Detecting Dark Matter at the LHC with Electroweak Bremsstrahlung

Ahmad Galea, with: N. Bell, J. Dent, T. Jacques, L. Krauss and T. Weiler.

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Dark Matter visible as high pT object + missing ET
Bremsstrahlung

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Electroweak Processes

- $Z$ – easily reconstructible invariant mass.
- Decays leptonically with a small branching fraction, has few backgrounds.
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Signal: Z + missing ET
Backgrounds

Signal: muons + missing ET
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Leptonic Backgrounds

\[
\begin{align*}
ZZ & \rightarrow \bar{\nu}\nu \quad \mu^+\mu^- \\
W^+Z & \rightarrow \nu l^+ \quad \mu^+\mu^- \\
W^-Z & \rightarrow \bar{\nu}l^- \quad \mu^+\mu^- \\
W^+W^- & \rightarrow \nu\mu^+ \quad \bar{\nu}\mu^-
\end{align*}
\]
Backgrounds

Signal: muons + missing ET

Leptonic Backgrounds

- $ZZ \rightarrow \nu \nu \mu^+ \mu^-$
- $W^+ Z \rightarrow \nu l^+ \mu^+ \mu^-$
- $W^- Z \rightarrow \bar{\nu} l^- \mu^+ \mu^-$
- $W^+ W^- \rightarrow \nu \mu^+ \bar{\nu} \mu^-$

- $ZZ/WW$ will have largest mET.
- WW largest x-section, no Z.
Backgrounds

Signal: muons + missing ET

Leptonic Backgrounds

\[ ZZ \rightarrow \bar{\nu}\nu \mu^+\mu^- \]
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- ZZ/WW will have largest mET.
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QCD Backgrounds

\[ t\bar{t} \rightarrow b\bar{b} W^+W^- \]
\[ Z + jets \]

- Large x-section, looks a lot like WW (can be removed with cuts).
- Miss-measurement, remove with mET cut.
Illustrative Toy Model

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- Introduce Majorana DM particle $\chi$, coloured scalar doublet $\eta$.

$$\mathcal{L}_{\text{int}} = f_{ud}(\eta_u \bar{u}_L + \eta_d \bar{d}_L)\chi_R + h.c.$$
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- Allows for processes:
Event Selection

Kinematic cuts

- Invariant mass cut.

\[ 61.2 \text{GeV} < m_{\mu\mu} < 121.2 \text{GeV} \]
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Preliminary Figure
Event Selection

Kinematic cuts

- Invariant mass cut: $61.2\,\text{GeV} < m_{\mu\mu} < 121.2\,\text{GeV}$
- Inclusive Muon $p_T > 50\,\text{GeV}$.
- Missing ET $> 100\,\text{GeV}$.
Event Selection

Geometric cuts

- $Z$ boosted, muons co-linear,
Event Selection

Geometric cuts

- $Z$ boosted, muons co-linear, low $\Delta R$.

$$\Delta R = \sqrt{\Delta \eta^2 + \Delta \phi^2}$$
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- Biases against non-Z backgrounds.
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$\Delta R < 1$
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Effectively removes WW background!
Results: Early Data

Upgraded energy
8TeV, 15fb$^{-1}$
tegrated luminosity.
Results

- Design energy of 14TeV for 100fb$^{-1}$ of data.

\[ m_{\chi} = 300\text{GeV} \]
\[ \sqrt{s} = 2 \]
- Clearly visible above backgrounds
Results

$m_\chi = 300\text{GeV}$

$\sqrt{\mu} = 2$

$m_\chi = 300\text{GeV}$

$\sqrt{\mu} = 5$
Results

$m_\chi = 300\text{GeV}$

$\sqrt{s} = 2$

$m_\chi = 500\text{GeV}$

$\sqrt{s} = 2$
Results

$m_\chi = 300 \text{GeV}$
$
\sqrt{\mu} = 2
$

$m_\chi = 1000 \text{GeV}$
$
\sqrt{\mu} = 2
$
Conclusions

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- $Z \rightarrow \mu \mu$ channel has few backgrounds and is easily distinguishable.

- Competitive with jet and photon searches.

- Models should be constrained by early data.

- Clearly visible at $100 \text{fb}^{-1}$ of data, heavy constraints should be placeable.
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At current LHC running energy of 7TeV and 1fb\(^{-1}\), signal comparable to jet searches.