Dark Matter searches at CMS

Andreas Albert on behalf of CMS
WIMP Dark Matter searches at CMS

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The LHC
LHC timeline

CMS Integrated Luminosity, pp

Data included from 2010-03-30 11:22 to 2016-10-27 14:12 UTC

- 2010: 7 TeV, 45.0 fb⁻¹
- 2011: 7 TeV, 6.1 fb⁻¹
- 2012: 8 TeV, 23.3 fb⁻¹
- 2015: 13 TeV, 4.2 fb⁻¹
- 2016: 13 TeV, 40.8 fb⁻¹

√s 7 TeV 8 TeV 13 TeV

Run 1 Run 2
Collider production of DM

Simplified SM extensions

SM + mediating boson + DM
$E_{T,\text{miss}} + X$ searches

H(125) decays to DM

No immediate need for new bosons
$E_{T,\text{miss}} + X$ searches

SUSY

More complex signatures

+ Others
Outline

- Introduction
- $E_{T,\text{miss}} + X$ searches
- SUSY searches
Two signal categories

Monojet

$\geq 1$ small-radius jet

Mono-V (V=W/Z)

$\geq 1$ large-radius ("fat") jet

Common Selection

$E_{T,\text{miss}} > 250$ GeV

No leptons, b jets

High cross-sections at hadron collider

Signal extraction in $E_{T,\text{miss}}$ distribution
Monojet / Mono-V(hadronic)

- 5 control regions, e.g. $Z \rightarrow ee$
- Recoil = $E_{T,\text{miss}}$ with leptons excluded

Combined maximum likelihood fit
Postfit uncertainties 3-13% (!)

No signal found!
Mono-Z(II)

- Lower cross-sections
- Z boson well reconstructable
- Back-to-back-topology

Signal region

3l control region

No signal found!
Dijet

Target mediator decays to quarks
No DM produced → no $E_{T,\text{miss}}$

Look for bump dijet mass spectrum
Low-mass from online analysis

No signal found!
Simplified models

Assume minimal additional particle content: SM + 1 mediator boson + DM fermion

Spin 1 mediator case:

\[ \mathcal{L}_{\text{vector}} = g_q \sum_{q=u,d,s,c,b,t} Z'_\mu \bar{q} \gamma^\mu q + g_\chi Z'_\mu \bar{\chi} \gamma^\mu \chi \]

\[ \mathcal{L}_{\text{axial-vector}} = g_q \sum_{q=u,d,s,c,b,t} Z'_\mu \bar{q} \gamma^\mu \gamma^5 q + g_\chi Z'_\mu \bar{\chi} \gamma^\mu \gamma^5 \chi \]

Parameters

Mediator properties
- Spin
- Color and electric charge
- Mass

DM properties
- Mass

Couplings
- \( g_q, g_l, g_{DM} \)
- coupling structure

→ Benchmark scenarios
DM Comparison: Spin 1 in $E_{T,\text{miss}} + X$

**Spin-1 interpretation: Standard Z’**
Electrically neutral, colorless s-channel mediator

![Graph showing exclusion regions for various mediator masses](image)
DM Comparison: Spin 1 in $E_{T,\text{miss}} + X$

Collider

- $M_{\text{med}}$ defines sensitivity
- $m_{\text{DM}}$ only relevant relative to $M_{\text{med}}$
- Hierarchy follows cross-sections

NB: Exclusion only valid for these parameters!
DM Comparison: Spin 1 in $E_{T,\text{miss}} + X$

**Indirect constraints**
- Resonances searches could detect mediator
- No DM produced
- Sensitivity also for $m_{\text{DM}} > M_{\text{med}}$

**Relic density**
- assuming simplified model and no further BSM
- more plausibility check than constraint
Spin-1 comparison to direct detection

Spin independent coupling
Collider complements DD at low $m_{\text{DM}}$

$$\sigma \propto \left( \frac{g_q g_{\text{DM}}}{M_{\text{med}}^4} \right)^2 \left( \frac{m_n m_{\text{DM}}}{m_n + m_{\text{DM}}} \right)^2$$
Spin-1 comparison to direct detection

Spin dependent coupling
Collider searches gives strong constraints across full $m_{DM}$ range

$$\sigma \propto \left(\frac{g_q g_{DM}}{M_{med}^4}\right)^2 \left(\frac{m_n m_{DM}}{m_n + m_{DM}}\right)^2$$
Spin-0 mediators

Diagram and Lagrangian credit: hep-ex:1507.00966

Assume Yukawa-couplings, $y^f \sim m_f / \text{vev}$

→ Coupling to light particles suppressed
Spin-0 mediators: Scalar

Not quite sensitive yet
Spin-0 mediators: Scalar

Heavy flavor update coming soon!

May 24th 2017
A. Albert – DM @ CMS
Spin-0 mediators: Pseudoscalar

Can probe with 2016 dataset!
Spin-0 mediators: Pseudoscalar

Monojet EXO-16-048

DM-nucleon cross-section suppressed by \( (q/m_{\text{Nucleon}})^4 \)

→ No direct detection constraints!
Monotop

More exotic: Single top + DM
Probe FCNC and colored, charged scalar mediators

Hadronic decays of high-p_T single top
- Single fat jet
- 3 sub jets, one of which is b tagged
- Jet mass \( \approx m_{\text{top}} \)
Is the scalar H(125) boson a portal to DM?

- Plain SM production + invisible decay
- No extra model dependence
- Probe in $E_{T,\text{miss}} + X$ topologies

Combined

- 2011, 2012 and 2015 data
- three search channels

Bottom Line

- $\text{BR}(H \rightarrow \text{inv.}) < 0.24$

VH ($\rightarrow \text{Mono-Z/W}$) and ggH($\rightarrow \text{monojet}$) already improved with 2016 data, qqH to come
Outline

• Introduction
• $E_{T,\text{miss}} + X$ searches
• SUSY searches
SUSY searches

LSP is natural DM candidate in R-parity conserving SUSY
Typically lightest Neutralino
Production inevitable in decay chains!

Categorization by primary supersymmetric particles

- **Gluinos**
- **Squarks**
- **Gauginos**

**Simplified models**
- Non-participating sparticles have infinite mass

**Parameters**
- masses, branching fractions

**Main sensitivity axis is primary sparticle mass**
SUSY in jets + $H_{T,\text{miss}}$

Target gluino and squark pair production

**Selection**

- At least two jets, no leptons
- Large hadronic activity:
  
  $$H_T = \sum_{\text{jets}} |p_T| > 300 \text{ GeV}$$

- Large missing momentum:
  
  $$|\vec{H}_{T,\text{miss}}| = |\sum_{\text{jets}} \vec{p}_T| > 300 \text{ GeV}$$

Search regions binned in $H_T$ and $H_{T,\text{miss}}$
+ additional categorization in $N_{\text{jet}}$, $N_b$
SUSY in jets + $H_{T,\text{miss}}$
SUSY in jets + $H_{T,\text{miss}}$

One category in $N_{\text{jet}}$

One sub-category in $N_{\text{b-jet}}$

One point per region

$35.9 \text{ fb}^{-1} \ (13 \text{ TeV})$

$N_{\text{jet}} \geq 9$

$7 \leq N_{\text{jet}} \leq 8$

$5 \leq N_{\text{jet}} \leq 6$

$3 \leq N_{\text{jet}} \leq 4$

$N_{\text{jet}} = 2$

$N_{\text{b-jet}} = 0$

$N_{\text{b-jet}} = 1$

$N_{\text{b-jet}} = 2$

Data

Hadronic $\tau$ lepton

Lost lepton

QCD
SUSY in jets + $H_{T,\text{miss}}$

No signal found!
SUSY in jets + $H_{T,\text{miss}}$

Gluinos

High cross-section

probe LSP neutralino up to $\approx 1.2$ TeV

low b mass $\rightarrow$
slightly higher reach

Squarks

Heavy flavor has slightly better S/B discrimination

But: 4 light flavors instead of 2 heavy
SUSY from multilepton events

Chargino-neutralino pair production
- Decay via sleptons → main sensitivity
- If sleptons heavy → direct chargino decay to LSP
- Charged leptons + $E_{T,\text{miss}}$ in final state
SUSY from multilepton events

Signal Region “A”:
- 3 leptons, at least one OSSF pair
- region numbering in $E_{T,\text{miss}}$

No signal found!

Exclusion:
- Depends on decay channel, branchings
- Exclude LSP neutralino up to $\approx 700$ GeV
Presented only two interesting results

There are > 50 results with run-II data

Similar implications for DM
Summary

$E_{T,\text{miss}} + X$ searches
- Signature driven
- Exact exclusion is model dependent, but searches are not!

Resonance searches
- High sensitivity for $m_{\text{med}}$ in TeV range
- Indirect, no actual DM produced $\rightarrow$ add. model dependence

SUSY searches
- Probe LSP neutralino up to $\approx 1.2$ TeV
- More model dependent than the above, but less so than you think

Large range of complementary searches

No signal yet

More data to come
More details are easy to find!

**Analyses**

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<td>SUSY in multilepton events</td>
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</table>

**LHC Dark Matter working group**

(models, benchmarks, conventions)

- arXiv:1507.00966
- arXiv:1603.04156
- arXiv:1703.05703
Backup
Monophoton

- Similar topology to other mono-X searches
- Profit from cross-section
- Challenging experimental backgrounds
- Cut & Count

No signal found!
Resonance search comparison

- Reducing $g_q$ from 0.25 to 0.1 kills dijet constraints
- For $g_q = g_\ell$, dilepton dominates
Resonance search comparison

- Similar power between dijet and dilepton for $g_q = 10 g_l$