MULTIPURPOSE MONOJETS AT THE LHC: NEUTRINOS & DARK MATTER

Ian M. Shoemaker
April 13, 2012


[arXiv: 1112.5457] IMS and Luca Vecchi
More complementarity

Colliders

Direct Detection

See talks online by Yu-Hsin and Roni

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Oscillation experiments

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Why do you care?

- Neutrinos certainly exist in Nature.
- Solar neutrino hints.
- Weakly constrained so far.
- The LHC can set world’s best limits.
Generalizing Fermi

Neutrino oscillations in matter

L. Wolfenstein
Carnegie-Mellon University, Pittsburgh, Pennsylvania 15213
(Received 6 October 1977; revised manuscript received 5 December 1977)

The effect of coherent forward scattering must be taken into account when considering the oscillations of neutrinos traveling through matter. In particular, for the case of massless neutrinos for which vacuum oscillations cannot occur, oscillations can occur in matter if the neutral current has an off-diagonal piece connecting different neutrino types. Applications discussed are solar neutrinos and a proposed experiment involving transmission of neutrinos through 1000 km of rock.

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

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]
A SNO-ball’s chance?

Dashed line: best fit to LMA solution

Blue: SNO solar neutrino data
“This could be the discovery of the century. Depending, of course, on how far down it goes.”
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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.
The nitty gritty

**MadGraph** for parton-level signal.

Pass to **Pythia** for hadronization/showering and ultimately analysis.
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Bounds obtained via a simple counting experiment.

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N_{\text{obs}} = 965
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N_{\text{bkg}} = 1010 \pm 37 \pm 65
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For example, ATLAS HighPt found:

\[ N_{obs} = 965 \]

\[ N_{bkg} = 1010 \pm 37 \pm 65 \]

\[ N_{BSM} < 192 \]

@ 95% CL
Tevatron and LHC constraints on NSI

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

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In agreement with [Fox, Harnik, Kopp, Tsai (2011)]
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- Up-quark couplings more constrained.
- Off-diagonal couplings stronger by \((\sqrt{2})\).
- Most stringent bounds to date on electron and tau-type NSIs.

E.g. previously \( \epsilon_{uR}^{ee} < 0.7 \) from DIS at CHARM (Davidson et al., 2003).

In agreement with [Fox, Harnik, Kopp, Tsai (2011)]
On-shellness

More model-independent, BUT only valid as long as the new physics scale is large compared to LHC energies.
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What if it’s not?
A simple leptophobic Z’ model

Minimal width, Z’ only couples to one quark flavor, chirality and a neutrino pair.

\[ \varepsilon \sim \frac{g_{Z'}^2}{M_{Z'}^2} \]
A simple leptophobic \( Z' \) model

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\[
\sqrt{s} = 7 \, \text{TeV} \quad \text{veryHighPT}
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\[ \sqrt{s} = 7 \text{ TeV} \]

“massless” Z'

Contact resonance

\[ M_{Z'} \text{ [GeV]} \]

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Beating the LHC from beyond the grave

$M_{Z'}$ [GeV]

CDF ADD
lowPT
veryHighPT
CDF GSNP
highPT

Broad resonance
Beating the LHC from beyond the grave

- Tevatron data is more constraining for $m_{Z'} \lesssim 200$ GeV
Beating the LHC from beyond the grave

- Tevatron data is more constraining for \( m_{Z'} \lesssim 200 \text{ GeV} \)

- Would a yet softer cut yield better bounds?
Latest CMS results

EXO-11-059

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$\int L \, dt = 4.7 \text{ fb}^{-1}$ at $\sqrt{s}=7 \text{ TeV}$
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1/fb ATLAS veryHighPt: \( \sigma_{BSM} < 0.015 \, pb \)
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1/fb ATLAS veryHighPt: $\sigma_{BSM} < 0.015 \text{ pb}$

4.7/fb CMS: $\sigma_{BSM} < 0.018 \text{ pb}$
Multileptons vs. monojets

NSI also produce...

\[ W^- \rightarrow \bar{l}_\alpha \quad l_\beta \quad W^+ \]

Not as constraining as monojets

\[ N_{4\ell} = 0.9 \times \left( \frac{\varepsilon^{uP}}{0.17} \right)^2 \]
Multileptons vs. monojets

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

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- Needs very high luminosity (~10 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 Effective Description

Suppose by analogy to the NSI case, we wish to constrain DM-quark interactions of the form:

$$\mathcal{O} = \frac{\bar{q} \gamma^\mu q \bar{X} \gamma_\mu X}{\Lambda^2}$$
Validity of Effective Description

Suppose by analogy to the NSI case, we wish to constrain DM-quark interactions of the form:

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

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

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

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

Assume heavy particles can be integrated out:

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

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

Unitarity implies: \( \Lambda \gtrsim 2 \text{ TeV} \)
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Unitarity implies:

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

Said differently, an effective DM theory with a 500 GeV cutoff is consistent if:

\[ s \lesssim 1.3 \text{ TeV} \]
Accessible Z’s

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

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

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

\[\sigma \propto g_q^2 g_X^2\]
Tevatron wins even in the off-shell regime

Soft cuts are good for light particles.
Upper bounds on quark-DM coupling

\[ + = \text{where ATLAS overtakes CDF} \]

Quarks with a large PDF delay the +

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

Friday, April 13, 2012
Quark-DM bounds

+ = where ATLAS overtakes CDF

Bounds are more constraining when $Z'$ is on-shell.

$$\sigma_{nX} \lesssim 10^{-36} \text{cm}^2 \left( \frac{20 \text{ GeV}}{m_{Z'}} \right)^4 \left( \frac{\Gamma_{Z'}/m_{Z'}}{10^{-2}} \right)$$

$m_{Z'} > 2m_X$

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Take aways

- Neutrinos aren’t just a background. Could hide new physics.
- Solar data give hints. Test this hypothesis at the LHC.
- The Tevatron 1/fb reigns supreme at low masses. Who can beat them?