LHC and string theory!!

- ❑ Can we interpret the new physics when it is discovered?
- ❑ Can we relate it to the underlying theory?

GK, Piyush Kumar, Jing Shao

hep-ph/0610038, and paper in preparation

Earlier approach hep-ph/0312248, Binetruy, GK, Nelson, Liantao Wang, Ting Wang

Gordy Kane

CERN, August 07

INTRODUCTION

Suppose LHC reports a signal beyond the SM

- Experimenters and SM theorists will get that right

WANT TO INTERPRET IT! Usual approach:

- Is it really supersymmetry? -- What superpartners are produced? -- Soft-breaking parameters?
- L_{soft} (EW)?
- L_{soft} (Unif)?
- Underlying theory?

"LHC inverse problem"

CHALLENGING!

-- there has been some study of EW scale issues

Effective Lagrangians, degeneracies, marmoset; Feldman, Liu, Nath

-- essentially no systematic study of high scale interpretation

Kumar, GK, Morrissey, Toharia; Choi, Nilles

Philosophy

- We live in a string vacuum
- Want to get evidence for that from data
- Want to learn some things about that vacuum

-- origin of matter? Why >1 family?
-- softly-broken N=1 supersymmetry?
-- origin of forces?
-- origin of EW scale, ~ TeV?
-- origin of Higgs mechanism?
-- nature of DM – LSP type?
-- origin of CPV?
-- origin of matter asymmetry?
-- inflaton?
-- how is our vacuum related to other string vacua?

For most of these need to understand susy breaking

So need to connect LHC and string theory

Most work relating to underlying theory – calculate top-down example, with specific guessed parameters -- hope what is found can be recognized as what was calculated

Today argue that phenomenologically it makes sense to try to map LHC signatures onto string theory – encourage doing that

Think about what experimenters actually report -- "signatures"

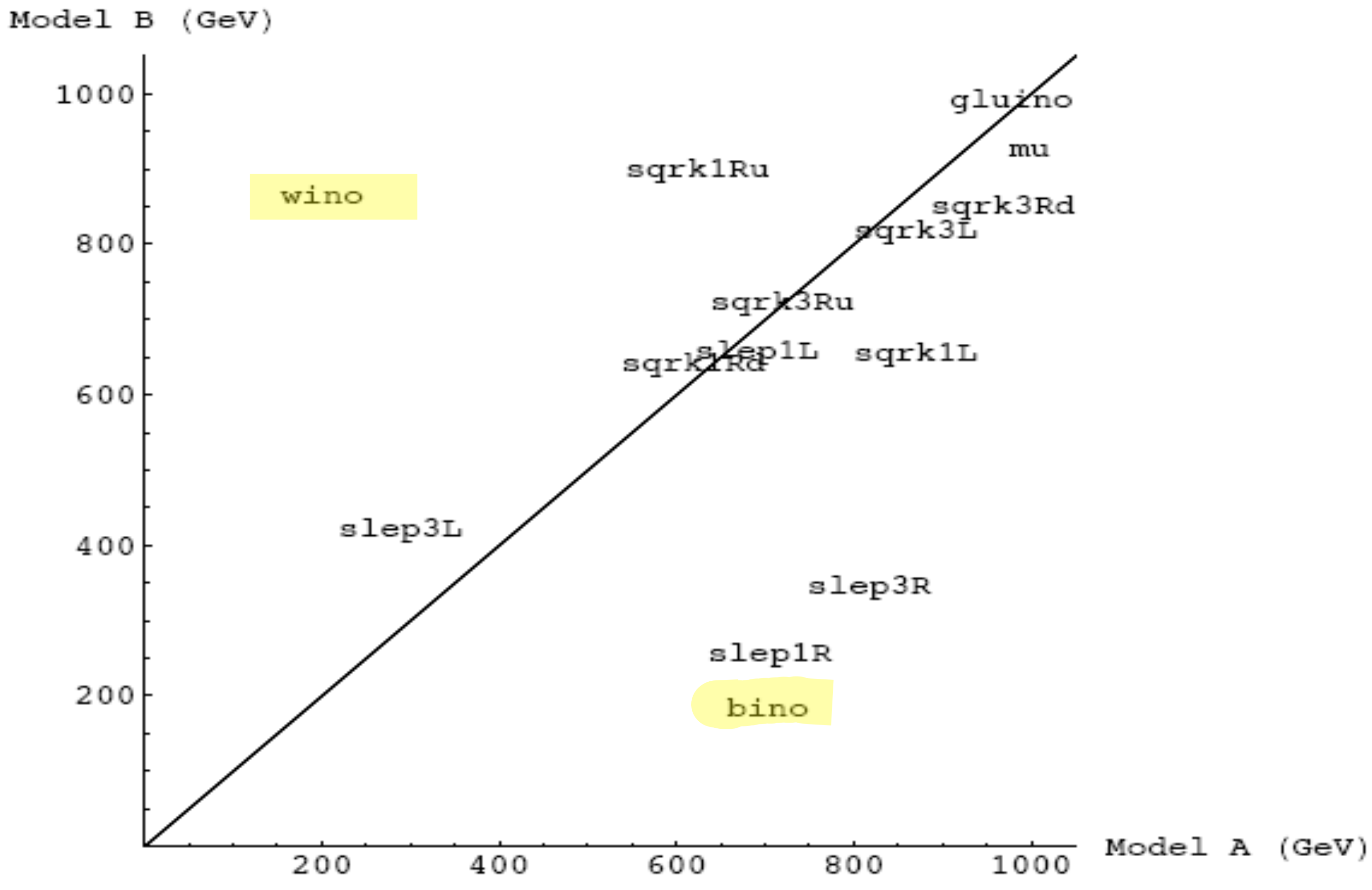
-- e.g. number of events with $\not{E}_T$ > 100 GeV, 2 or more jets (E>50 GeV), etc, and distribution of such events vs. P_T of most energetic jet – and number of events with lepton pairs with same sign charge and opposite flavor and $\not{E}_T$>100GeV, etc

In addition to usual issues, such as recognizing what particles give the signatures, there are degeneracies – same LHC signatures from different sets of soft parameters

[Arkani-Hamed, GK, Thaler, Wang ph/0512190]

Two models with same signatures but different parameters and very different physics

Flippers: 17653 vs. 20026



Note degeneracy issue from point of view of string theory – underlying (string) theory will have some not-yet-determined parameters (that affect collider results) at its natural scale ~ M_{pl} – the low scale effective theory will have many parameters, e.g. the 105 parameters of L_{soft} – but all those are calculable from the underlying theory – if express the (~ 20) collider parameters in terms of the high scale underlying theory parameters, many degeneracies are eliminated

Of course, don't know the correct underlying theory (yet)

In general not possible to reconstruct lots of superpartner masses, particularly at low integrated luminosity, over next few years

But the signatures do depend on masses, and so the patterns of signatures reflect the masses

Could pursue this approach in any theory – use string theory since well motivated, addresses all issues (but Λ) -- can do reliable calculations in cases with moduli stabilized – currently several known, so can compare – have string-based models that esentially have SM, GCU, supersymmetry

Carry out effective theory low scale analyses and this approach in parallel

SO – PROCEED TO CALCULATE STRING THEORY PREDICTIONS FOR LHC DATA

-- pick some corner of "string theory", e.g. heterotic, or IIA, or M theory, etc

-- compactify to 4D – on Z_3 orbifold, or appropriate D-branes, or C-Y 6D space, or 7D manifold with G_2 holonomy, etc

-- stabilize moduli, break supersymmetry and establish mediation mechanism – higgen sector gaugino condensation, or anti-D-brane, etc

-- generate or accommodate Planck-EW hierarchy

-- take 4D field theory limit, e.g. supergravity

-- set CC const to be small

→ "string-susy-model"

There already exist constructions that allow most of above – may also have matter spectrum calculated -- make reasonable assumptions about visible matter spectrum, MSSM

Later look for additional constructions and variations on these

- Write high (~compactification) scale string theory effective 4D Lagrangian – e.g. determine f, W, K from underlying microscopic theory – use supergravity techniques to calculate L_{soft} – gives initial conditions for calculating collider scale values

- Use RGEs to run down to EW scale – programs already exist for MSSM and some extensions, softsusy, spheno, suspect…

- Impose constraints – consistent EW symmetry breaking – experimental bounds on higgs, superpartner masses – upper bound on LSP relic density – CPV and flavor constraints, etc – in a complete model more can be calculated

- Generate events for short distance processes such as superpartner production, with Pythia, madgraph, alpgen, comphep (calchep), herwig

- Hadronize to long distances, quarks and gluons into jets, decay taus – pythia, isajet, herwig

- Cuts, triggering, combine overlapping jets – PGS

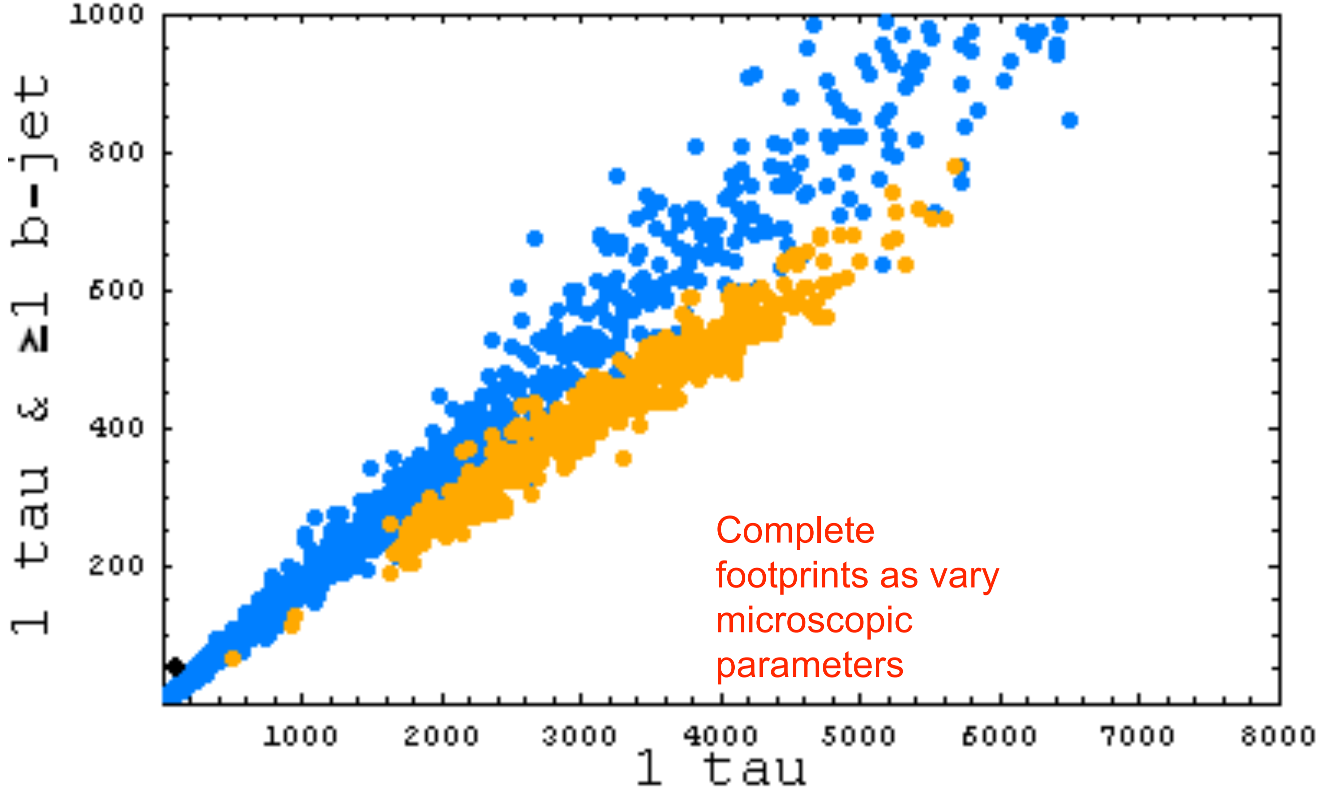
Sounds complicated

But software exists for every part – as a result of LHC Olympics, software user friendly, and mostly linked – useable for some new physics models or MSSM plus some exotics – software being improved

Can access most software at LHCO website

Vary all the as-yet unknown microscopic parameters that may affect LHC predictions – e.g. modular weights, rank of gaugino condensation groups, integer coefficients of moduli in G_2 gauge kinetic function, etc

→ "footprint" of that string-susy-model in "signature space"



Pt (Jet) > 200GeV, Pt (Lepton)>10GeV,
Missing Et > 100GeV

CLAIM 1

- For any string-susy-model, one can meaningfully calculate experimental low scale observables (such as LHC signatures) from the string construction -- the footprint in signature space and for distributions is interestingly-limited, and characteristic

True for all we have looked at, and easily understandable and expected

Even early at LHC will have many signatures and distributions

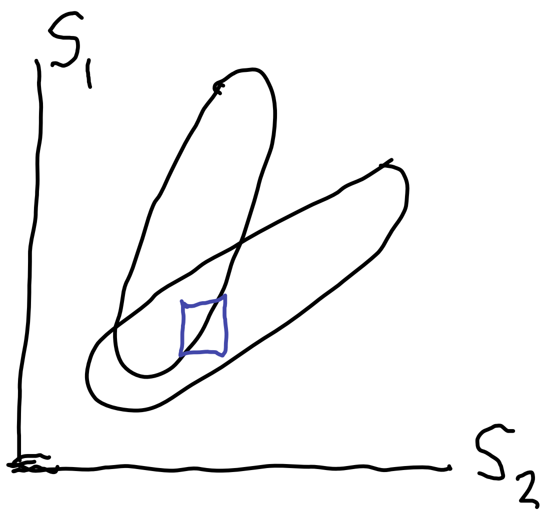
- Take all events with $\not{E}_T$ > 100 GeV
- Split into "2 or more jets" vs "1 or no jets"
- No charged leptons; one lepton; two leptons with SSSF, SSDF, OSSF, OSDF; trileptons
- Etc

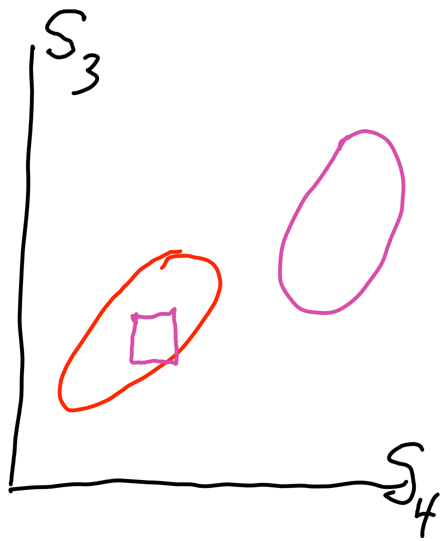
Imagine a signature space, S1, S2, … Sn

Plot in (many) pairs:

In general any two different string-models have different footprints, maybe overlapping in any given signature space plot

The parameters for which they overlap in one signature space plot are in general different from those for a different plot





Focus here on two Type IIB N=1 compactifications, plus M theory compactified on a manifold with G_2 holonomy – main examples for which moduli stabilized

KKLT1, KKLT2

LARGE volume

G_2

Discuss constructions with moduli stabilized so don't worry results could change – would like lots more – for each, would like to vary compactification and ~~SUSY~~, etc, too

CLAIM 2

- The pattern of signature space and distribution plots will distinguish string-susy-model predictions

CLAIM 3

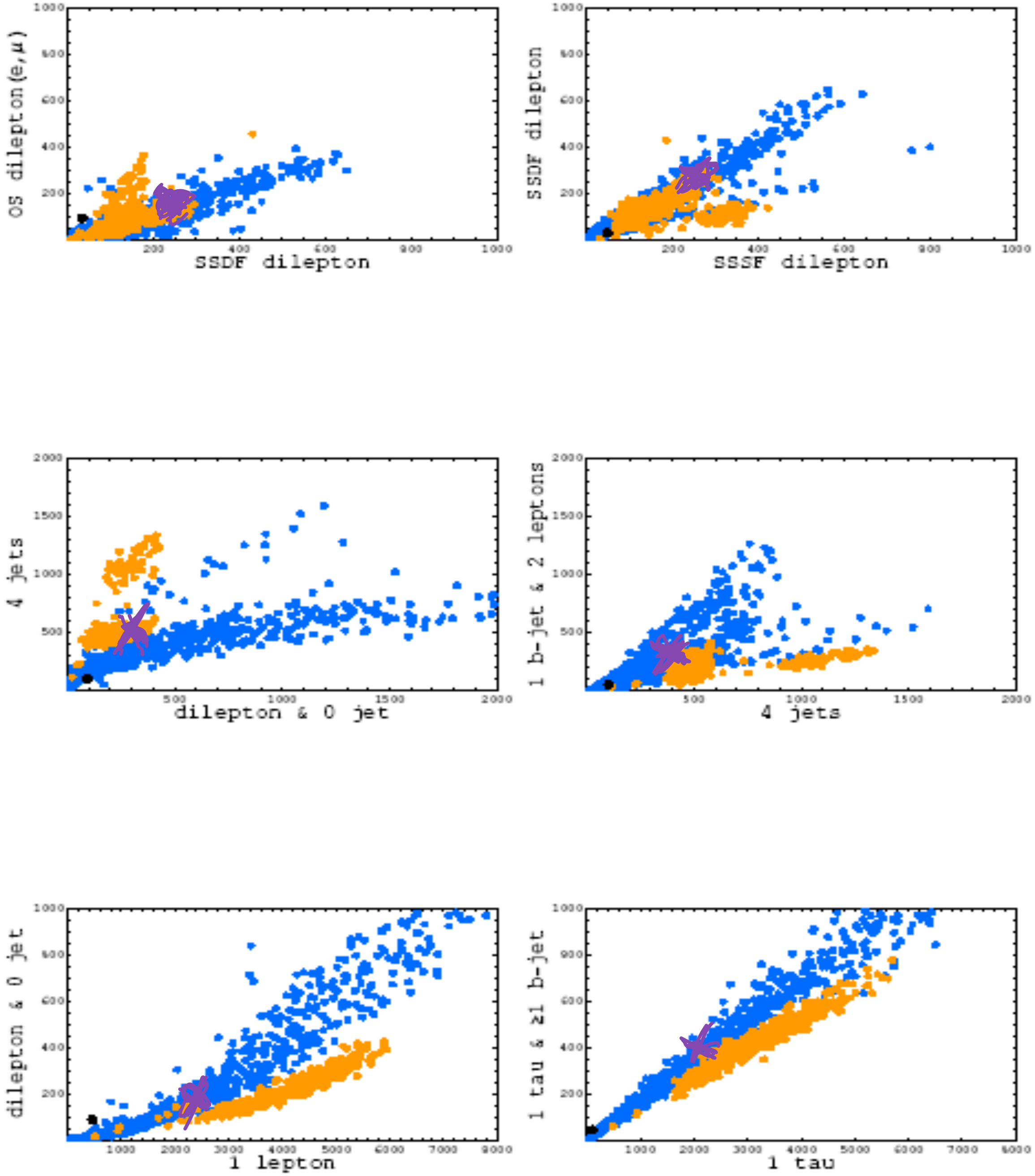
- When there is data, it will point toward some corners of string theory (or none), and away from others

SM backgrounds?

-- when there is a real signal experimenters will report the excesses – some signatures yes, some not – both contain useful information

-- we have found a good way to study issues is to estimate the level at which SM processes will enter and just indicate that on the plots

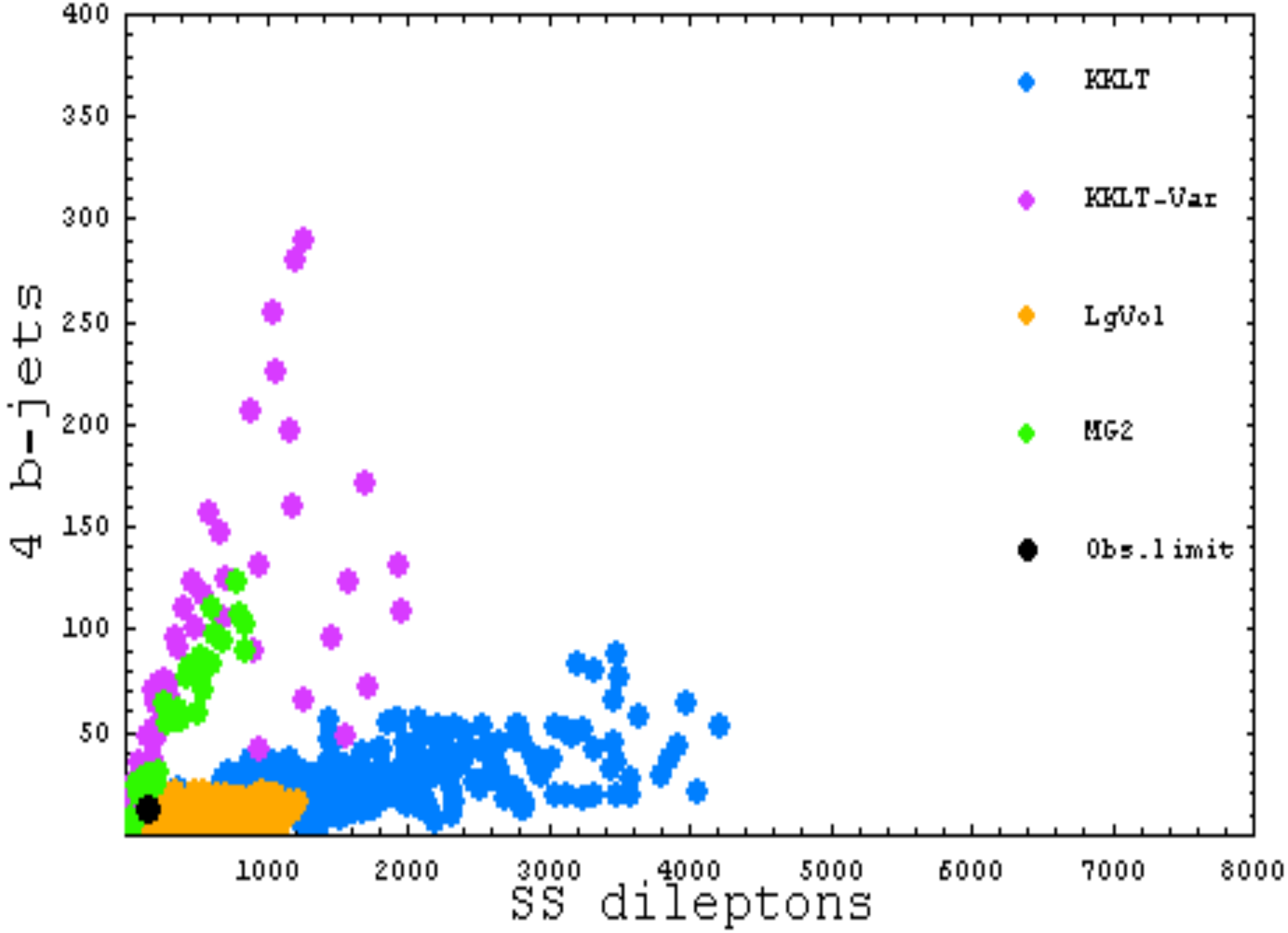
All event rates for 5 fb^{-1}



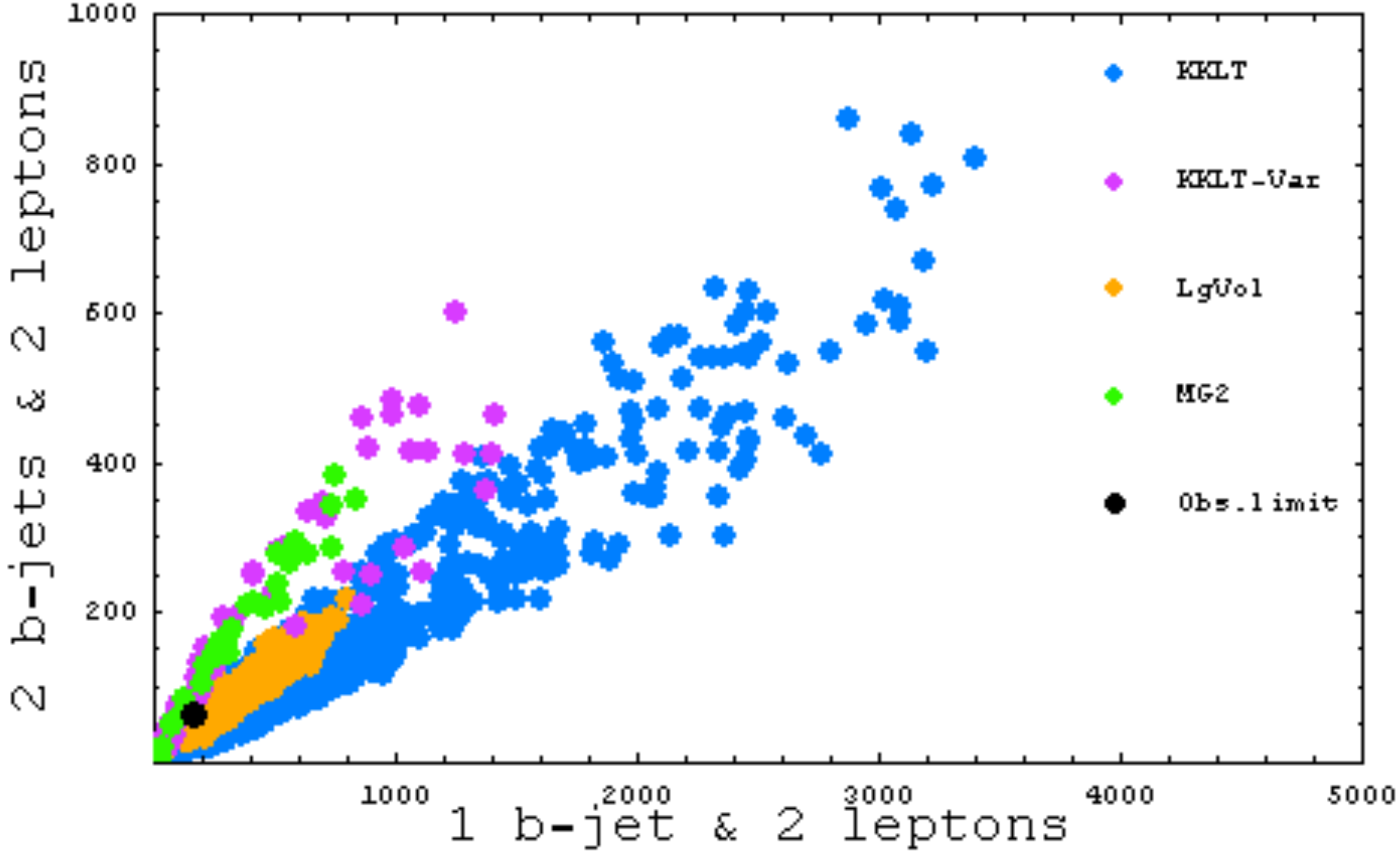
KKLT1 vs LARGE volume

$$\text{KKLT}: \qquad 353 \to 231 \to 79 \to 6 \to 2 \to 0$$

$$\text{LgVol}: \qquad 458 \to 396 \to 315 \to 86 \to 32 \to 0$$



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



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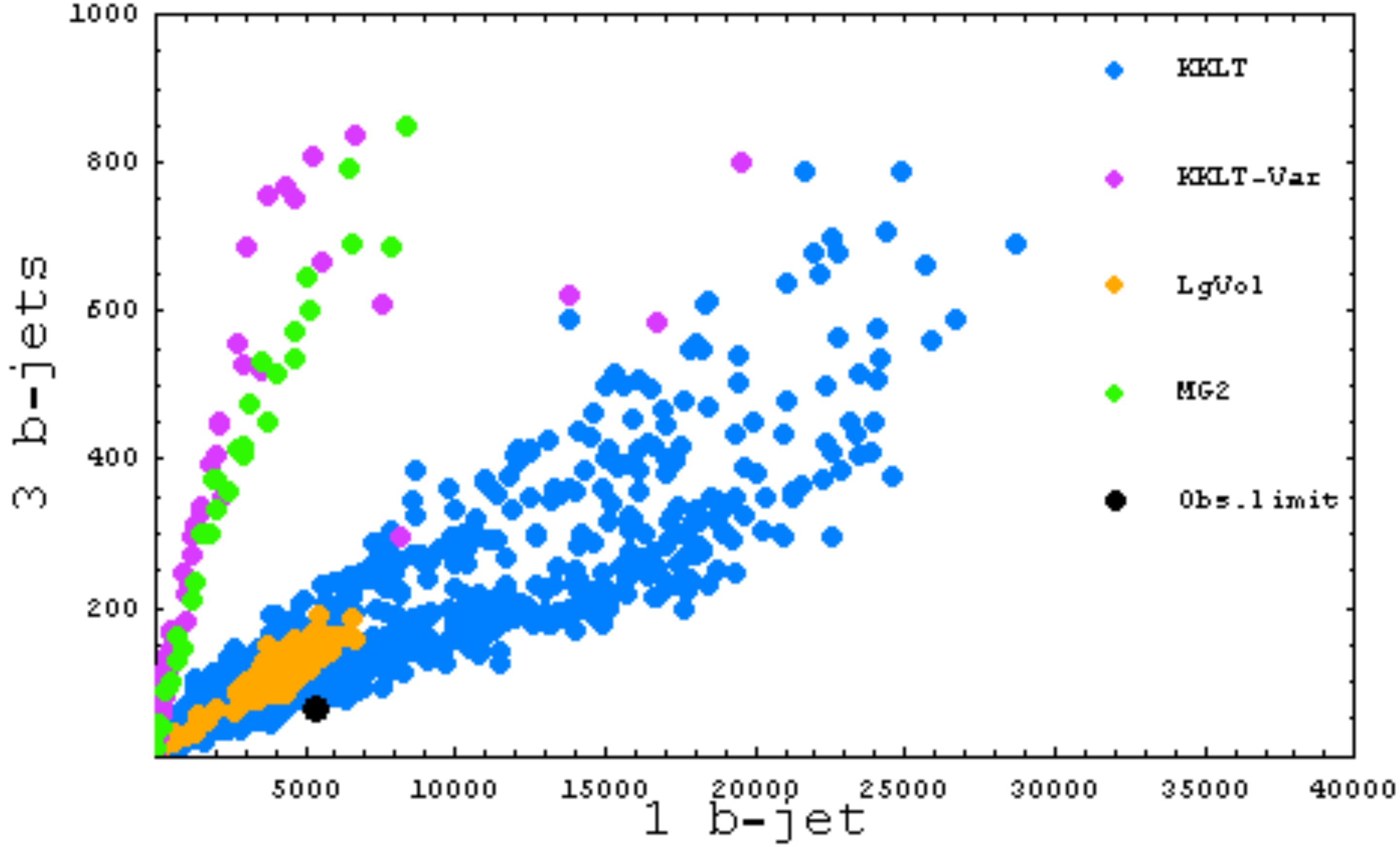

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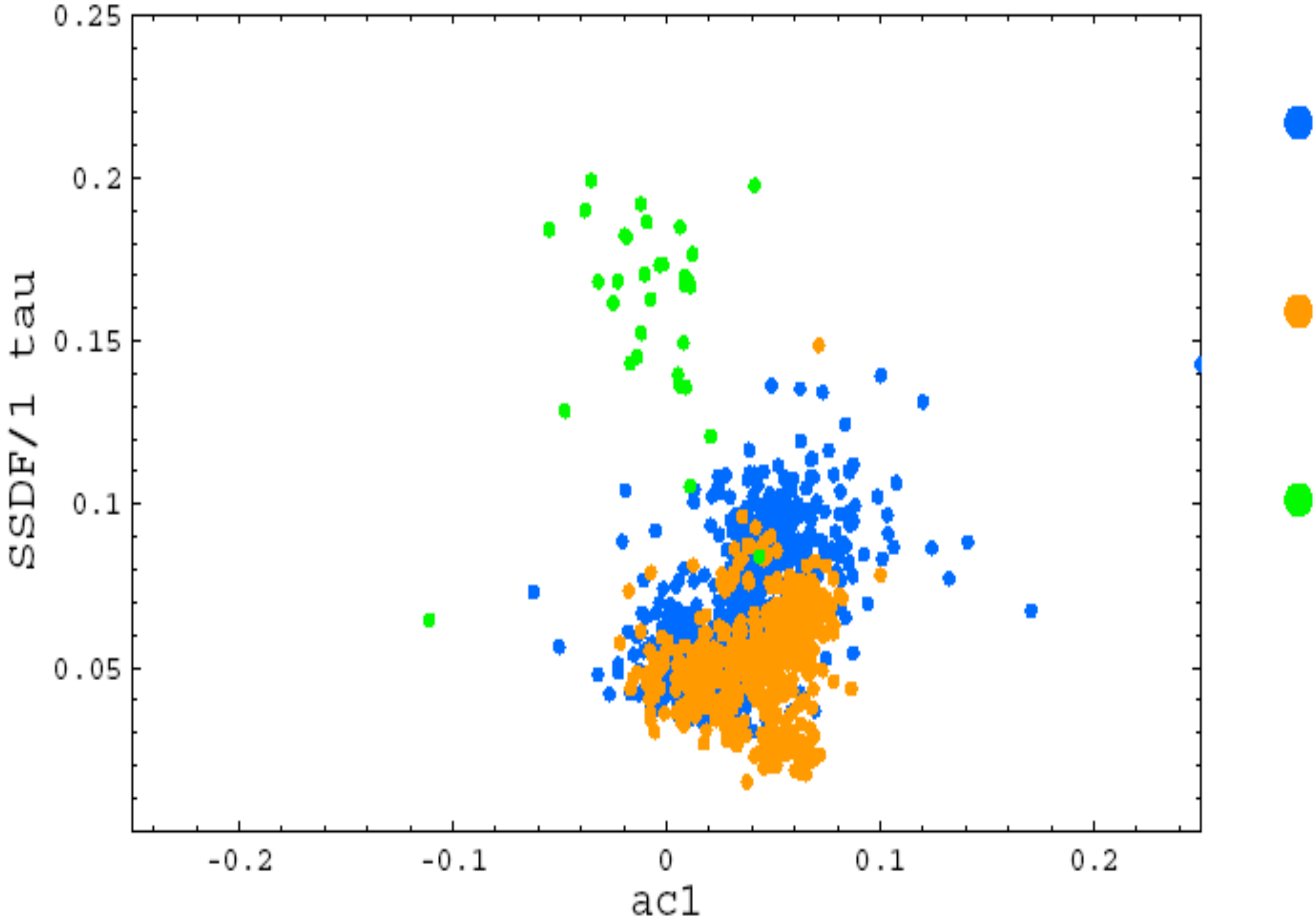
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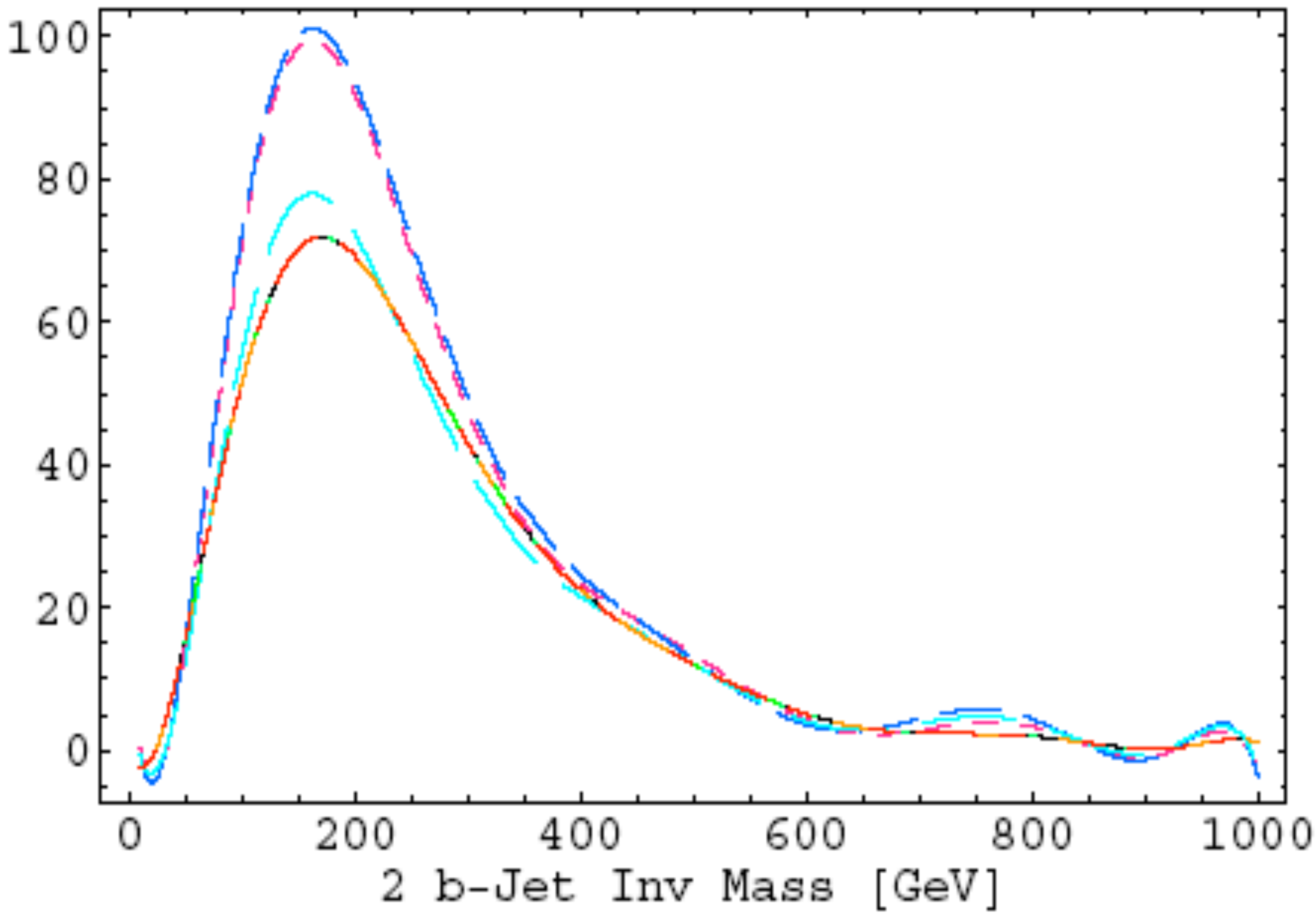
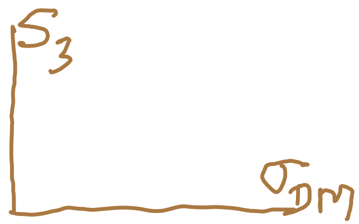


Figure 3: 2 b-jet invariant mass spreading for G_2 models

When there is data, put it on plots, point toward some theories and away from others – then focus on promising ones!

Zoom in, look at subsets of signatures for channels with a lot of events – take theories that work and calculate more predictions – distinguish better with more luminosity

Note with this method can include dark matter if you trust the cosmology (which is likely to be a part of the theory, e.g. thermal or non-thermal DM)



Can include g-2 – sensitive to tanβ

If the theory incorporates flavor and phases can also include rare decays, EDMs, etc.

CLAIM 4

- ❑ Can always understand how string-susy-theories differ in qualitative terms

e.g.

-- universality of tree level gaugino masses?

[Choi and Nilles, ph/07-2146]

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

-- origin, size of μ, Bμ?

-- hierarchy of scalar vs gaugino masses?

-- nature and content of LSP

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

This approach will be much more powerful if a number of people study it, calculate for different string-models, look for weaknesses – make catalog of footprints of string-susy-models, e.g. several ways of compactifying – study very different “corners” of M-theory

Need more constructions → L_{soft} at string scale, varying general construction and also compactification, how susy broken, etc

Why String Phenomenology at all?

-- Do not yet have non-perturbative and background independent definition of String/M theory.

-- Poor understanding of the full M theory landscape.

-- "Can get anything from every string theory"

-- Just wait?

No, because,

1) Some corners of the M theory Moduli space already reasonably well understood.
2) Many features of the SM can be naturally obtained in string theory -- non-abelian gauge fields, chiral fermions, hierarchical yukawas, etc.
3) Recently, considerable progress in dynamical issues as well -- moduli stabilization and ~~SUSY~~.
4) Actually a given string theory gives very limited and characteristic predictions
5) ***I think string theorists will learn a lot about string theory by studying its phenomenology as well as the theory***

There are many string theories – unlikely to find relevant ones?

No, choices of string theories to study is not random – select those that can give SM-like spectra, softly-broken N=1 supersymmetry, inflation, dark matter, etc.

REMEMBER

- ❖ New approach to relating collider data and phenomenology, model building, and underlying string theory
- ❖ Different classes of string constructions give limited footprints in signature space
- ❖ LHC signatures of a particular class of vacua sensitive to at least some of the underlying structure of the theory
- ❖ Different string constructions can be distinguished by systematically adding and studying pattern of signature space plots and distributions, and qualitatively understand why – also dark matter, etc
- ❖ Software, techniques already exist to carry out such a program – can be improved – e.g. not full RGEs for all exotics
- ❖ Need much more study of useful and interesting signature space plots
- ❖ Needs to be studied for more string constructions, and more complete string constructions – connect matter and gauge group form, and inflation etc – non-collider observables
- ❖ Consistent with having lots of string solutions, and lack of a dynamical vacuum selection principle – we do live in a particular string vacuum and we want to know more about it
- ❖ Learn lots about string theory by doing such analyses