Summary: SUSY, Higgs, BSM, & Cosmology

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Outline

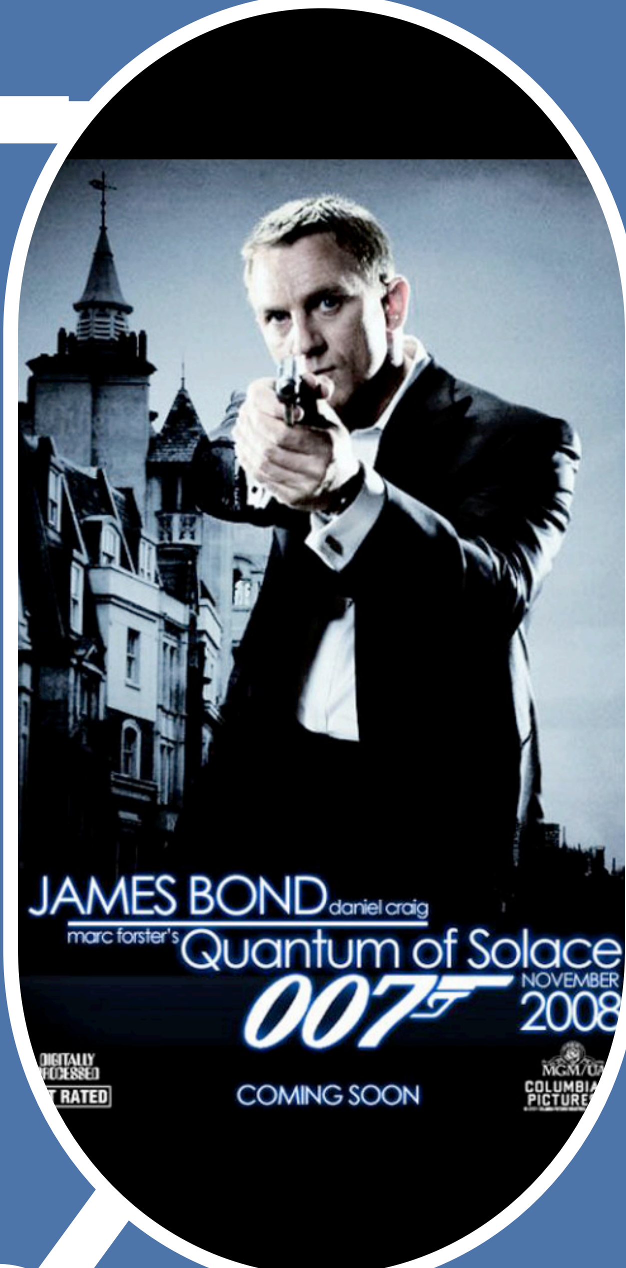
- Higgs
- Supersymmetry
- Beyond the Standard Model
- Cosmological Connections
- Outlook

Disclaimer

- These talks are not supposed to be a summary of all of the interesting results which we heard about at the workshop.
- Which is a good thing, because twenty-five minutes is an impossibly short time to try to summarize even one of the four topics covered here, especially with so many great talks.
- I'll cover some of the developments in all of the fields, but will necessarily be very personal and incomplete!

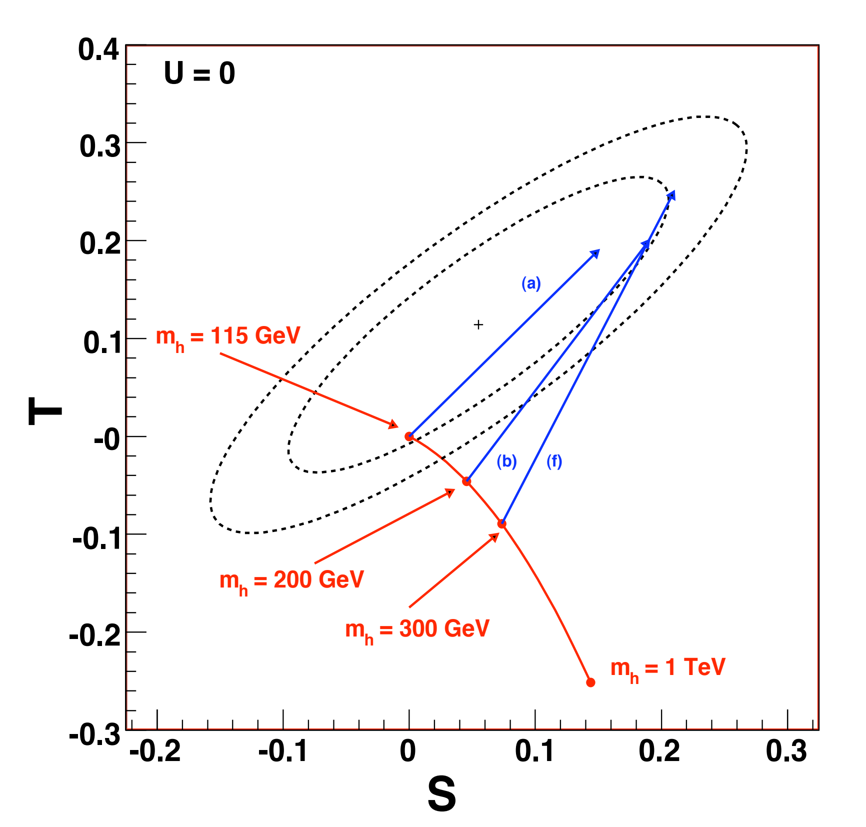
Higgs

- A linear collider is to a “light” Higgs what LEP and SLC were to the Z boson.
  - Establishing the Higgs properties is essential to confirm it as the agent of Electroweak breaking.
  - Is the Higgs the unique quantum of mass generation?
  - Since most of what we don’t like about the Standard Model is related to the Higgs sector, it is the most natural place to look for deviations from SM predictions.



Higgs Mass

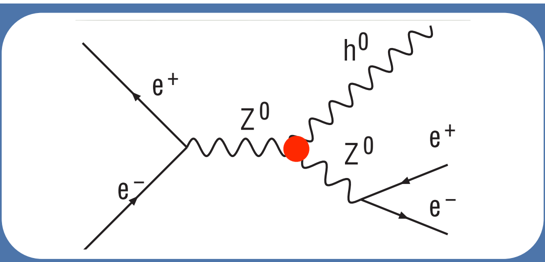
- Precision measurements of its mass also empower the precision electroweak data to constrain / reveal new physics.
- For example, a heavy enough Higgs is inconsistent with SM EW fits and would actually require more new physics to fit the data we already have.
- A fourth generation is one example, but there are many, many, other similar ones (e.g., Peskin & Wells '01)

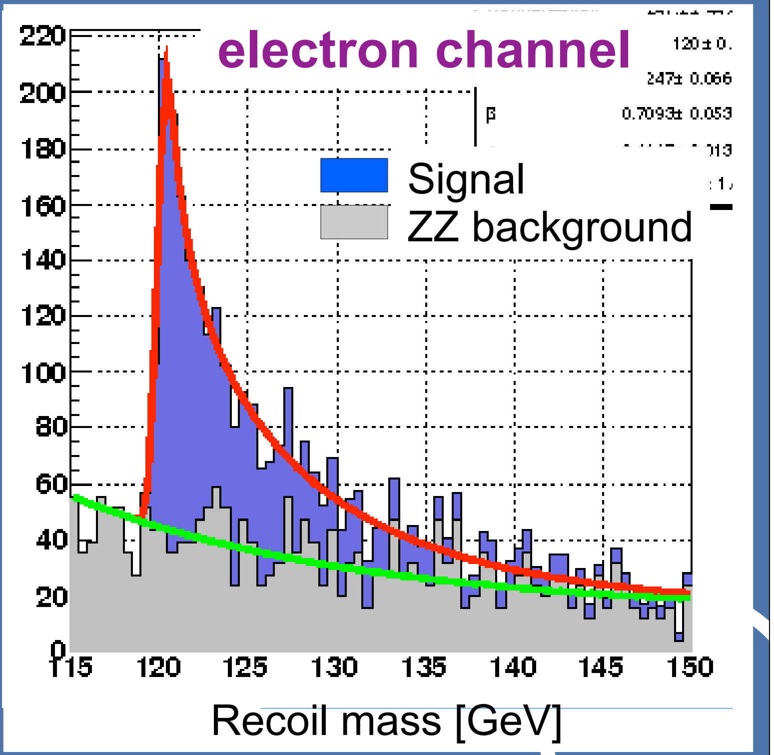


A Chiral Fourth Generation Example
Kribs, Plehn, Spannowsky, TT '07

Higgs Mass

- Precise measurements of the Higgs mass and cross section are a key test of its properties.
- We just saw how the mass pins down the EW fit.
- The h-Z-Z coupling is a direct result of the fact that the Higgs gave mass to the Z boson. Measuring it through Z h production confirms the Higgs as the agent of the Electroweak symmetry breaking





Kazutoshi Ito

Mass and σ

250 GeV, 500 fb^{-1}

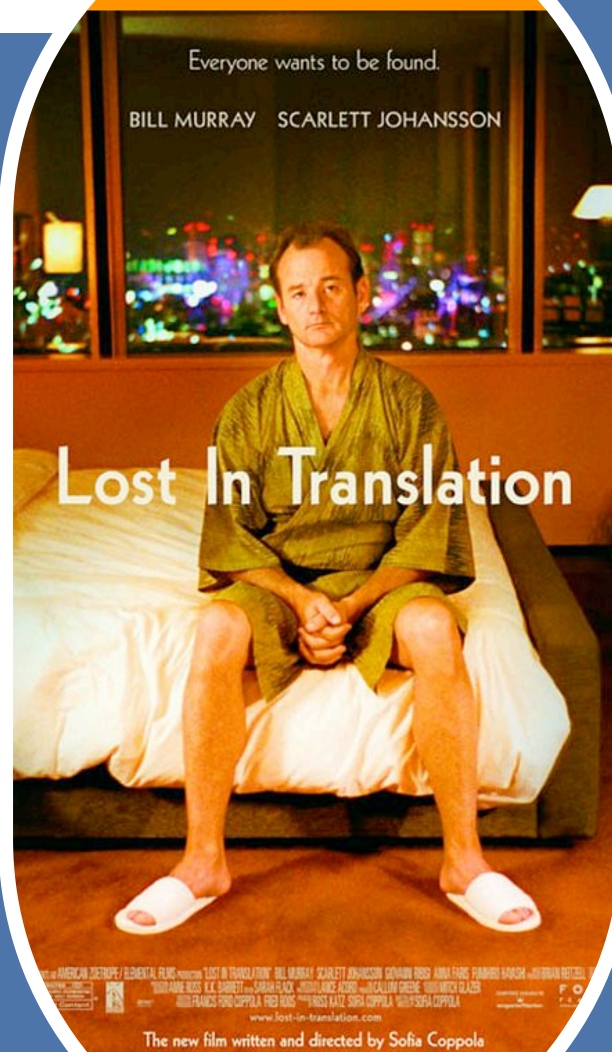
Li, Richard, Poschl

Ecm (GeV)	Detector Model	Channel	M_{recoil} Stat. Err (MeV)	Cross Section Stat. Err (fb)	Mass Resolution (MeV)
250	LDCPrime_02Sc	e	47	0.52	540 ± 25
		μ	23	0.28	500 ± 12
	LDC01_06Sc	e	47	0.49	560 ± 28
		μ	23	0.27	550 ± 12
	LDC_GLD_01Sc	e	51	0.52	490 ± 27
		μ	29	0.32	530 ± 15

The "recoil" technique is powerful and fairly model-independent. Comparable measurements from three different detector models provide amazing precision on the Higgs mass and cross section measurement at the 5%ish level.

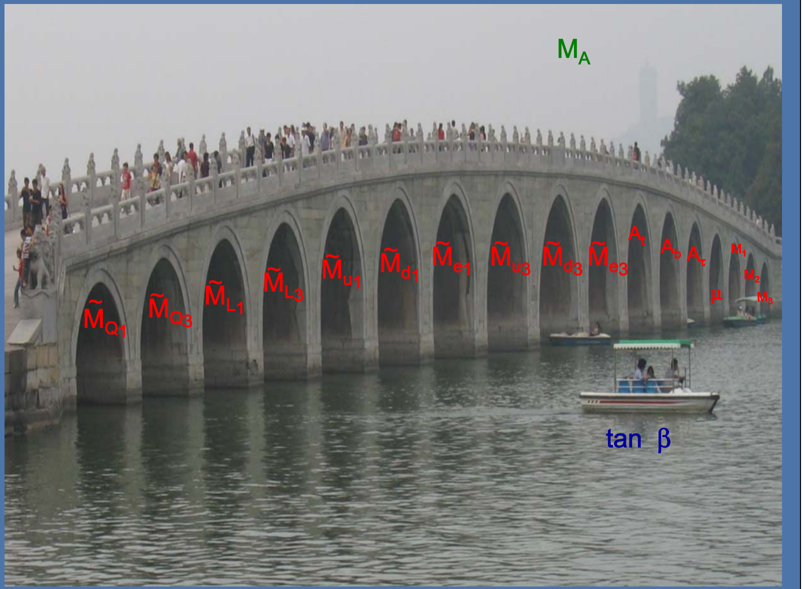
Lost in (SUSY) Parameter Space

- We all love supersymmetry - it solves the electroweak hierarchy problem, leads to unification of couplings, contains dark matter, and is a integral part of our best hope for a theory of quantum gravity.
- Supersymmetric theories have many parameters and only complicated regions of them do the things we want.
- If SUSY exists, a linear collider can provide very precise measurements of super-particle masses and couplings. This may be an essential key to take us from observation to a model of SUSY breaking.



Understanding SUSY

- Just understanding the supersymmetry parameter space is a challenge. Many of us have a lot of experience with isolated regions of parameter space, but the big picture is hard to keep in focus.
- Also, though we understand trends, there is always the nagging worry that there may be interesting regions of parameter space which are disconnected from our favorite regions. They may be consistent with all data, but they could be easily overlooked.

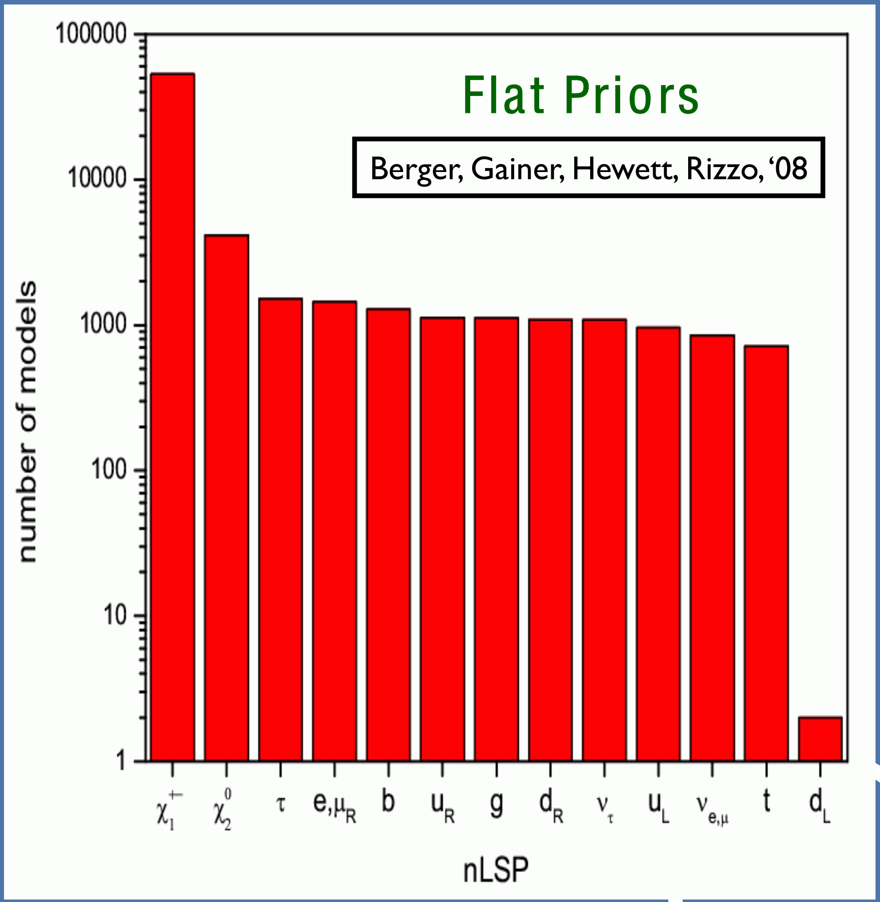


A recent effort to understand a 19 parameter take on the MSSM parameter space.

"FEATURE"
Berger, Gainer, Hewett, Rizzo,
arXiv:0811.xxxx

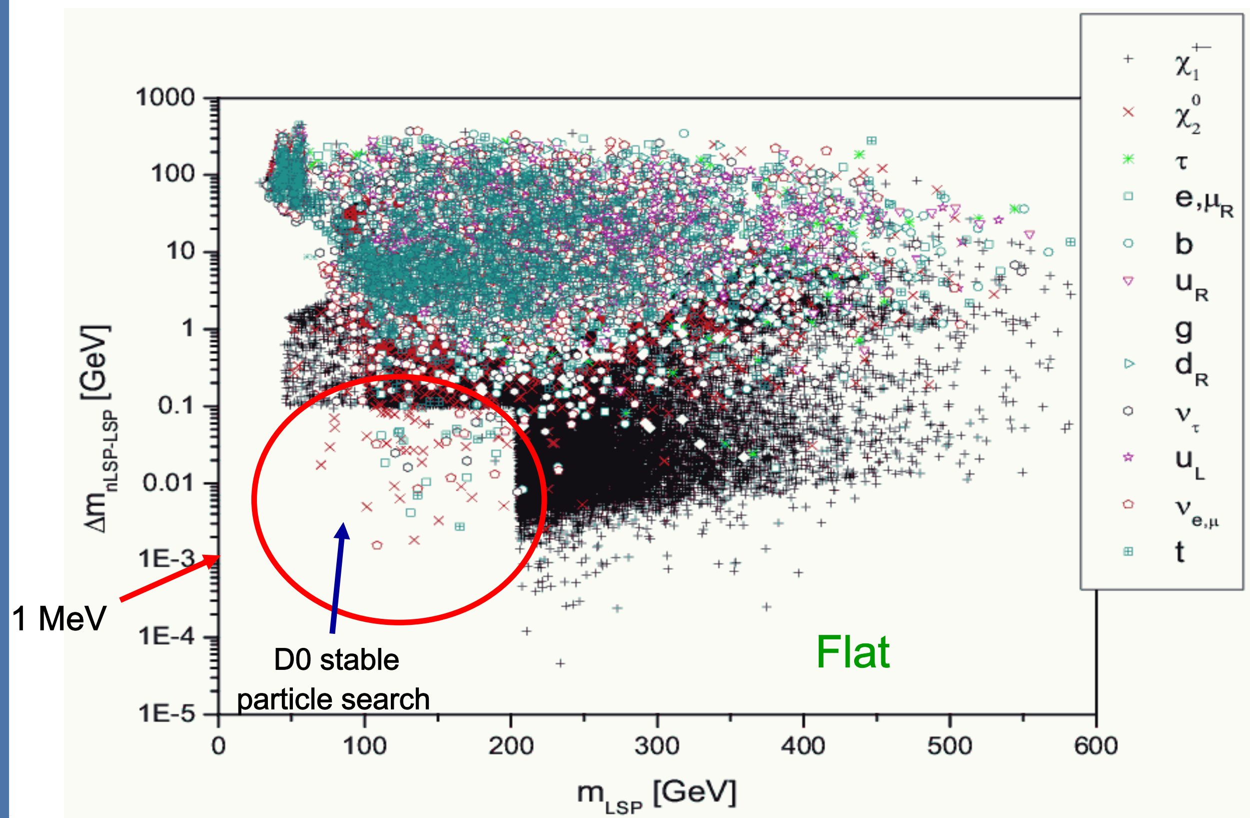
SUSY Parameters

- To weed out the models inconsistent with what we know, constraints from precision electroweak, flavor physics, dark matter searches, and collider bounds were imposed.
- The result is the most complete picture of the allowed parameter space of the (almost) general MSSM.
- We can also look for possibilities and trends relevant for future searches.



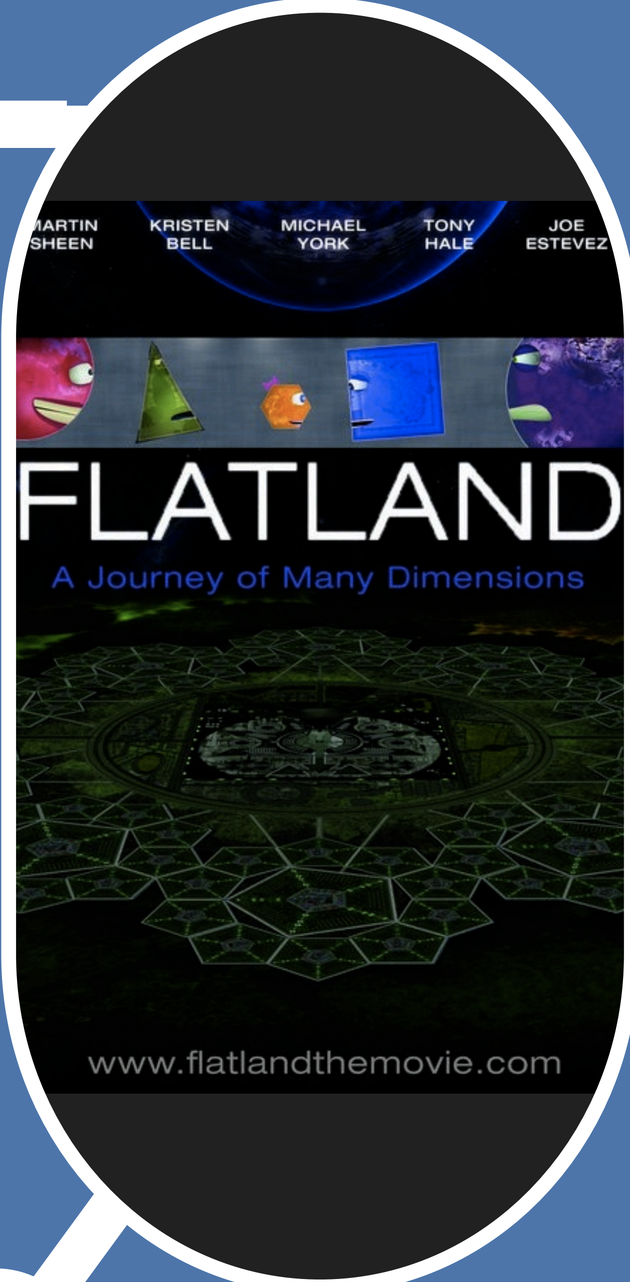
Effective Searches

nLSP-LSP Mass Difference



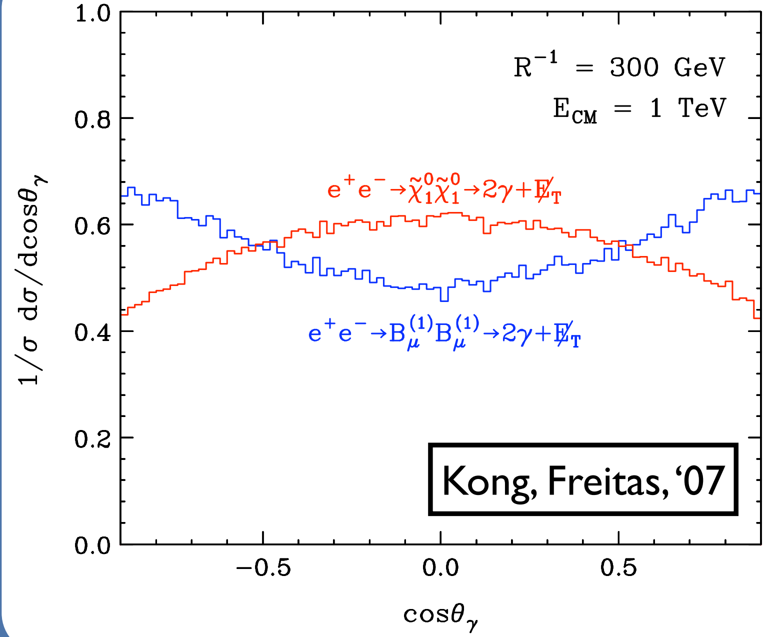
Beyond Supersymmetry

- Beyond supersymmetry, there is an array of interesting theories aiming to explain physics beyond the Standard Model.
- Extra dimensions, new strong dynamics, unparticles, Little Higgs, Z’s, ... and the list goes on.
- The ILC has a take on all of these options, either through precision measurements of couplings, direct production of new states, or high energy behavior of cross sections.



The Chiral Square

- An interesting 6d UED compactification is the chiral square. Dobrescu, Ponton, '04
- The LKP is usually a scalar singlet state. It's relic density points to few hundred GeV masses. Dobrescu, Hooper, Kong, Mahbubani, '07
- Production of KK leptons at a linear collider provides an interesting arena to test spins and determine the nature of the new physics.



Spin from Interference

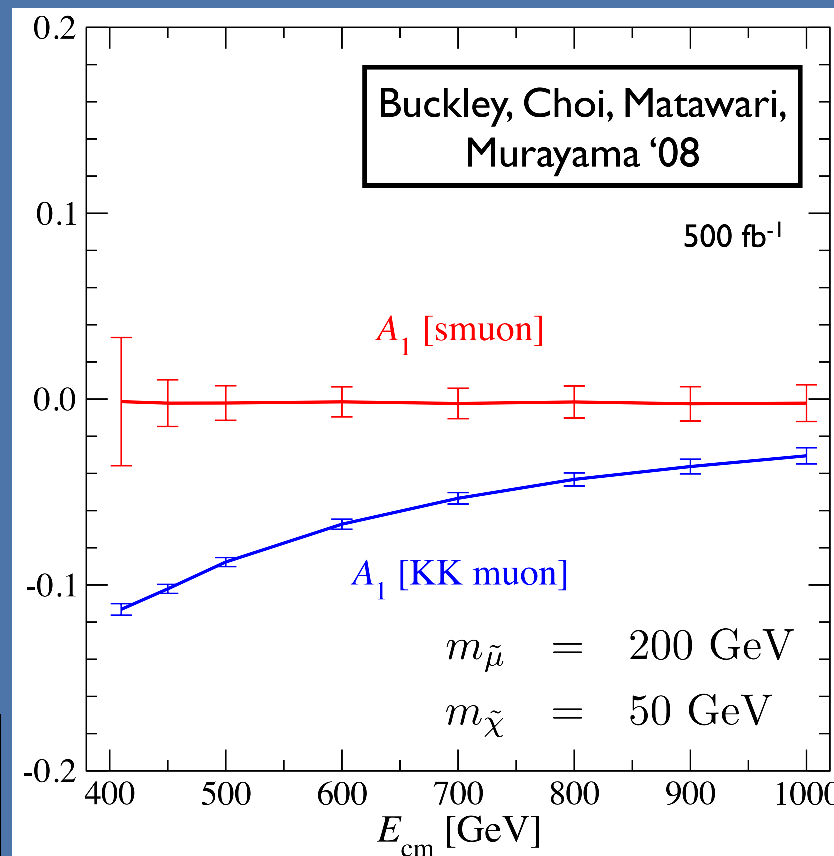
- An interesting idea to reconstruct spin information makes use of quantum mechanical interference between different helicity states.

Buckley, Choi, Heinemann, Klem, Mawatari, Murayama, Rentala, '07, '08

- This fact is reflected in the azimuthal dependence of decay products.
- To illustrate how it works, consider production of smuons or KK muons decaying into muons and missing E_T.

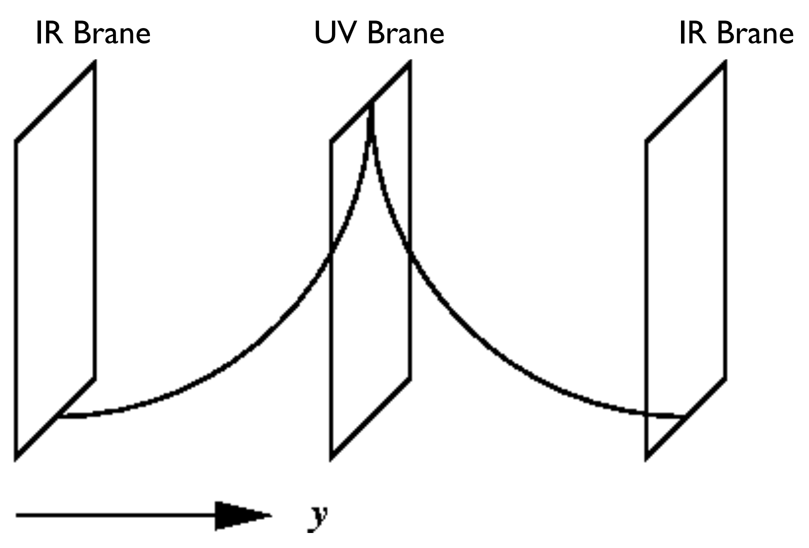
$$A_1 = \frac{\pi^2 m^2_{\mu^\pm_{R1}}}{8(s+2m^2_{\mu^\pm_{R1}})}\left(\frac{1-2m^2_{\gamma_1}/m^2_{\mu^\pm_{R1}}}{1+2m^2_{\gamma_1}/m^2_{\mu^\pm_{R1}}}\right)^2 \leq \pi^2/48 \approx 0.206$$

$$e^+e^- \to \tilde{\mu}^+\tilde{\mu}^- \to \mu^+\mu^-\tilde{\chi}^0\tilde{\chi}^0$$



KK Parity in RS

- A new construction of RS glues two copies of the warped space to either side of the UV brane.
- This results in a KK parity, like UED models, and odd KK modes will be pair produced, with the lightest one stable.
- This provides a dark matter candidate and collider phenomenology which is a hybrid with both UED and RS features.
- Open questions about realizing the desired spectrum remain... more work for model builders!

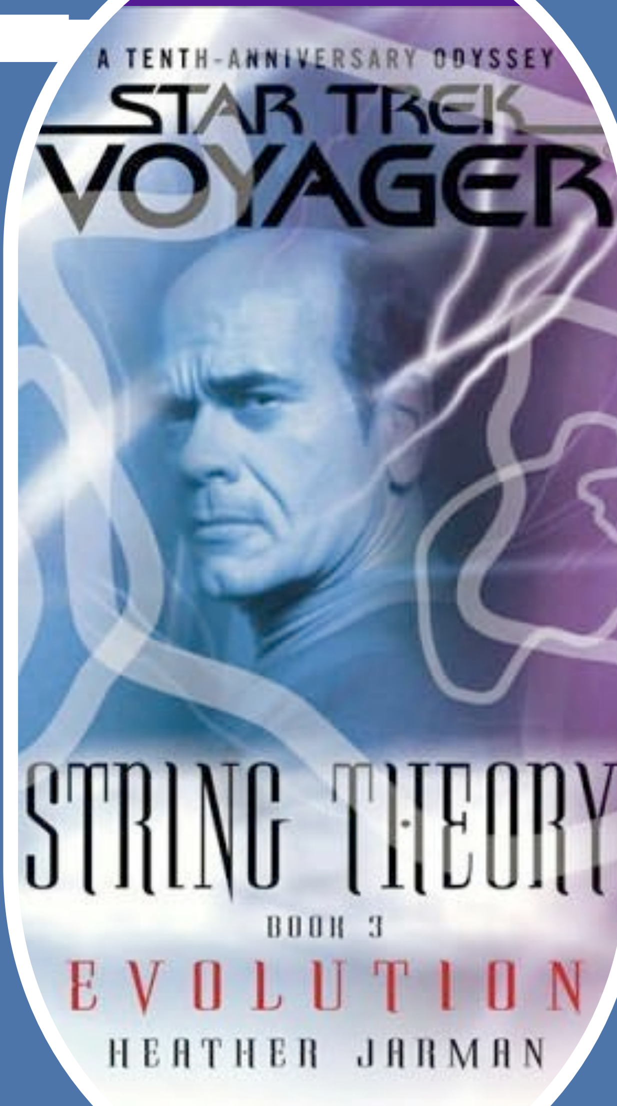


$$a(y) = e^{-k|y|}$$

Agashe, Falkowski, Servant, '07

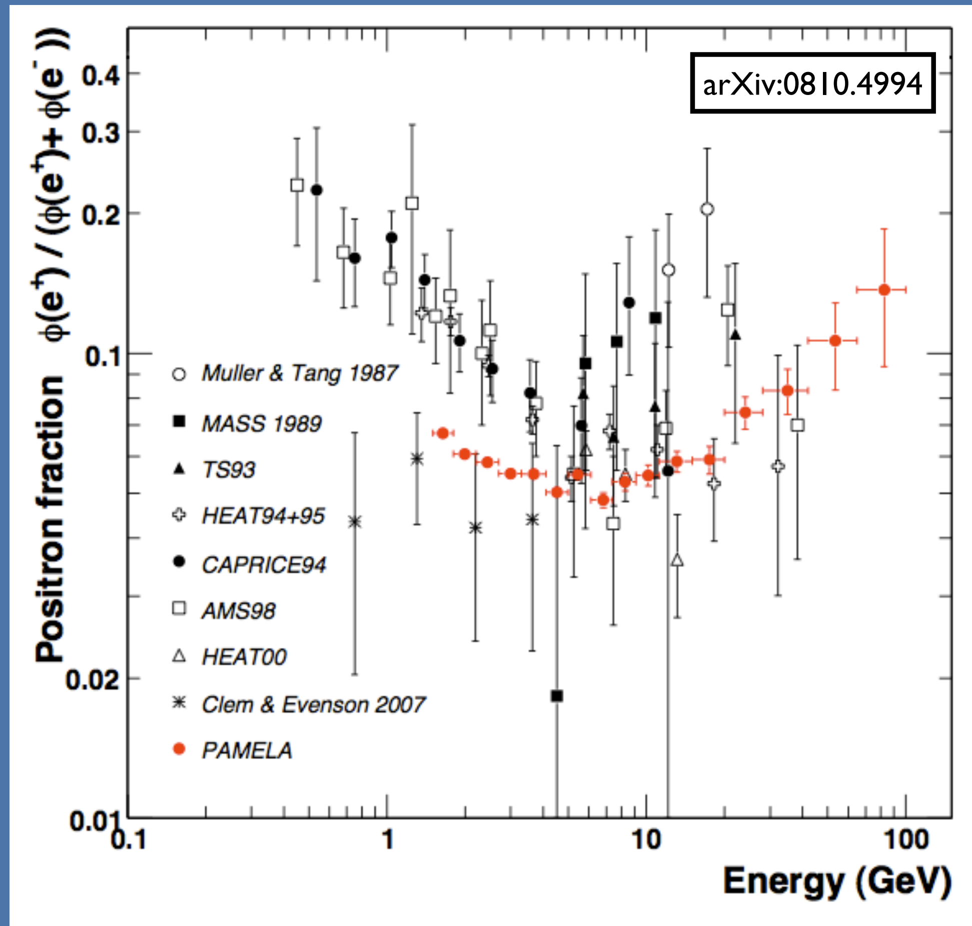
Cosmo Connection

- Finally, the ILC is a window through which we can hope to understand the early Universe.
- To understand high temperatures, we need particle physics to provide an understanding of the degrees of freedom.
- The ILC is the perfect machine to provide this understanding up to the TeV scale.
- Detailed understanding of dark matter microphysics could confirm the picture of a thermal relic.



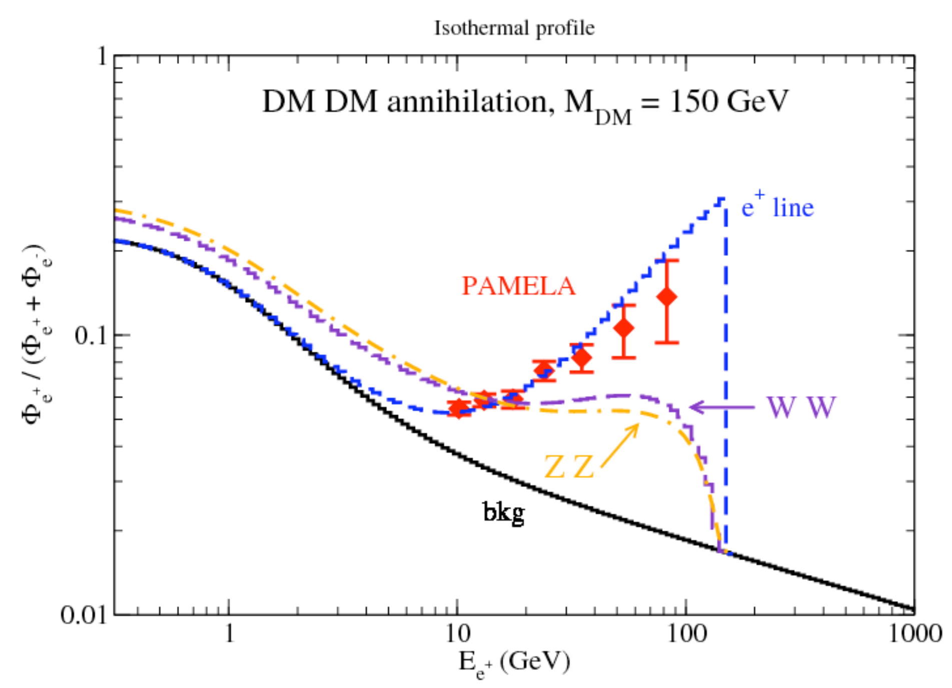
WIMPs from PAMELA?

- Recently, PAMELA has released its latest data for the ratio of the $e^+ / (e^+ + e^-)$ fluxes as a function of energy.
- The data shows an unexpected (by conventional astro models) upturn above around 10 GeV, strengthening previous hints from HEAT and AMS.
- Interesting similarities with the ATIC signal.



Dark Annihilation?

Barger, Keung, Marfatia, Shaughnessy, '08



- PAMELA argues for an unaccounted source of positrons.
- It could be nearby pulsars. Fermi/GLAST should help explore that possibility. Hooper, Blasi, Serpico. '08
- It could also be WIMPs annihilating in the halo and producing energetic positrons!

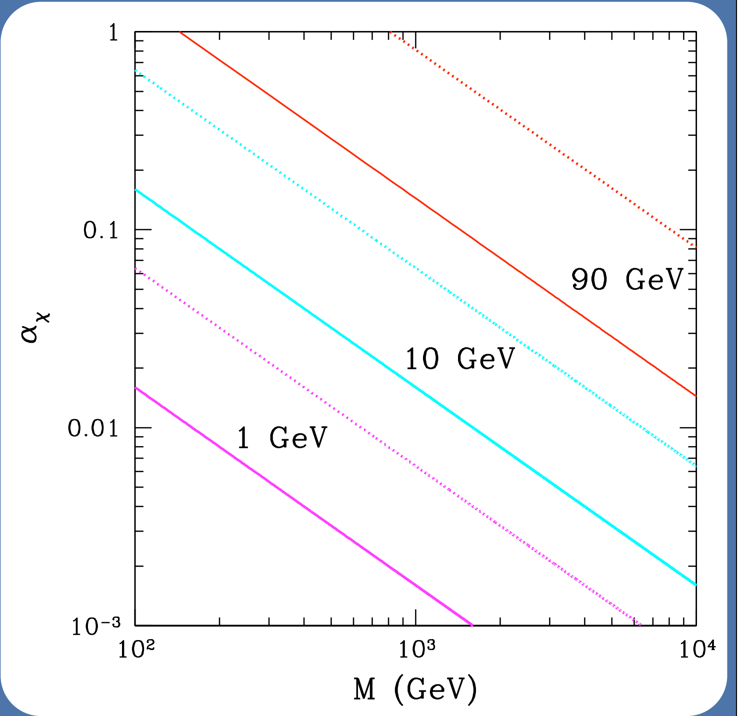
Goodenough, Hooper, Simet, Weiner, '08, Harnik, Kribs, '08
Bergstrom. Bringmann, Edsjo, '08, Chen, Takahasi, Yanagida, '08
Arkani-Hamed, Finkbeiner, Slayter, Weiner, '08, Cirelli, Strumia, '08
Nelson, Spitzer, '08, Pospelov, Ritz '08

WIMPonium?

- The large rate at PAMELA may be asking for a Sommerfeld enhancement for consistency with a thermal relic density.

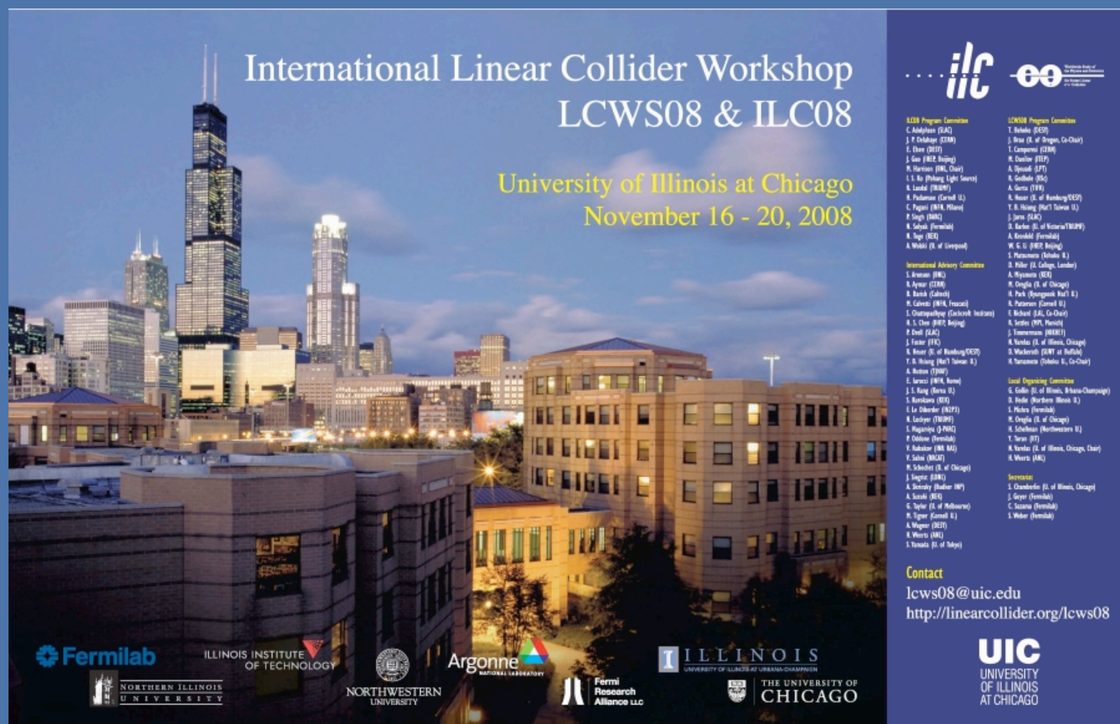
Arkani-Hamed, Finkbeiner, Slayter, Weiner, '08, Pospelov, Ritz '08

- Independently, it is interesting to ask what if WIMPs feel a new not-so-weak, not-so-long range force?
- The result can be bound states of WIMPs - WIMPonium. In many cases, we can even produce these states at colliders!
- The ILC is a perfect machine to discover & explore these weakly coupled resonances!



Shepherd, TT, Zaharijas, '08
(in progress)

Outlook



The physics case for the ILC only gets stronger with time.