



# Search for New Physics at CMS Collaboration

---

PEDRO MERCADANTE

SPRACE - UFABC

“We propose to build a general purpose detector designed to run at the highest luminosity at the LHC. The CMS (Compact Muon Solenoid) detector has been optimized for the search of the SM Higgs boson over a mass range from 90 GeV to 1 TeV, but it also allows detection of a wide range of possible signatures from alternative electro-weak symmetry breaking mechanisms.”

Abstract of the CMS Letter of Intent, submitted to the LHC Experiments Committee (LHCC) on 1 October 1992

“Significant advances [in science] will be marked by the *confirmation* of *bold* conjectures or the *falsification* of *cautious* conjectures.”

A. F. Chalmers  
*What is this thing called Science?* (1999)

# Beyond Standard Model Physics with CMS

---

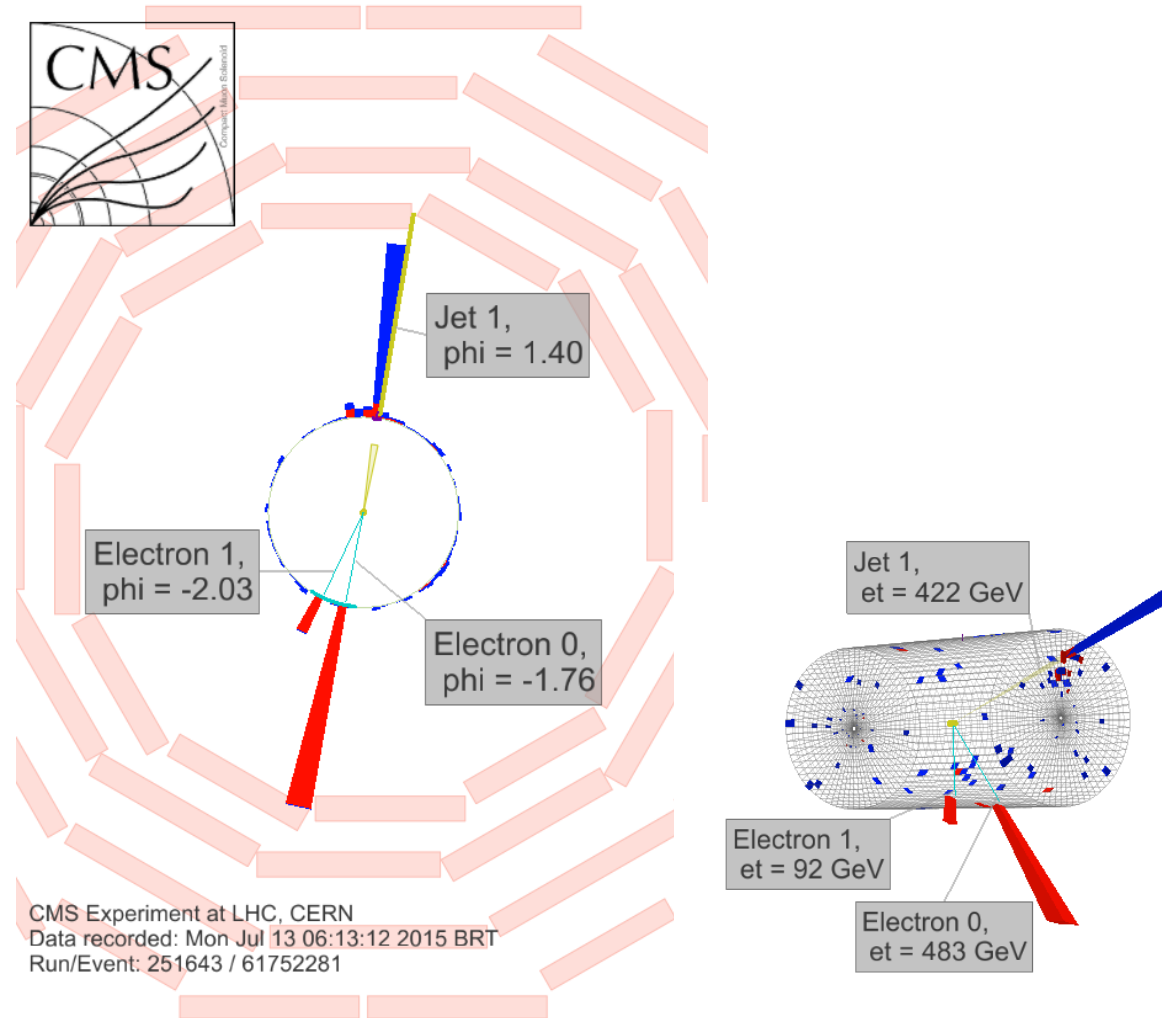
SELECTED RESULTS

# Heavy Resonances

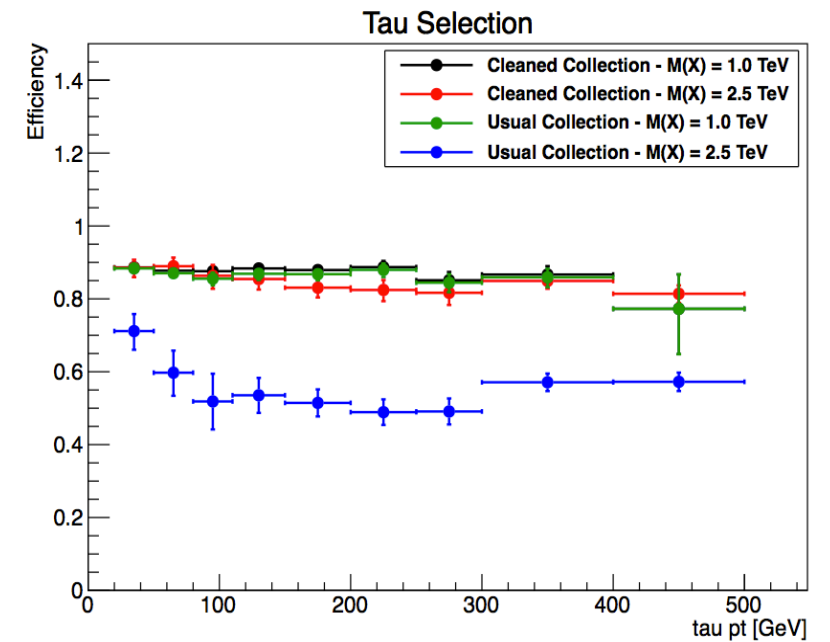
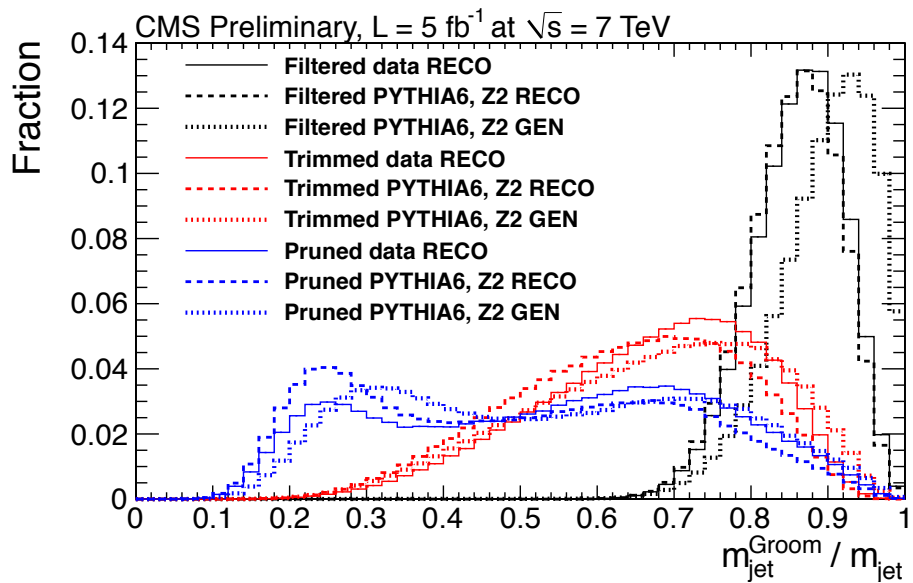
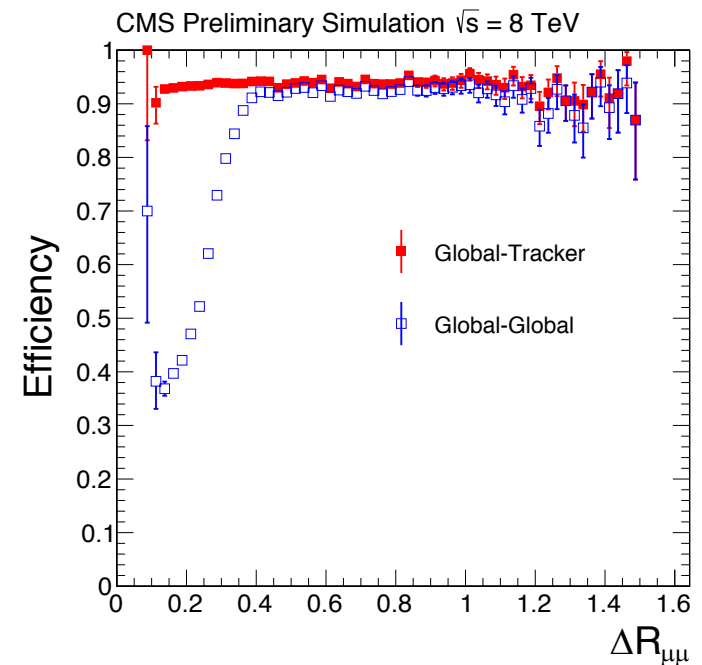
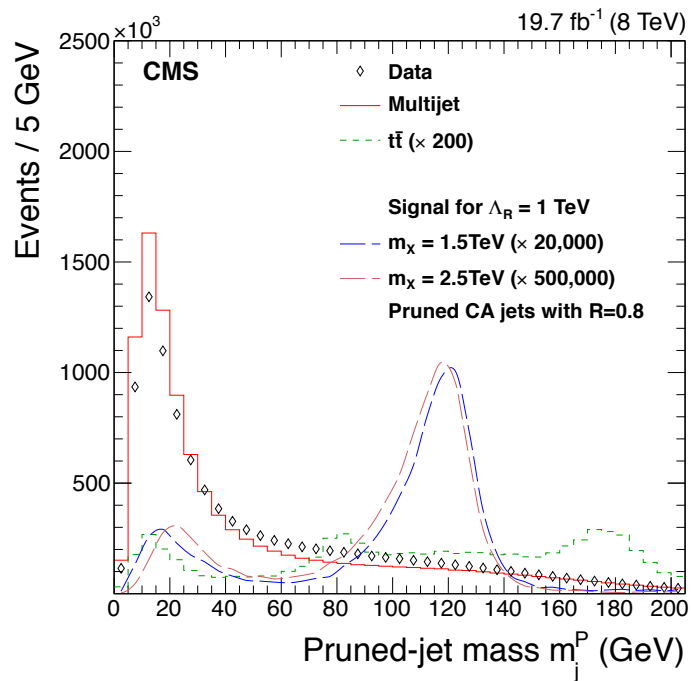
## LHC High Energy

- ❑ Heavy particles production
- ❑ Decay to high momentum particles
  - Boosted Topologies
- ❑ Experimental Challenge:
  - Jets overlap
  - Leptons overlap

## SPRACE: Searches for boosted topology



# Boosted Objects



# Searches for Diboson Resonances

Search for  $X \rightarrow VV, VH, HH$

- $V = W$  or  $Z$  boson
- Benchmark models
  - WED radion (HH)
  - WED bulk graviton (ZZ, WW)
  - $HVT_B W', Z'$  (WH, ZH, WW, ZZ)

Can shed light on the electroweak symmetry breaking phenomena

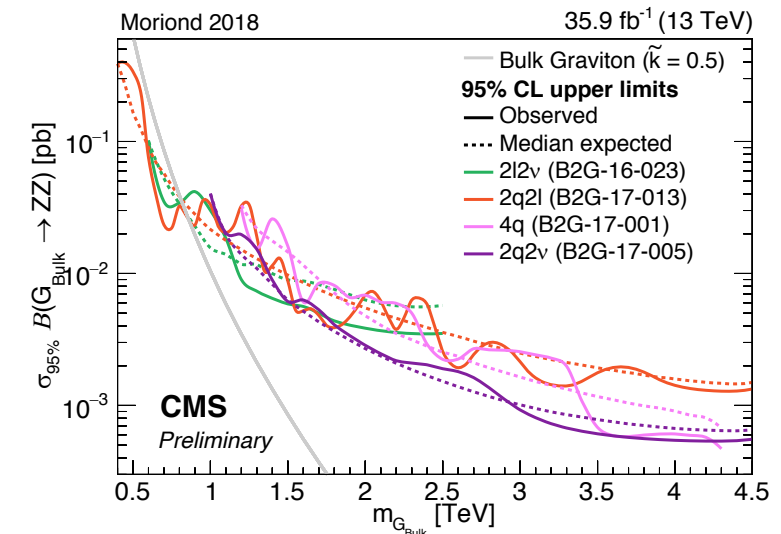
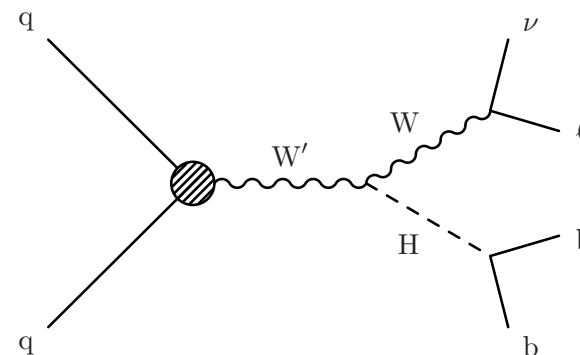
- Is it really just the Higgs, W, Z and photon?

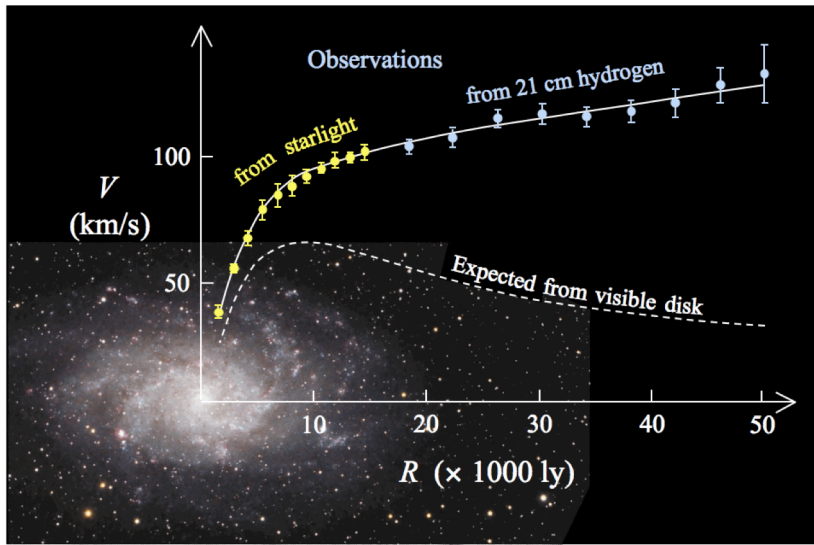
Studied at CMS since beginning of Run 1

- Coordinated efforts / combinations of all analyses now standard

Different channels and different strategies

- Merged jets
- b-tagging
- tau-tagging
- High-energy leptons

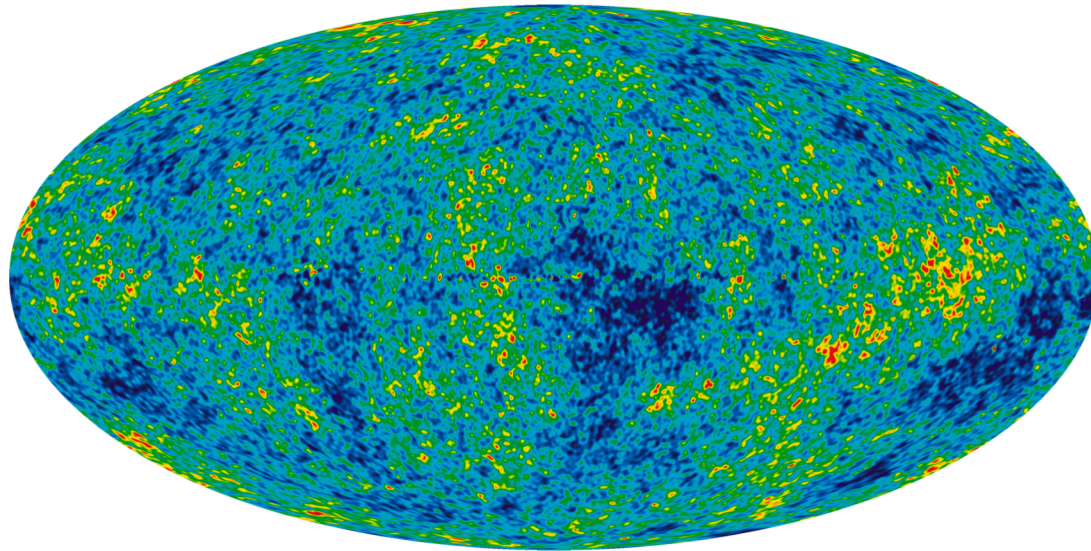




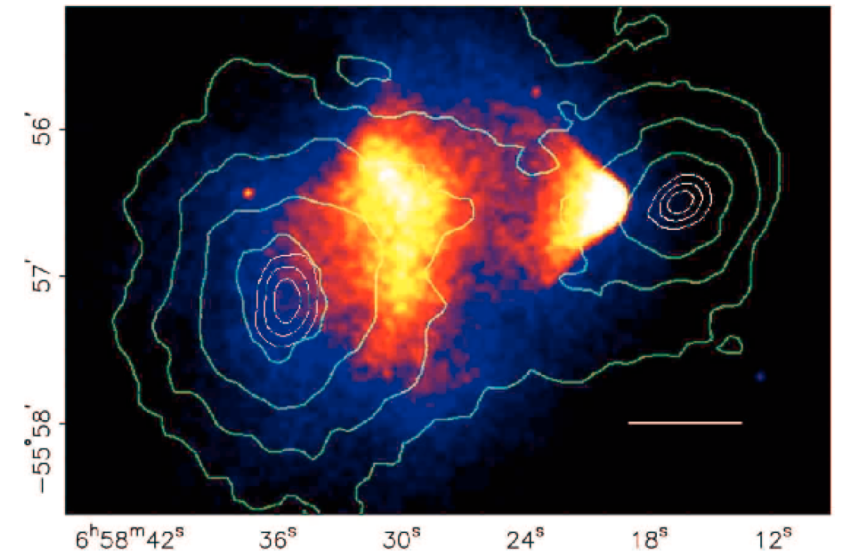
Galaxy Rotation Curves



Strong Gravitational Lensing



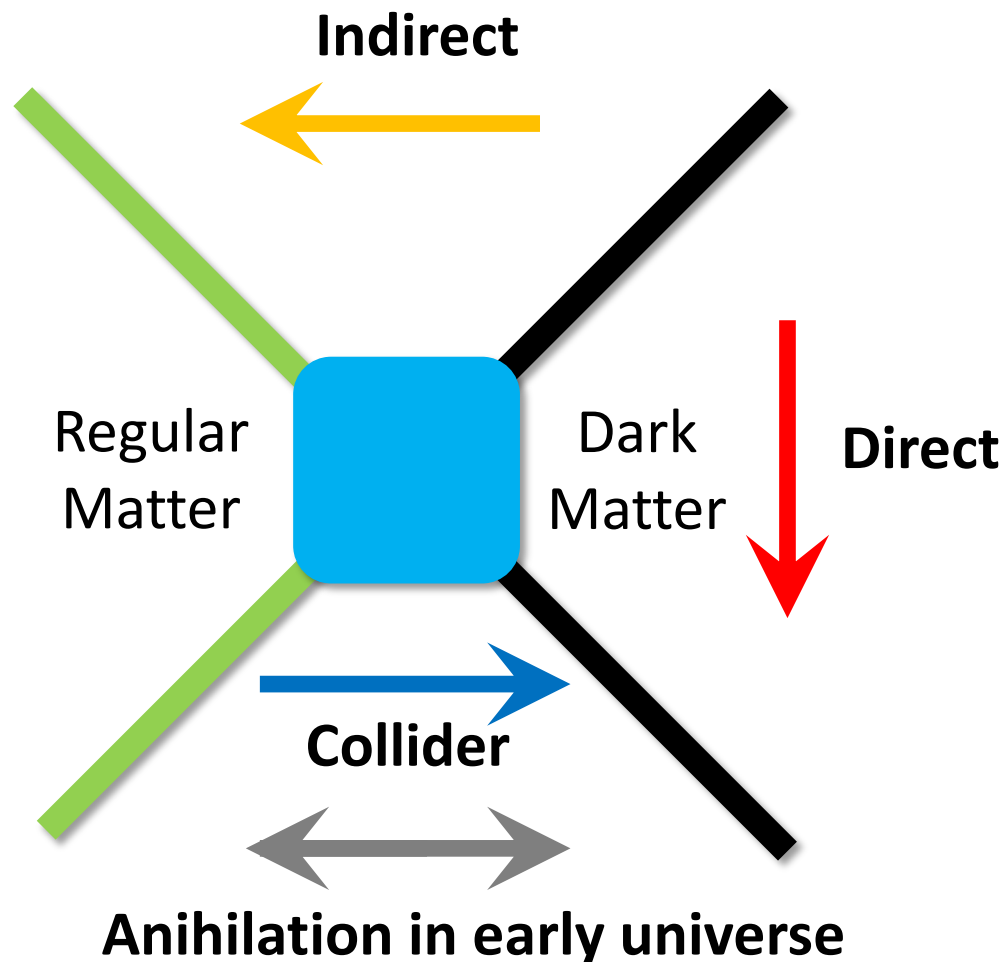
Cosmic Microwave Background



Bullet Cluster



# Strategies to Search for Dark Matter



## Direct detection

- DM-nucleus scattering

## Indirect detection

- DM Annihilation products

## Collider production

- Production of DM at the lab (e.g. LHC)
  - Clear strategy for WIMP
  - Sensitive to a large DM mass range

# Dark Matter Searches at LHC

The nature of Dark Matter is still unknown

- Atomic hypothesis: it is a particle!

One of the most challenging quests of Science

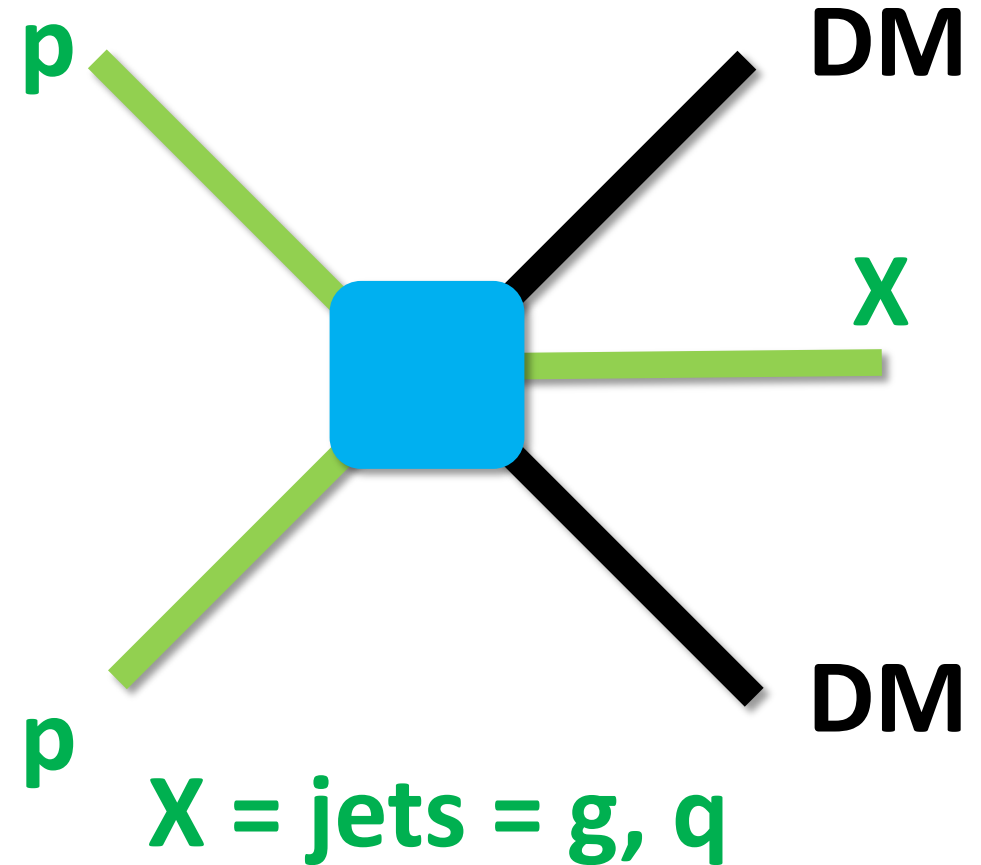
High profile analysis for LHC Run 2

Mono-X is the signature of choice

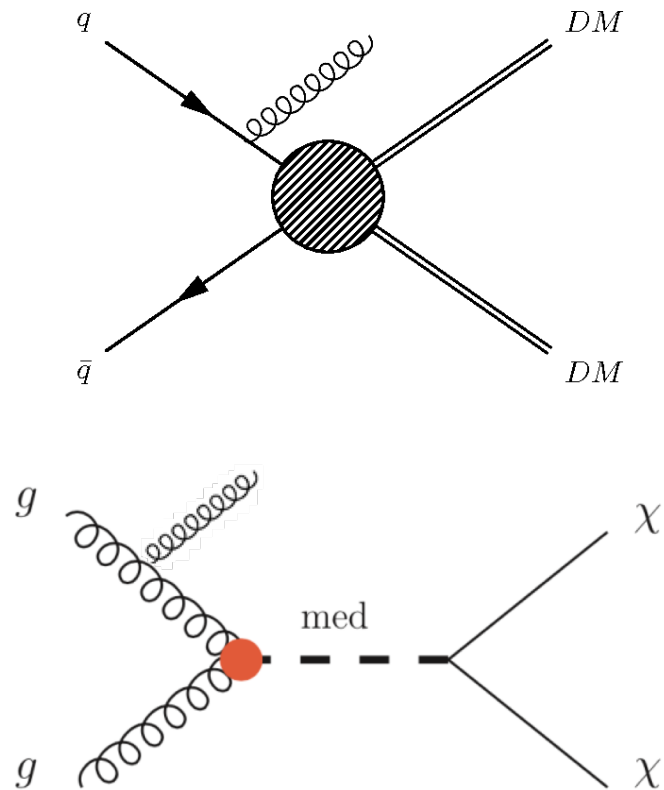
- SM particle X recoils against DM
  - Typically some form of Initial State Radiation (ISR)
- Infer the existence of DM
  - Large amount of missing energy (imbalance)

The monojet

- The most promising channel



# Modeling Dark Matter Production at the LHC



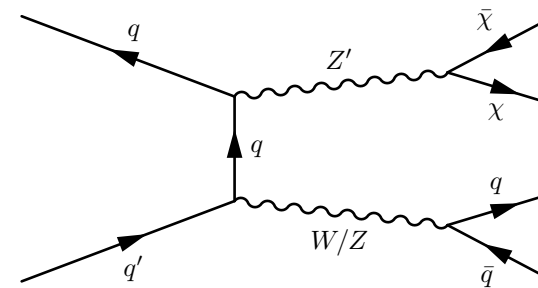
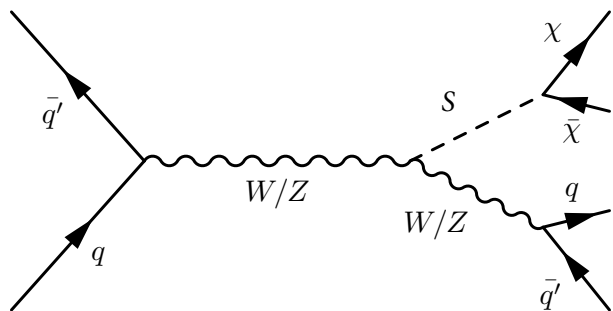
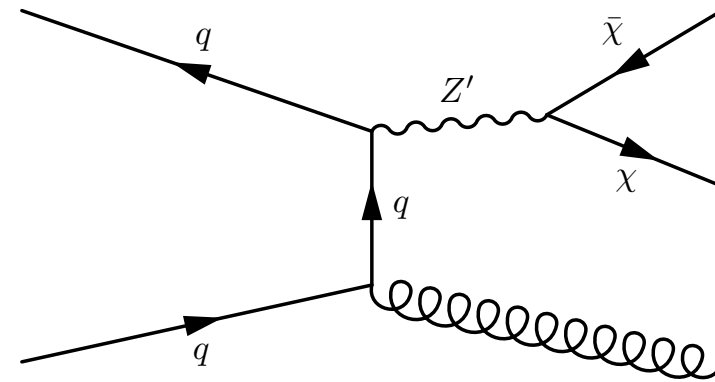
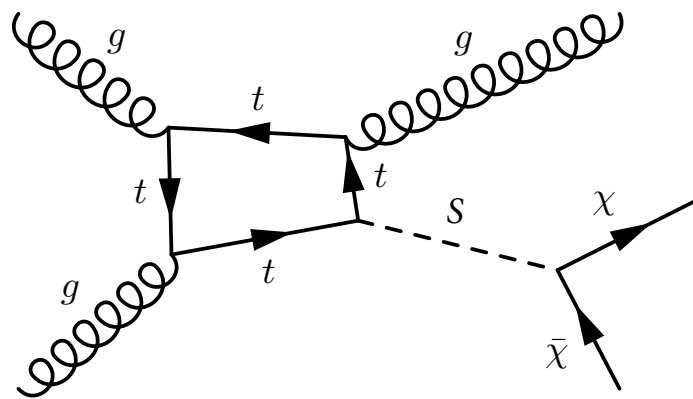
## Model-independent search

- ❑ Contact Interaction
  - Limited at LHC energies
- ❑ Simplified Models
  - DM: pair-produced Dirac fermion
  - Mediator: (vector or scalar), NWA
  - Minimal flavor violation
  - Parameters:  
Coupling structure,  $M_{\text{med}}$ ,  $M_{\text{DM}}$ ,  $g_{\text{sm}}$ ,  $g_{\text{DM}}$

## Benchmark model search

- ❑ SUSY
- ❑ Inert Two-Higgs Doublets Model

# Simp. Model DM Diagrams for Monojet



# Monojet Search – 2016 data (1712.02345)

## Main backgrounds

- ❑  $W \rightarrow \ell\nu + \text{jets}$  (missing lepton)
- ❑  $Z \rightarrow \nu\nu + \text{jets}$

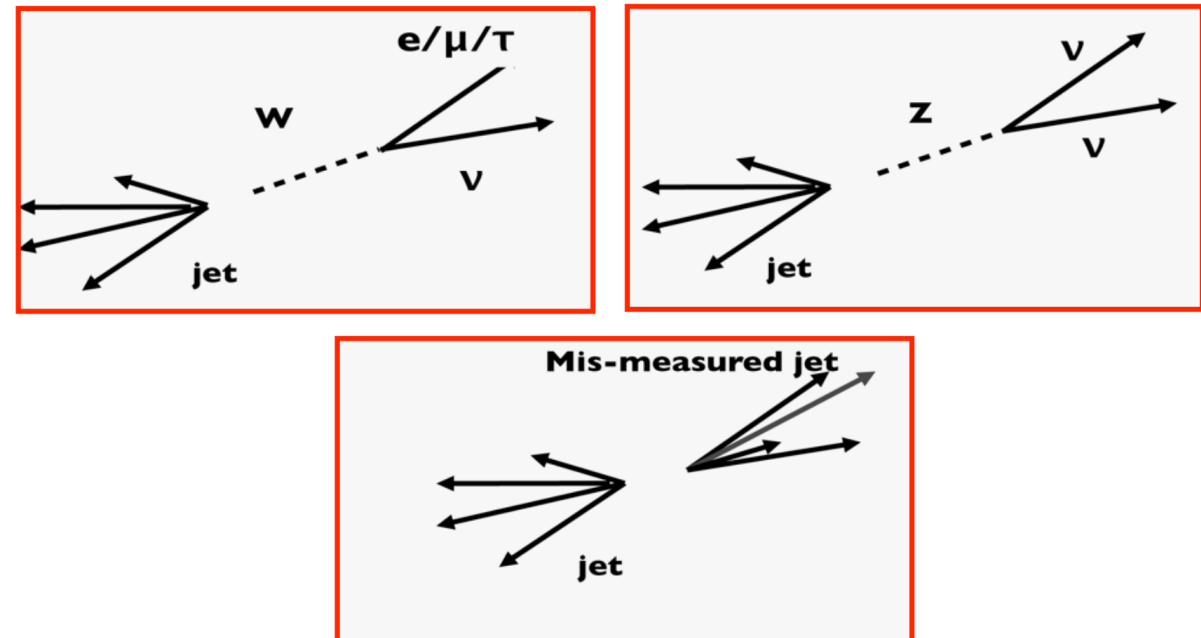
## Subdominant backgrounds

- ❑ QCD multijets
- ❑ Top quark, SM dibosons

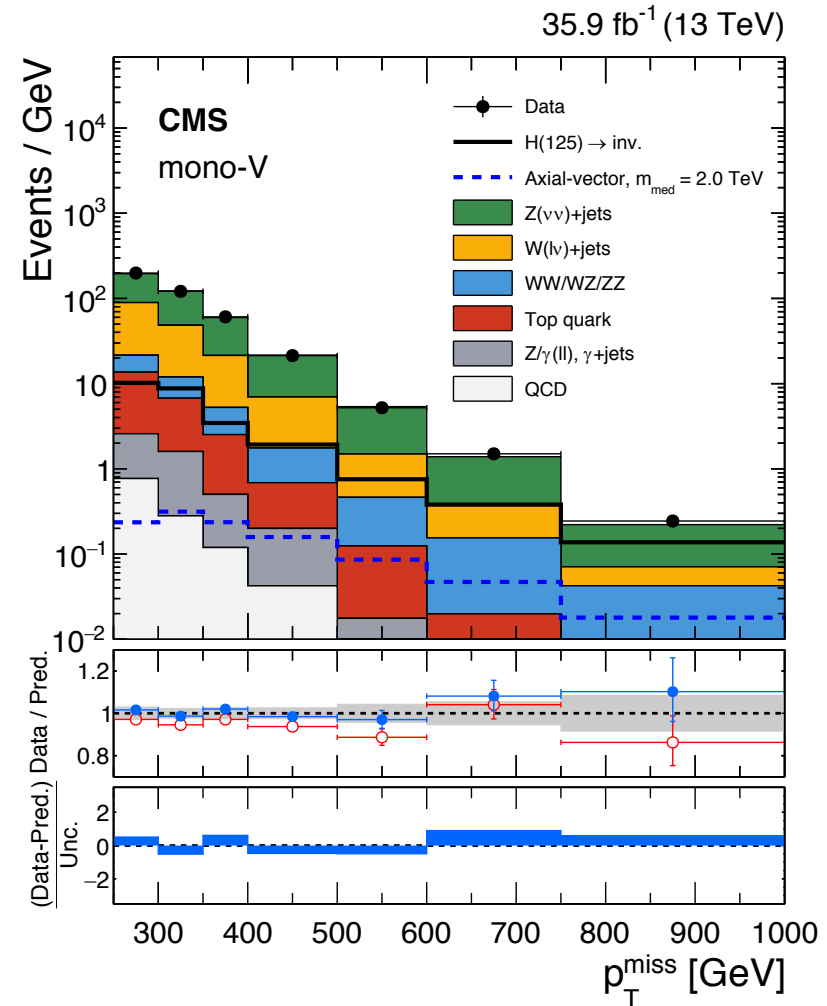
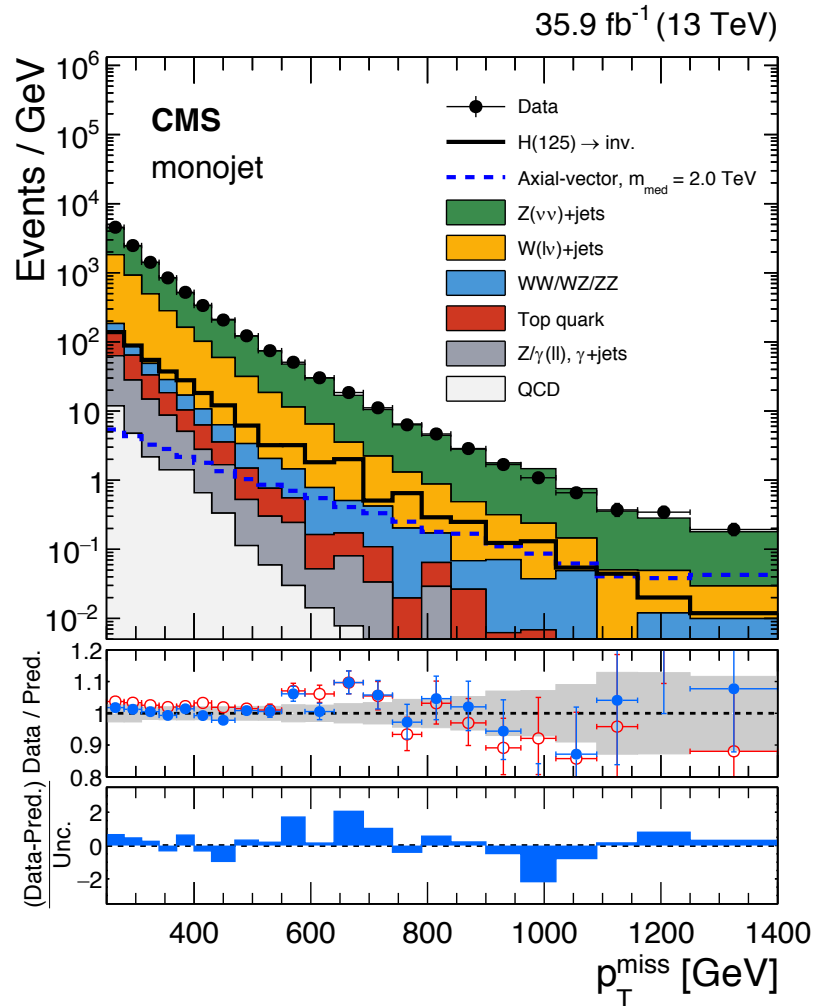
## Estimation

- ❑ Bosons: control regions + transfer factors
  - W / Z / gamma symmetry from SM
  - Binned likelihood simultaneous fit
- ❑ Multijet:  $\Delta\phi$  extrapolation method
- ❑ Top, SM dibosons: simulation

Variable	Selection	Target background
Muon (electron) veto	$p_T > 10 \text{ GeV},  \eta  < 2.4(2.5)$	$Z(\ell\ell)+\text{jets}, W(\ell\nu)+\text{jets}$
$\tau$ lepton veto	$p_T > 18 \text{ GeV},  \eta  < 2.3$	$Z(\ell\ell)+\text{jets}, W(\ell\nu)+\text{jets}$
Photon veto	$p_T > 15 \text{ GeV},  \eta  < 2.5$	$\gamma+\text{jets}$
Bottom jet veto	$\text{CSVv2} < 0.8484, p_T > 15 \text{ GeV},  \eta  < 2.4$	Top quark
$p_T^{\text{miss}}$	$> 250 \text{ GeV}$	QCD, top quark, $Z(\ell\ell)+\text{jets}$
$\Delta\phi(\vec{p}_T^{\text{jet}}, \vec{p}_T^{\text{miss}})$	$> 0.5 \text{ radians}$	QCD
Leading AK4 jet $p_T$ and $\eta$	$> 100 \text{ GeV}$ and $ \eta  < 2.4$	All

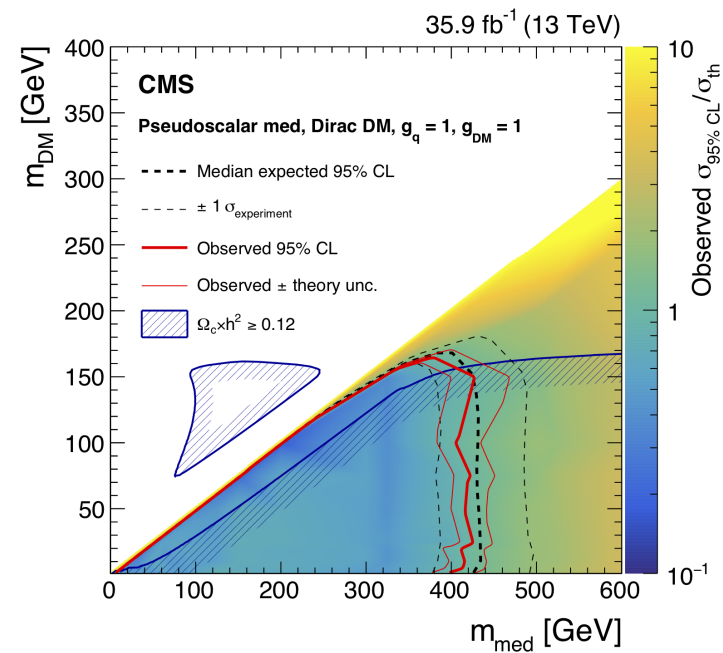
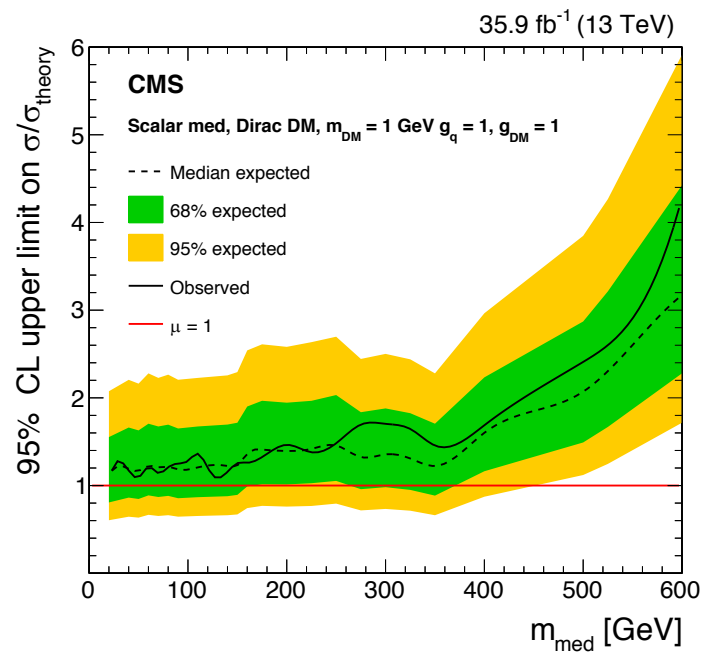
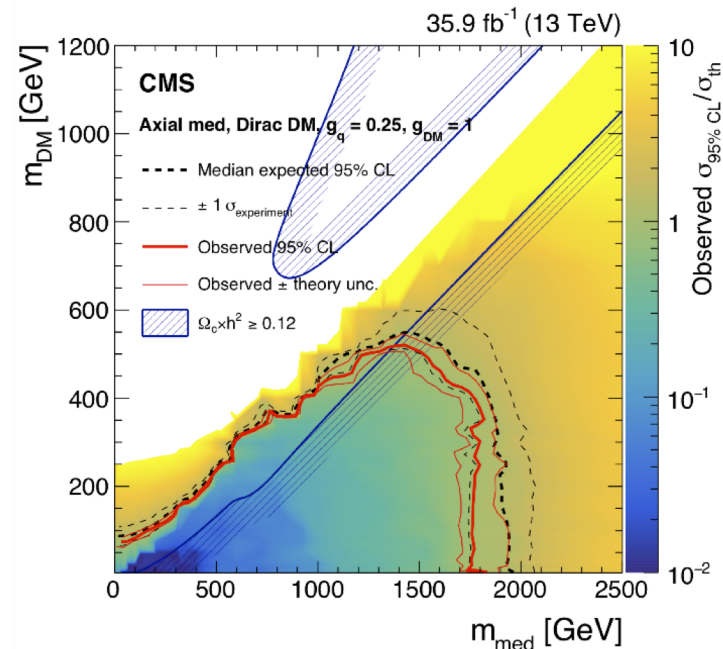
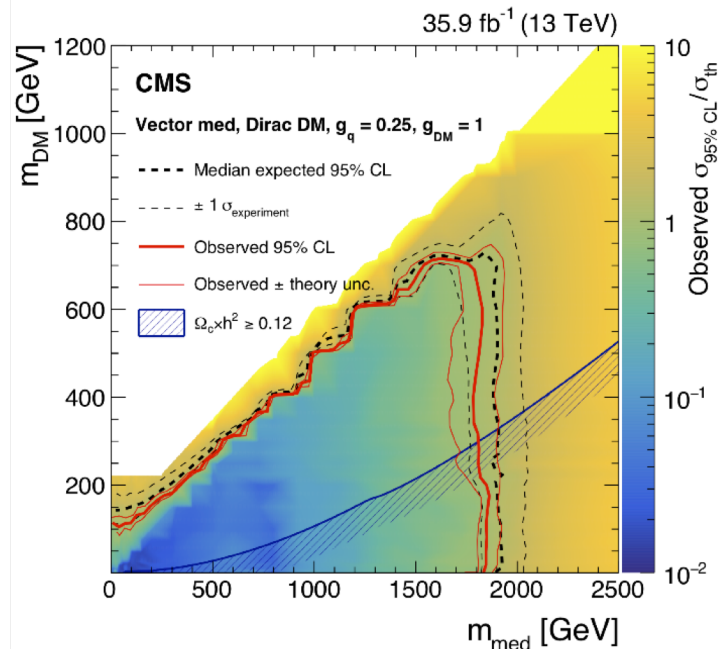


# DM Search in CMS – Data/Background

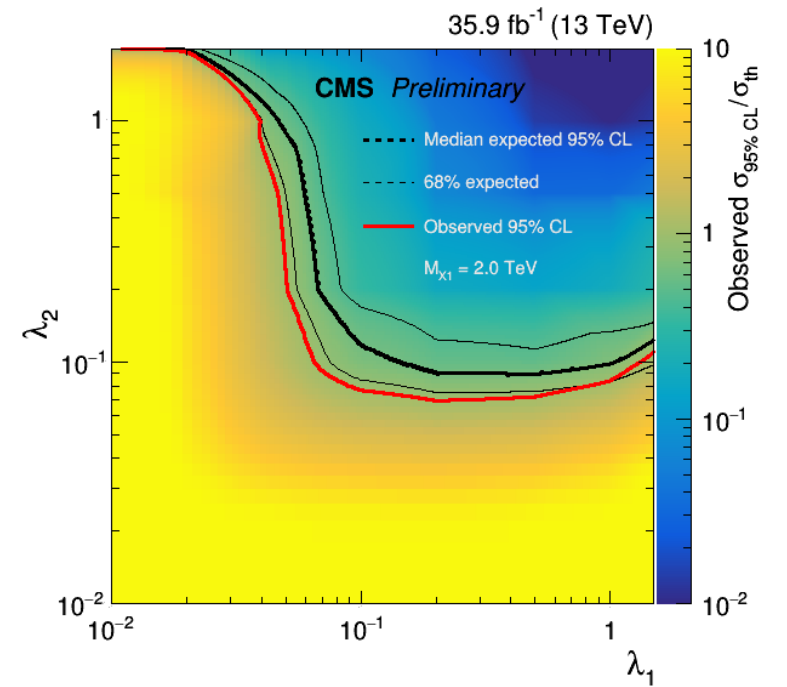
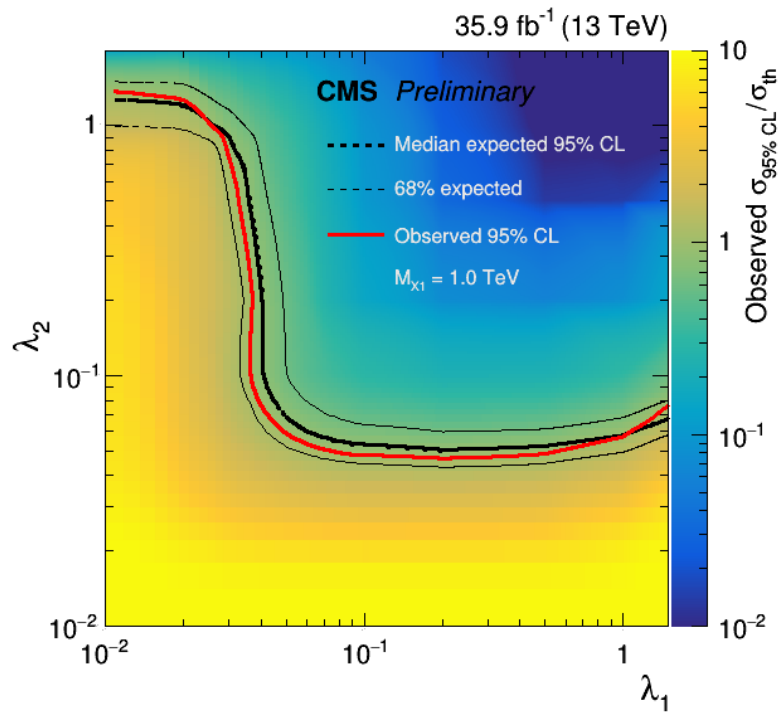
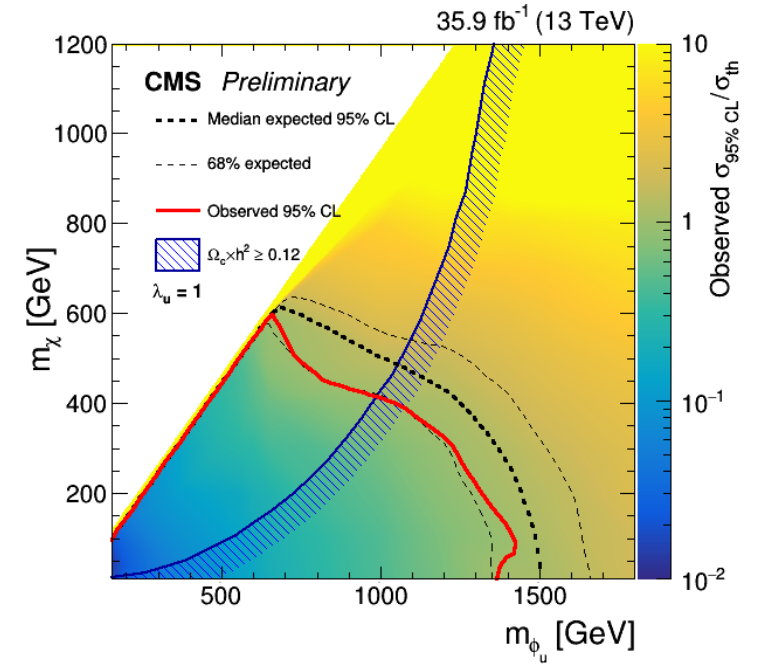
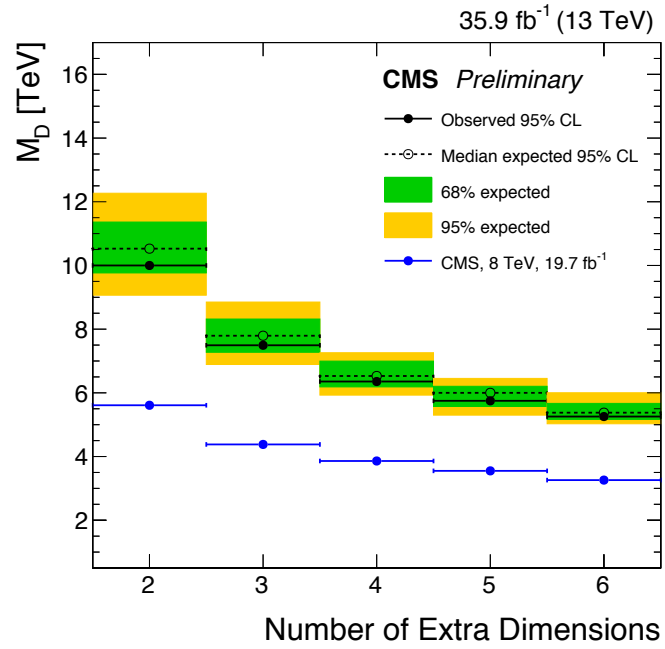


# DM Search in CMS – Results

May 2018



# Alternative Model Interpretation





# Summary and Perspective

---

SPRACE group has large experience on searching for Beyond Standard model physics

Experience in Search for heavy resonances:

- Boosted objects
- Several final states
  - $\tau$  jet
  - b-jet
  - Leptons

Focus now on search for Dark Matter

Monojet channel

- Rich channel to look for Missing  $E_T$  signature
- Looking to include all kinds of jet on the analysis (fat jet, b-jet, gluon jet ...)