

# *Connecting the LHC & Underlying Theories - opportunities and challenges*

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PRD 77:116005,2008; J.Phys. G 34, 2007

Earlier approach [hep-ph/0312248](#),

P Binetrui, Gordon Kane, Brent Nelson, Liantao Wang, Ting Wang

## String Phenomenology Workshop

### CERN

### August 6th, 2008

**Piyush Kumar**

**U C Berkeley**

In the LHC era,

Given experimenters report a signal beyond the SM,

The most important task for theorists would be coming to terms with:

## “THE LHC Inverse Problem”

Actually many problems:

- What is the origin of new physics at  $\sim \text{TeV}$ ? Susy or Something else?  
 $\longrightarrow L_{\text{TeV}} ?$
- Can it be related to a  $L_{\text{microscopic}}$  at some microscopic (high) scale?
- What is the nature of the microscopic (string) theory?

# EXTREMELY CHALLENGING!

1) Most study of the Inverse Problem focussed on EW scale issues.

Many difficult Issues – Large Number of Parameters, Degeneracies, etc.

*Arkani-Hamed, Kane, Thaler, Wang, hep-ph/0512190*

However, many techniques being developed, hopeful.

2) Little study of obstacles to naïve extrapolation of low scale results to high scales. For example,

a) From intermediate matter - Majorana Neutrinos, Exotics, etc.

*Kane, PK, Morrissey, Toharia* (PRD75:115018,2007; hep-ph/0612287)

b) From strongly coupled hidden sector effects.

*Cohen, Roy, Schmaltz* (JHEP 0702:027,2007), *Murayama, Nomura, Poland* (PRD77,2008)

Some progress made. But much more work needed.

### 3) Obstacles in understanding the microscopic theoretical structure itself, especially

- those related to technical mathematical issues.
- those crucial and relevant for prediction of low-energy physics
- different theoretical setups could give rise to similar low energy physics at first sight.

## **VERY DIFFICULT**

In this talk, study some simplified (but still reasonable) situations in which the microscopic theoretical framework can be connected to low energy physics in a reliable manner.

Have done a simple analysis. Can be readily improved both at the levels of theoretical and phenomenological analyses.

**Still a great learning exercise. We find that :**

- The pattern of signatures (real experimental observables) of the microscopic framework is interestingly limited and characteristic of the framework. Thus, these have the ability to distinguish among different frameworks.
- Moreover, many aspects of the pattern of signatures can be understood in terms of the theoretical details.

**This gives rise to the hope that (at least if one is optimistic)**

The much more difficult situation in the REALWORLD can be addressed in a similar manner, albeit with lot more hard work, and if nature is kind to us.

In recent years, it has come to be recognized that string/M theory appears to give rise to a vast set of 4D vacua.

Therefore, it makes sense to analyze classes of vacua arising from various microscopic frameworks.

### **In this talk, look at classes of vacua:**

Already emphasized in Peter's Talk

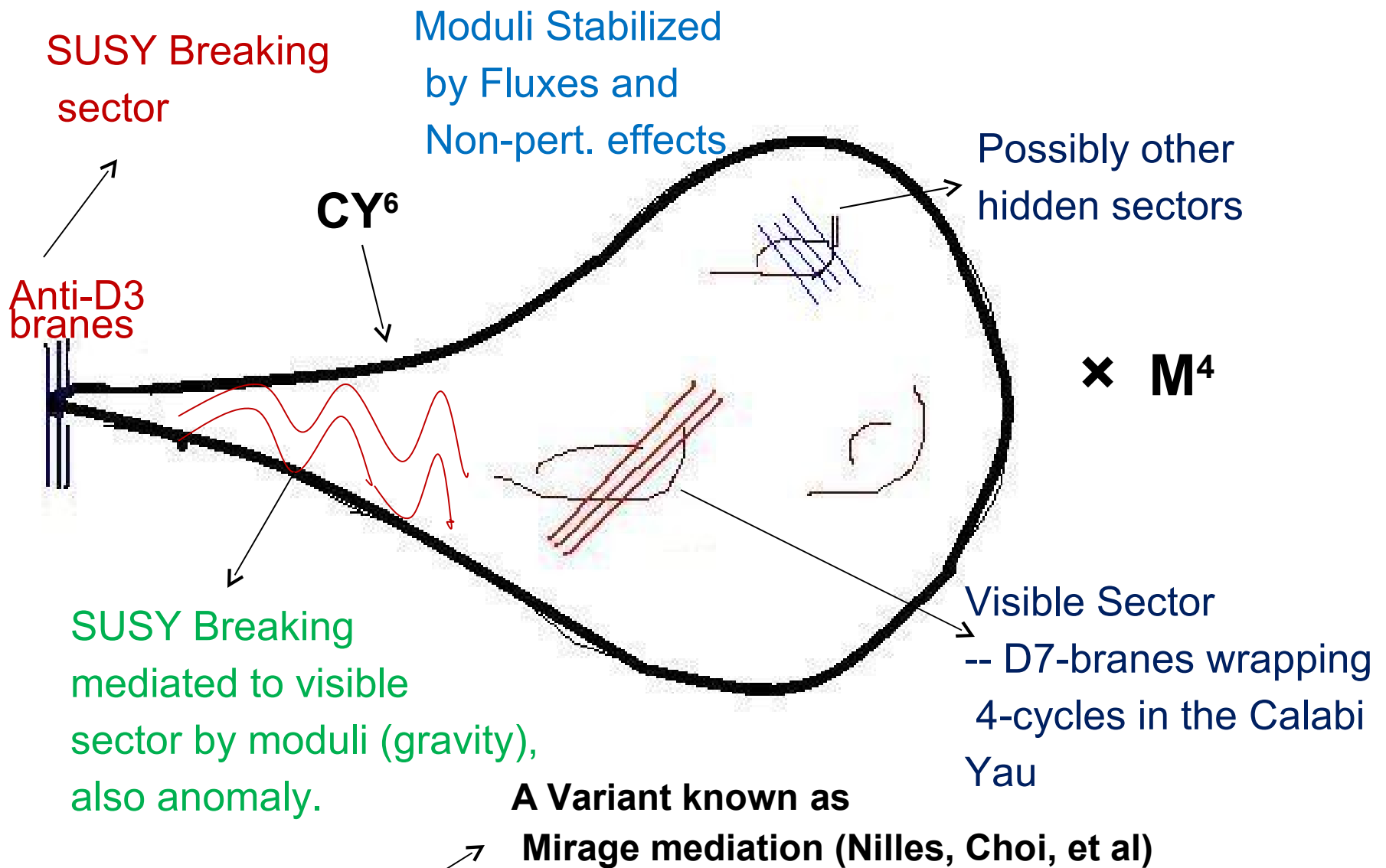
-- stabilizing the Hierarchy as well as the moduli.

Low energy Susy

-- (Assume that) the Visible Sector consists of the MSSM gauge and matter spectrum. —> Good starting point.

-- At present, these criteria satisfied separately in many cases in a more reliable manner, but explicit constructions do not meet all criteria at once.

-- However, can consider *frameworks* in which the relevant effects of the underlying mechanisms may be assumed to exist self-consistently.



**KKLT FRAMEWORK** – Possible to study pheno. implications of this framework. Has been done in the literature. Similarly for others.

# **We study four string/M Theory Frameworks with an MSSM visible sector**

- (Original) Type IIB KKLT, (KKLT-1) *(Kachru,Kallosch,Linde,Trivedi).*  
*Choi, Falkowski, Nilles, Pokorski :NPB718:113(2005);PRD75:095012; Falkowski, Lebedev,Mambrini JHEP 11(2005)034, Choi, Jeong, Kobayashi, Okumura, JHEP 2005,2006; Others.*
- Type IIB KKLT with F-term uplifting, (KKLT-2)  
*Lebedev, Nilles,Ratz JHEP 2006; Abe, Higaki, Kobayashi, Omura, PRD 2007;*  
*Dudas,Papineau,Pokorski JHEP 2007, others.*
- Type IIB LARGE Volume, (LGVol). *Balasubramanian,Conlon,Quevedo, JHEP 2005*  
• *Conlon, Quevedo, JHEP 2005,2006,2007,2008.*
- M Theory on  $G_2$  manifolds, ( $G_2$ ). *Acharya,Bobkov,Kane,PK,Shao, PRL 2006, PRD 2007*

**These Frameworks – Completely specified by a few “microscopic” parameters of the underlying theoretical construction.**

**Their consequences for the LHC can be readily predicted by standard methods and is Testable. However, to compute characteristic predictions, analysis of entire Microscopic parameter space necessary.**



- Write effective 4D Lagrangian of the Framework at the compactification scale  $M_{\text{unif}}$ ;  $L_{\text{soft}}$  in terms of the “microscopic” parameters.
  - gives initial conditions for the RGE evolution of the soft parameters.

**The remaining steps the same as in any other approach at  $M_{\text{unif}}$**

- Use RGEs to run down to EW scale – programs already exist for MSSM and some extensions.

Examples - **softsusy**, spheno, suspect...

- Impose Experimental constraints.
- Generate events for short distance processes such as superpartner production.  
(Eg.  $q + q \longrightarrow \tilde{g} + \tilde{g}$ )

Examples - **Pythia**, madgraph, alpgen, comphep (calchep), herwig

- Hadronize to long distances, quarks and gluons into jets, decay taus.  
Examples - **Pythia**, isajet, herwig, etc.

- Cuts, triggering, combine overlapping jets, detector simulation –  
Examples - **PGS**, ATL FAST, GEANT, etc.

# Backgrounds

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- Used PYTHIA and PGS to simulate some SM backgrounds.  
Estimated the remaining.

Observability Criteria:  $N_{\text{sig}} / \sqrt{N_{\text{bkg}}} > 5$  ;  $N_{\text{sig}} / N_{\text{bkg}} > 0.1$  ;  $N_{\text{sig}} > 5$ .

- Have done a simplified analysis of backgrounds at present.

But since results depend on intrinsic correlations due to

theoretical structure, should not change qualitative results at an early stage.

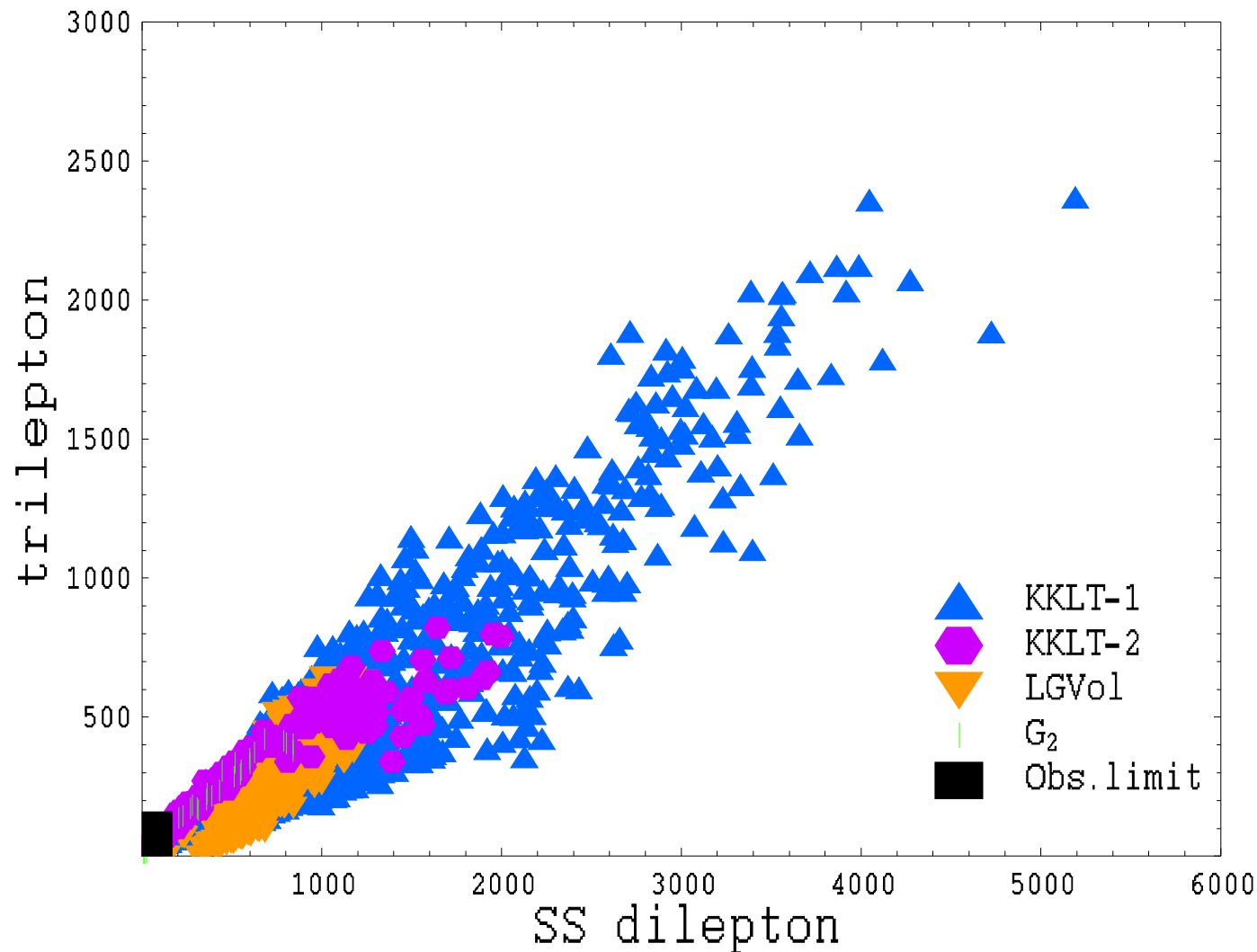
Want to avoid relying on signals for which backgrounds too large, use signals which are likely to be above background.

By varying (sampling) the microscopic parameters consistent with all theoretical and experimental constraints, one obtains :

a “footprint” of that framework in “signature space”.

- ❑ The footprint in signature space is interestingly limited and characteristic of the framework.

True for all frameworks we have looked at, and is understandable.



Black Region  
implies signal not  
observable above  
background.

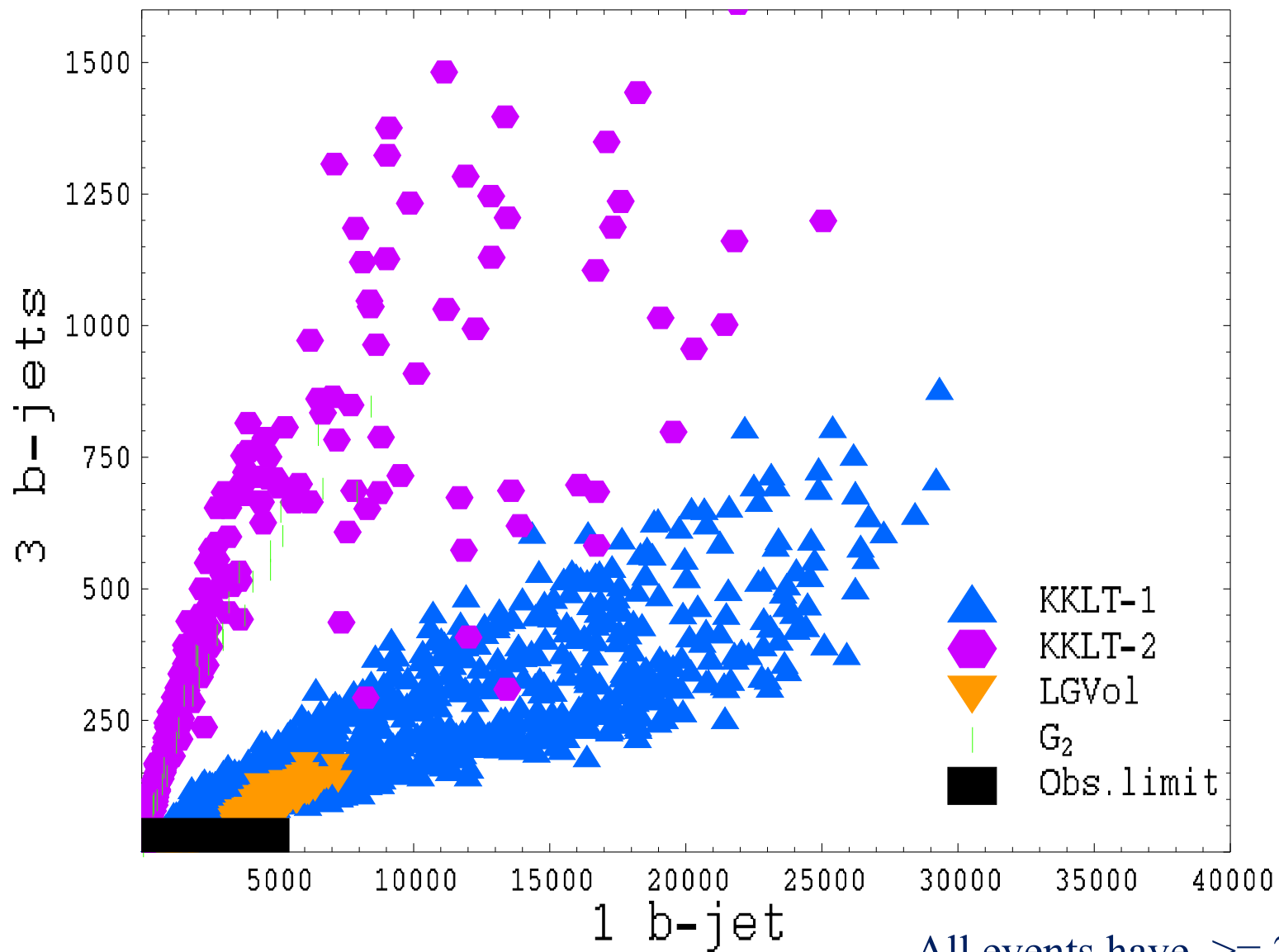
All events have  $\geq 2$   
hard jets and large  
Missing ET

Lum = 5 fb<sup>-1</sup>

L2 Trigger -- PGS

Pt (Jet) > 50GeV, Pt (Lepton) > 10GeV,  
Missing Et > 100GeV

**2D slices of footprints as  
microscopic parameters  
are varied**



All events have  $\geq 2$  hard jets and large Missing ET

**Can use distributions in addition to counting signatures**

# Some Generic Features of Footprints

For simplicity, stick to counting signatures.

- Counting Signatures always bounded from above by the maximum cross-section, due to lower limits on superpartner masses. So, 2D footprints with counting signatures bounded along the **radial direction**.
- **Angular Dispersion** – Due to variation in the spectrum, Leading to a variation in the BRs, hence signatures.

Exact spread depends upon many factors - structure of the model as well as real-world “detector effects”.

**The patterns of signatures can distinguish among different framework predictions.**

## **Origin of Distinguishability- Correlations**

- $s_i = s_i(m_j) = s_i(m_j(\zeta_k))$
- For arbitrary MSSM parameters  $m_j$ , very large region in signature space.
- However, if non-trivial dependence of  $m_j$  on microscopic parameters  $\zeta_k$ , then MSSM parameters  $m_j$ , and hence signatures  $s_i$  correlated with each other.
- Therefore, understanding how correlations among soft parameters are connected to the structure of the underlying theory can help us understand the position and shape of the footprints.

- Try to understand -- A) Footprint in terms of qualitative features of spectra and soft parameters.

B) Qualitative features in terms of microscopic parameters.

A) In the context of susy, a combination of the qualitative features of the spectra determines the footprint. Some of the most important ones are:

-- universality of tree level gaugino masses?

*[Choi and Nilles, hep-ph/072146]*

-- relative size of tree level and anomaly mediation gaugino masses?

-- origin, size of  $\mu$ ,  $B\mu$ ?

-- hierarchy of scalar vs gaugino masses?

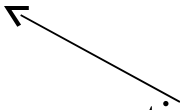
-- nature and content of LSP

-- hierarchy among scalars, e.g. 3<sup>rd</sup> family vs 1<sup>st</sup>, 2<sup>nd</sup> families



## Simple Examples

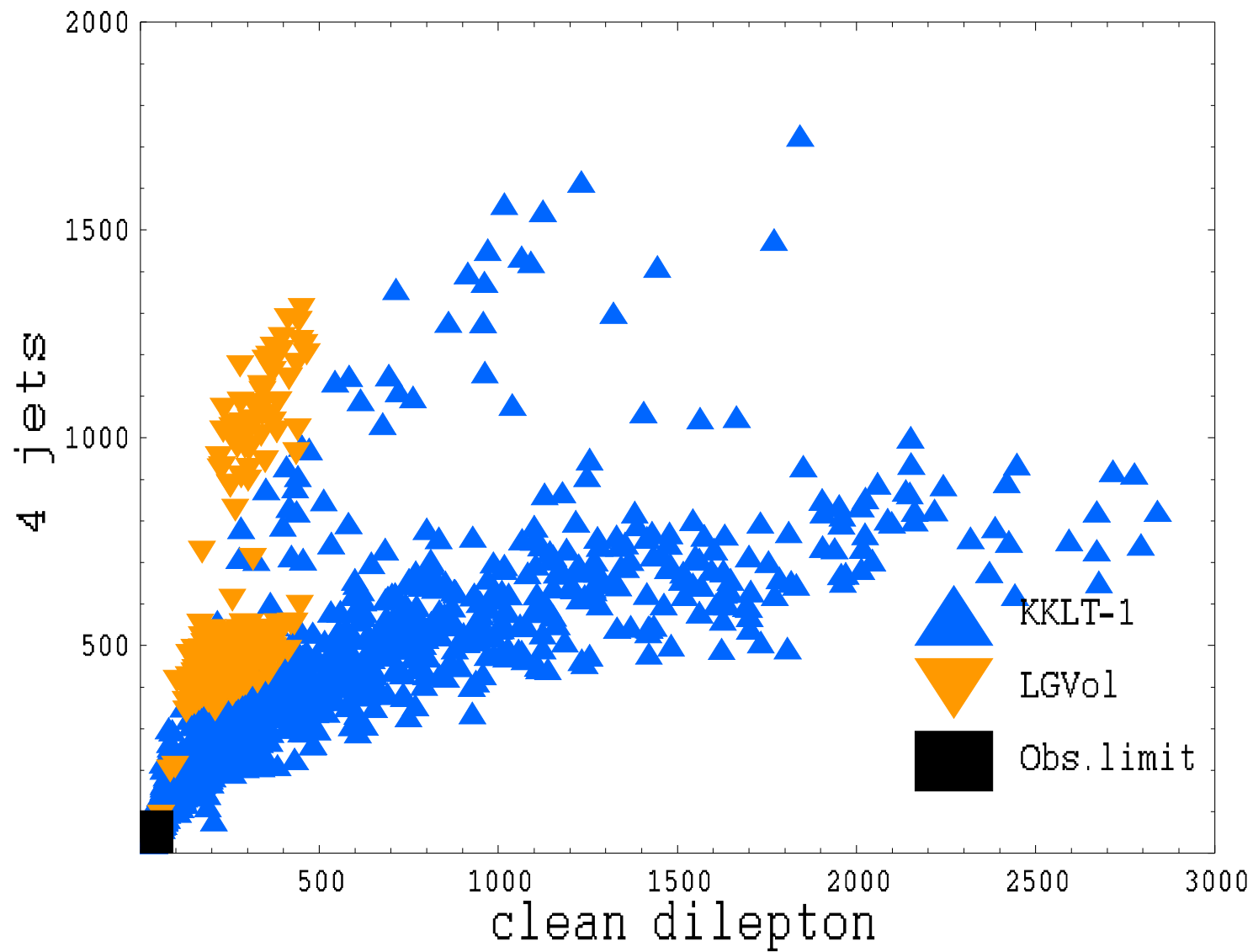
Peter's Talk

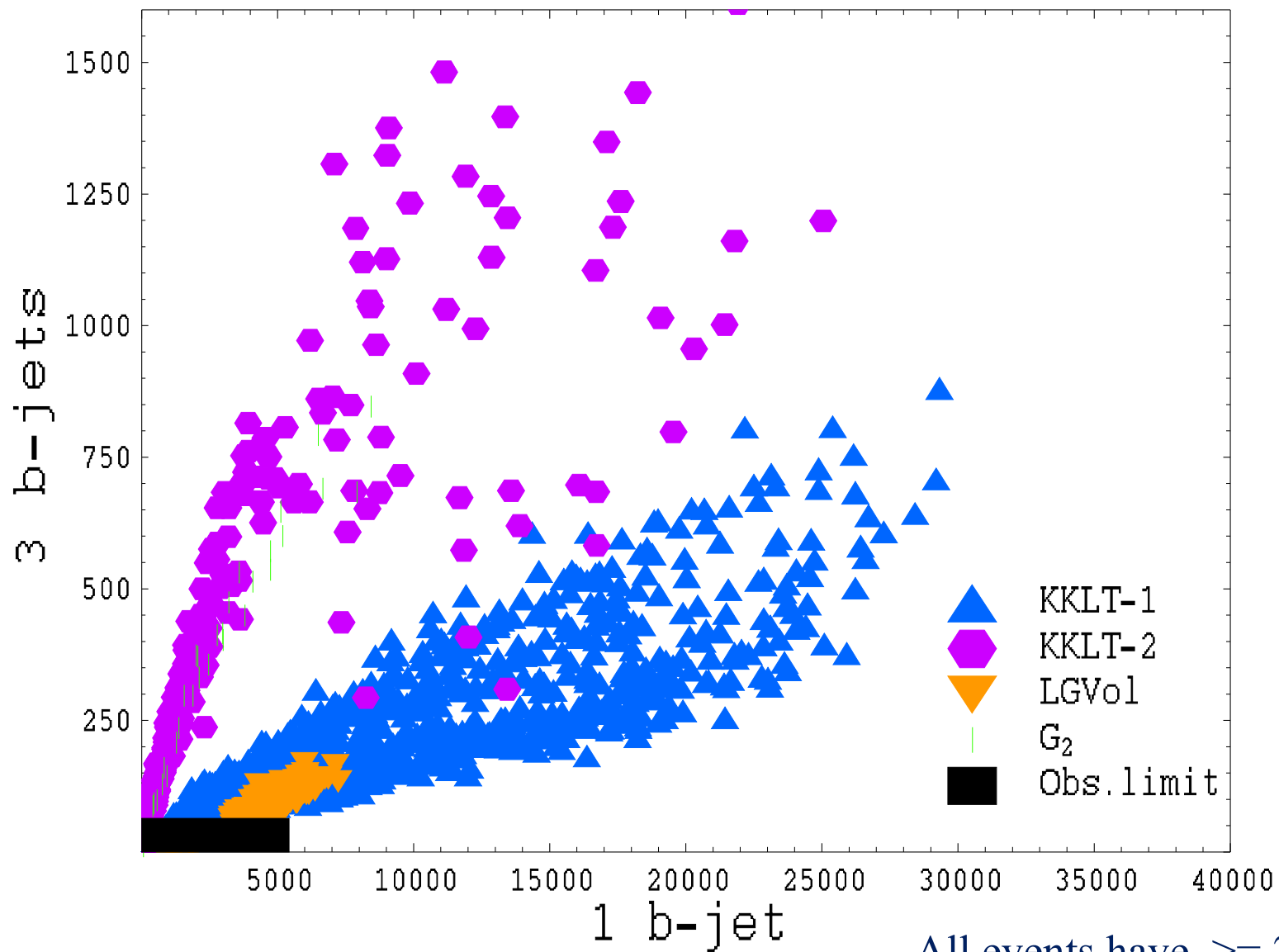


- Gaugino mass ratios are different for different models, which lead to difference in the jet multiplicity.

KKLT-1 has a smaller difference between the gluino and LSP compared to that in LGVol and  $G_2$  models. (for the same  $m_{\text{gluino}}$ )

Using a hard  $PT(\text{jet})$  cut ( $> 200 \text{ GeV}$ ), very few 4 jet events pass the cuts for KKLT-1 compared to LGVol as these events mostly come from  $\sim g\sim g$  production. So, this can partially distinguish among these frameworks. Overlap for heavy gluinos.

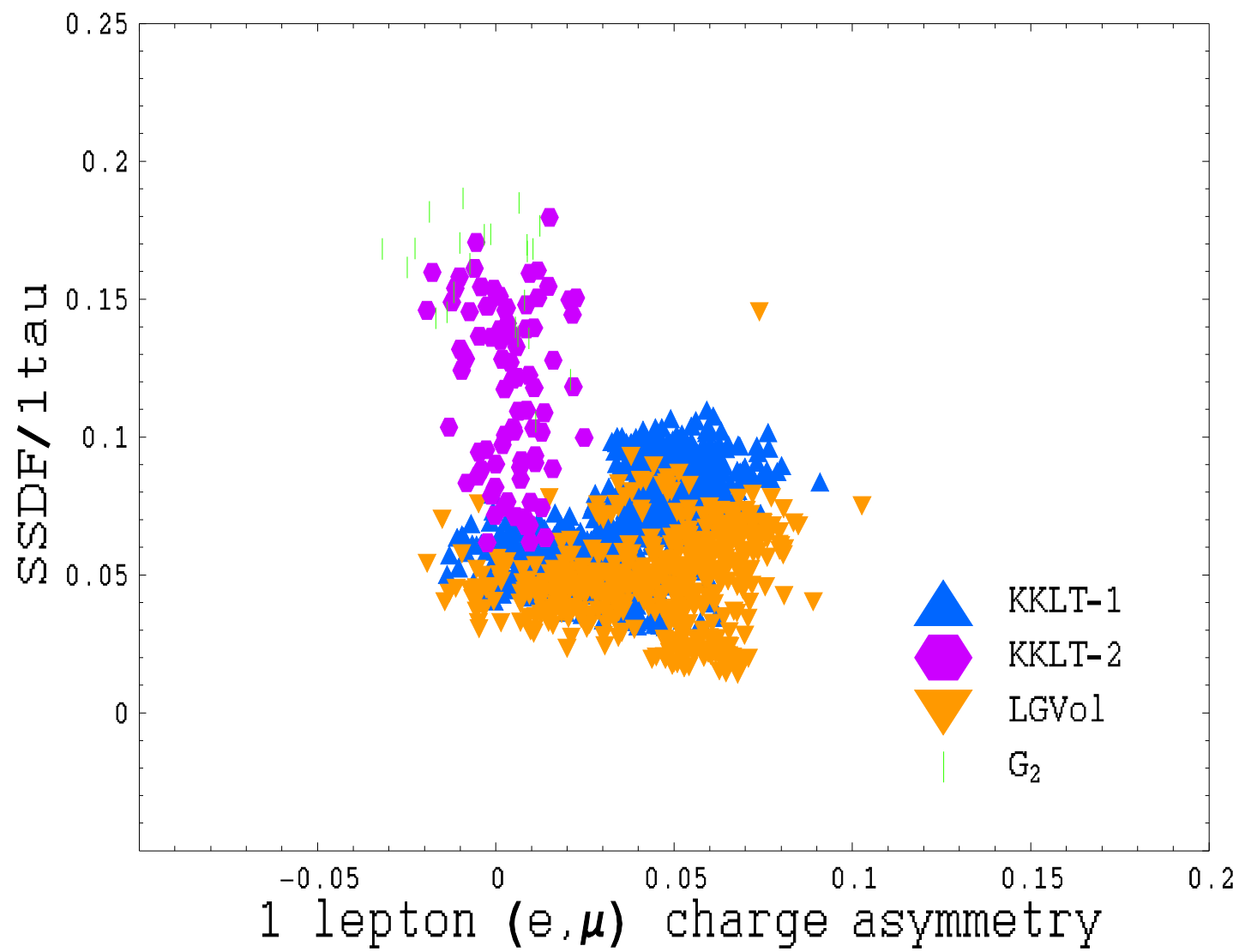




All events have  $\geq 2$  hard jets and large Missing ET

- For KKLT-1 and LGVol frameworks, turns out that squarks are lighter than gluinos. On the other hand, for  $G_2$ - and KKLT-2 models, squarks are heavier than gluinos.

$\tilde{q}\tilde{q}$  or  $\tilde{q}\tilde{g}$  production dominant for KKLT-1 and LGVol compared to  $\tilde{g}\tilde{g}$  for KKLT-2 and  $G_2$ . Leads to a difference in the lepton charge asymmetry.



## **□ Qualitative features of the spectra in terms of microscopic parameters.**

Can be understood as well. Explained in papers dealing with details of the framework.

# Systematic Way of Distinguishing Models

- Basic Idea

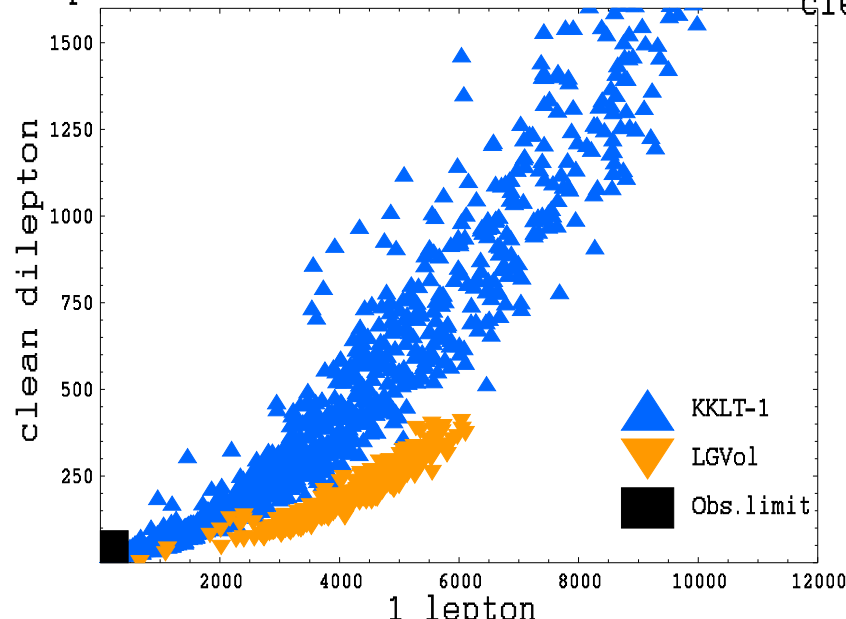
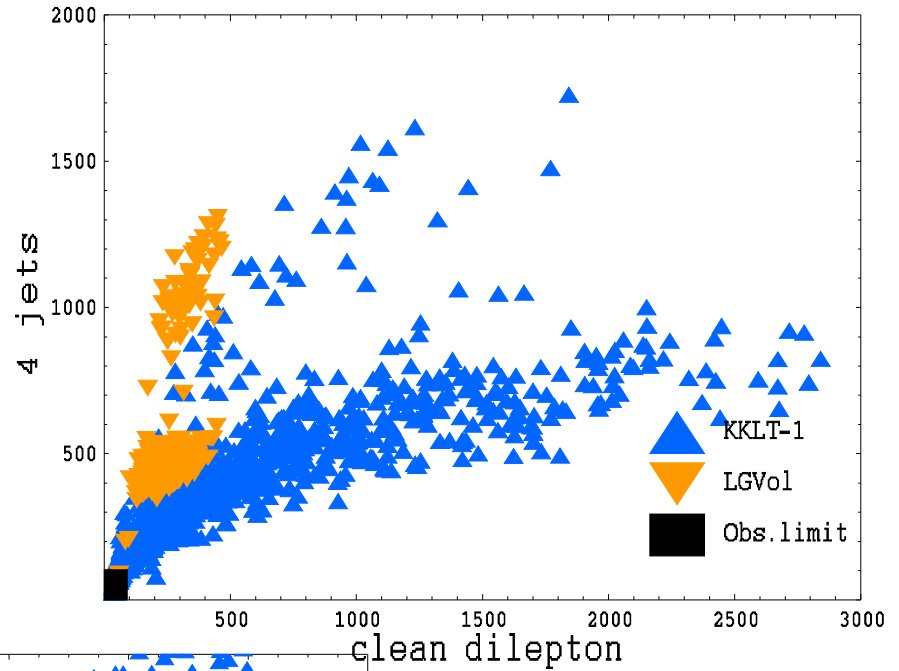
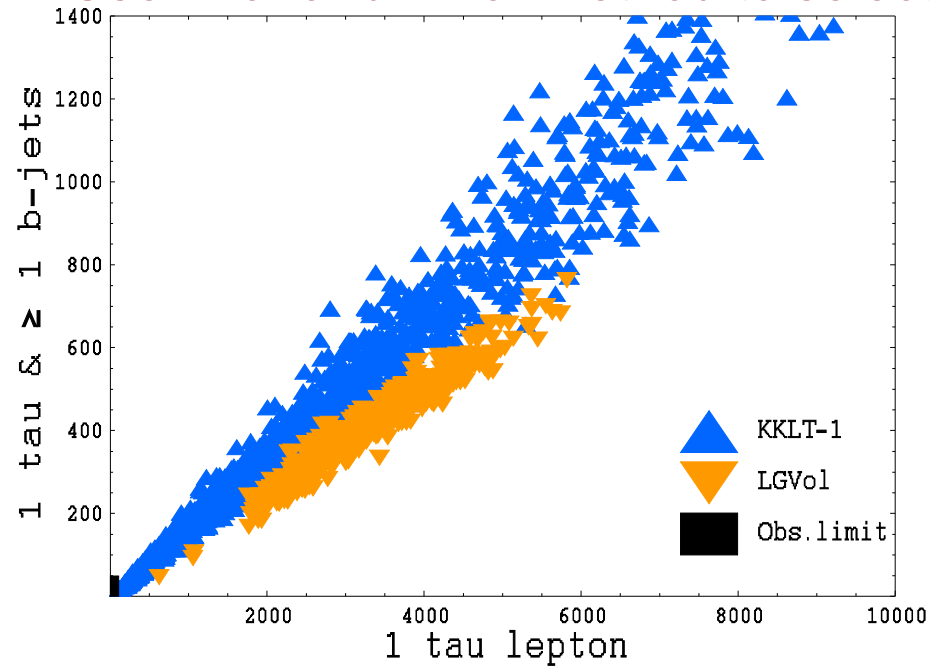
Look at various 2D signature plots, starting with the first plot, keep track of microscopic parameters and eliminate them if they are not in the overlap region, continue in this way until the number of models in the overlapping region vanishes or reaches a minimum.

More Technically,

- $$(\Delta S_{A_i B_j})^2 = \frac{1}{2} \left[ \left( \frac{s_x^{A_i} - s_x^{B_j}}{\sigma_x^{A_i B_j}} \right)^2 + \left( \frac{s_y^{A_i} - s_y^{B_j}}{\sigma_y^{A_i B_j}} \right)^2 \right],$$
- Two points  $A_i \in A$  and  $B_j \in B$  degenerate in 2D signature space (x,y) if  $(\Delta S_{A_i B_j})^2$  smaller than the statistical fluctuation  $(\Delta S_0)^2$ .

# Example – KKLT-1 and LGVol

- Use Trial-and-Error method to select “good” signature plots – converges fast



All signatures  
include large  
MET and  $\geq 2$   
jets



- KKLT (500 models) -- 119 → 4 → 0
- LARGE Volume (500 models) -- 237 → 17 → 0

The above implies that the number of models in the overlap quickly decreases if one uses “good” signatures. The precise number depends on how densely the parameter space is sampled.

To test robustness, we use 1000 more KKLT-1 models and repeat the Procedure. We find :

- KKLT (1500 models) -- 451 → 37 → 6
- LARGE Volume (500 models) -- 477 → 289 → 69

However, if use different combinations of the same signatures *in addition*, we find (with  $\Delta S_0 = 1.5$ )

- KKLT (1500 models) -- 451 → 37 → 6 → 4 → 1 → 0
- LARGE Volume (500 models) -- 477 → 289 → 69 → 11 → 1 → 0

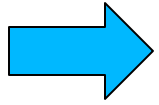
# When there is data

**Favor some frameworks over others.**

Iterative procedure required to untangle Physics at EW scale and to make connections with possible microscopic frameworks

 **Zoom in on frameworks which are consistent with data :**

- Use advanced collider analysis techniques with more luminosity (many groups working on these, but more needs to be done).
- Try to understand the frameworks better from a theoretical perspective and minimize assumptions.
- Bring them in contact with more expt. Observables including non-Collider ones, for eg. - Dark Matter,  $(g-2)_\mu$ , Rare Decays, Other astrophysical and Cosmological Observables, etc.



**Frameworks not favored by initial data may still not be ruled out**

One could consider variants with:

- Different mechanism of SUSY breaking (or explaining the hierarchy) and its mediation to the visible sector.
- Different Matter and Gauge Content.
- Intermediate Matter.

which could be compatible with the data.

This kind of analysis only possible by collaboration of theorists, phenomenologists and experimentalists.

# Conclusions

The LHC (and cosmological observations) present a great opportunity (although quite challenging) to connect string theory with the real world.

and ...

We may have a shot with lots of hard work and of course, luck.

**EXTRA SLIDES**

## Example – Characteristic Features of KKLT-1 Framework (kachru,kallosch,linde,trivedi)

- Type IIB  $N=1$ ,  $D=4$  compactification with all moduli stabilized in the SUGRA regime.
- Fluxes stabilize complex. structure and dilaton moduli. Obtain  $W_0$ .
- Non-pert. corrections to  $W$  stabilize the kahler moduli.
- Obtain SUSY AdS vacua.
- Use anti-D3 branes to break SUSY as well as tune the C.C.
- mechanism for generating  $O(\text{TeV})$   $m_{3/2}$  -- by requiring a flux  
(to solve the Hierarchy Problem) superpotential ( $W_0$ )  $\ll 1$ .

$$m_{3/2} \sim W_0 / V \quad (\text{in Planck units})$$

Described by Microscopic Parameters :  $\{ (W_0/V = m_{3/2}), \alpha, n_l, n_q, n_h \}$ ;  
 Similarly for other frameworks ( $\tan\beta$ )

## Other Examples – Very Brief

- **LARGE Volume Vacua**  
(Balasubramanian, Conlon, Quevedo.)
  - Also Type IIB, but now  $W_0 \sim O(1)$ .
  - SUSY broken predominantly by fluxes.
  - Vacua in different region of moduli space compared to KKLT-1.
- **Fluxless M Theory Vacua**  
(Acharya, Bobkov, Kane, PK, Shao)  
*Phys. Rev. Lett. 2006;hep-th/0701034*
  - N=1, D=4 compactifications ( $G_2$  holonomy)
  - Stabilize moduli and generate Hierarchy by strong gauge dynamics.
  - Obtain metastable dS vacua consistent with standard gauge unification.

**For distributions, sometimes more useful to use  
quantiles (deciles) to represent them.**

