WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

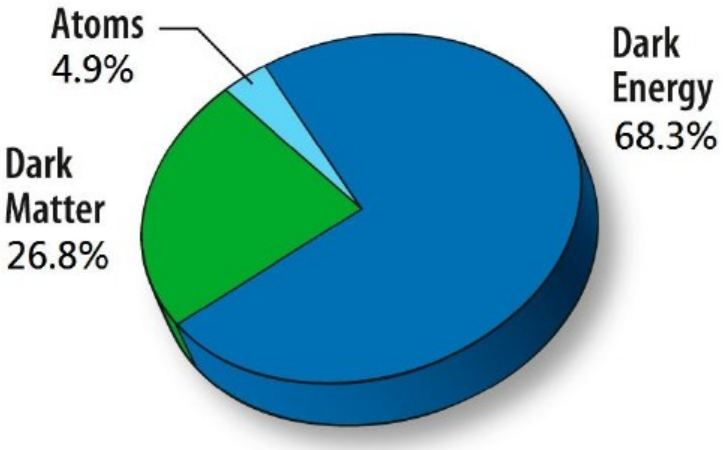
Recent Results on Searches for Dark Matter with CMS

Isabelle De Bruyn (UW-Madison)
for the CMS collaboration

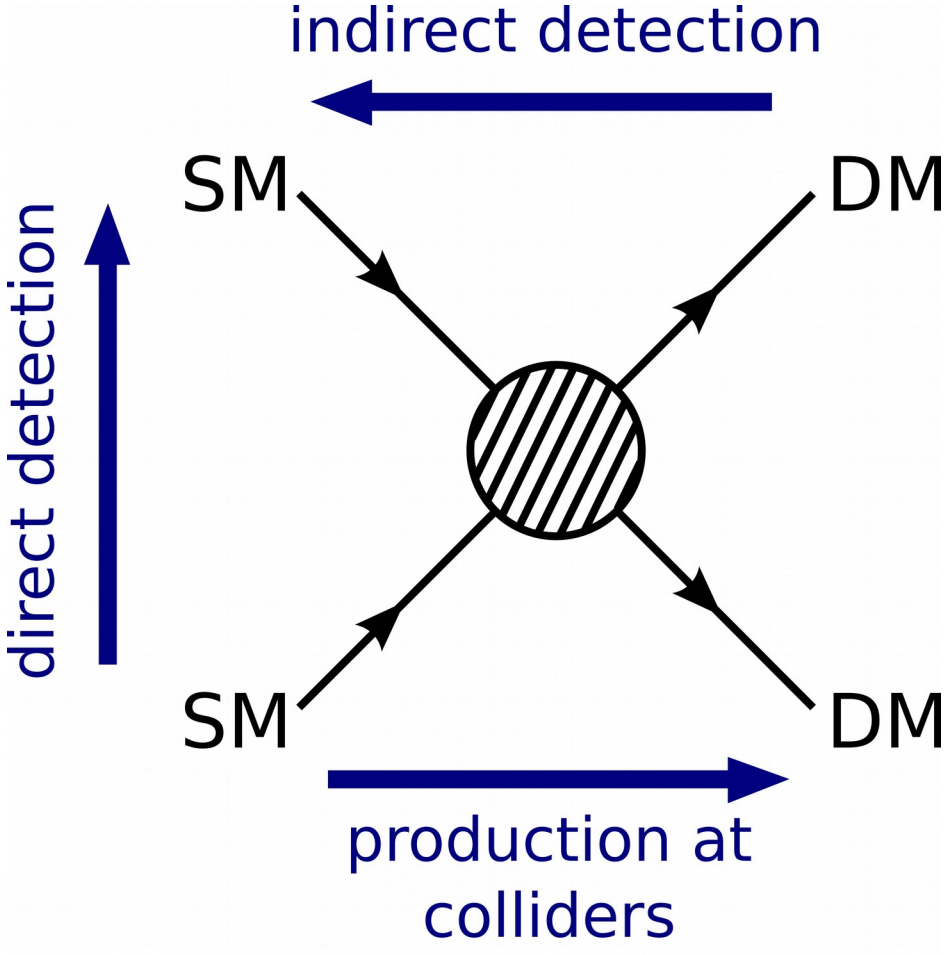
Dark matter

Accumulated substantial evidence that dark matter exists

- bullet cluster
- gravitational lensing
- rotation of galaxies
- ...



Dark matter at colliders



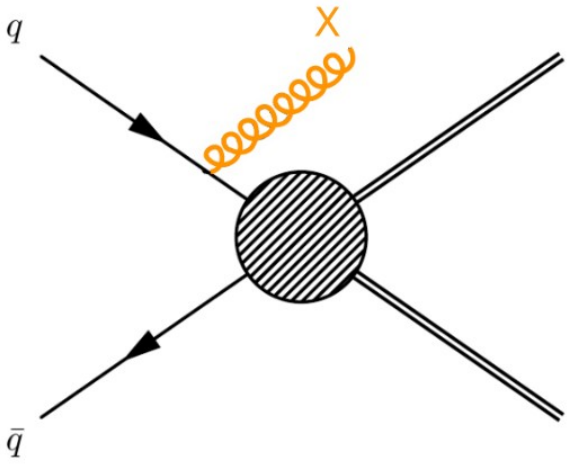
- **Direct detection:** scattering of dark matter particles with nuclei
- **Indirect detection:** particles or radiation produced in the annihilation of dark matter particles
- **Collider searches:** production of DM particles and mediators
  - complement direct and indirect detection
  - many different signatures to investigate

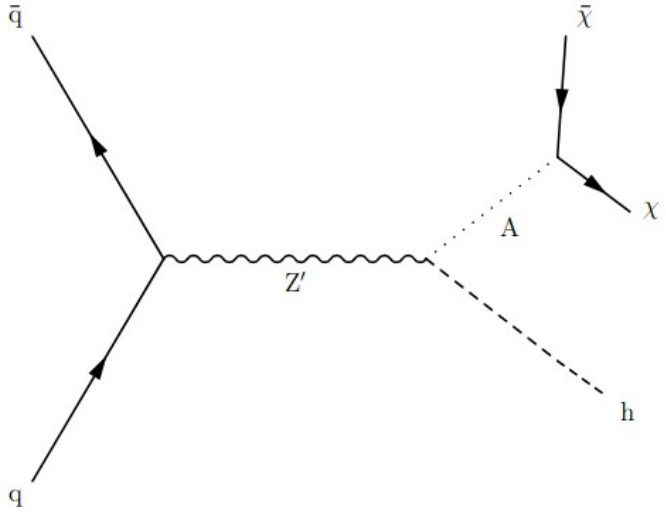
Signatures

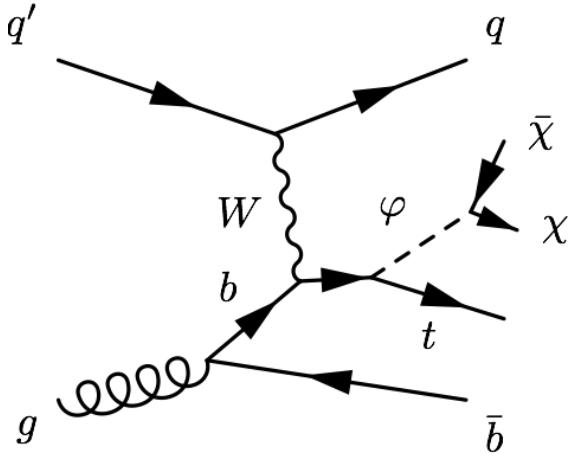
Dark matter particles (χ) cross the detector without leaving a trace
→ missing transverse energy

Trigger on events using recoiling Standard Model particles (X)

=> **mono-X signature**

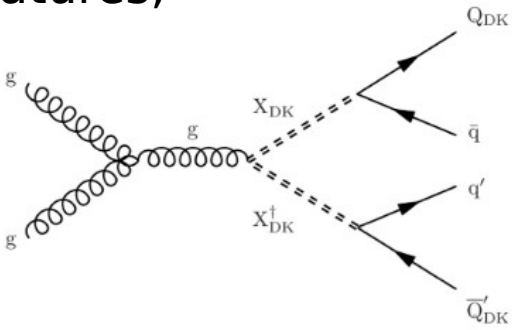


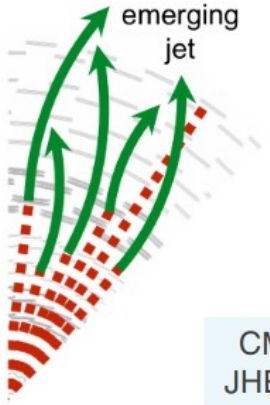




More searches

- But sometimes more exotic signatures, e.g. from **long-lived particles**:





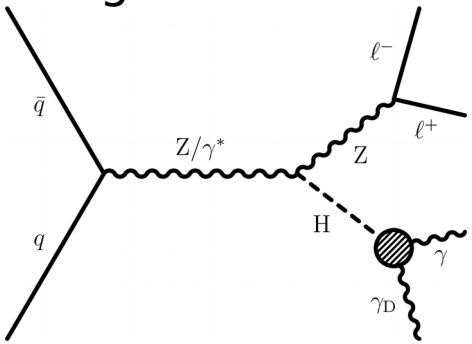
CMS-EXO-18-001
JHEP 02 (2019) 179

→ CMS talk by A. Hart (Friday)

- Looking for **new resonances**, e.g. dijet searches in invariant mass range from 10 GeV to almost 8 TeV, requiring different trigger strategies

→ CMS talk by D.Beghin (Thursday)

- Focusing on models with a **dark sector**



Dark photons (γ_D) in ZH decays:

First upper limits on final states with undetected dark photons using Higgs boson decays at the LHC!

→ CMS talk by V. Sharma (Friday)

CMS mono-X searches

SM particle	Publication	Integrated luminosity
Higgs	CMS-PAS-EXO-18-011	36 fb-1
Top quark(s)	CMS-EXO-18-010, JHEP 03 (2019) 141 CMS-EXO-16-051, JHEP 06 (2018) 027	
Photon	CMS-EXO-16-053, JHEP 02 (2019) 074	
Jets or hadronic Z/W	CMS-EXO-16-048, Phys Rev D 97 (2018) 092005	

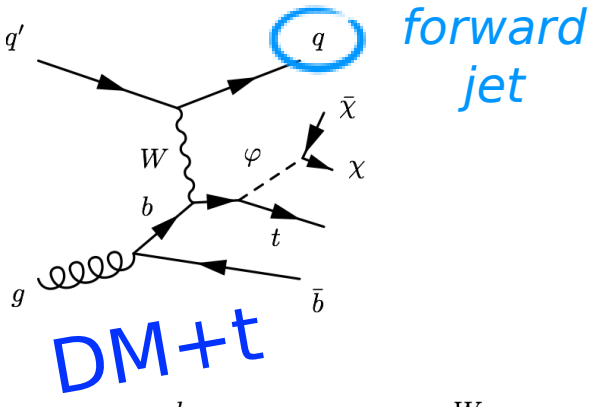
In this talk, focusing on 2 recent result:

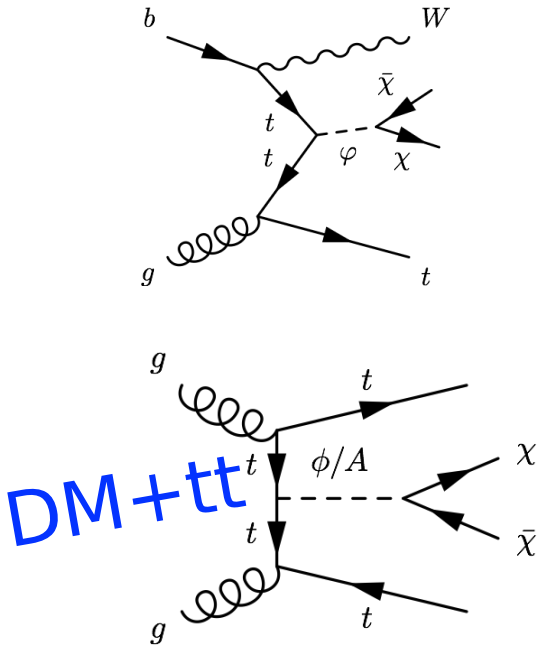
Search for dark matter produced in association with a single top quark or a top quark pair in proton-protoncollisions at √s = 13 TeV CMS-EXO-18-010

Search for dark matter particles produced in association with the Higgs boson in proton-proton collisions at √s = 13 TeV CMS-PAS-EXO-18-011

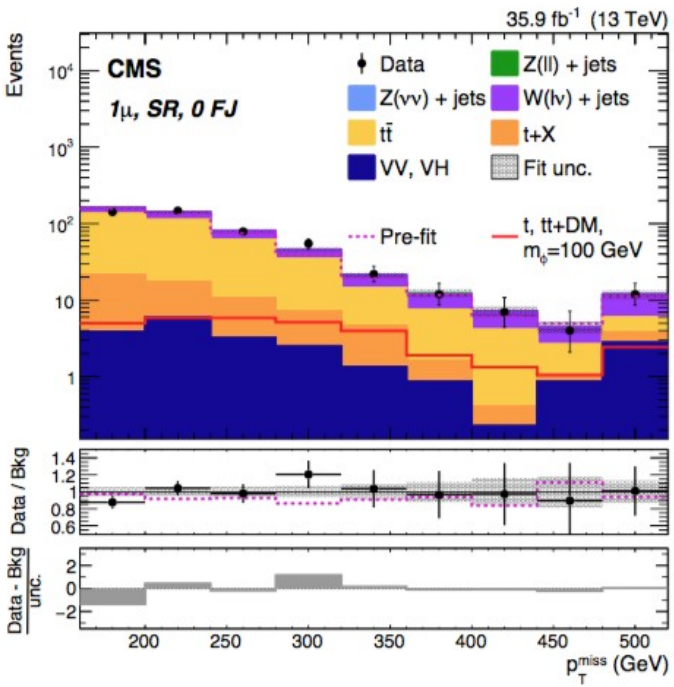
CMS-EXO-18-010
JHEP 03 (2019) 141

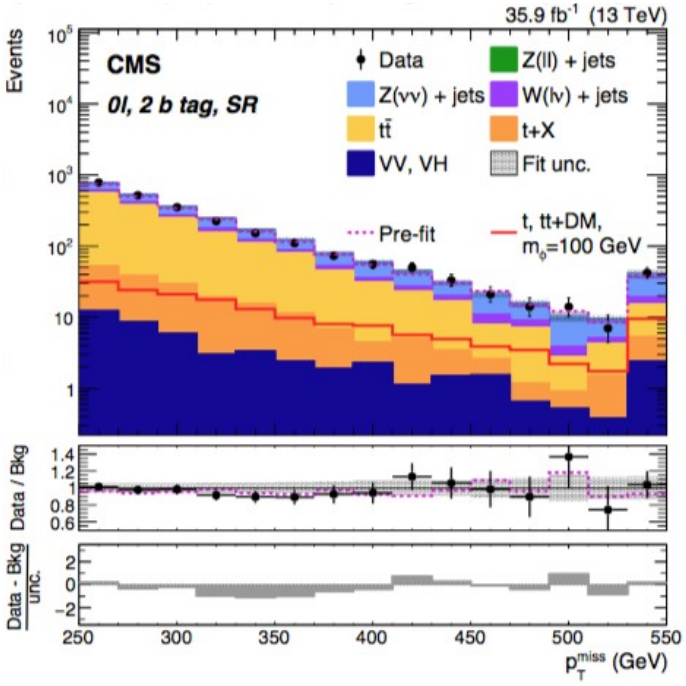
DM + t(tt) search





- Events categorized based on #leptons, # b-jets and #forward jets
- Main backgrounds: $t\bar{t}$, V+jets
- Combined fit of p_T^{miss} distribution in signal and control region

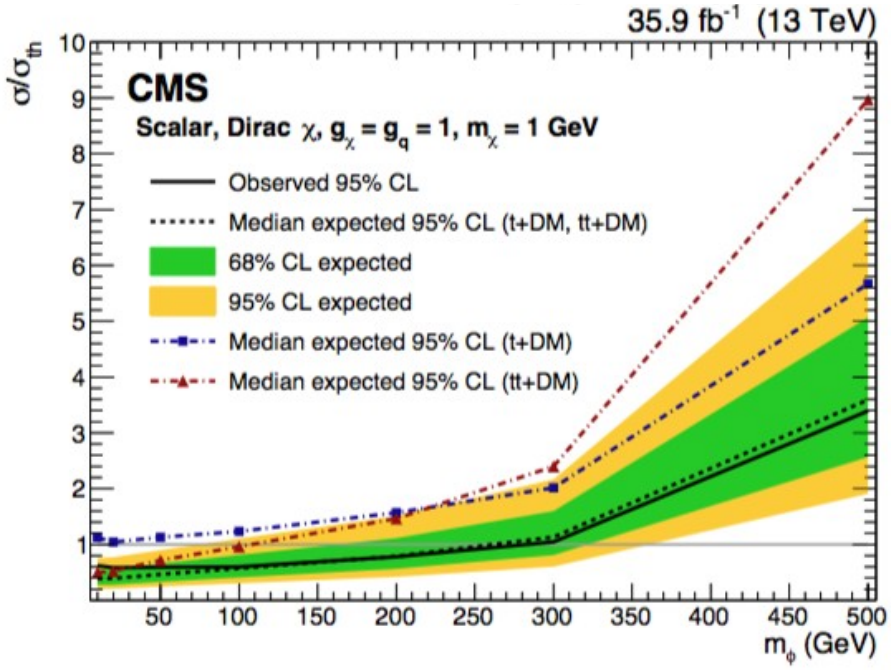


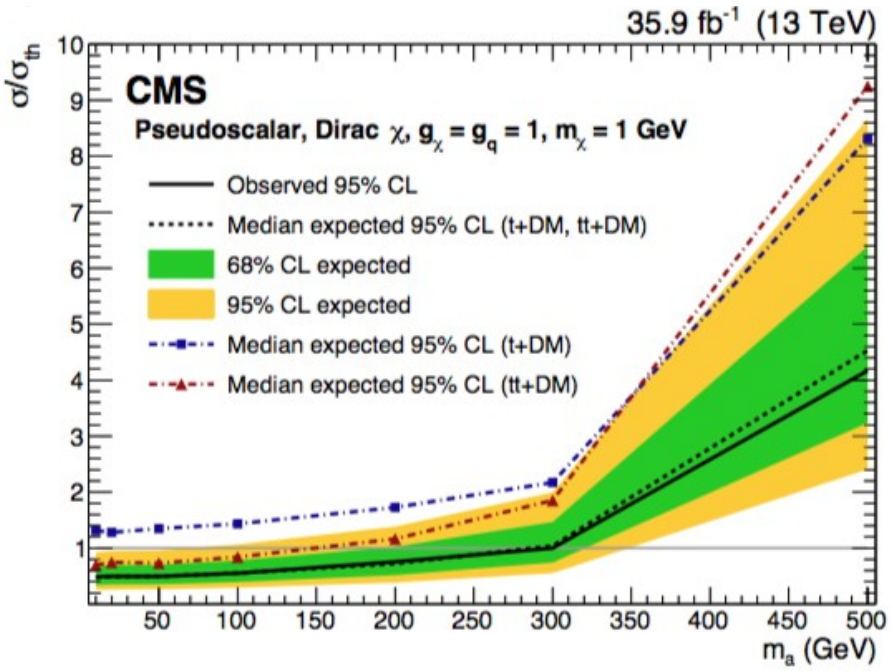


CMS-EXO-18-010
JHEP 03 (2019) 141

DM + t(tt) search: results

Interpretation in terms of dark matter model with Dirac dark matter upper limits at 95% CL on xsec



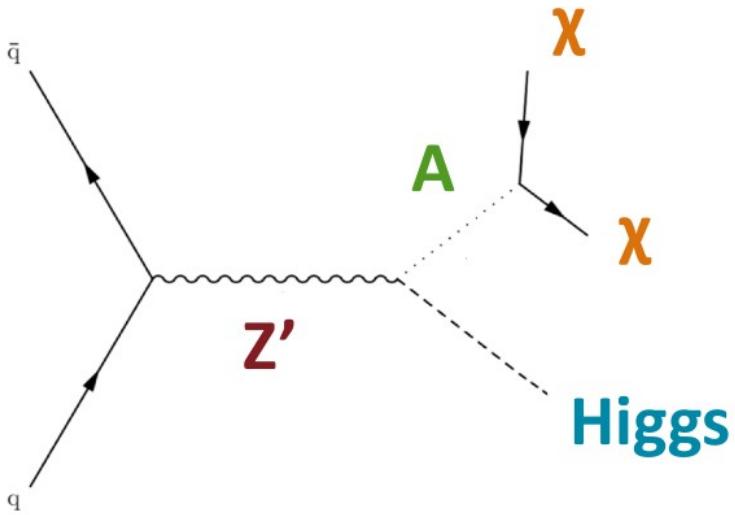


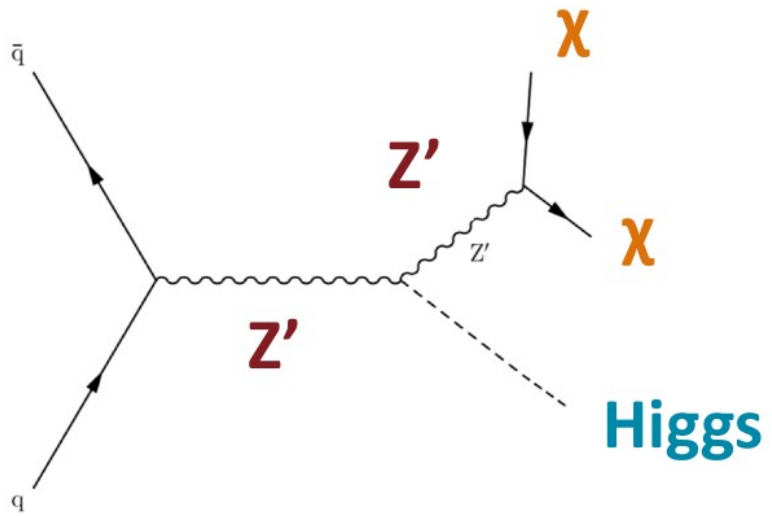
First search at LHC for DM+t or DM+tt in scalar/pseudoscalar interactions

Up to **x2 limits improvement** at high mediator masses wrt previous DM+tt results

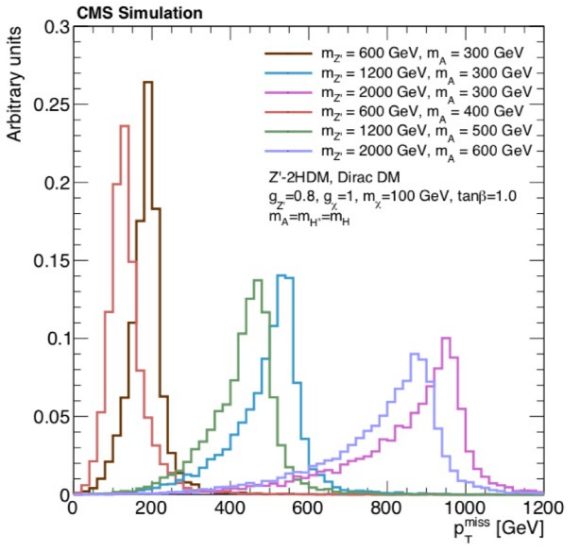
http://inspirehep.net/record/1722691
CMS-PAS-EXO-18-011

Search for mono-Higgs

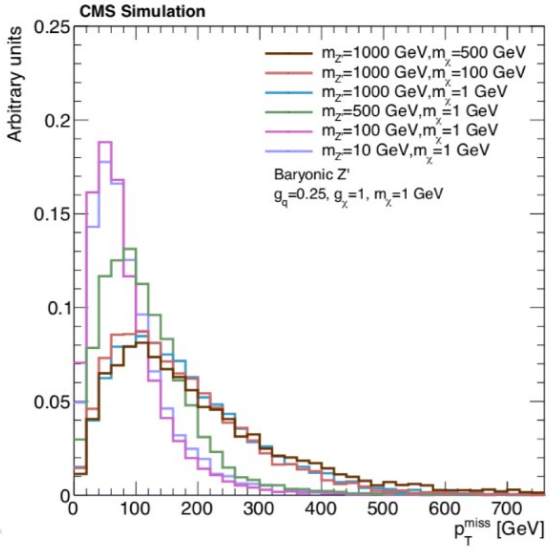




Z’-2HDM: type-II two Higgs doublet model extended by $U(1)_{Z'}$



Baryonic Z’: Extended SM with $U(1)_B$ with gauge boson Z’



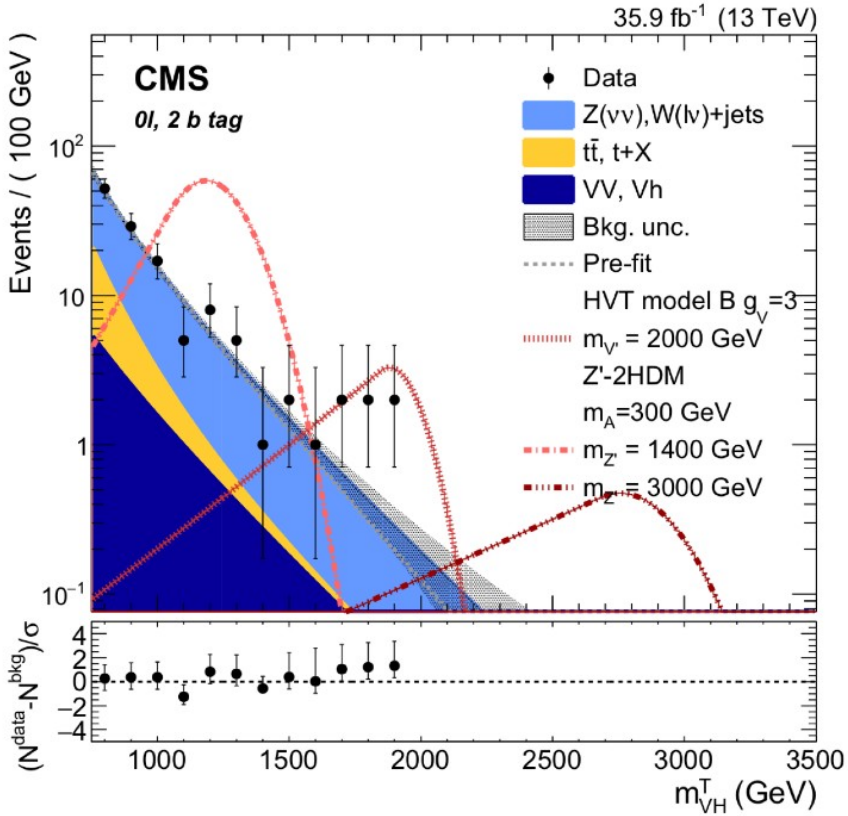
CMS-B2G-17-004
JHEP 11 (2018) 172

Decay channels: h → bb

- Most sensitive channel for most $m_{Z'}$ masses
- 2 different analyses using the 2 different models
- Main backgrounds: $t\bar{t}$, V+jets

Z'-2HDM analysis:

- large-radius jet, with 1 or 2 b-tagged subjets
- Higgs candidate with mass in 105-135 GeV range
- background model is fit to data in 2 sidebands of Higgs jet mass distribution
- look for bump in resonance candidate transverse mass



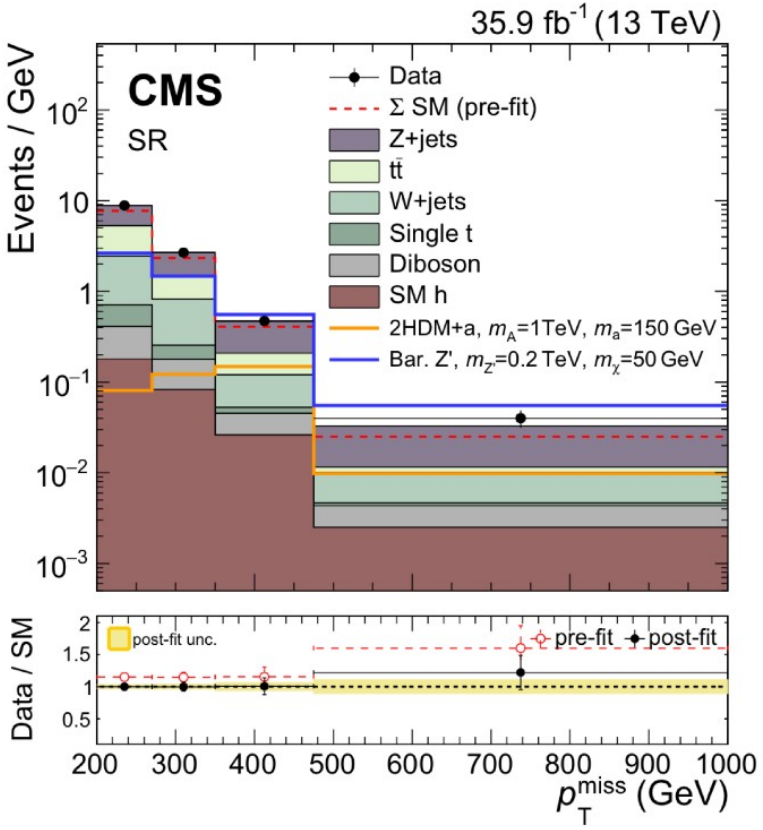
CMS-EXO-16-050
Eur. Phys. J. C79 (2019) 280

Decay channels: h → bb

- Most sensitive channel for most $m_{Z'}$ masses
- 2 different analyses using the 2 different models
- Main backgrounds: $t\bar{t}$, V+jets

Baryonic Z' analysis:

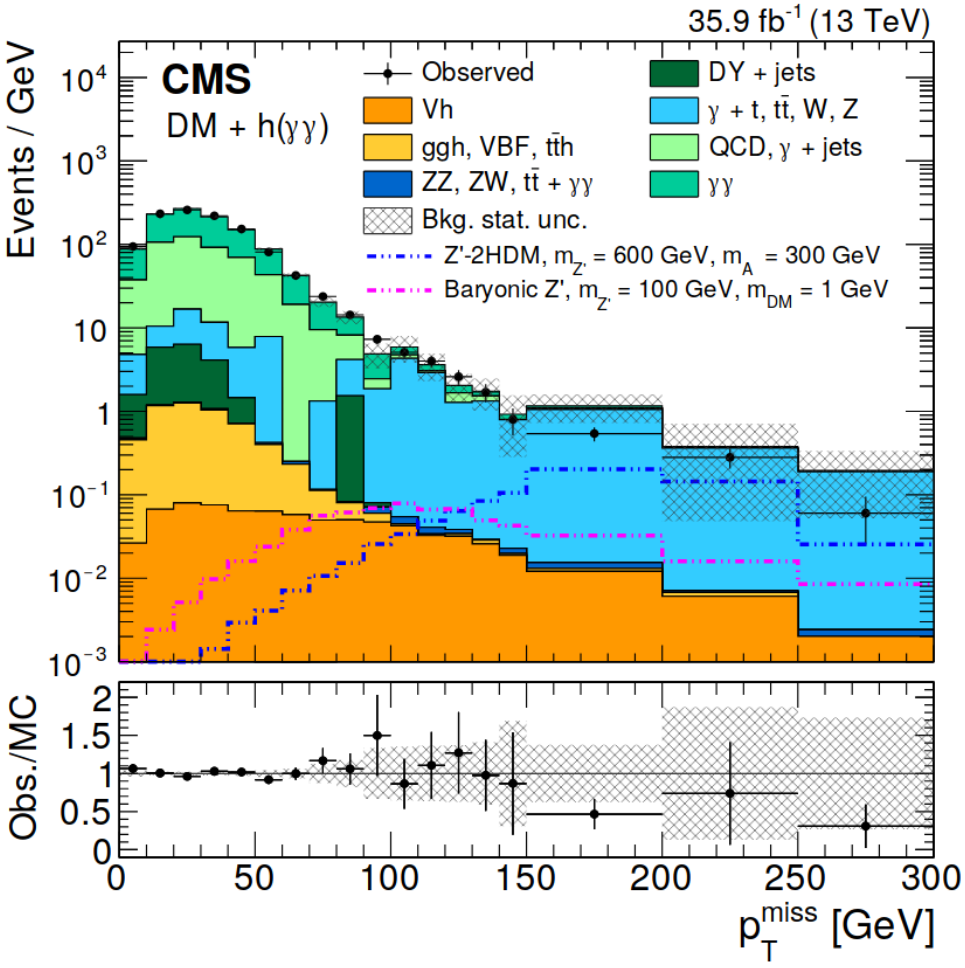
- 2 large-radius jets
- MVA double b-tagging algorithm
- Higgs candidate with mass in 100-150 GeV range
- simultaneous fit of p_T^{miss} in signal region and dedicated control regions



CMS-EXO-16-055
JHEP 09 (2018) 046

Decay channels: h → γγ

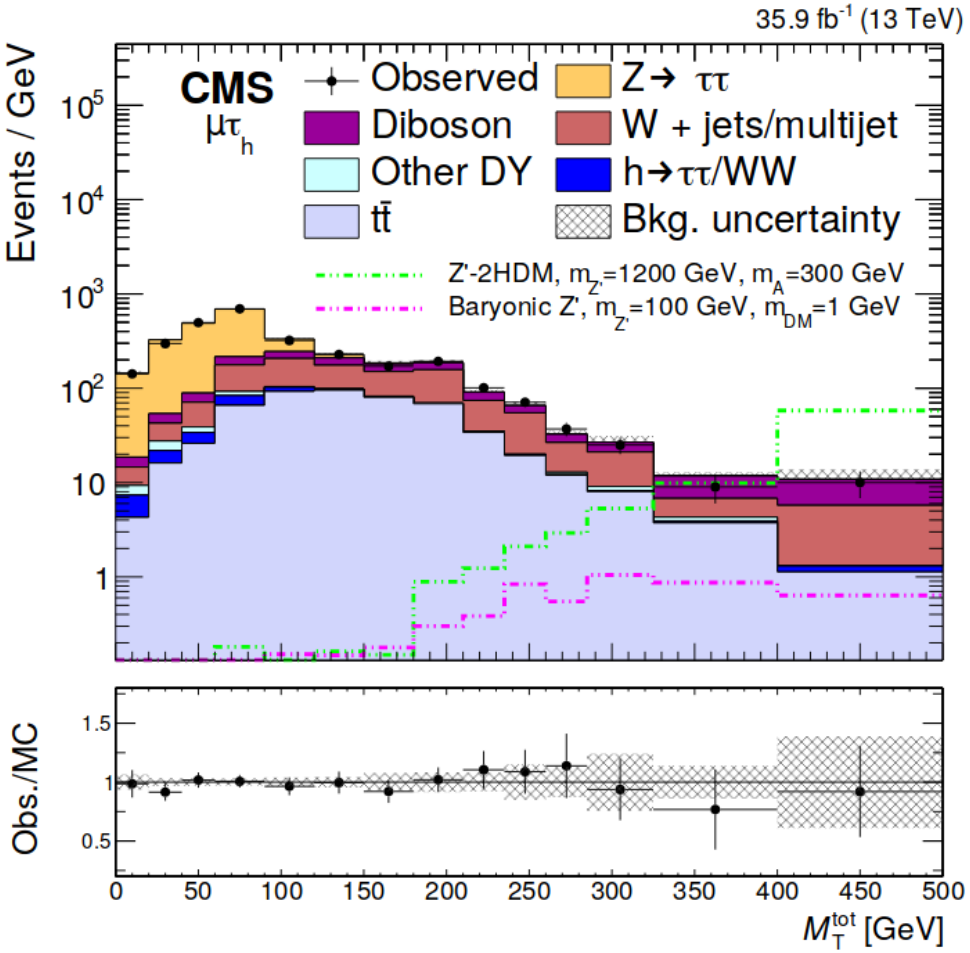
- smaller branching fraction, but higher precision in reconstructed invariant mass
- can probe scenarios with lower missing energy
  => complementary to
  h → bb channel
- photon isolation not applied to photons withing ΔR < 0.3 of each other (boosted Higgs)
- low p_T^{miss} region optimized for baryonic Z' and high p_T^{miss} region for both models
- fit in diphoton invariant mass to extract signal yield



CMS-EXO-16-055
JHEP 09 (2018) 046

Decay channels: h → ττ

- hadronic and semi-leptonic channels ($\mu\tau_h$, $e\tau_h$, $\tau_h\tau_h$)
- smaller branching fraction but smaller background
- can probe scenarios with lower missing energy
  => complementary to
  h → bb channel
- signal extracted by simultaneous fit to transverse mass of missing energy and 2 τ leptons in signal and control regions



Decay channels: h → WW

First time mono-h search performed in this decay channel!

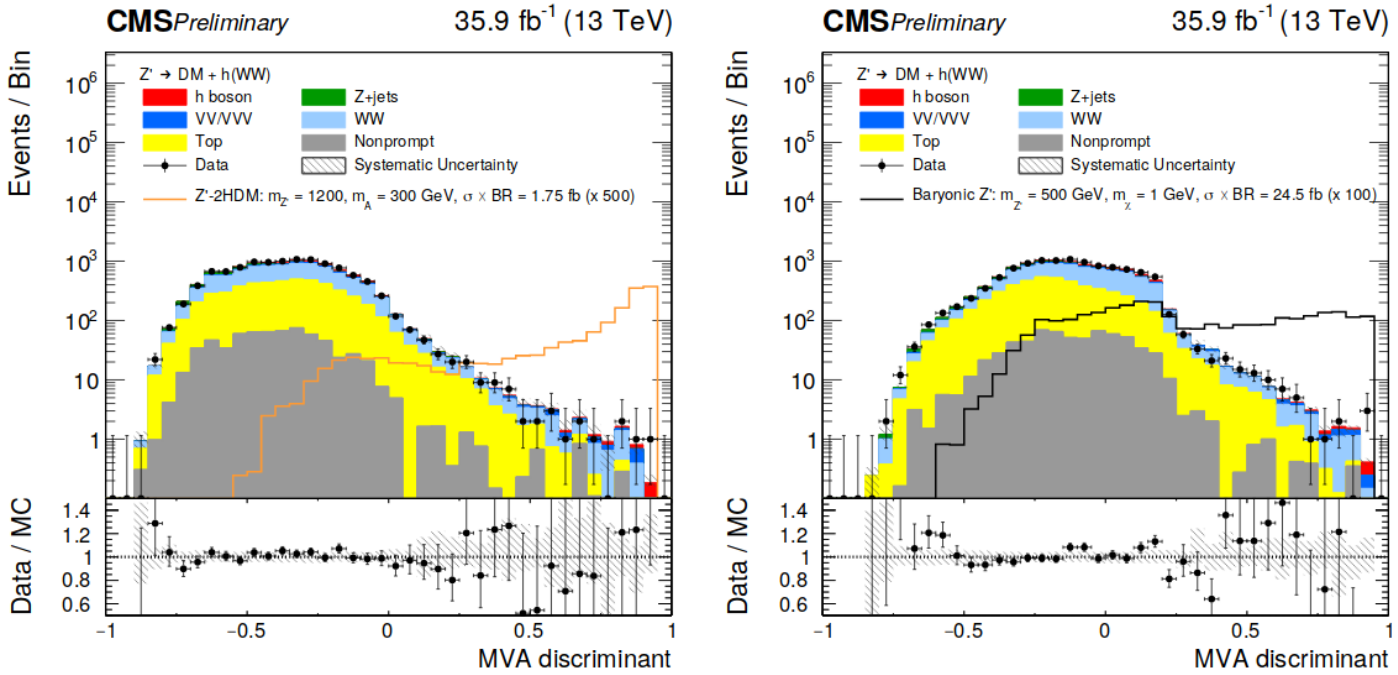
Uses fully leptonic opposite-sign different-flavor final stat (eμ)

→ minimally affected by background (e.g. Z boson)

Main backgrounds: $t\bar{t}$, nonresonant WW

No kinematic reconstruction of Higgs possible (ν)

→ BDT, trained for each signal model



Decay channels: h → ZZ

First time mono-h search performed in this decay channel!

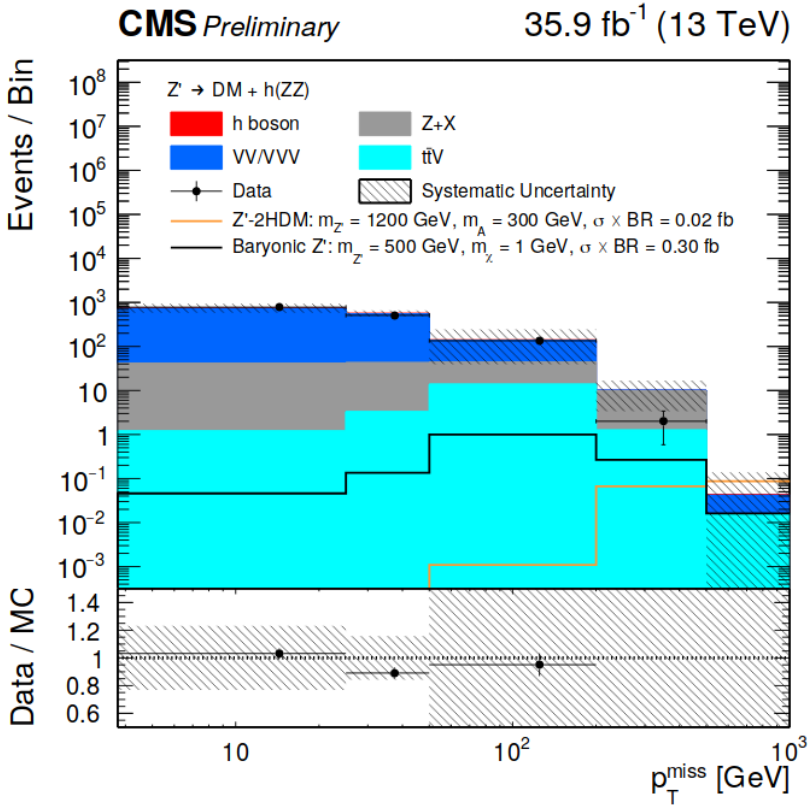
All-leptonic final states (4μ, 4e, 2μ2e)

- easily reducible backgrounds
- fully reconstructable Higgs
- good mass resolution,
- but small branching fraction

Main backgrounds: SM Higgs (Vh),
nonresonant ZZ

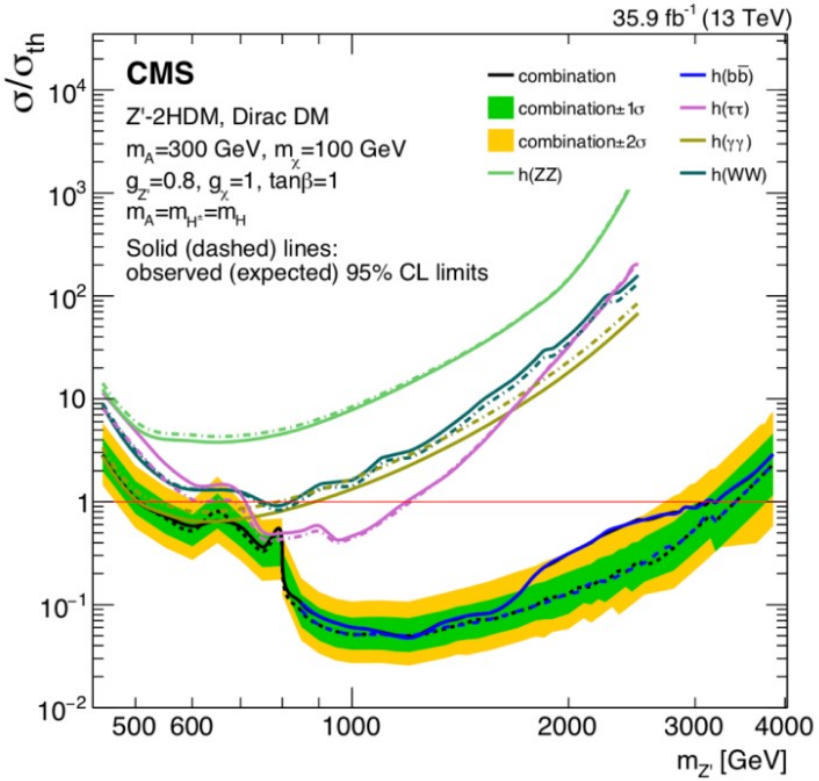
Z+X background from non-prompt leptons inside jets:

misidentification rate estimated from data

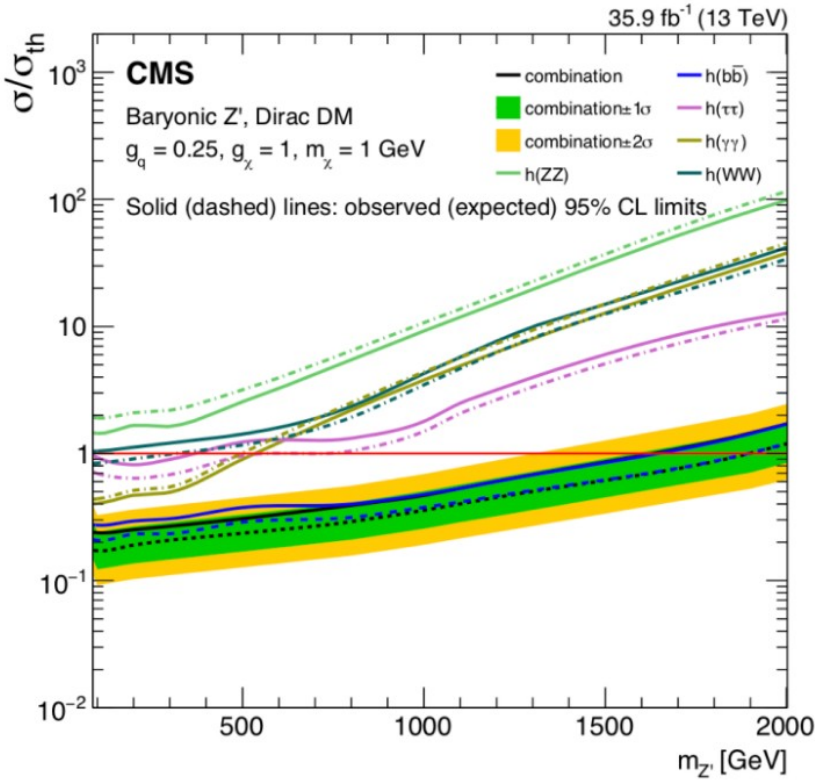


Results

Exclude $500 < m_{Z'} < 3200$ GeV for **Z'-2HDM** at $m_A = 300$ GeV at 95% CL



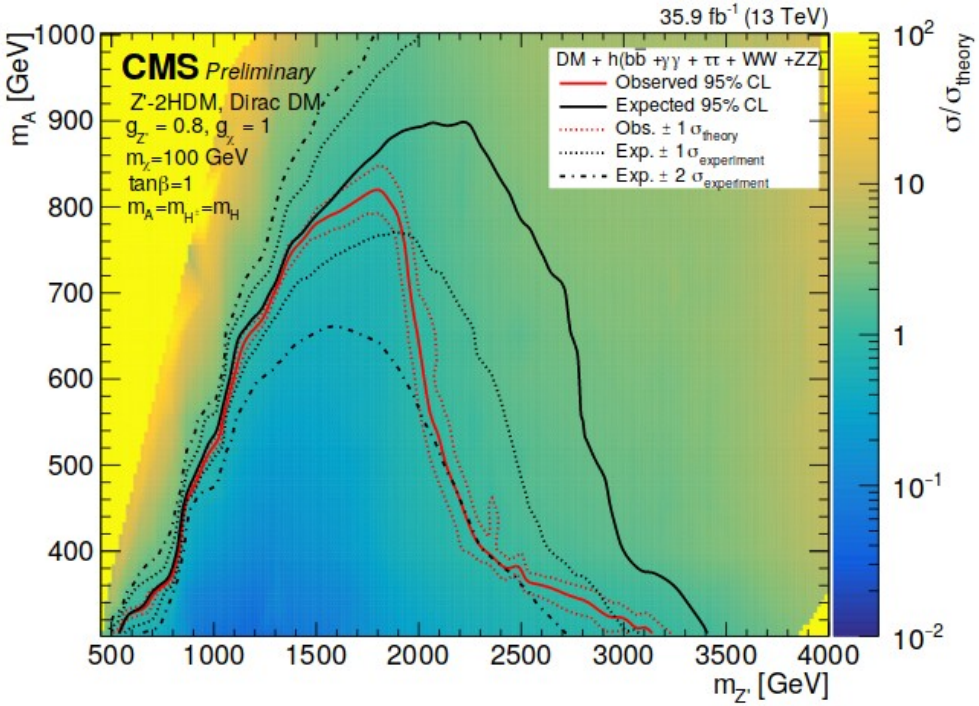
Exclude $100 < m_{Z'} < 1600$ GeV for **Baryonic Z'** at $m_\chi = 1$ GeV at 95% CL

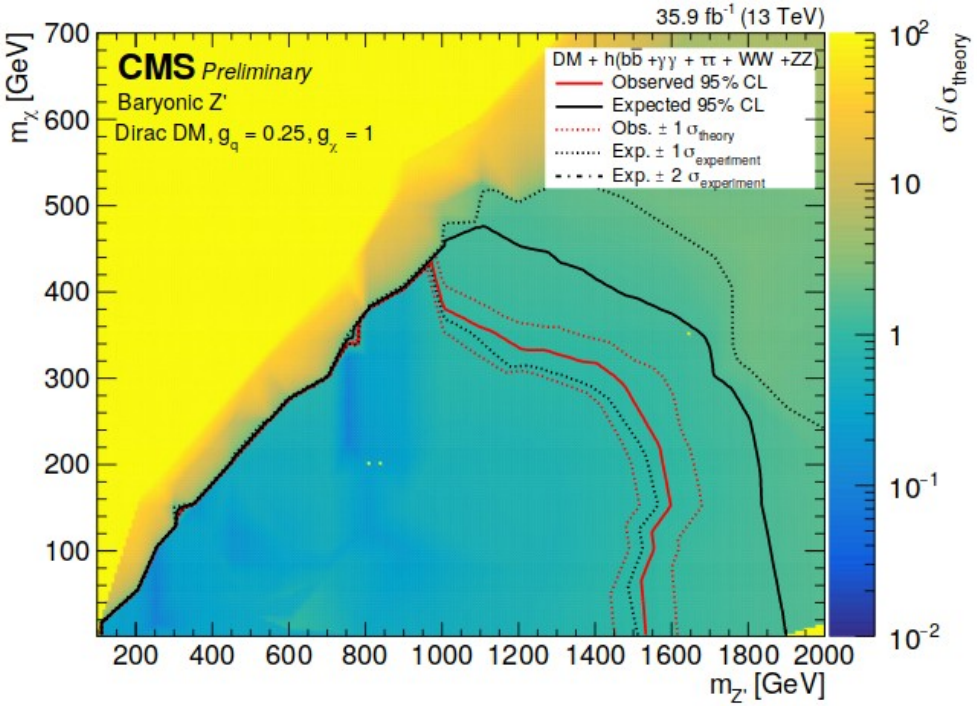


h → bb is main decay channel
ττ and γγ channels contribute at low mass

Results

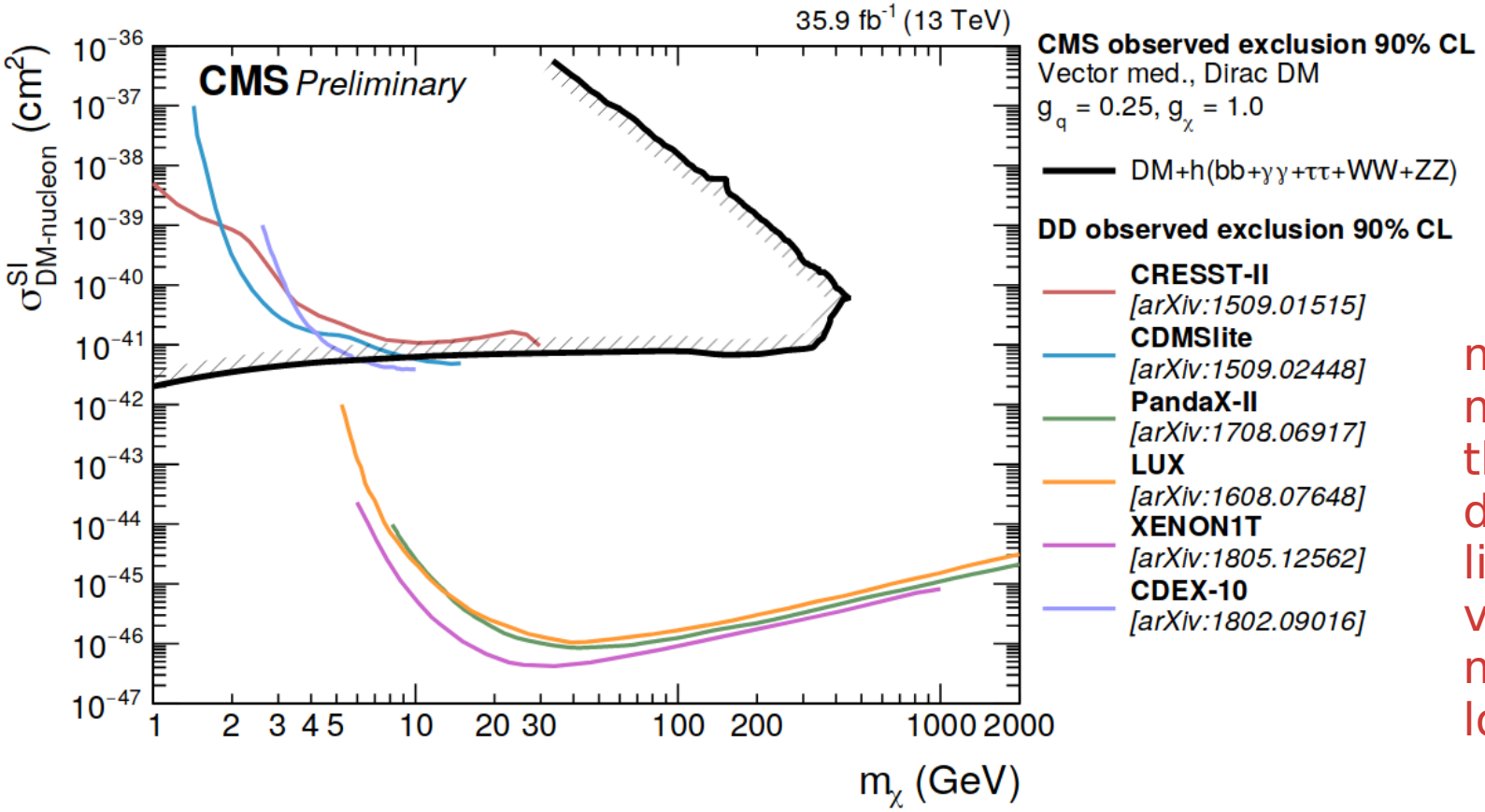
95% CL exclusion contours on σ/σ_{th} in $m_{Z'}$ - m_A (Z'-2HDM) and $m_{Z'}$ - m_χ (baryonic Z') plane





Comparison with direct detection

Reinterpretation of baryonic Z' model in terms of 90% CL limits on spin-independent cross section for dark matter-nucleon scattering (following LHC DM working group recomendations)



mono-H result more stringent than direct detection limits for vector mediator at low masses

Conclusions

CMS is continuing to perform dark matter searches using many different signatures and analysis methods

Mono-Higgs Combination

- first combination of 5 Higgs decay channels in mono-H
- first time mono-H is performed in h → WW and h → ZZ channels
- stronger limits on vector mediator than direct detection for low dark matter masses

Only 25% of Run 2 data included in the shown results

Many more full Run 2 results are coming – stay tuned!