SLAC
HEP
Theory Group

M. E. Peskin
2007 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)

numerous visitors, Stanford graduate students

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.

In this talk, I would like to discuss the following:

SLAC HEP Theory and LHC

and three topics from our recent research:

3- and 4-loop technology for QCD (Dixon)

new extra dimensions in string theory (Silverstein)

stable sleptons and superWIMPs (KItano-Ibe)

In many places, theorists are cautious about the LHC. Not here! It is not the time to be asking what happens if the LHC 'does not see anything' or 'merely' confirms the Standard Model.

The expection for the LHC is that it will discover a new sector of particles associated with electroweak symmetry breaking and dark matter. The discovery and characterization of these particles will be very challenging. We need to be ready.

Supporters of the ILC need to be especially concerned that new physics should be discovered early -- and correctly -- in the LHC program.

We have been concerned for some time about wheher our group would have the intellectual resources to interact with and build on the results expected from the LHC.

However, over the past few years, this situation has changed.

In addition to the traditional strength of our group (and Dimopoulos's group at Stanford) in model-building and the collider phenomenology of physics beyond the Standard Model, we have developed new areas of strength in perturbative QCD and in collider event simulation. We have added a new faculty member, Jay Wacker, who is strong in both model-building and collider physics. We are interacting strongly with the new SLAC ATLAS group.

Our ambition is to be the place with the best resources for young people, both theorists and experimenters, who would like to think hard about the LHC data.

As a part of this, we help to organize two seminar series:

The SLAC ATLAS Forum

a weekly joint seminar of the SLAC ATLAS group and the Theory group

phone+Web meeting with SLAC ATLAS in Geneva; UCSC, Oregon, Washington, Columbia often call in.

SLAC ATLAS Forum

at ***SLAC: B-Hive CL G214***
chaired by:
Su Dong (Stanford Linear Accelerator Center SLAC)
support:
sudong@slac.stanford.edu

Description: SLAC ATLAS forum for detector and physics studies.
Phone conference: 510-665-5437 code=9035#.
Meeting time is US Pacific time.

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12:00 Jets/MET at Tevatron (35') (Slides) Jacob Wacker (*SLAC*)

12:35 Missing Et Significance Studies (35') (Slides) Ariel Schwartzman

The West Coast LHC Theory Network

A series of meetings to educate the West Coast theory community in LHC physics, and to bring together university and lab theorists with expertise in diverse areas. These are 1-day meetings attended by theorists from Seattle to Tucson.

2/06: LBL :
Tour of ATLAS (Gilchreise, Loch)

5/06 UC San Diego :
Tour of CMS (Branson, Dasu, Campagnari)

12/06 UC Davis:
What is a jet, exactly ? (Ellis, Soper, Huston)

5/07 UC Irvine:
How to turn a hep-ph paper into an event generator
(Peskin, Alwall, Goh, Thaler)

Now I will discuss some recent research results of the group.

At the moment, the state of the art in perturbative QCD is 2-loop calculation for 2→1 processes

$$q\bar{q} \to W, Z \quad gg \to h$$

and 1-loop calculation in 2→n processes for n up to 4. Three groups, include Bern, Berger, Dixon, Forde, and Kosower, have published full 1-loop results for $gg \to 4g$.

We will hear more about 1-loop 2→n for large n tomorrow.

Eventually, we will want to compute higher terms in the perturbation expansion. Where will the methods come from ? How will we know the answers are right ?

A way to attach this problem is to perform computations in the most highly supersymmetric theory, N=4 super-Yang-Mills theory for large N_c .

This is a theory of gluons, color octet quarks, and scalars.   Its calculational problems are similar to those of QCD. However,

This theory is scale-invariant: $\beta(g) = 0$

The anomalous dimensions of the theory are related to integrable spin chains.

There are arguments that the entire theory is integrable, and this might be reflected in the form of scattering amplitudes.

String theory, through AdS/CFT, gives information about the strong-coupling limit.

In the past year, there were remarkable developments concerning the cusp anomalous dimension, the factor f(g) in the formula for the dimensions of ‘twist-2 operators’:

$$\gamma = f(g)\, log J + \cdots \quad (J \gg 1)$$

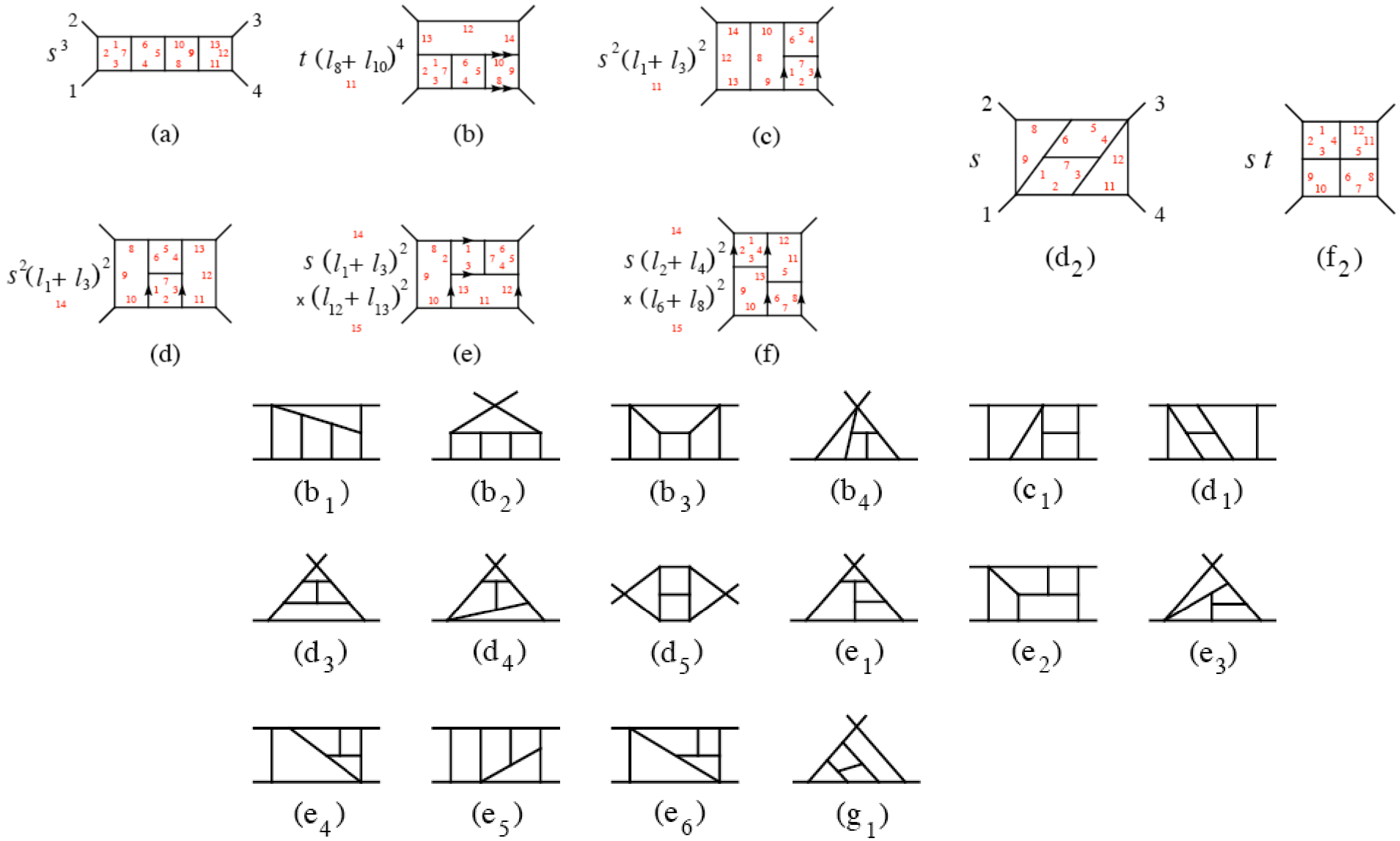
Based the the idea that the exact answer is given by an integrable spin chain, Beisert, Eden, and Staudacher made a series of proposals for the exact, all orders, result for f(g).

In perturbation theory, these proposals differ from one another for the first time in the 4-loop term.

The first two terms in the $g \rightarrow \infty$ limit of f(g) were computed from string theory by Frolov and Tseytlin.

The 4-loop computation of f(g) provided an interesting challenge for advanced methods in perturbative QCD.

There are just a few diagrams:

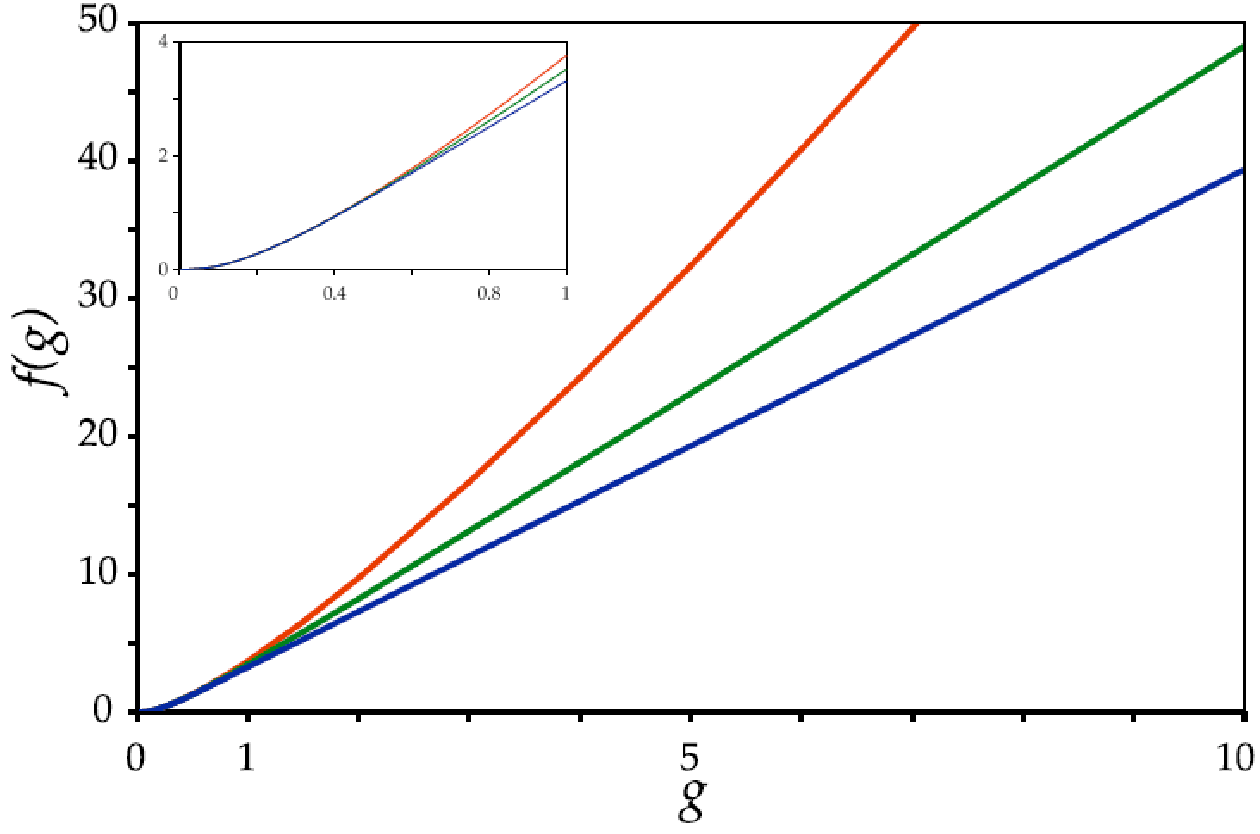


Bern, Czakon, Dixon, Kosower, and Smirnov found

$$f(g) \quad = \quad 8\frac{g^2 N_c}{4\pi} - \frac{8}{3}\pi^2(\frac{g^2 N_c}{4\pi})^2 + \frac{88}{45}\pi^4(\frac{g^2 N_c}{4\pi})^3$$
$$-16[\frac{73}{630}\pi^6 + 4\zeta(3)^2](\frac{g^2 N_c}{4\pi})^4 + \cdots$$

The pieces fit together!

The solution of the final BES integral equation, given by the blue curve, agrees with this perturbation series and extrapolates correctly to the strong coupling result.



Benna, Benvenuti, Klebanov, Scardicchio

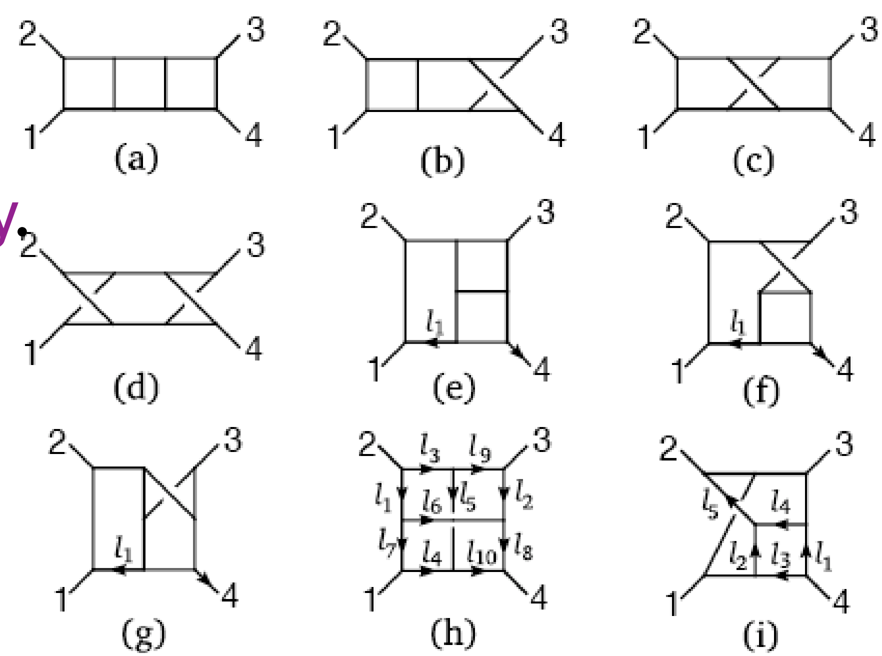
There are some interesting conjectures further down the road.

Bern, Dixon, and Smirnov have proposed an all-orders structure of the 2→2 scattering amplitude, of the form

$$\mathcal{M} = \mathcal{M}_{tree}\mathcal{M}_{IR}(s)\mathcal{M}_{IR}(t)\exp\left[\frac{f(g)}{8}\log^2\frac{s}{t} + c(g)\right]$$

Alday and Maldacena have shown this factorization is correct in the strong-coupling limit. Maybe it is possible to obtain the exact result for this amplitude!

The same methods allow computation of 2→2 amplitudes in N=8 supergravity. Carrasco, Bern, Dixon, Johansson, Kosower, and Roiban completed the 3-loop computation. Unexpected cancellations arise, suggesting that N=8 supergravity is a finite local quantum theory of gravity.



The next topic is even more abstruse, but it is also an exploration of new theoretical territory.

In string theory, we build models of quarks, leptons, and gauge bosons by modeling these as strings that wind around small extra dimensions.

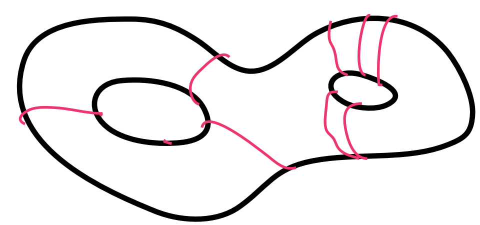
In string theory of the 1980's, these extra dimensions were studied in the straightforward way. The theory was 10-dimensional, so 6 dimensions must curl up, and strings can wind on this 6-dimensional surface.

In 1995, Witten showed that a sequence of black hole solutions of the 10-d theory could be reinterpreted as the momentum spectrum of an 11th dimension. This and other duality transformations lead to new places in the theory to put the quarks and leptons.

Perhaps we still have not found the 'right' place to put Standard Model particles.

There is a new place.

On a surface of constant negative curvature, e.g. a genus g Riemann surface, the number of states of winding strings grow exponentially, like the number of string oscillation states. These winding strings can be interpreted as adding to the number of dimensions of the system.



For a 2-d surface larger than the string scale, this is a small effect. As the surface shrinks, the size of the effect grows.

Green, Lawrence, McGreevy, Morrison, Starr, and Silverstein have argued that a very small Riemann surface has effectively dimension 2g and is dual to its "Jacobian torus".

This concept of dimension passes the standard array of tests. It is consistent with known string dualities and with various levels of supersymmetry in the models.

The new dimensions appear correctly in the dilaton equation of motion. This means that dimension can vary with time, and that continuous change of dimension might have a role in very early cosmology.

Finally, an example from particle phenomenology.

I stated at the beginning of this talk that we expect at the LHC to discover a spectrum of new particles associated with electroweak symmetry breaking. This would lead most people to look for missing energy + multijet events and 100 GeV WIMP dark matter.

But there are other possibilities. Three interesting ones,

stable charged particles, superWIMPs, and nonthermal dark matter

are realized in a new model proposed by Kitano and Ibe.

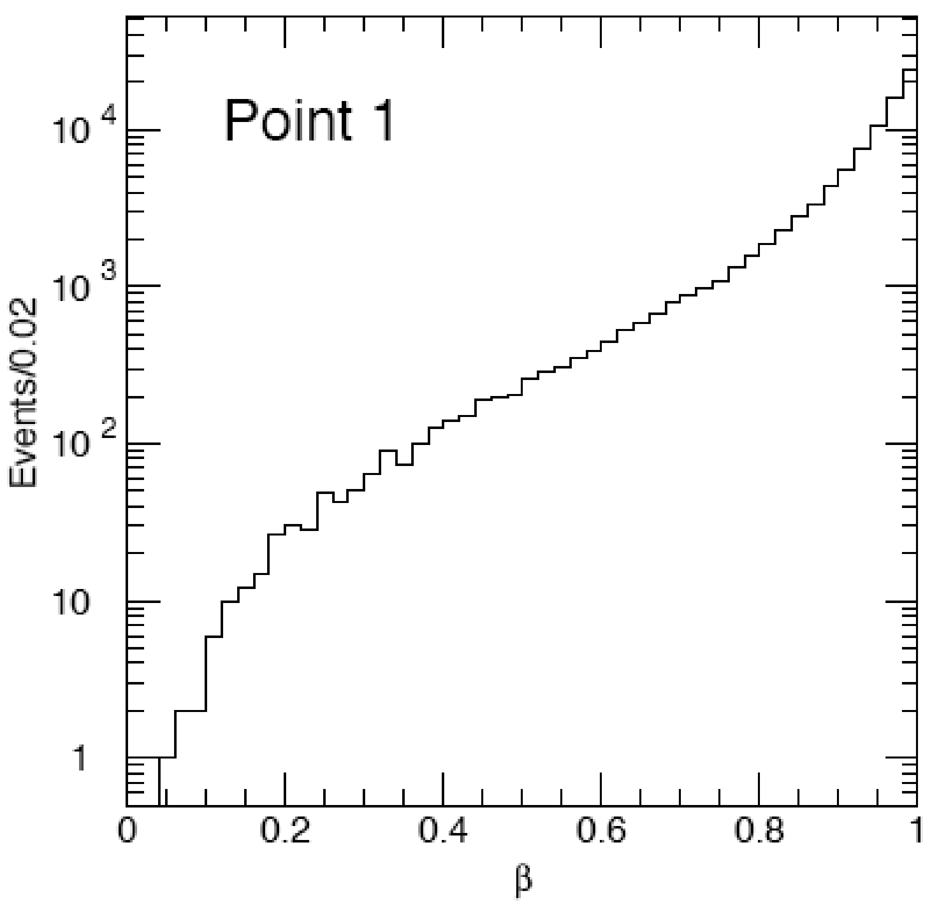
The model is a supersymmetric unified theory with gauge mediation and a gravitino mass of 1 GeV. I'll spare you further details.

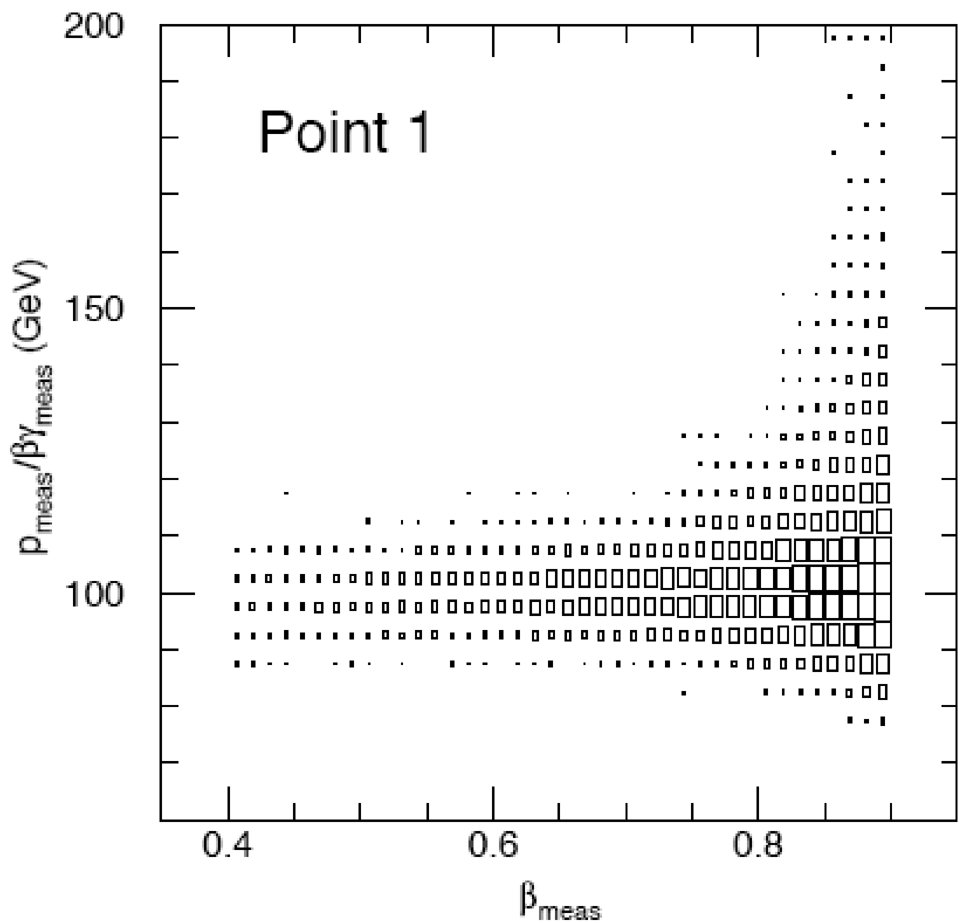
If the gravitino is light, SUSY particles will decay rapidly to the lightest Standard Model SUSY particle (NLSP), which then decays slowly to the gravitino. The NLSP is typically the $\widetilde{\tau}_R$ or the $\widetilde{b}$. The $\widetilde{\tau}_R$ avoids possible problems with primordial element abundances.

In this model, the $\widetilde{\tau}_R$ is favored, and its lifetime is about 20 min. This is a stable particle at the LHC. Its mass is about 100 GeV. Every LHC event contains two such stable sleptons.

Stable sleptons appear as muons which are slow but can still be within the time bucket of the muon system. This is a very easy signature of SUSY compared to the usual ones.

Using $\beta\ vs.\ p$, it is possible to measure the mass to 0.1%.



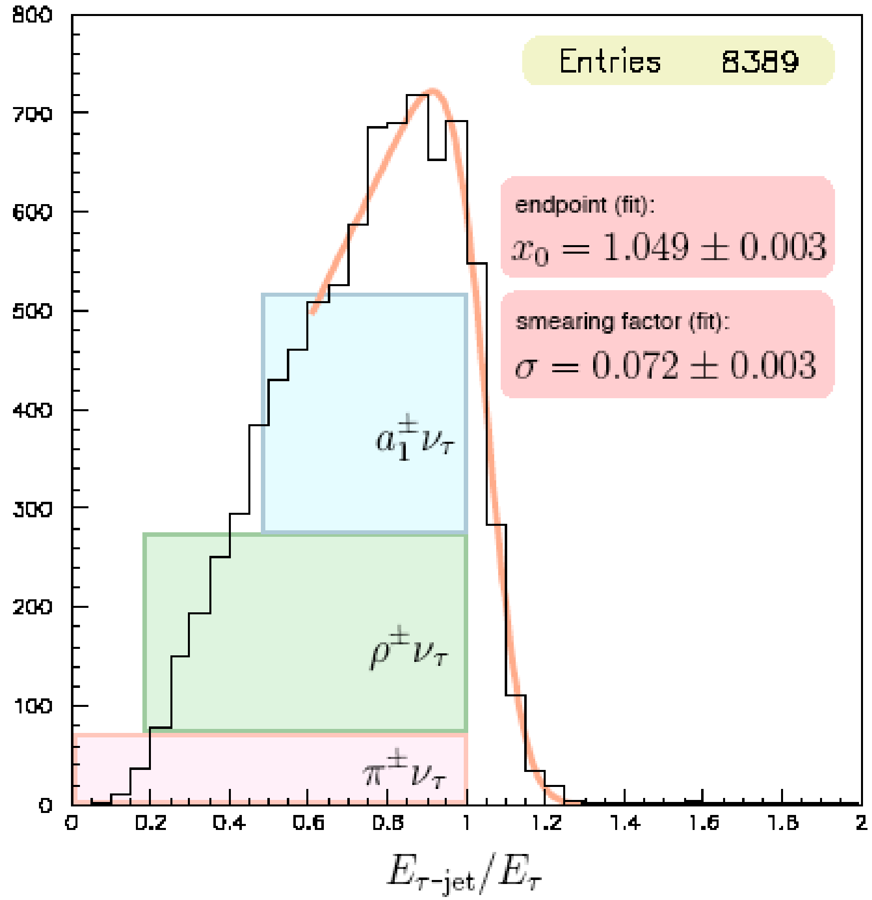


Ambrosanio, Mele, Petrarca, Polesello, Rimoldi

Gauginos decay to the NLSP by

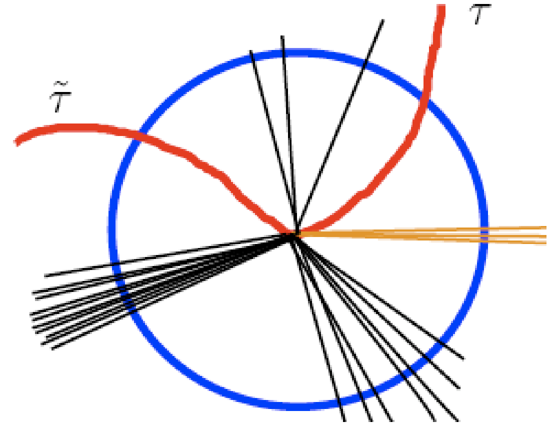
$$\widetilde{\chi}_i^0 \to \tau^+ \widetilde{\tau}^-$$

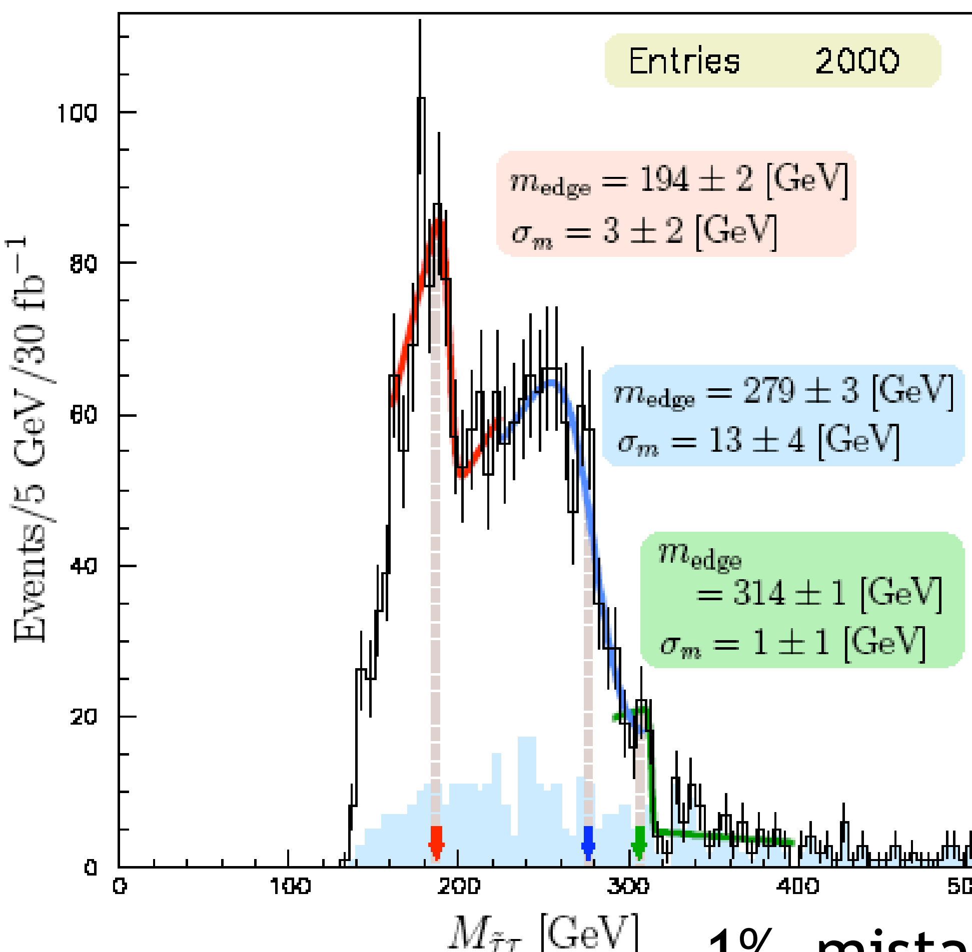
so we can measure the spectrum of gauginos by associating τ jets with staus. Of course, the τ is not observed completely. But in hadronic τ decays, the LHC detectors can see most of the energy.

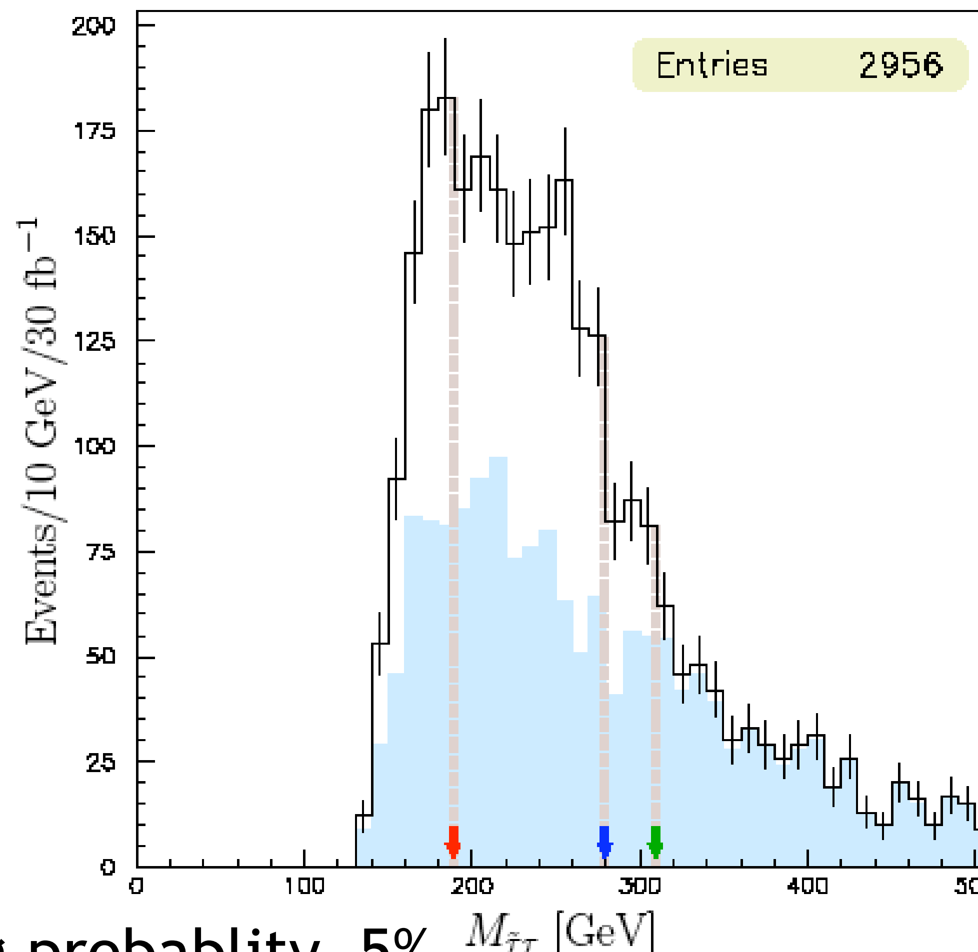


HERWIG + TAOULA + AcerDET

So we can combine stable $\tilde{\tau}$s with τ jets and look for resonances. Including detector effects, these appear as kinematic edges.







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The gravitino dark matter is a superWIMP, a concept introduced by Feng, Rajaraman, and Takayama. Its annihilation and scattering cross sections are essentially zero. It makes no signals in underground detectors or in cosmic rays.

However, there is a define relation linking the lifetime of the slepton, the gravitino mass, and the gravitational constant, given by

$$\tau = \frac{6}{G_N} \frac{m_{\widetilde{G}}^2}{m_{\widetilde{\tau}}^5} \Big(1 - \frac{m_{\widetilde{G}}^2}{m_{\widetilde{\tau}}^2}\Big)^{-4}$$

This potentially allows us to test the dark matter model with particle physics.

We need roughly 100 times more dark matter particles than are produced by the usual mechanism of thermal production and freeze-out. However, in the Kitano-Ibe model, the singlet field responsible for SUSY breaking has coherent oscillations at the end of inflation and decays to gravitinos. This nonthermal production mechanism gives the desidered abundance.

Nonthermal production of dark matter is a double-edged sword, and it has a beneficial edge as well.

If the gravitino is heavier than the lightest neutralino and it is the neutralino that is produced nonthermally, we obtain a conventional WIMP with a very large annihilation cross section. Then GLAST will see a huge signal in WIMP annihilation gamma rays.

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

We are excited about the start of experimentation at the LHC, and we are excited about many new directions that are opening in theory.

In the 1960’s and 1970’s, data drove deep theoretical work, and vice versa. We hope that theory and experiment will again find deep connections in the LHC era.