Recent Results on Searches for Dark Matter with CMS

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Dark matter

Accumulated substantial evidence that dark matter exists

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

[Pie chart showing composition of the universe: Dark Energy 68.3%, Dark Matter 26.8%, Atoms 4.9%]
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 ($\chi$) 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:

  \[ \gamma \]

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

  \[ \rightarrow \text{CMS talk by A. Hart (Friday)} \]

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

  \[ \rightarrow \text{CMS talk by D. Beghin (Thursday)} \]

- Focusing on models with a dark sector

  Dark photons (\(\gamma_D\)) in ZH decays:

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

  \[ \rightarrow \text{CMS talk by V. Sharma (Friday)} \]
CMS mono-X searches

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<td>Top quark(s)</td>
<td>CMS-EXO-18-010, JHEP 03 (2019) 141</td>
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<td>CMS-EXO-16-051, JHEP 06 (2018) 027</td>
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<td>Photon</td>
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In this talk, focusing on 2 recent results:

*Search for dark matter produced in association with a single top quark or a top quark pair in proton-proton collisions at \( \sqrt{s} = 13 \) TeV*  CMS-EXO-18-010

*Search for dark matter particles produced in association with the Higgs boson in proton-proton collisions at \( \sqrt{s} = 13 \) TeV*  CMS-PAS-EXO-18-011
DM + t(tt) search

- Events categorized based on #leptons, # b-jets and #forward jets
- Main backgrounds: tt, V+jets
- Combined fit of $p_T^{\text{miss}}$ distribution in signal and control region
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
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 $Z'$
Decay channels: $h \rightarrow bb$

- 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
Decay channels: $h \rightarrow bb$

- 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
Decay channels: $h \rightarrow \gamma\gamma$

- smaller branching fraction, but higher precision in reconstructed invariant mass
- can probe scenarios with lower missing energy
  => complementary to $h \rightarrow bb$ channel
- photon isolation not applied to photons within $\Delta R < 0.3$ 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
Decay channels: $h \rightarrow \tau\tau$

- 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 $h \rightarrow bb$ channel

- signal extracted by simultaneous fit to transverse mass of missing energy and 2 $\tau$ leptons in signal and control regions
**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: tt, nonresonant WW

No kinematic reconstruction of Higgs possible (ν)
→ BDT, trained for each signal model
Decay channels: $h \to ZZ$

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

All-leptonic final states ($4\mu$, $4e$, $2\mu2e$)
- 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

h → bb is main decay channel
ττ and γγ channels contribute at low mass
95% CL exclusion contours on $\sigma/\sigma_{th}$ in $m_{Z'} - m_A$ (Z'-2HDM) and $m_{Z'} - m_\chi$ (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 recommendations)

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 $h \rightarrow WW$ and $h \rightarrow ZZ$ 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!