Discussion Session:

Exotics

Keith R. Dienes
University of Arizona

Workshop: *"Dark Matter at a Future Hadron Collider"*
Fermilab
December 6, 2015

I've been asked to lead a Discussion Session on future prospects for a next-generation hadron collider, viewed from an “exotic” dark-matter perspective. Developing a strong scientific case for such a large-scale project is ultimately critical in order to gather the kinds of federal and international support that would be needed in order to bring such a collider into existence.

Towards this end, this presentation will be devoted to defining an overall scientific question and then posing a (long) set of questions for the audience to consider. I will not discuss my own personal research or that of any other physicists in the audience, nor will I offer any personal opinions concerning the science itself. I will merely pose a set of relevant questions for group discussion, and then step back and let the discussion commence!

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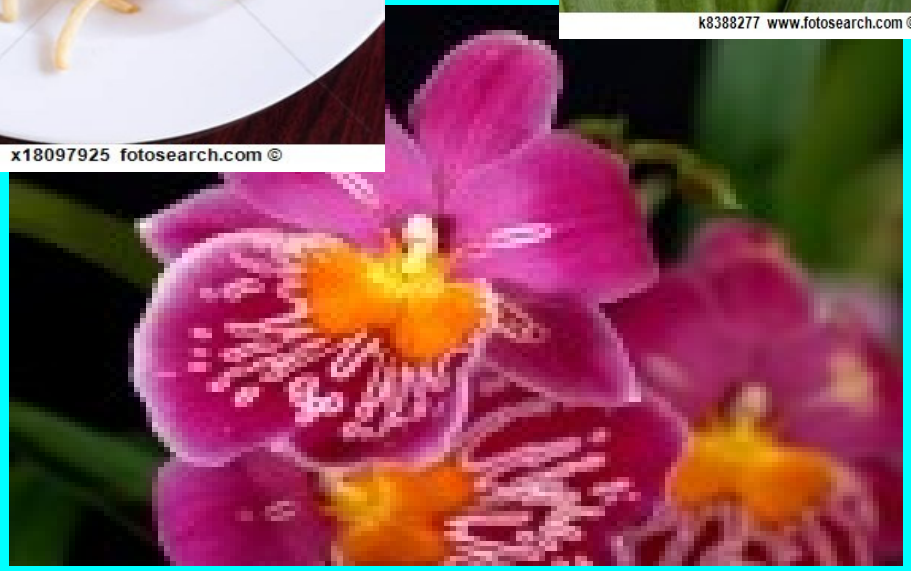


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Discussion Session:

Non-Minimal Dark Sectors

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Non-Minimal Dark Sectors

Dark sectors which are non-minimal in terms of either:

- the numbers of degrees of freedom contained therein, or
- non-trivial decay widths/lifetimes for these individual components.

What is the unique particle physics, astrophysics, and cosmology associated with non-minimal dark sectors??

Note that a non-minimal dark sector can mean much more than simply multi-component dark *matter*.

- Dark photons / additional dark forces
- Extended gauge sectors
- Hidden valleys and other secluded structure
- Alternative mechanisms for generating DM abundances
- Extended and modified complementarities

The notion of a non-minimal dark *sector* includes *all* of this!

Discussion Topics:

Non-Minimal Dark Sectors at Colliders

- What are the most important channels and search strategies for probing non-minimality in the dark sector at hadron colliders? What kinds of dark-sector non-minimality will be within reach at the upgraded LHC? ***How does the possibility of dark-sector non-minimality enhance the physics case for a 100-TeV circular collider?***
- What are the advantages that a future hadron collider can provide over lepton colliders in terms of probing dark-sector non-minimality?
- What are the comparative advantages afforded by fixed-target experiments such as the upcoming electron-beam experiments at JLab?
- What kinds of searches are important for probing non-minimal dark sectors which don't conform to the standard ATLAS and CMS neutralino searches, searches in mono-anything channels, etc.?
- What additional kinematic variables (such as MT2 and its variants) can be developed for events with large missing energies in order to enhance our sensitivity to non-minimality in the dark sector?

- What particular strategies for event selection might be adopted in order to ensure that we do not lose critical information which resides not only in signals relative to backgrounds, but also in the full distribution of a particular kinematic variable?
- What are the optimal search strategies and detection channels for scenarios involving light mediators or other dark-sector particles which do not themselves contribute significantly to the dark-matter cosmological abundance?
- How can we distinguish the properties of the portal from those of the dark sector itself? How can we probe the physics of the portal directly? What portals most directly facilitate the exploration of a non-minimal dark sector? Are certain "portals" particularly helpful for the experimental observation of a non-minimal dark sector at the current COM energy at LHC? At a 100-TeV collider? Particularly difficult?

Discussion Topics:

The Astrophysics and Cosmology of Non-Minimal Dark Sectors

- Are there non-standard ways in which cosmological constraints on dark matter from BBN, the CMB, etc., can be accommodated within the context of non-minimal dark sectors?
- What can more precise measurements of the properties of the CMB tell us about complexity in the dark sector?
- What impact will data from gravitational-lensing surveys such as those to be performed by LSST have on our ability to probe non-minimality in the dark sector?
- Are there particular benchmark scenarios with non-minimal dark sectors that we would strongly recommend be included in simulations of structure formation?
- What methods/observations provide the best prospects for constraining dark-matter self-interactions in a non-minimal framework?

Discussion Topics:

Indirect Detection of Non-Minimal Dark Sectors

- Might non-minimal dark sectors provide new, unique methods of evading otherwise significant large and unknown astrophysics uncertainties (e.g., when observing the galactic center)?
- Are there non-standard ways in which astrophysical constraints on dark matter from X-ray and gamma-ray telescopes, cosmic-ray detectors, etc., can be accommodated within the context of non-minimal dark sectors?
- To what extent might future instruments such as the Cerenkov Telescope Array (CTA), ASTRO-H, etc., provide evidence of non-minimality in the dark sector?
- What useful information might neutrino detectors such as IceCube provide for dark-sector non-minimality?

Discussion Topics:

Dedicated Searches for Non-Minimal Dark Sectors

(direct detection, axion searches, etc...)

- Do non-minimal dark sectors pose special requirements for low-background experiments? Are existing experiments adequate?
- Does the neutrino background pose any special difficulties for the detection of non-minimal dark sectors relative to minimal dark sectors?
- Are direct-detection experiments using certain targets advantageous relative to others if the dark sector is non-minimal? Do some targets have broader sensitivies across a wide range of kinematic conditions (e.g., different dark-matter masses and/or cross sections or dark form factors within a multi-component dark sector) rather than a focused sensitivity to a certain set of conditions?
- What constraints can be imposed on dark-sector non-minimality from stellar evolution (e.g., supernova emissions) and other astrophysical processes?
- What connections might exist between dark-sector non-minimality and experimental anomalies such as those from positron-flux measurements? total e+/e- fluxes? possible photon-line observations? photon excesses from the galactic center?
- To what extent do uncertainties in cosmic-ray propagation modelling constrain our ability to probe dark-sector non-minimality?

Discussion Topics:

Theoretical Challenges for Non-Minimal Dark Sectors

- What are the caveats to keep in mind when deriving constaints on non-minimal dark sectors (and their couplings to the visible sector) within the framework of effective-operator analyses?
- How can constraints on interaction "portals" between the dark and visible sectors be modified for extended dark sectors??

Final “Synthesis” Questions...

- Which are the most important experimental directions to pursue in order to effectively probe non-minimal dark sectors? Which areas of phase space do we emphasize?
- What additional theory/computational resources will be needed in order to fully probe the structure of, and/or simulate the dynamics of, a non-minimal dark sector?
- If the dark sector is ultimately detected through non-collider experiments, what could we learn about its structure? (For example, could we determine the spins of its individual components? Would we be able to discern the portal through which it interacts with Standard-Model matter? *etc*.)
- How can we most effectively measure the abundances associated with individual dark-sector degrees of freedom? How can we best constrain their individual lifetimes, interaction cross sections, decay rates, etc., both in absolute terms or relative to each other?

- Is it more likely for the discovery of a non-minimal dark sector to come all at once, or in sequential steps, after the discovery of a first dark particle? How does this depend on the discovery channel? The particular portal or coupling structure to the SM?
    - If a single DM particle is discovered, how could we use this data to learn that there must remain additional undiscovered DM particles? Through abundance measurements? Other techniques?
- What would it take to convince ourselves we have a discovery of a non-minimal dark sector? What would it take to convince ourselves that we have
    - a discovery of dark matter?
    - a discovery of a non-minimal dark sector?
    - a discovery of ***all*** of the dark matter?
    - a false signal of a dark-matter discovery?
- In what ways can we use the enriched complementarities associated with non-minimal dark sectors in order to probe their underlying physics? The particle nature of their individual components?

- In indirect detection of dark matter, it is notoriously difficult to rule out all hypotheses that a signal is of astrophysical origin. Would a non-minimal dark sector help or hurt this effort? What kinds of measurement accuracies would be needed? Could direct detection provide the needed accuracies?

- If the dark sector has no SM interactions stronger than gravitational, are there any prospects for discovering its particle nature? Are these properties enhanced for a non-minimal dark sector? What if only a portion of the dark sector is SM-neutral, but there are interactions between these different dark-sector components? What if there aren't?