MULTIPURPOSE MONOJETS AT THE LHC: DARK MATTER & NEUTRINOS

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[arXiv: 1111.5331] w/ Alex Friedland, Michael Graesser, and Luca Vecchi
[arXiv: 1112.5457] w/Luca Vecchi
Monojets and direct detection, only $90^\circ$ apart

Birkedal, Matchev, Perelstein (2004)
Bai, Fox, Harnik (2010)

Beltran, Hooper, Kolb, Krusberg, Tait (2010)
Rajaraman, Shepherd, Tait, Wijanco (2011)

Goodman, Ibe, Rajaraman, Shepherd, Tait, Yu (2010)
Fox, Harnik, Kopp, Tsai (2011)

...
The LHC and Direct detection on one plot

Fox, Harnik, Kopp, Tsai [1109.4398]

- Bounds are fantastic.

- But what if we see something?
Missing energy $\rightarrow$ DM?

At the LHC, nobody knows you’re dark matter.
• Easy to cut out SM produced neutrinos.

• But what about neutrinos with non-SM interactions?

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Generalizing Fermi

\[ \mathcal{L}_{\text{NSI}} = -2\sqrt{2}G_F \epsilon_{\alpha\beta}^f (\bar{\nu}_\alpha \gamma^\rho \nu_\beta)(f_\gamma P f) \]

Laid the foundation for the MSW effect and pointed out that NSI can modify neutrino propagation.
Solar Neutrinos and the LHC: a UV-IR duality?

Recently, both SNO and Super-K lowered thresholds to discover the MSW “upturn:”

neither see it

Borexino recently targeted 8B neutrinos and also found *no evidence.*

Combined >2σ discrepancy.

Palazzo [arXiv:1101.3875]
Not all MET is created equal

Jets + MET searches can bound many invisible things, like ADD gravitons, DM, (sterile) neutrinos, unparticles.

1) Yet, only SM neutrinos can interfere with the SM:

\[ \sigma(pp/p\bar{p} \rightarrow j+\text{MET}) = \sigma_{\text{SM}} + \epsilon \sigma_{\text{int}} + \epsilon^2 \sigma_{\text{NSI}} \]

2) SM neutrinos have nonzero electroweak charge.
An aside: monojets provide strongest bounds on some epsilons.
Tevatron and LHC constraints on NSI

\[ \mathcal{L}_{\text{NSI}} = -2\sqrt{2} G_F \epsilon^{f P}_{\alpha \beta} (\bar{\nu}_\alpha \gamma^\rho \nu_\beta)(\bar{f} \gamma^\rho Pf) \]

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<thead>
<tr>
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<th>CDF</th>
<th>ATLAS [24]</th>
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<tr>
<td></td>
<td>GSNP [25]</td>
<td>ADD [4, 5]</td>
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<td>( \epsilon^{uP}_{\alpha \beta = \alpha} )</td>
<td>0.45</td>
<td>0.51</td>
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<td>( \epsilon^{dP}_{\alpha \beta = \alpha} )</td>
<td>1.12</td>
<td>1.43</td>
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<td>( \epsilon^{uP}_{\alpha \beta \neq \alpha} )</td>
<td>0.32</td>
<td>0.36</td>
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<td>( \epsilon^{dP}_{\alpha \beta \neq \alpha} )</td>
<td>0.79</td>
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Most stringent bounds to date on electron and tau-type NSIs.

E.g. previously \( \epsilon^{ee}_{uR} < 0.7 \) from DIS at CHARM (Davidson et al., 2003).
**Multileptons vs. monojets**

NSI also produce...

Not as constraining as monojets. With $2.1\,\text{fb}^{-1}$

$$N_{4\ell} = 0.9 \times \left( \frac{\varepsilon_{\alpha \alpha} u^P}{0.17} \right)^2$$

[ATLAS-CONF-2011-144]

- Needs very high luminosity ($\sim 10\,\text{fb}^{-1}$) to compete with monojets.

- Clean lepton final states offer a probe on NSI with different systematics than monojets.
Part Two: Dark Matter
Validity of an Effective Description

If new physics become relevant at some high energy scale, its effects will be encoded in some high-dim operator(s), e.g.

\[ \mathcal{O} = \frac{\bar{q} \gamma^\mu q \bar{X} \gamma_\mu X}{\Lambda^2} \]

When \( E \sim \Lambda \), other operators become important and our effective description breaks down.

Can we be more rigorous than \( E \sim \Lambda \)?
Partial-wave unitarity

\[ \mathcal{M} = 16\pi \sum_j (2j + 1) P_j (\cos \theta) a_J(s) \]

**Unitarity:** \((\text{Re}(a_J))^2 + (\text{Im}(a_J) - 1/2)^2 \leq 1/4\)

E.g. Higgs mass (Lee, Quigg, Thacker 1977)

\[ W^+W^- \rightarrow W^+W^- \quad m_h \leq \sqrt{\frac{8\pi}{5\sqrt{2}G_F}} \approx 780 \text{ GeV} \]
Effective dark matter interactions

Assume heavy particles can be integrated out:

\[
O = \frac{\bar{q} \gamma^\mu q \, \bar{X} \gamma^\mu X}{\Lambda^2}
\]

\[
\Rightarrow \quad M(q\bar{q} \rightarrow X\bar{X}) = 2\sqrt{N_c} \frac{s}{\Lambda^2}
\]

Unitarity implies: \( \Lambda \gtrsim 2 \) TeV

Whereas monojets require: \( \Lambda \gtrsim 700 \) GeV
In the contact limit, monojets do not provide constraints stronger than unitarity.

The mediator of DAMA/CoGeNT interactions cannot be integrated out at the LHC!
Going on-shell

How do LHC bounds change?
Accessible Z’s

With a $Z'$ coupling to DM and a single quark flavor there are 4 parameters in the full parameter space:

\[ (m_X, m_{Z'}, \sqrt{g_X g_q}, \Gamma_{Z'}) \]

\[ \sigma \propto g_q^2 \times \text{BR} (Z' \rightarrow X X) \]

\[ \sigma \propto g^2 q g^2 X \]
Besting the LHC from beyond the grave

Soft cuts are good for light particles.
Light mediators weaken monojet bounds

\[ m_{Z'} < 2 m_X \]

+ = where ATLAS overtakes CDF

Quarks with a large PDF delay the +

\[ \sigma_{nX} \lesssim 10^{-34} \text{ cm}^2 \left( \frac{20 \text{ GeV}}{m_{Z'}} \right)^4 \]
Take aways

✦ Dark matter doesn’t have a monopoly on monojets.
✦ The LHC will be the arbiter of multiple anomalies: solar neutrinos & DAMA/CoGeNT.
✦ The Tevatron reigns supreme at low masses.
✦ The mediator of DAMA/CoGeNT interactions is kinematically accessible at the LHC.
✦ Monojets are already quite constraining and may lead to the discovery of DM and/or non-standard neutrino interactions.