# Model Independent Collider Dark Matter Searches

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hep-ph/0506151 [B. McElrath]
hep-ph/0509024 [J. Gunion, D. Hooper, B. McElrath]
hep-ph/xxxxxxx [H.S.Cheng,J.Gunion,G.Marandella,B.McElrath]
hep-ph/xxxxxxx [T. Plehn, B. McElrath]
hep-ph/xxxxxxx [D. Hooper, B. McElrath]

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What if a lack of discoveries at the LHC leads to the ILC not being funded?

# Post-LHC

At that point we will say:

- We had an excellent opportunity with B-factories to study in the low-mass region $M_\chi < 5$ GeV, why didn't we take it?

- We had an excellent opportunity with the LHC to scrutinize missing energy signatures. Did we do everything we could?

My interest is in ensuring that all possible places particle dark matter might be hiding are thoroughly explored.

Unlike the Higgs, it is difficult or impossible to state any kind of guarantee that a particular experiment (or even the set of all experiments) will discover dark matter assuming it exists. [See work of J.Gunion on Higgs "no-lose" theorems]

# Missed Opportunities

Why didn't we take the opportunity to study $M_\chi < 5$ GeV at B-Factories?

*Because theorists told us the best solution to the* **Hierarchy Problem** *is the MSSM*

What if the solution to the Hierarchy Problem is unrelated to Dark Matter?

What if there is no dark matter and the phenomena currently attributed to Dark Matter is due to a modification of gravity, or related to the quantization of gravity in an unexpected way?

What if the MSSM *isn't* the solution the the Hierarchy Problem? Can we quantify the probability that the MSSM is correct?

Polls of theorists tend to favor the "unexpected" possiblity by 70%-90%.

Let's try to solve *only* the Dark Matter problem.

# Light Dark Matter

Evidence

- DAMA Dark Matter signal can be made compatible with newer CDMS results if Dark Matter is light ($\lesssim 6$ GeV). [Gondolo, Gelmini, Savage, Freese]

- 511 keV $\gamma$ line observed by INTEGRAL can be compatible with Dark Matter with $m_e < M_\chi < 20$ MeV.

Collider Experiments

- Invisible quarkonium decays [B.McElrath, Phys.Rev.D72:103508,2005]; $\Upsilon \to \chi\chi$, $\eta \to \chi\chi$, etc. We should place limits on all invisible decays for which the measurement is practical.

- Radiative quarkonium decays [J. Gunion, D. Hooper, B. McElrath, Phys.Rev.D73:015011,2006]; $\Upsilon \to \gamma + \chi\chi$; $B \to K + \chi\chi$

# Activity Light Dark Matter

BES has already published a limit on $\eta \to \chi\chi$ and $\eta' \to \chi\chi$. [hep-ex/0607006] This measurement could confirm the INTEGRAL observation with $M_\chi < 20$ MeV, with the light pseudoscalar Higgs $A_1$ mediator that we proposed. I have been invited to Bejing in February to talk about this work.

Belle has already taken a several-day "Engineering run" on the $\Upsilon(3S)$ which was presented at the B-Factories and New Measurements conference at KEK, to which I was invited. There are serious proposals to install far-forward calorimeters to reduce the peaking background, to do further runs on the $\Upsilon(3S)$, and for SLAC to take data on the $\Upsilon(3S)$ as well.

An analysis of $\Upsilon(1S) \to \chi\chi$ is underway at BaBar using $\Upsilon(4S)$ and off-peak data. CLEO has expressed significant interest.

With Dan Hooper, I have written down a simple effective theory containing a Dark Matter particle $\chi$ and a mediator $U$ capable of explaining light Dark Matter. We are mapping out viable parameter space in the $M_\chi$ vs. $M_U$ plane.

## Heav(ier) Dark Matter

At high energy (LHC/ILC), the problem comes down to the question

> Given the messy nature of hadronic data, and the large number of final states typical of SUSY/UED/T-Parity theories, what is the best way to extract parametric information?

For most existing phenomenological analyses this question is recast into

> Given this *pile of Monte Carlo events* how do I write down $f(p_i^\mu|\mathbf{Y})$ which is a good one-dimensional estimator for the parameter $\mathbf{Y}$?

The answer is that "simple" one-dimensional estimators *may not exist*.

# Heav(ier) Dark Matter estimators

So... why were we considering only one dimension again?

The fully differential cross section contains *all the information there is to have*, and we know how to write it down!

$$P(\vec{p}_1, \ldots, \vec{p}_N | \mathbf{Y}) = \frac{1}{\sigma} \frac{d\sigma}{\prod_i d^3\vec{p}} = \frac{(2\pi)^{4-3N}}{2^N F \sigma \prod_i E_i} \left| \mathcal{M}(p_0^\mu, p_i^\mu, \mathbf{Y}) \right|^2 \delta^4 \left( p_0^\mu - \textstyle\sum_i p_i^\mu \right)$$

This quantity can then be used for hypothesis testing, given different hypothesis Matrix Elements $\mathcal{M}$.

The Likelihood, constructed from $P(\mathbf{X}|\mathbf{Y})$ has been proven to be the optimal one-dimensional estimator for *all* the parameters $\mathbf{Y}$, assuming the input 4-vectors $\mathbf{X}$ are uncorrelated.

This work is *totally general* and can be applied to any process, not only those with missing energy.

# Heavy Dark Matter ctd...

We are finding efficient ways to evaluate this $P(\mathbf{X}|\mathbf{Y})$ retaining all information.

It is necessary to integrate out any missing particles (this is actually the hard part). I am producing a library that will allow one to input any Matrix Element. We will then apply this to many processes, including SUSY (with H.S.Cheng, J.Gunion, and G.Marandella), gluino cascades (with T. Plehn), and of course, $t\bar{t}$.

This is closely related to the "Matrix Element Method"(s) used by the $t\bar{t}$ searches at CDF and D0. Most of these analyses still rely on a series of 1-dimensional projections of the data, however.

I won a fellowship to attend the Vancouver Linear Collider Workshop in July and present this work.

Preliminary results indicate that with as few as 50 events, we have sub-GeV resolution on the overall mass scale.

# Summary/Conclusions

- Model independence is *important*! We cannot possibly enumerate all possible theories, and even if we did, constraining them one-by-one is an inefficient means to cover the experimentally accessable space.

- Low energy collider experiments (BaBar, Belle, CLEO, BES, DAFNE, etc) with high luminosity have a unique, high-precision view on light Dark Matter that simply beats high-energy experiments. We *need both* collider and direct detection to prove the Dark Matter hypothesis.

- There is interesting work to do in clever data analysis for the LHC/ILC. Invariant mass plots simply will not get us very far in the LHC era. Preliminary results using fully differential information are extremely promising.