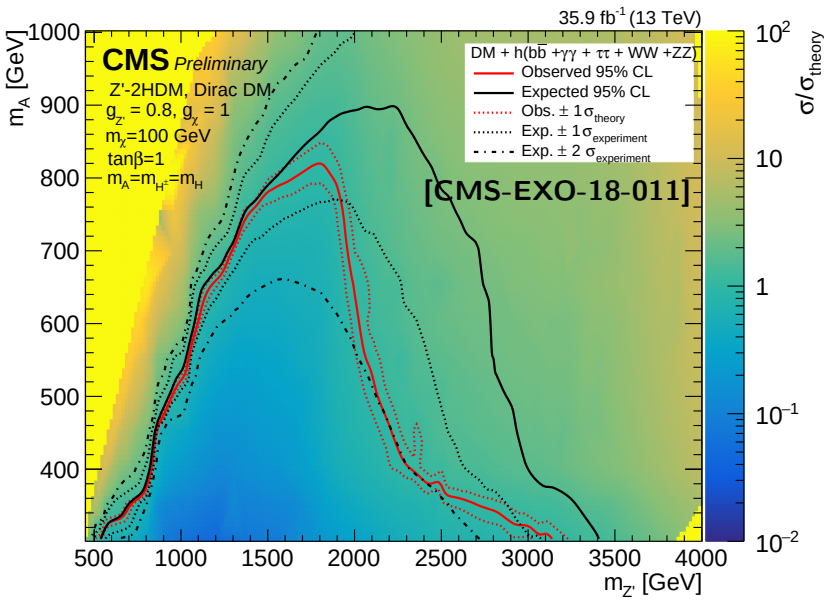


Combination of Results

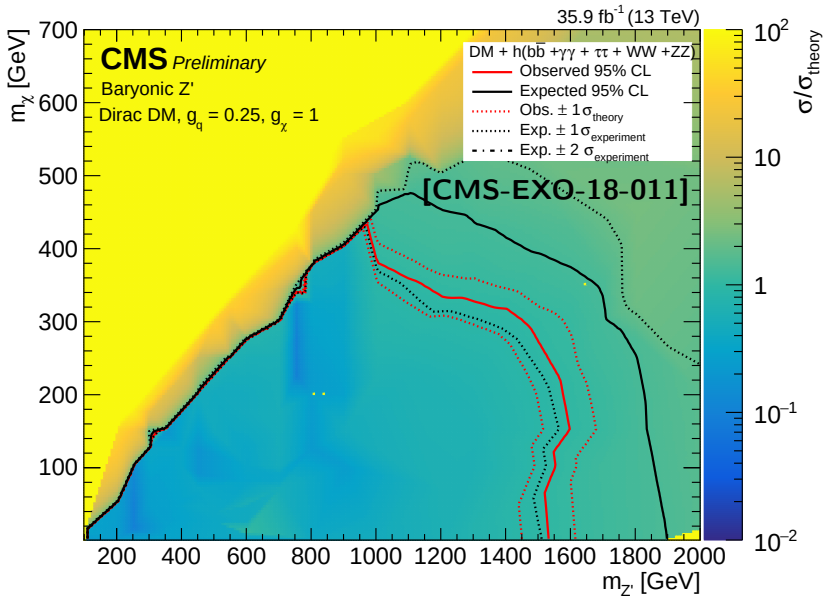
Results of the WW channel have been **combined with other final states**

- bb, $\gamma\gamma$, $\tau\tau$, and ZZ
- **Sensitivity driven by bb channel** due to much larger branching fraction
- **Z'-2HDM** model: 500 GeV $< m_{Z'} <$ 3200 GeV and 300 GeV $< m_A <$ 800 GeV excluded
- **Baryonic Z'** model: 100 GeV $< m_{Z'} <$ 1500 GeV and 1 GeV $< m_\chi <$ 420 GeV excluded

Z'-2HDM Model



Baryonic Z' Model

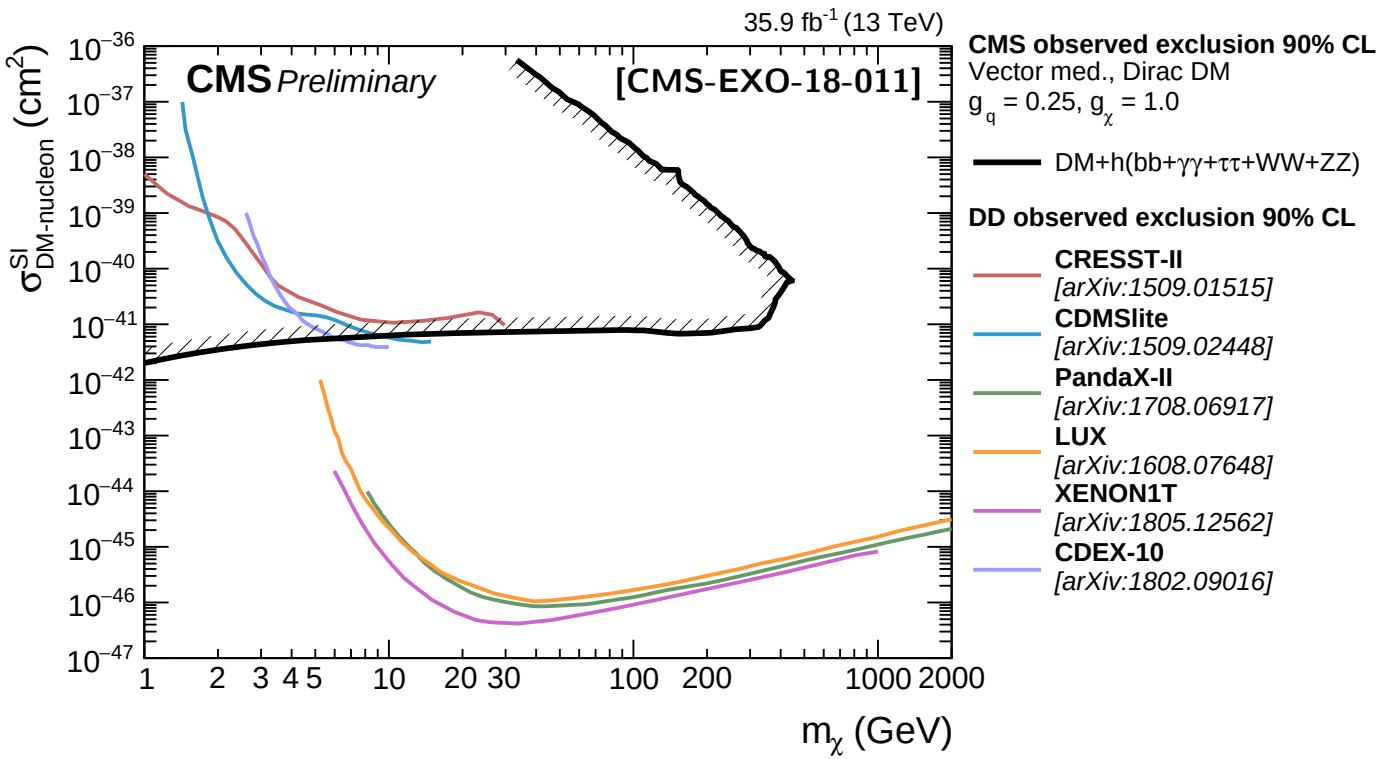


Reinterpretation of Results

The limits on the **Baryonic Z' model are reinterpreted in terms of spin-independent cross section σ^{SI} for dark matter scattering off a nucleus**, allowing a comparison with direct detection experiments [**CMS-EXO-18-011**]

$$\sigma^{\mathrm{SI}} = \frac{f^2(g_q) g_{DM}^2 \mu_{n\chi}^2}{\pi m_{med}^4}$$

- $f(g_q)$ = mediator-nucleon coupling
- $\mu_{n\chi}^2$ = reduced mass of nucleon-DM system



Conclusions

The current CMS searches for mono-Higgs signature have been presented

- **Main focus** of the talk **on the WW final state**
  - In the context of the **combination of 5 Higgs decay channels**
- Two simplified models have been considered
  - **Z'-2HDM**: Z' mediator of mass from **1 TeV to 3 TeV** and A mediator of mass up to 800 GeV are exluded
  - **Z'-Baryonic**: **Z' masses up to 1500 GeV** and DM particle masses up to 420 GeV are excluded
- **Spin-Independent** DM-nucleus cross section σ^{SI} limits have been set
  - Based on the Baryonic Z' model
  - Assuming the couplings of the Z' mediator $g_q = 0.25$ and $g_\chi = 1$
  - Values of σ^{SI} larger than 10^{-42} cm^2 are excluded for light DM particles
- **Future plans**
  - Look at **full Run-2 dataset**
  - Explore additionally the **2HDM+a model**

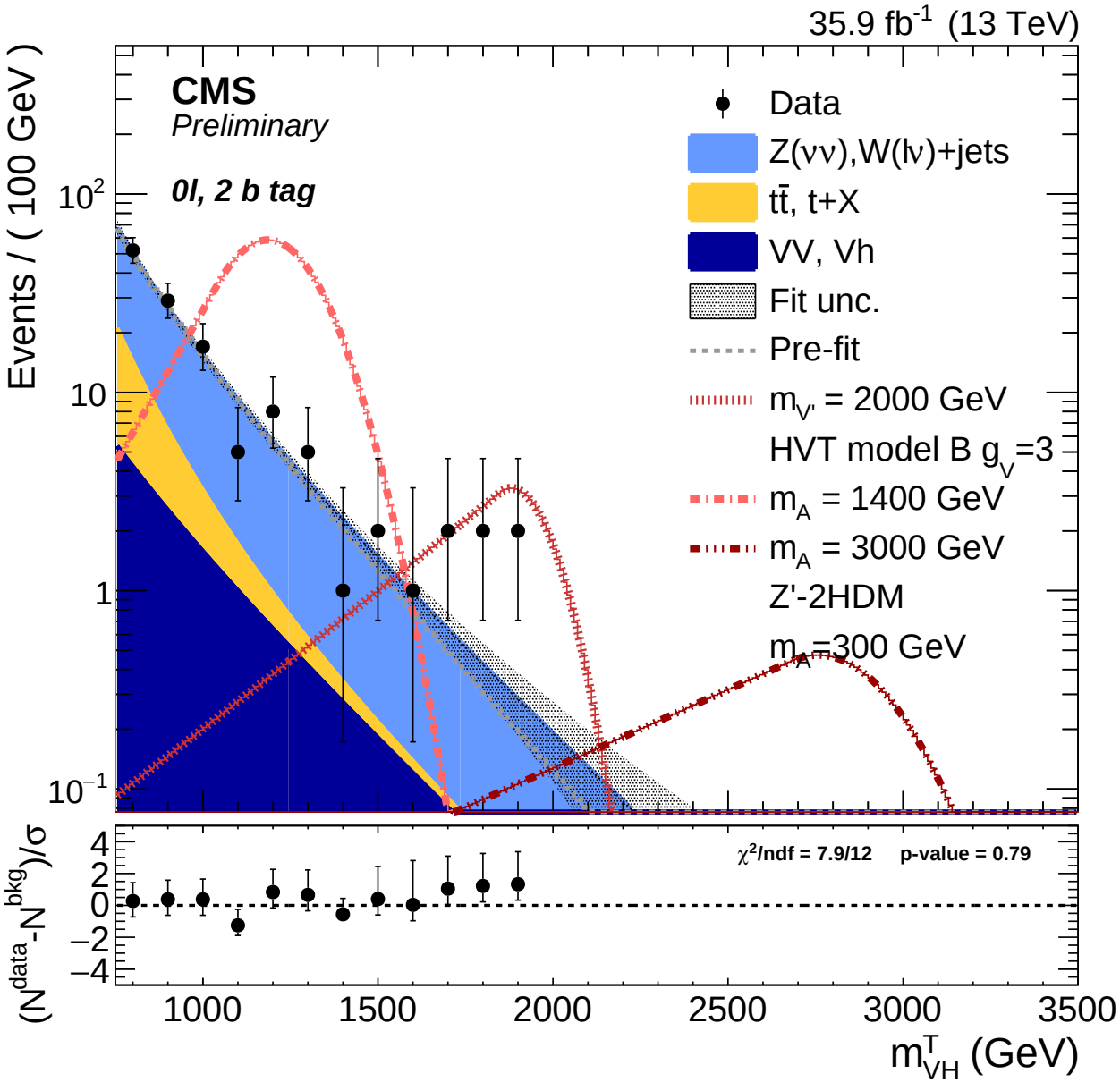
Former CMS Results

CMS has released different results on the mono-Higgs search using data taken at 13 TeV

Channel	Dataset	Luminosity	Model
h$\to \gamma\gamma$ + h$\to$ bb	2015	2.3 fb^{-1}	Z'-2HDM
h$\to \gamma\gamma$ + h$\to \tau\tau$	2016	35.9 fb^{-1}	Z'-2HDM + Baryonic Z '
h$\to$ bb	2016	35.9 fb^{-1}	Z'-2HDM + Baryonic Z' + 2HDM+a

The focus of the talk is on the **newest results**, obtained inspecting the WW final state and combining 5 different Higgs decay channels (bb, $\gamma\gamma$, $\tau\tau$, WW, ZZ)

h→bb Data-MC in High-Purity Phase Space



2HDM + a Model