SLAC
HEP
Theory Group

M. E. Peskin
2008 Program Review

The SLAC HEP Theory Group is one of the largest theoretical physics groups in high-energy physics, and also, we feel, one of the best.

We are: 8 faculty members + 2 senior staff (7 + 1.5 FTE)

8 postdoctoral fellows (7.5 FTE)

14 Stanford graduate students (11 FTE)

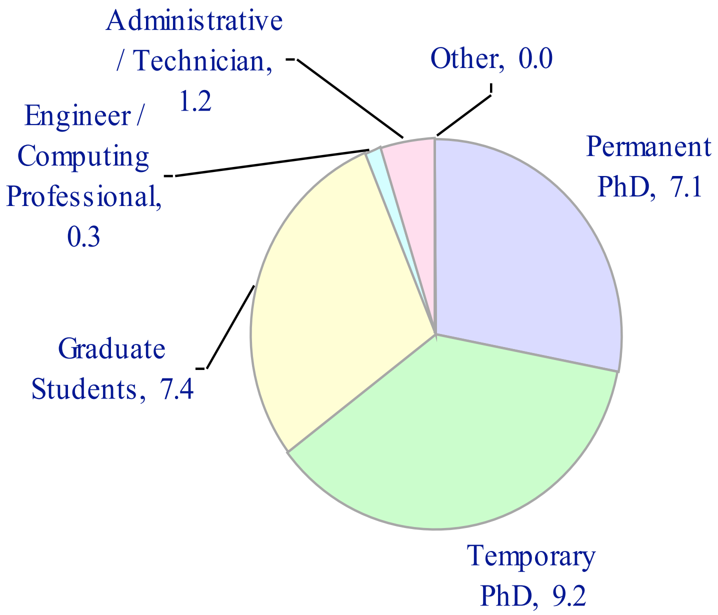
long- and short-term visitors

and strong collaborations with Stanford, UCSC

The interests of the group cover all aspects of theoretical high-energy physics from hadron structure to string cosmology.

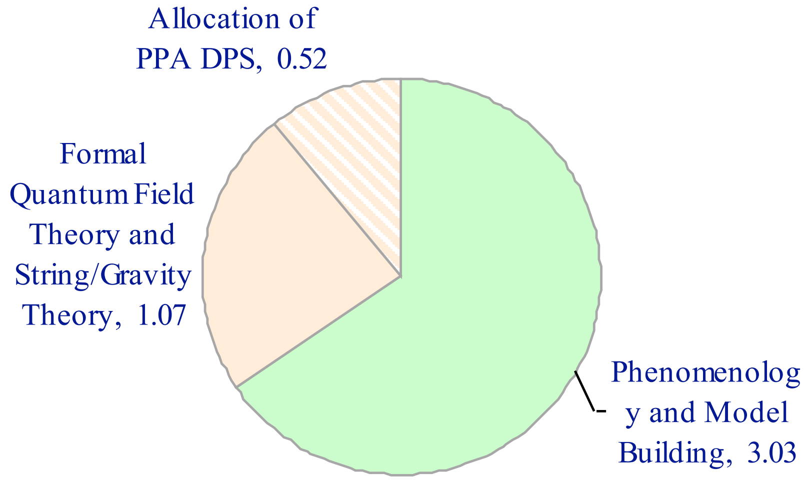
All of this will be detailed in the parallel session tomorrow.

Overview of Financial Data FY 2008



FY 2008 FTE by Job Category
Theory

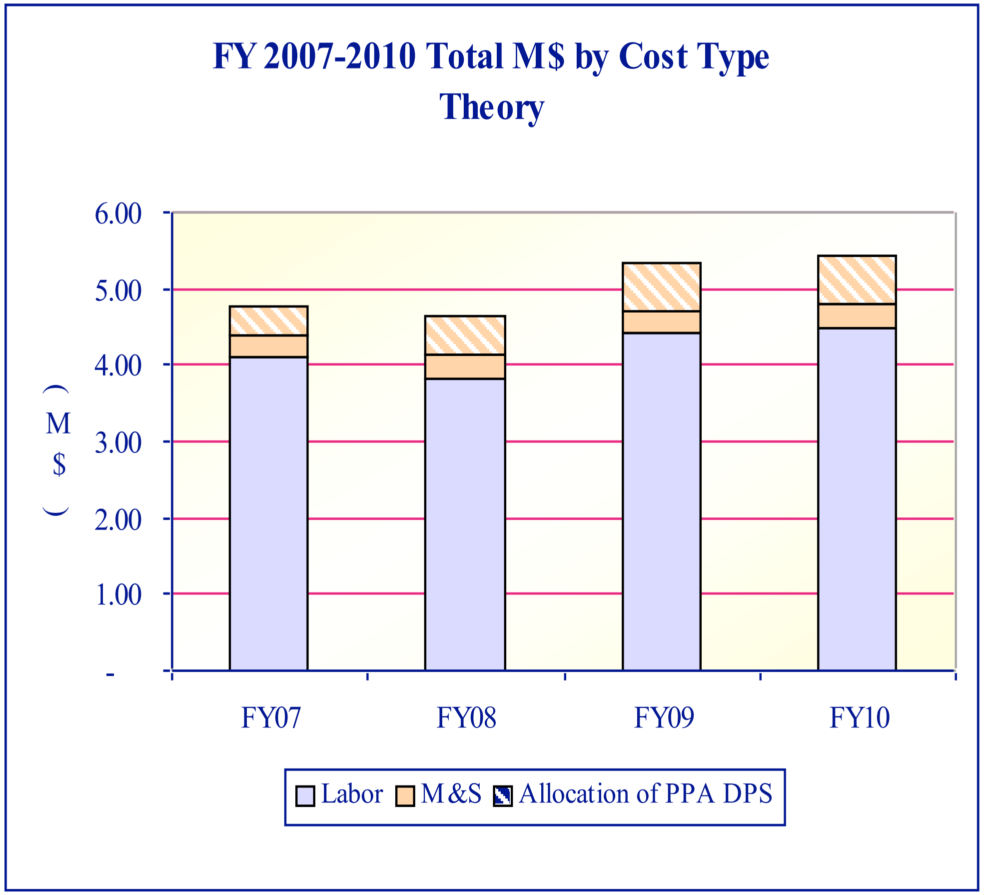
Total FTE: 25.3

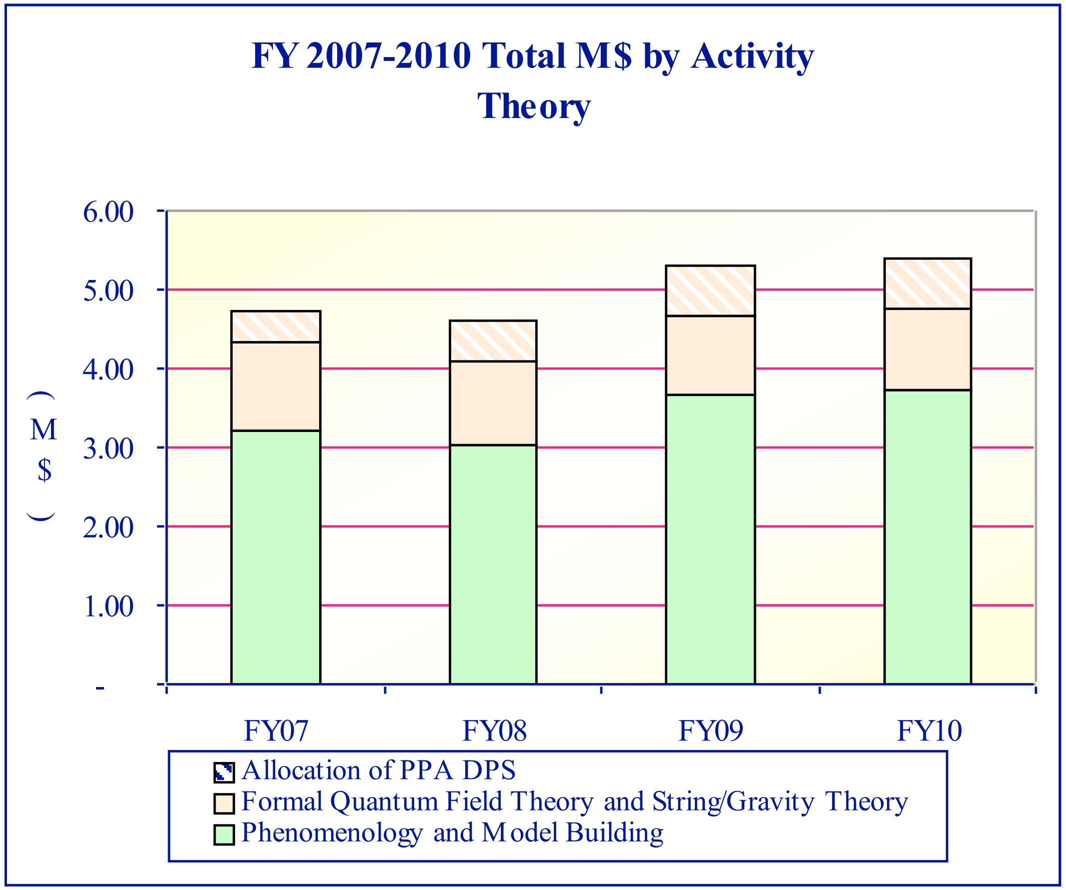


FY 2008 Total M$ by Activity
Theory

Total M$ of Theory: 4.1

Overview of Financial Data FY 2007 - 10





(pending review of the 6 National Laboratory theory groups later this month)

In this talk, I will first discuss our vision for the future of the SLAC HEP Theory Group.

Then I will give three examples from our current research

- the state of the art in QFT loop calculations
- supersymmetry phenomenology without prejudice
- superstrings and the cosmic microwave background

Experiments in HEP are becoming increasingly consolidated, with fewer spigots and larger collaborations.

At the same time, we are increasing our ability to communicate and to distribute data worldwide. BaBar and DO have demonstrated that experimental collaborators can contribute creative new analyses at an ocean's remove from the accelerator.

The LHC carries this model to the extreme: one accelerator for the world community. The start of LHC physics forces us to move aggressively to this new mode of working.

To be successful, this new mode requires regional centers of expertise. SLAC, partnering with LBL and UCSC, is well along in building such a center for the ATLAS collaboration.

In the SLAC HEP Theory Group, we have oriented ourselves strongly to LHC physics.

We believe that the next important developments in high-energy physics will come from
new particles spectroscopy at the TeV energy scale.

This belief drives our theoretical program and our relation to experiments, here and elsewhere.

Accordingly, the HEP Theory Group has build up expertise in all of the areas required for LHC physics:

computational QCD :

NNLO Drell-Yan and Higgs, NLO multi-parton amplitudes

collider phenomenology :

key observables for extra-dimensions, non-mSUGRA SUSY

model building :

(new approaches: “sweeet spot”, “quirks”)

event generation :

basic development; members of MadGraph and SHERPA teams

The HEP theory group has a close relationship with the SLAC ATLAS group, including a joint seminar (open by phone-meeting).

We are starting a working group on data-driven estimates of MET backgrounds (A. Schwartzman, P. Schuster, N. Toro)

M. Peskin and R. Cahn (LBL) organize the West Coast LHC Theory Network meetings, a series of 1-day meetings to educate university and lab theories and to encourage collaboration on problems related to LHC.

We see it as our responsibility to provide resources both for experimenters and for university theorists in the West Coast region.

Stanford is an important center for studies of dark matter (CDMS, GLAST, LSST, astrophysical theory). We are keenly interested in linking new results in this area to discoveries at the LHC.

Though our largest activity is now LHC physics, we have activities in many other areas:

Brodsky has lectured extensively on the theory of the \`light-cone wavefunction', which has emerged as a major tool in low-energy QCD, nuclear QCD, and 'hadron physics'.

We continue to be involved in the BaBar data analysis.

Kachru and Silverstein interact with KIPAC experiments on the cosmic microwave background.

Our group played a major role in making the physics case for a high-energy e+e- linear collider. We will continue to work with experimenters and accelerator-builders to see that an international linear collider is constructed.

Now I will present some recent research results from our group.

First, perturbative QCD:

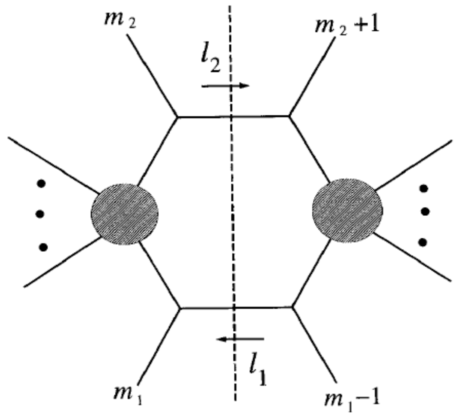
There is no question that we need very accurate QCD calculations for the LHC, both to understand the basic Standard Model processes and to evaluate backgrounds to new physics.

State of the art Monte Carlos for W + jets are still based on LO QCD. We need new methods; where will they come from ?

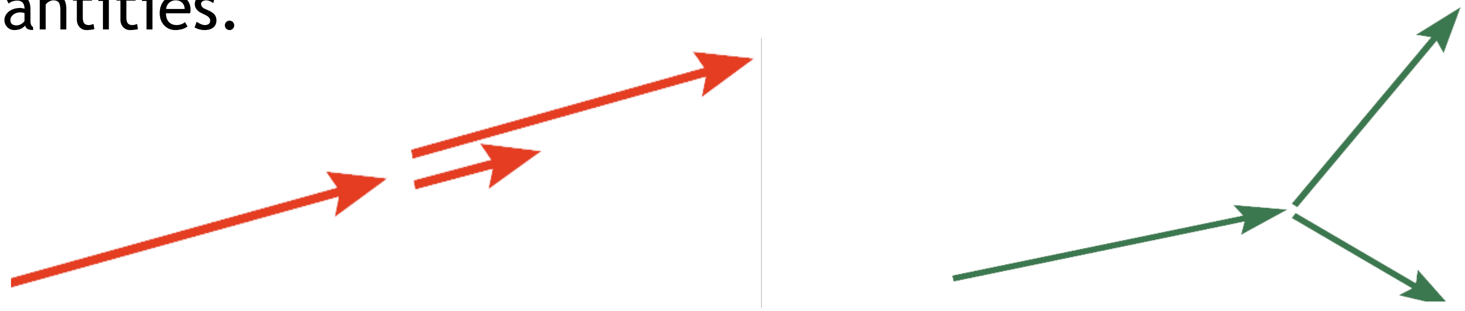
In the past few years, there has been tremendous development in methods for NLO QCD, based on

the unitarity method (Bern, Dixon, and Kosower)
complex momenta (Witten; Britto, Cachazo, and Feng).

The unitarity method allows reconstruction of loop integrals from unitarity cuts. This was first applied to N=4 super-Yang-Mills, where a small and denumerable set of basic integrals arise.



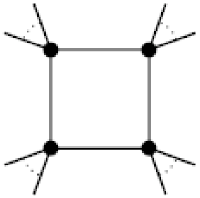
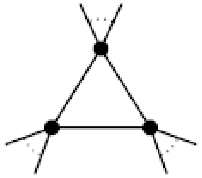
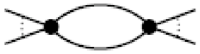
Complex momenta allow on-shell gauge theory amplitudes to be built up from the on-shell 3-point amplitude bypassing off-shell quantities.



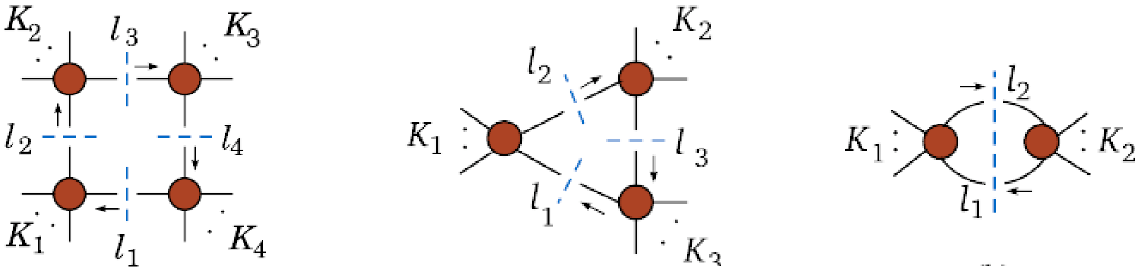
Combining these ideas, and using multiple cuts, allows us to evaluate amplitudes either by direct assembly or by recursion formulae.

These ideas have now become sufficiently mature that they can be applied to calculations of practical interest in QCD. Write

$$A = R + C$$

$$C = \sum_i b_i$$

$$+ \sum_i c_i$$

$$+ \sum_i d_i$$


C, the cut part, can be evaluated from unitarity



R, the rational part, can be evalulated by recursion formulae.

In the parallel session, we will describe a code called BlackHat that gives an automatic implementation of these methods. This code is now tests for n-gluon amplitudes up to n = 8.

The authors are: Berger *, Dixon, Forde, Maitre (SLAC), Bern, Febres Cordero, Ita (UCLA), Kosower (Saclay)

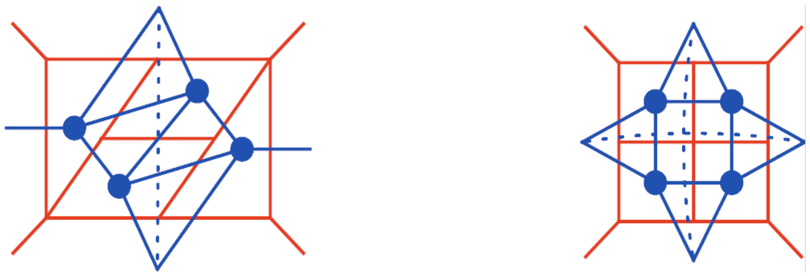
To go to higher-loop order, we need new methods. As a first step, develop these for N=4 super-Yang-Mills. Bern, Dixon, and Smirnov computed scattering amplitudes in N=4 s-Y-M and proposed the following as an exact formula:

$$\boxed{\mathcal{M}_n = \exp\left[\sum_{l=1}^{\infty} a^l \left(f^{(l)}(\epsilon) M_n^{(1)}(l\epsilon) + C^{(l)} + \mathcal{O}(\epsilon)\right)\right]}$$

constants, independent of scattering angle

known 1-loop amplitude

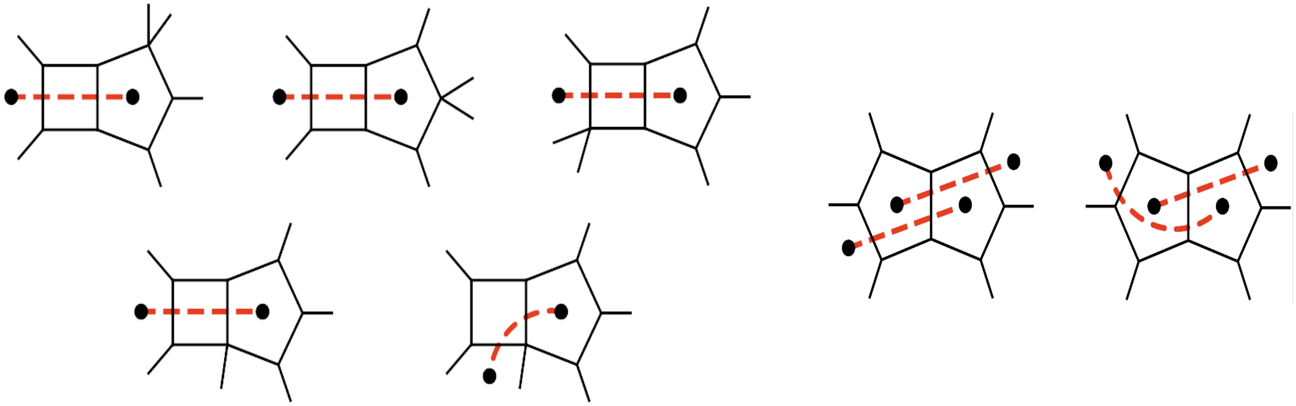
Using unitarity, BDS checked this formula through 3 loops for 4- and 5-point amplitudes



Alday and Maldacena computed the strong-coupling limit, using string theory in AdS, and found agreement with this result. However, they found a problem for n-point amplitudes for large n.

Drummond, Henn, Korchemsky, and Sokatchev found a conformal invariance that fixes the BDS result for n = 4,5. However, for n=6, there is a new arbitrary function of invariants.

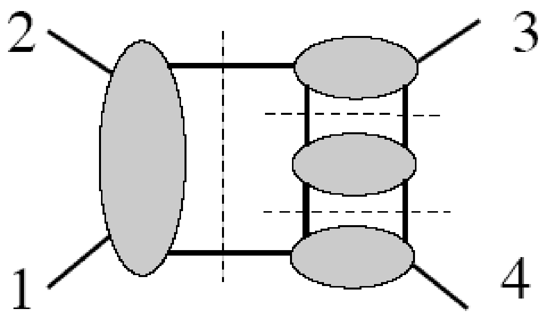
Dixon and collaborators computed the 6-point amplitude explicitly and showed that the result disagrees with BDS

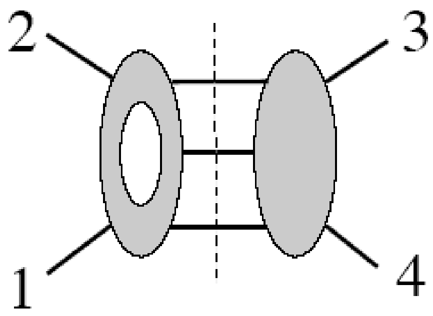


However, the result agrees with the expectation value of a Wilson loop with light-like edges. This seems to be a clue to the correct answer, so stay tuned !

These methods can also be used to perform loop computations in highly supersymmetric gravity theories.

Bern, Dixon, and Roiban have computed the scattering amplitudes of N=8 supergravity to 3 loops and found cancellations that reduce the power behavior of loop integrals to those in N = 4 super-Yang-Mills.





It is thus suggested that N=8 supergravity is finite to all orders in perturbation theory.

Next, turn to supersymmetry phenomenology.

Most studies of SUSY at colliders have been done in the context of mSUGRA, a 4-parameter reduction of the full parameter space. We hope to discover SUSY in the next few years,so it is appropriate to ask some questions about the larger space:

mSUGRA predicts mass relations among SUSY particles such as

$$m(\widetilde{g})/m(\widetilde{b}) = 7.0$$

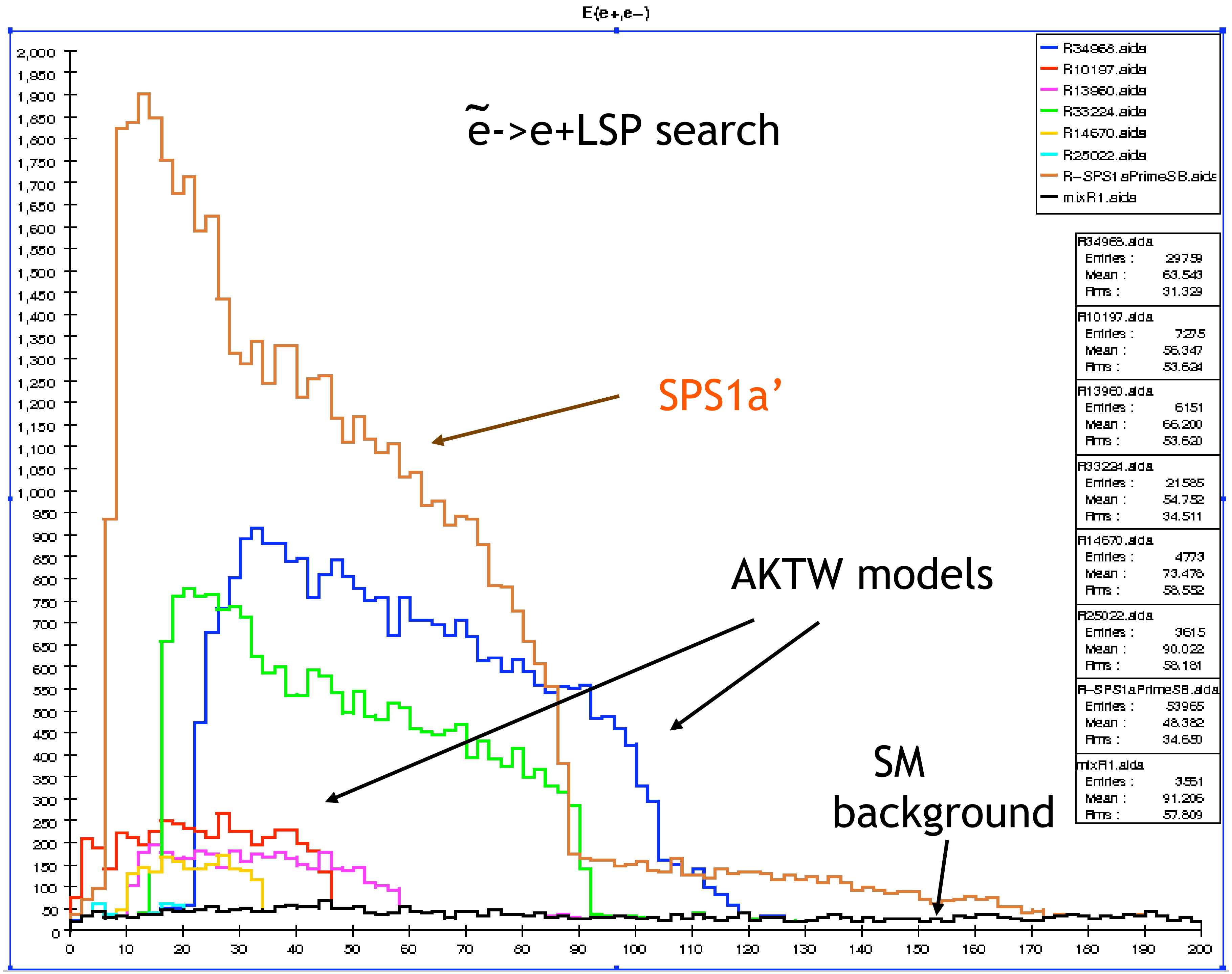
Then a gluino will decay to many visible jets. Can we discover SUSY if we relax this condition ? In the parallel session, we will present work of Alwall, Le, Lisanti, and Wacker that answers this question.

More generally, can we systematically study SUSY phenomenology over a more general parameter space. Can we measure all of the parameters, either at the LHC or the ILC ?

Berger, Gainer, Lillie, Hewett, and Rizzo have been studying the problem of SUSY parameter determination at the ILC.

The starting point of this study was a list of 162 pairs of models generated by Arkani-Hamed, Kane, Thaler, and Wang that give indistinguishable signals at the LHC.   Could the ILC discriminate them ?

Berger et al. studied these models with the SiD fast simulation, using realistic beam spectra and a full set of SM backgrounds (1016 processes) generated by Barklow for SiD using the WHIZARD event generator. Previous ILC studies used only a handful of model points, all in mSUGRA.



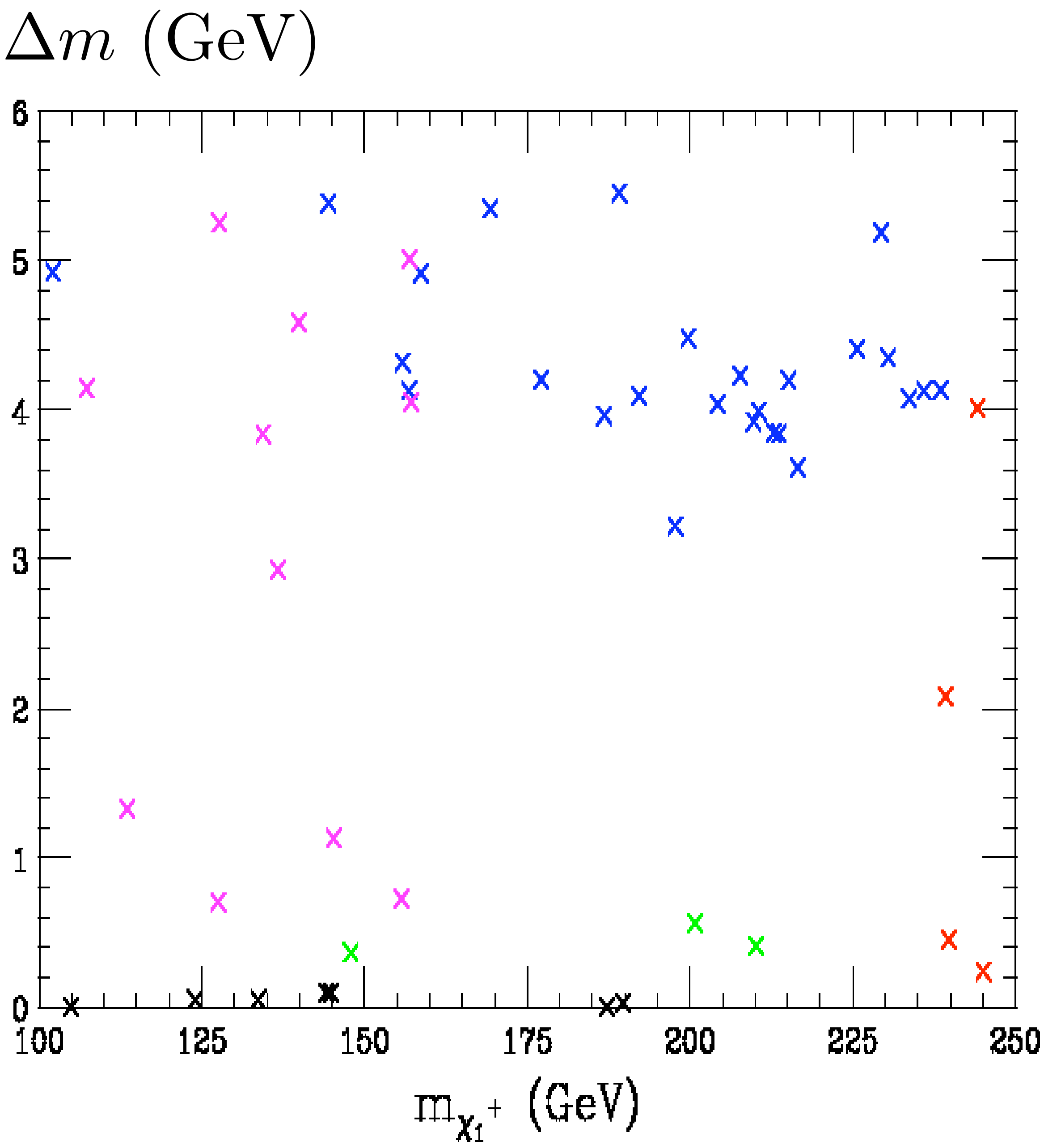
$\tilde{e}$->e+LSP search

SPS1a’

AKTW models

SM background

E(e)



Charginos often have small mass splittings with the LSP, requiring many different searches to cover the whole model space:

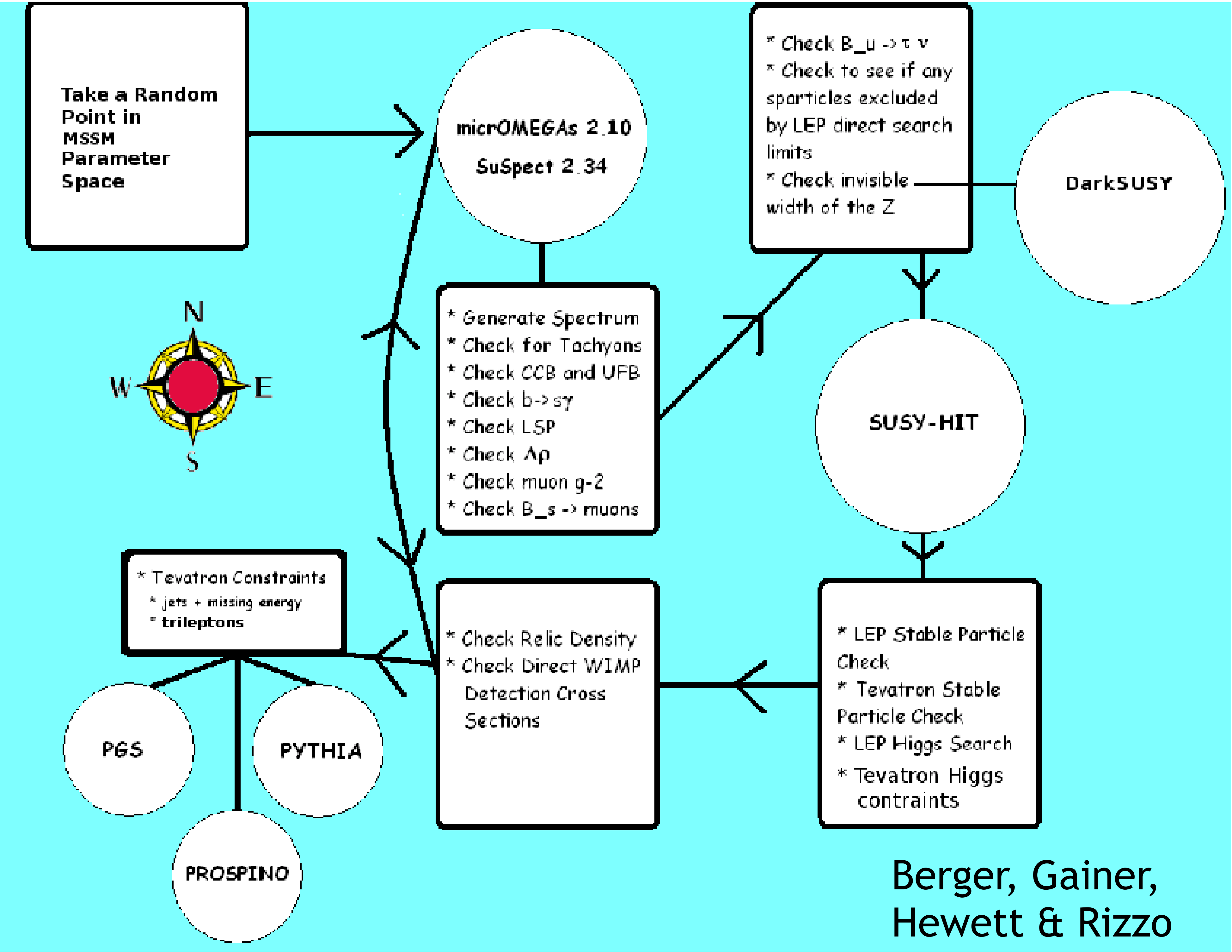
stable particles,
photon tagging,
soft jets,
or a combination.

4 points are missed due to tiny phase space.

In almost all cases, Berger et al. do find analyses that are sensitive to charged particles with small mass splittings in the realistic environment.

Models where only neutralinos are kinematically accessible are much more difficult, with proper treatment of background processes. For these models, running at higher energy would be needed.

The next stage of this project is to build a general analysis tool for the 20-parameter CP- and flavor-conserving MSSM.



Take a Random Point in MSSM Parameter Space

micrOMEGAs 2.10

SuSpect 2.34

- Generate Spectrum
- Check for Tachyons
- Check CCB and UFB
- Check b-> sγ
- Check LSP
- Check Δρ
- Check muon g-2
- Check B_s -> muons

- Check B_u -> τ ν
- Check to see if any sparticles excluded by LEP direct search limits
- Check invisible width of the Z

DarkSUSY

SUSY-HIT

- LEP Stable Particle Check
- Tevatron Stable Particle Check
- LEP Higgs Search
- Tevatron Higgs contraints

- Check Relic Density
- Check Direct WIMP Detection Cross Sections

- Tevatron Constraints
  - jets + missing energy
  - trileptons

PGS

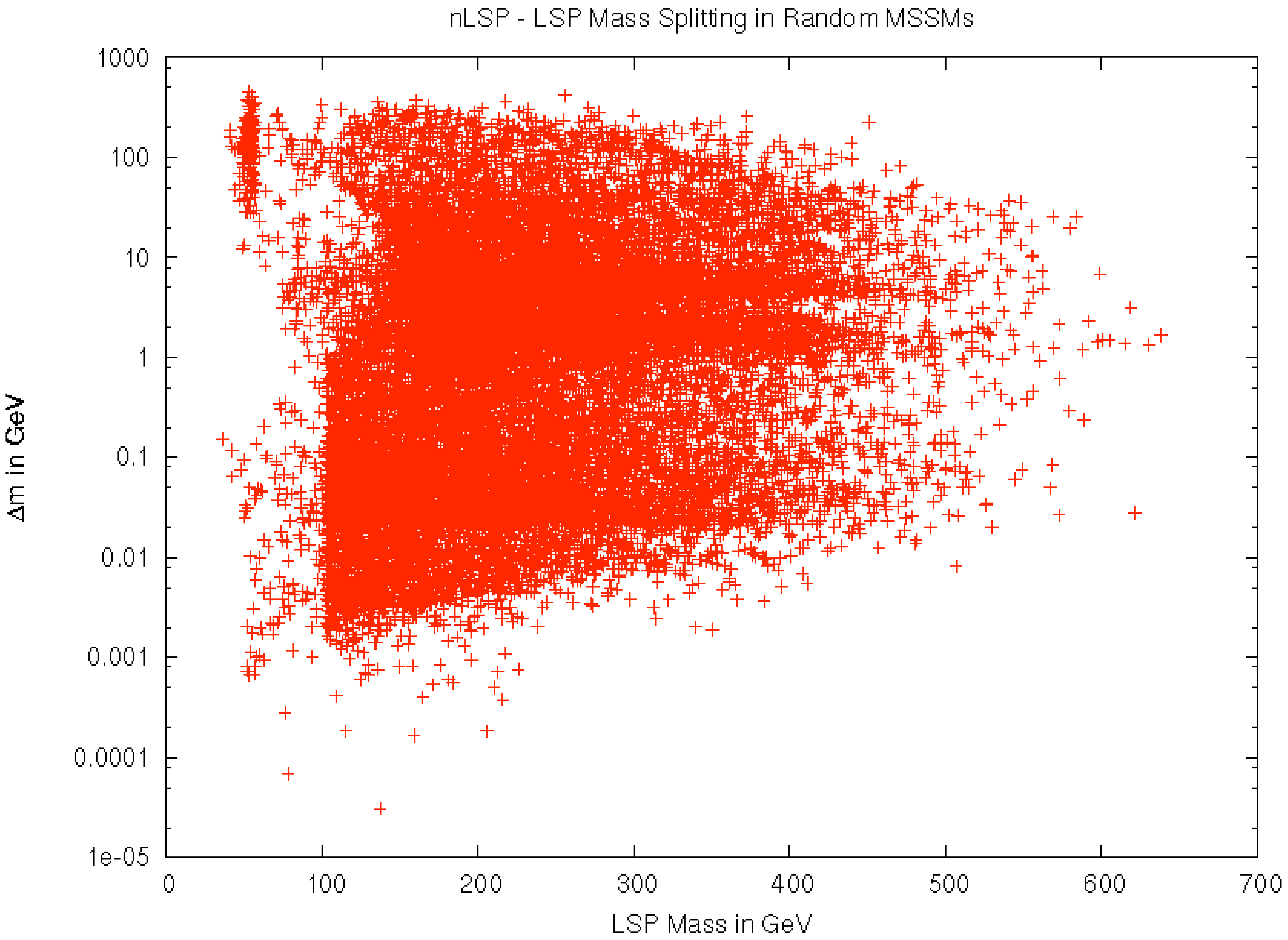
PYTHIA

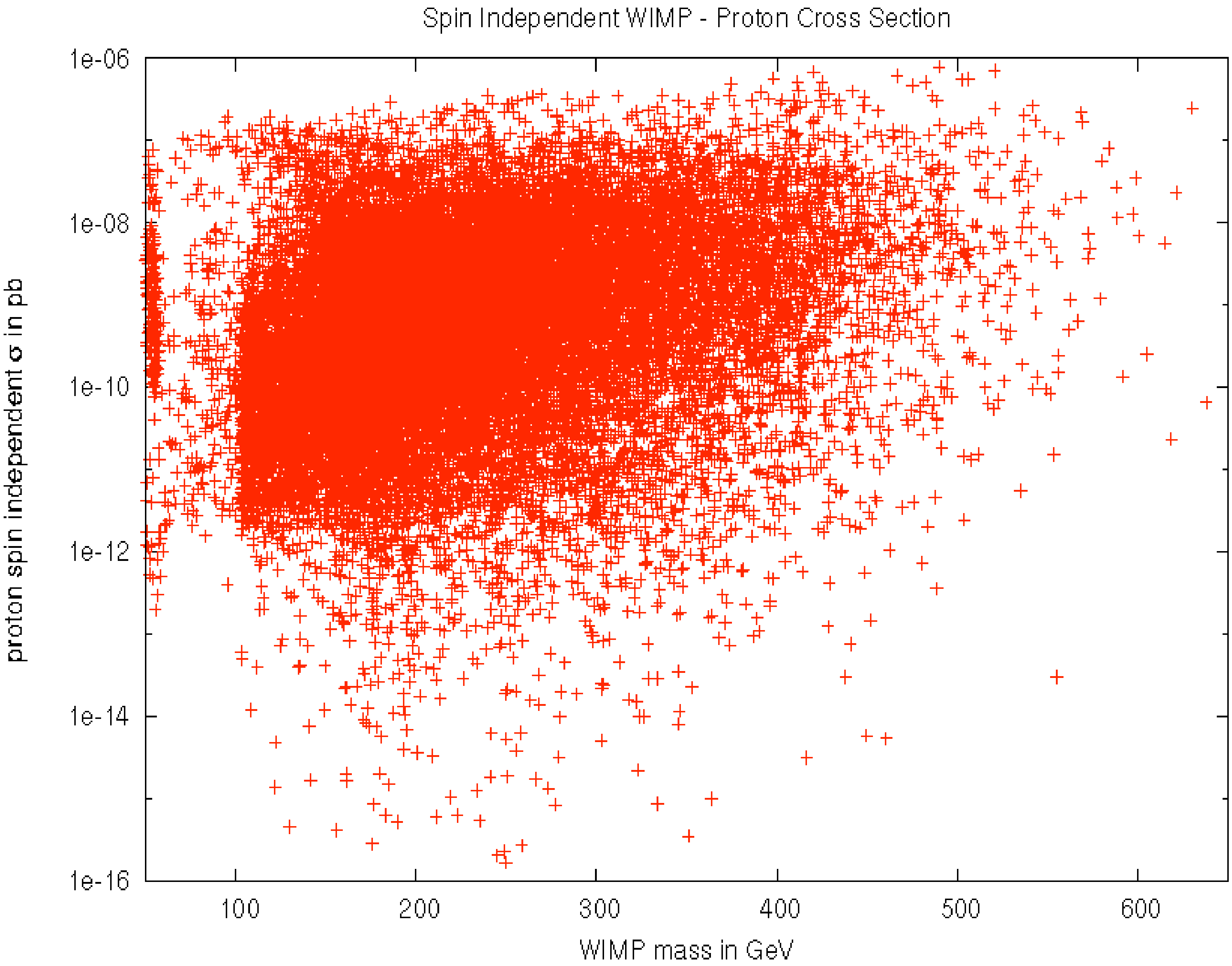
PROSPINO

Berger, Gainer, Hewett & Rizzo

Implementing the Tevatron constraints is nontrivial. Berger et al. use Prospino to generate SUSY cross section, PGS4 for detector simulation, and compare to published upper limit event numbers in the CDF and DO search regions for:

trileptons + $\not{E}_T$
like-sign dileptons + $\not{E}_T$
2, 3, 4 jets + $\not{E}_T$
dedicated stop and sbottom searches


nLSP - LSP Mass Splitting in Random MSSMs
Δm in GeV
LSP Mass in GeV
1000
100
10
1
0.1
0.01
0.001
0.0001
1e-05
0
100
200
300
400
500
600
700


Spin Independent WIMP - Proton Cross Section
1e-06
1e-08
1e-10
1e-12
1e-14
1e-16
proton spin independent σ in pb
100
200
300
400
500
600
WIMP mass in GeV

Finally, I will discuss models of inflation testable from the cosmic microwave background.

To build such models, you need string theory (or another consistent theory of quantum gravity)

For successful ‘slow roll’, generating 60 e-folds of inflation, the potential for the inflaton must be very flat. Higher-dimension operators, e.g.

$$V \cdot (\phi - \phi_0)^2 / m_{\rm Pl}^2$$

can ruin the flatness.

Higher-derivative terms in the inflaton Lagrangian can affect the perturbations about the slow-roll solution and the predictions for non-Gaussianity. (see Chen, Wang, Kachru, Shiu)

New scenarios for inflation can be found by considering nonlinear Lagrangians for the inflaton. These can arise geometrically in string theory (e.g. DBI inflation, Alishahiha, Silverstein, and Tong)

Models of inflation with V close to the Planck scale require $\phi \gg m_{\rm Pl}$ for a long enough slow roll. Without this condition, V is not large enough to allow observation of gravity wave perturbations in the CMB.

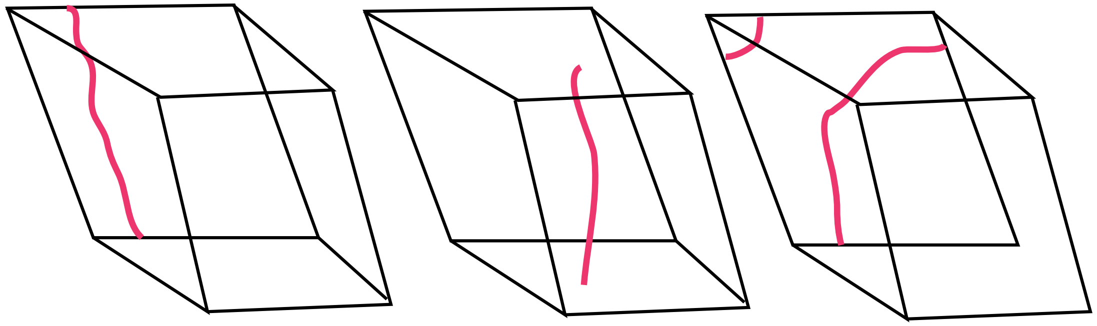
But, in string theory, the sizes of typical compact dimensions are of order the string scale

$$\sqrt{\alpha'} \sim m_{\rm Pl}^{-1}$$

This means that fields (e.g. string moduli) that are typical candidates for the inflaton cannot have a large range.

However, Silverstein and Westphal have found examples that allow large field excursions.

Consider a D-brane that wraps a torus embedded in a higher geometry. In a sufficiently twisted geometry, the wrapping can depend on the a coordinate, and increase arbitrarily:

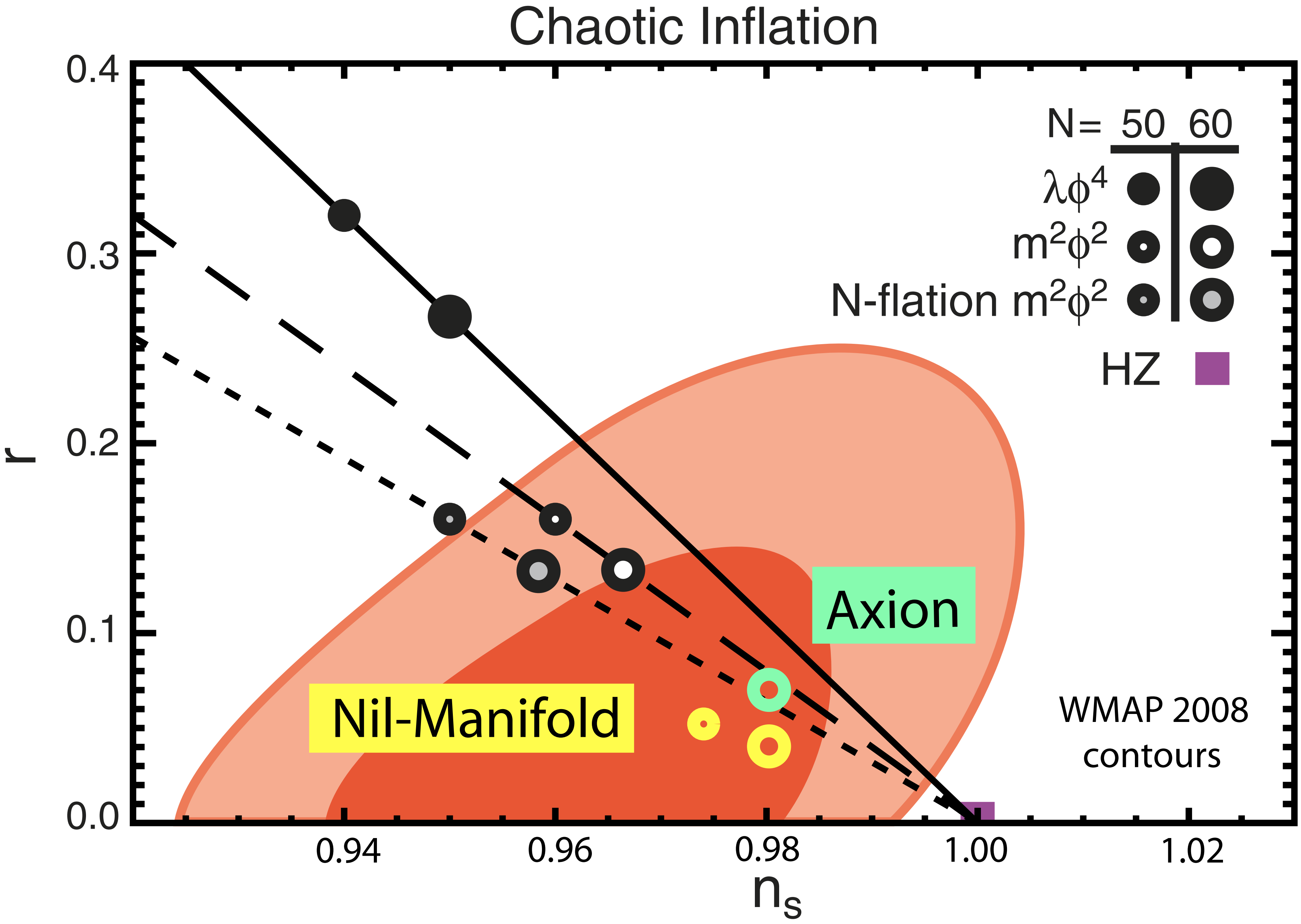


Silverstein and Westphal realize this for Type IIA string theory compactified on a Nil manifold.

The brane of increasing length generates a potential

$$V(\phi) \sim \phi^{2/3}$$

this leads to unique predictions for the CMB observables r (gravity wave amplitude) and (n-1) (power law deviation).



The prediction for a second model with an axion field with large excusion is also plotted.

In this talk, I have given a sampling of the ideas that we are exploring in the SLAC HEP Theory Group.

It has been true in the development of our field, and it continues to be true, that developments in ‘pure theory’ lead naturally to new observables and experimental tests.

We will continue to push the boundaries of theory as we work with experiments that explore new physics at the TeV scale and beyond.