Search for Dark Matter at CMS

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Search for Dark Matter at CMS

Outline

- introduction

- CMS searches, all with full 20/fb dataset
  - monojet: CMS-PAS-EXO-12-048
  - monophoton: CMS-PAS-EXO-12-047
  - monolepton: CMS-PAS-EXO-13-004
  - monotop: CMS-PAS-B2G-12-022
  - ditop+MET: CMS-PAS-B2G-13-004
  - see: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

- summary and outlook
Introduction

Dark Matter: evidence for BSM physics

• known to us for over 80 years through gravitational effects
  ▪ now lots of evidence from very diverse scales and effects
• still we know very little else
  ▪ particle, electrically neutral, not short-lived, not baryonic, not hot

• as a result, the theoretical landscape is huge
• three complementary search strategies
  ▪ direct detection
  ▪ indirect detection
  ▪ production at colliders
Introduction

Production at colliders

DM produced in cascade decays from heavier new states

- Example: **SUSY**
  - LSP stable if R-parity conserved
  - always 2 LSP's yielding observable momentum imbalance (MET)

- Example: **Higgs portal**
  - SM scalar coupling to dark sector
  - still large invisible Higgs decay width allowed
  - kinematic limit from Higgs mass
  - see talk Daniele Trocino on invisible Higgs decays

DM produced directly

- **pair production** featured in most scenarios
  - but back-to-back DM particles are invisible
- higher-order diagrams provide probe recoiling against DM pair

\[ \bar{q} \rightarrow \chi, \gamma, W/Z \]

\[ q \rightarrow \chi, \bar{\chi} \]
Modelling DM production

- focus on description of direct DM production only
- **effective theories**: collapse SM-DM interaction in effective 4-point operator
  - different operator depending on mediator's couplings
  - only few parameters: $m_{DM}$, EFT scale $\Lambda = \frac{M}{\sqrt{g_{X}g_{q}}}$
  - easy to translate to elastic DM-nucleon cross section
    \[ \sigma(\chi N \rightarrow \chi N) \sim \frac{g_{q}^{2}g_{X}^{2}}{M^{4}} \mu_{XN}^{2} \]
  - limitation: $M$ has to be much larger than the energy scale of the collision
  - probes one interaction at a time
- **simplified models**: only SM + DM sector
  - mediator and interactions specified explicitly
  - more parameter space to scan
  - more and more effort in this direction
CMS DM Searches

Mono-jet search

- large MET from DM recoils against a jet from QCD ISR
- selection highlights
  - MET trigger defines lowest analysis cut: MET > 250 GeV
  - one central jet $p_T > 110$ GeV
  - 2nd softer jet allowed close to 1st one
  - control fake jets / instrumental MET
  - electron, muon and tau vetoes
    suppresses $W \rightarrow \ell \nu$
- irreducible $Z \rightarrow \nu\nu$ dominant background after selection
- Both $Z \rightarrow \nu\nu$ and $W \rightarrow \ell\nu$ backgrounds predicted from $Z \rightarrow \mu\mu$ control sample
Mono-photon search

- large MET from DM recoils against a photon from QED ISR
- selection highlights
  - photon and photon+MET trigger defines lowest analysis cuts: $p_T^{\gamma} > 145 \text{ GeV}$ and $\text{MET} > 140 \text{ GeV}$, and $\Delta\phi(\gamma, \text{MET}) > 2$
  - photon ID cuts to reject fakes
  - vetos on electron, muon and hadronic activity
- irreducible $Z(\rightarrow \nu\nu)\gamma$ dominant background after selection
  - other background with genuine photon: $W(\rightarrow\ell\nu)\gamma$
  - fake-photon backgrounds: $W\rightarrow\text{ev}$, QCD, beam halo
**CMS DM Searches**

**Mono-lepton search**

- DM pair produced along with a recoiling W boson

**selection highlights**

- muon / electron trigger drives analysis cuts $p_T (e/\mu) > 100/45$ GeV
- $0.4 < p_T^{e/\mu}/\text{MET} < 1.5$ and $\Delta\phi(e/\mu, \text{MET}) > 0.8 \pi$

- irreducible $W(\rightarrow\ell\nu)$ dominant background after selection
CMS DM Searches

Interpretation of mono-jet/photon/lepton

- data compatible with background expectations
- 90% CL limits set on EFT scale $\Lambda$ using effective operators
  - from there set limits on elastic DM-nucleon cross section versus DM mass
- complementary, unique, coverage at low mass and strong sensitivity for spin-dependent interactions

![Graph 1: $\chi$-Nucleon Cross Section vs. $M_\chi$ (GeV)]

- Spin Independent, Vector Operator $\langle q\nu|\chi\gamma^\mu q\rangle$

![Graph 2: $\chi$-Nucleon Cross Section vs. $M_\chi$ (GeV)]

- Spin Dependent, Axial-vector operator $\langle \gamma^\mu\gamma_5\chi|\gamma^\nu q\rangle$
CMS DM Searches

- strong dependence on interference for monolepton
  - negative interference for $\xi=+1$ is the most pessimistic scenario
CMS DM Searches

- also looked at simplified model in monojet analysis
  - here assuming vector mediator
  - production cross section enhancement when mediator can be on-shell
  - EFT limit recovered for large mediator mass
CMS DM Searches

Mono-top search

- DM preferentially couples to heavy quarks through FCNC diagrams

- selection highlights
  - MET > 350 GeV
  - 3 jets, of which 1 b-tagged
  - electron and muon veto

- scalar / vector DM excluded @ 95% CL for masses below 327 / 655 GeV

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CMS DM Searches

Di-top + MET search

• **EFT scalar interaction** least constrained: $L_{\text{int}} = \frac{m_q}{M^{3_*}} \bar{q}q\tilde{\chi}\tilde{\chi}$
  - quark mass dependence → top coupling enhanced

• selection highlights
  - 2 electrons/muons and ≥2 jets
  - MET > 320 GeV
  - cuts on scalar sums of leptons and jets, and lepton opening angle
  - $\sigma > 0.09$ (0.24) pb excluded at 95% CL for $m_{\text{DM}} = 50$ (1000) GeV

<table>
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<th>Yield</th>
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<td>$t\bar{t}$</td>
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<td>Di-boson</td>
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<td>Drell-Yan</td>
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<td>One Mis-ID lepton</td>
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<td>Double Mis-ID leptons</td>
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<tr>
<td>Signal</td>
<td>1.88 ± 0.11 ± 0.07</td>
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Summary and outlook

- several searches presented for direct DM production in CMS
  - all data compatible with background expectation
- limits set on scale in EFT approach for different operators describing the type of interaction
- first limits in simplified model considered

- LHC Run II: expect further exploration
  - of the analysis landscape
  - of interpretations using eg. simplified models

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