

SLAC High-Energy Theory Group

M. E. Peskin
2004 DOE Program Review

To begin, discuss the personnel of the Theory Group and its recent evolution:

our budget is \$ 2.7 M.

93% of this is for staff salaries.

our primary discretionary expense is the salaries of postdoctoral fellows

Faculty and Staff

Stan Brodsky

Lance Dixon

JoAnne Hewett

Shamit Kachru

Michael Peskin

Helen Quinn

Tom Rizzo

Eva Silverstein

Marvin Weinstein

emeritus

James Bjorken

Richard Blankenbecler

Sid Drell

Pierre Noyes

Yung-Su Tsai

Postdoctoral Fellows

Stephon Alexander
Charalampos Anastasiou
Thomas Becher
Richard Hill
Amir Kashani-Poor
Adam Lewandowski
Alex Maloney
Aaron Pierce

next year:

Carola Berger
Emmanuel Katz

last 5 years:
18 offers, 15 accepted

Long-Term Visitors

Yasaman Farzan
Yuval Grossman
Wolfgang Kilian

James Lindesay
Manuel Masip
Jorg Raufeisen

Graduate Students

Michael Binger

Brodsky

Wu-Yen Chuang

Peskin

Michal Fabinger

Silverstein

plus 2-3 rotating

Ben Lille

Hewett

1st year students

Xiao Liu

Kachru

per quarter

Darius Sadri

Hewett/Thomas

Alex Saltman

Silverstein

Mark Schreiber

Dixon

Our group also hosts the high-energy theory groups from the Stanford Physics Department and from U C Santa Cruz 2 days/week. There is easy and continuing collaboration among our three groups.

Stanford faculty:

Dimopoulos, Kallosh, Linde, Shenker, Susskind, Thomas

UCSC faculty:

Banks, Dine, Haber

recent changes in the group:

Tsai, Bjorken retirements

we replaced each by a postdoctoral fellow

Blankenbecler, Noyes retirements

1 position to Kavli Institute

1 open search

(emphasizing model-building/particle astro)

The majority of our recent postdoctoral fellows have gone on to faculty positions at major institutions:

1990:

Vittorio Del Duca > Torino
Carl Schmidt > Michigan State

1991:

Adam Falk > Johns Hopkins
Patrick Huet
Roberto Vega > SMU

1992:

Alex Kagan > Cincinnati
Wai-Keung Tang

1993:

David Atwood > Iowa State
Valya Khoze > Durham
Eric Sather

1994:

Scott Thomas > Stanford

1995:

Damien Pierce
Mihir Worah
James Wells > Michigan

1996:

Yuval Grossman > Technion

1997:

Nima Arkani-Hamed > Harvard

1998:

John Brodie > (postdoc)
Hooman Davoudiasl > (postdoc)
Martin Schmaltz > Boston U

1999:

Gundrun Hiller > Munich
Albion Lawrence > Brandeis
Kirill Melnikov > Hawaii

2000:

Simeon Hellerman > (postdoc)

2001:

Charalampos Anastasiou > (postdoc)
Thomas Becher > Fermilab
David E. Kaplan > Johns Hopkins

2004:

Emmanuel Katz > Boston U

I emphasize the quality and careers of our postdoctoral fellows, because they play a major part in determining the scientific direction of the group.

We on the faculty consider it one of our important roles to help the postdoctoral fellows pursue and solve the problems they are interested in.

Over time, this has produced some of our major work.

1994-7: Supersymmetry spectroscopy;
phenomenology of gauge-mediated supersymmetry

Thomas, Pierce, Wells / Feng, Strassler

1995-8: Systematics of new physics contributions
to CP violation in B exclusive decays

Atwood, Grossman, Worah (and Nir)

1998-2000: Effects of extra space dimensions
in elementary particle physics

Arkani-Hamed, Schmaltz, Davoudiasl / Perelstein

2001-4: Computational perturbative QCD

Anastasiou, Melnikov, Thomas / Petriello

How are we theorists connected to the experimental program ?

We have a continuing **day-to-day** connection to experimenters on site.

Our theoretical investigations help to **define** the lab's future experimental projects.

Our investigations have call attention to important **observables** for current and future experiments and clarified their relation to theory.

We organize **formal programs** that bring together SLAC experimenters and theorists from the broader community.

The last of these is easiest to illustrate ...



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Second Workshop on the Discovery Potential of an Asymmetric B Factory at 10^{36} Luminosity

SLAC

Wednesday-Friday, October 22-24, 2003

Announcement:

With the now rather precise measurement of $\sin 2\beta$ by BABAR and Belle, it is likely that all Standard Model CKM phase accounts for the CP-violating effects measured to date. The inability of the Standard Model CP violation to account for the matter-antimatter asymmetry of the universe tells us, however, that there must be sources of CP violation beyond the Standard Model.

This workshop is aimed at refining our understanding of the capabilities of an asymmetric B Factory at the very high luminosity of $10^{36} \text{ cm}^{-2}\text{s}^{-1}$ to uncover effects in rare heavy quark decays that could lead to progress in finding physics beyond the Standard Model. By confronting detailed predictions of Standard Model extensions such as supersymmetry, little Higgs or extra dimensions, with experiments feasible with an



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V_{xb} Workshop

A workshop on semileptonic and radiative B decays

SLAC

Friday-Saturday, December 12-13, 2003

Purpose:

Like in the last two years ([2001](#), [2002](#)), this workshop is intended to bring theorists and BABAR experimentalists together for an appraisal of the theoretical and experimental uncertainties and prospects related to measurements of semileptonic and radiative rare B decays. The intent is to have an informal meeting focusing on physics issues, primarily the interpretation of current and future measurements and theoretical uncertainties. Specifically, we are interested in $b \rightarrow c$, $b \rightarrow u$ and $b \rightarrow s$ measurements, OPE and



ALCPG 2004 Winter Workshop
SLAC, January 7-10, 2004

Linear Collider Connections to Astrophysics and Cosmology

AGENDA

Thursday, January 8, 1:45-3:45

Neutralino Dark Matter (joint session with SUSY WG)

Chair: Jonathan Feng

Room: ROB C

1:45 - 2:05

[Accurate neutralino relic density](#)

[Paolo Gondolo](#), U of Utah

2:10 - 2:30

[Experimental Issues in CDM-inspired cMSSM Scenarios](#)

[Marco Battaglia](#), UC Berkeley

2:35 - 2:55

[Measurements of slepton parameters at the LC](#)

[Uriel Nauenberg](#), U of Colorado

3:00 - 3:20

[Study of the stau coannihilation region at the LC](#)

[Bhaskar Dutta](#), U of Regina

3:25 - 3:45

[LC capabilities for SUSY in dark-matter-allowed regions of the mSUGRA model](#)

[Howard Baer](#), Florida State U

Thursday, January 8, 4:05-6:05

More about Dark Matter

Chair: Mark Trodden

Room: ROB C

4:05 - 4:25

[CMSSM likelihood analysis and Its implication for future colliders](#)

[Yudi Santoso](#), U of Minnesota

LHC / LC Study Group

The aim of the LHC / LC Study Group is to investigate how analyses at the LHC could profit from results obtained at a LC and vice versa. It is furthermore studied how informations obtained at both machines can most effectively be put together in order to explore the physics of weak and strong electroweak symmetry breaking, Supersymmetric models, new gauge theories, models with extra dimensions, and electroweak and QCD precision physics.



For further information about the LHC / LC Study Group, please contact
Georg.Weiglein@durham.ac.uk

Now I would like to discuss **three** of the group's current physics projects.

There is no time to list everything we are working on, but we will go over the whole menu in the breakout session.

1. Drell-Yan cross sections in QCD at NNLO

For the next ten years, all of our new information about particle physics at the highest energies will come from hadron colliders. To make the best use of this information, we need precision theoretical predictions for QCD processes. To reach the few-percent level, we need to do perturbative QCD at the two-loop (NNLO) level.

These calculations are truly daunting. There are hundreds of Feynman diagrams per process, tens of thousands of terms per diagram. **Brute strength is not sufficient.** New ideas are needed to organize the perturbative calculation and guide its execution.

In the early 1990's, **Dixon**, with **Bern** and **Kosower**, made a major breakthrough on the related problem of computing $2 \rightarrow 3$ processes at NLO in QCD. They created a new set of methods based on simplifications of the **massless limit**, **unitarity**, and constraints from **string theory** and **supersymmetry** to organize the perturbative calculation into relatively simple elements.

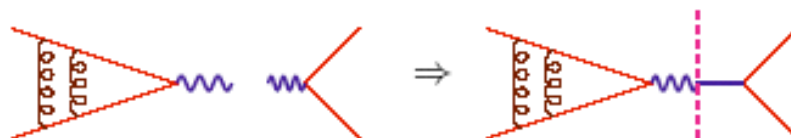
Recently, Bern and Dixon have been working to extend these methods and discover new ones to provide a technology for NNLO computations.

A venerable method for evaluating multiloop integrals, pioneered by **Tkachov** and his group at INR, Moscow, is to use integration by parts to related more complex intergrals to a small group of “master integrals”.

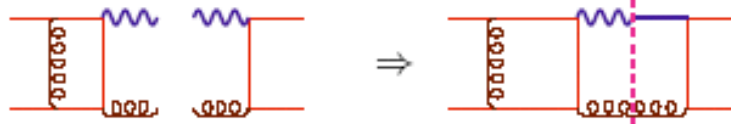
Anastasiou developed an automated version of this process that reduces the tens of thousands of two-loop integrals needed for a realistic QCD computation to about ten master integrals. The program runs on a local PC, loopy.slac.stanford.edu , which does integration by parts for us 24/7.

Anastasiou and Melnikov showed that this method can be applied not only to 2-loop diagrams but also to diagrams with multiparticle phase space, but writing real particle emissions formally as cuts of loop diagrams:

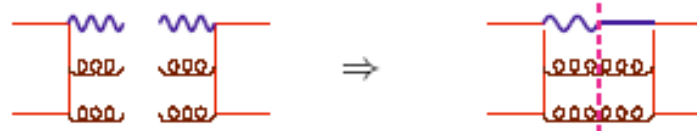
- Virtual-Virtual;



- Real-Virtual;



- Real-Real.



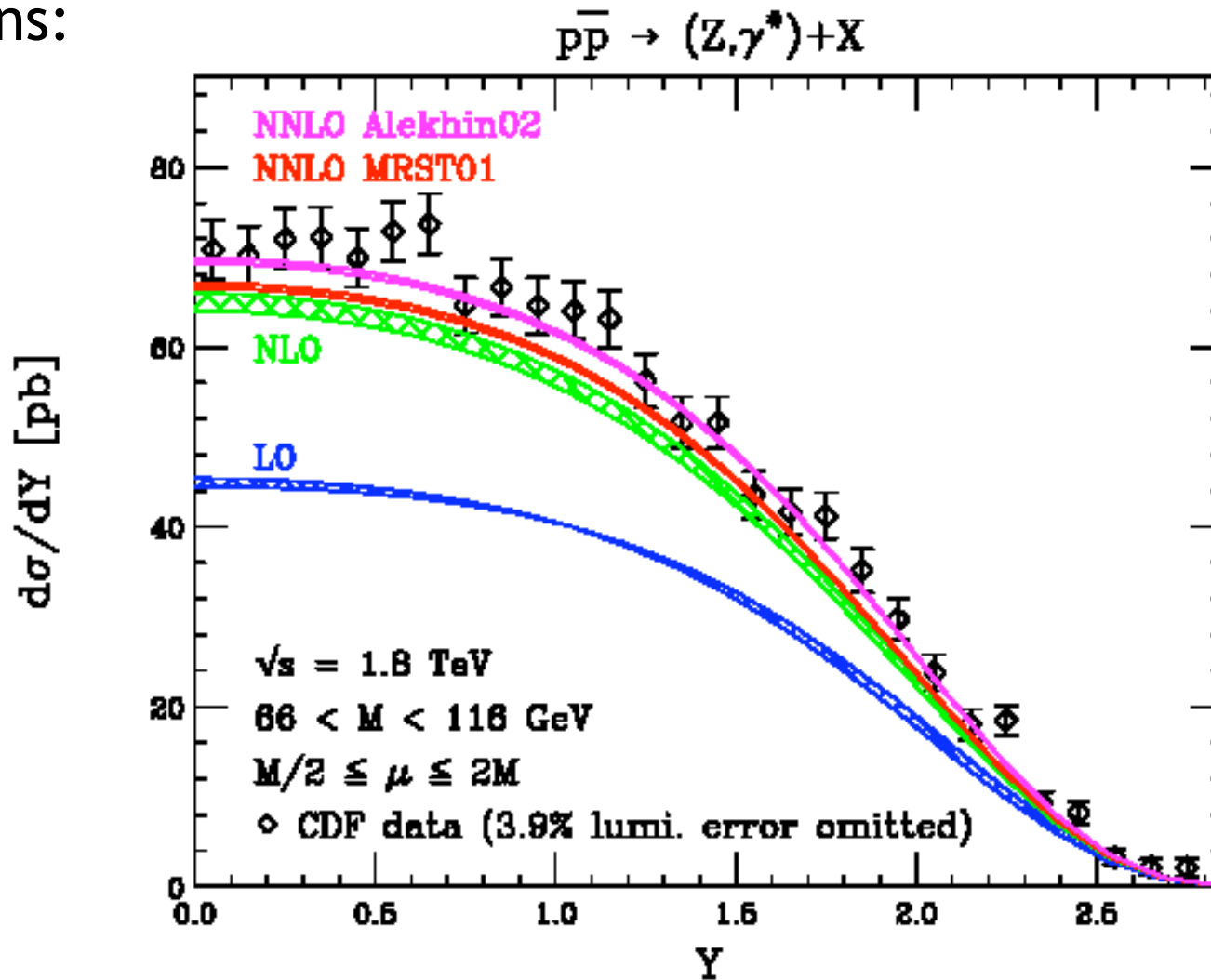
Using this method, one can evaluate all of the ingredients of an NNLO calculation.

The method can be used straightforwardly to evaluate total cross sections. But it can also be used to compute **differential cross sections** by introducing new propagators whose cuts are appropriate delta functions:

$$\delta\left(\frac{q \cdot p_1}{q \cdot p_2} - u\right) \leftarrow \frac{q \cdot p_2}{q \cdot (p_1 - up_2) + i\epsilon}$$

Anastasiou, Dixon, Melnikov, and Petriello have used this method to compute the Drell-Yan cross section as a function of q^2 and rapidity to NNLO. **This is the first differential cross section calculated to NNLO in QCD.**

To illustrate the results, here is the Drell-Yan rapidity distribution at the Tevatron, comparing LO, NLO, and NNLO for the MRST parton distributions, and an alternative set of NNLO parton distributions:



With the LHC data, this calculation will give us quark and antiquark distributions to 1% accuracy.

2. Dark matter and precision SUSY measurements

It is well known that supersymmetry provides a good candidate for cosmic dark matter. What is needed is a **stable, neutral, weakly interacting massive particle** with an annihilation cross section

$$\langle \sigma_{NN} v \rangle = 1 \text{ pb}$$

The “neutralino” - the superpartner of $(\gamma, Z^0, h_d^0, h_u^0)$ has roughly these properties.

What is also “well-known” but not as well appreciated is that this picture no longer works quantitatively in a simple way.

In the 1980’s, when Weinberg, Ellis, Goldberg, and others wrote about SUSY dark matter, they found good agreement for slepton masses of ~ 20 GeV and $\Omega_{DM} \sim 1$.

Today, we know that slepton masses are greater than 100 GeV and $\Omega_{DM} = 0.2$.

WMAP gives us 8% precision on this value. Planck will give 1% precision. So - if the neutralino is the dark matter - we will have a tight constraint between microscopic and cosmic measurements of $\langle \sigma_{NN} v \rangle$, if we can find a scenario that works at all.

Some proposed mechanisms for large $\langle\sigma v\rangle$ are :

$m(\tilde{\ell}) \sim m_N$: use **slepton coannihilation** $\tilde{\ell}N \rightarrow \gamma + \ell, Z^0 + \ell$

$m(\tilde{\tau}) \sim m_N$: use **stau coannihilation** (large $\tan\beta$)

$\tilde{w}\tilde{h}$ **mixing** : use $NN \rightarrow W^+W^-$ (“focus point region”)

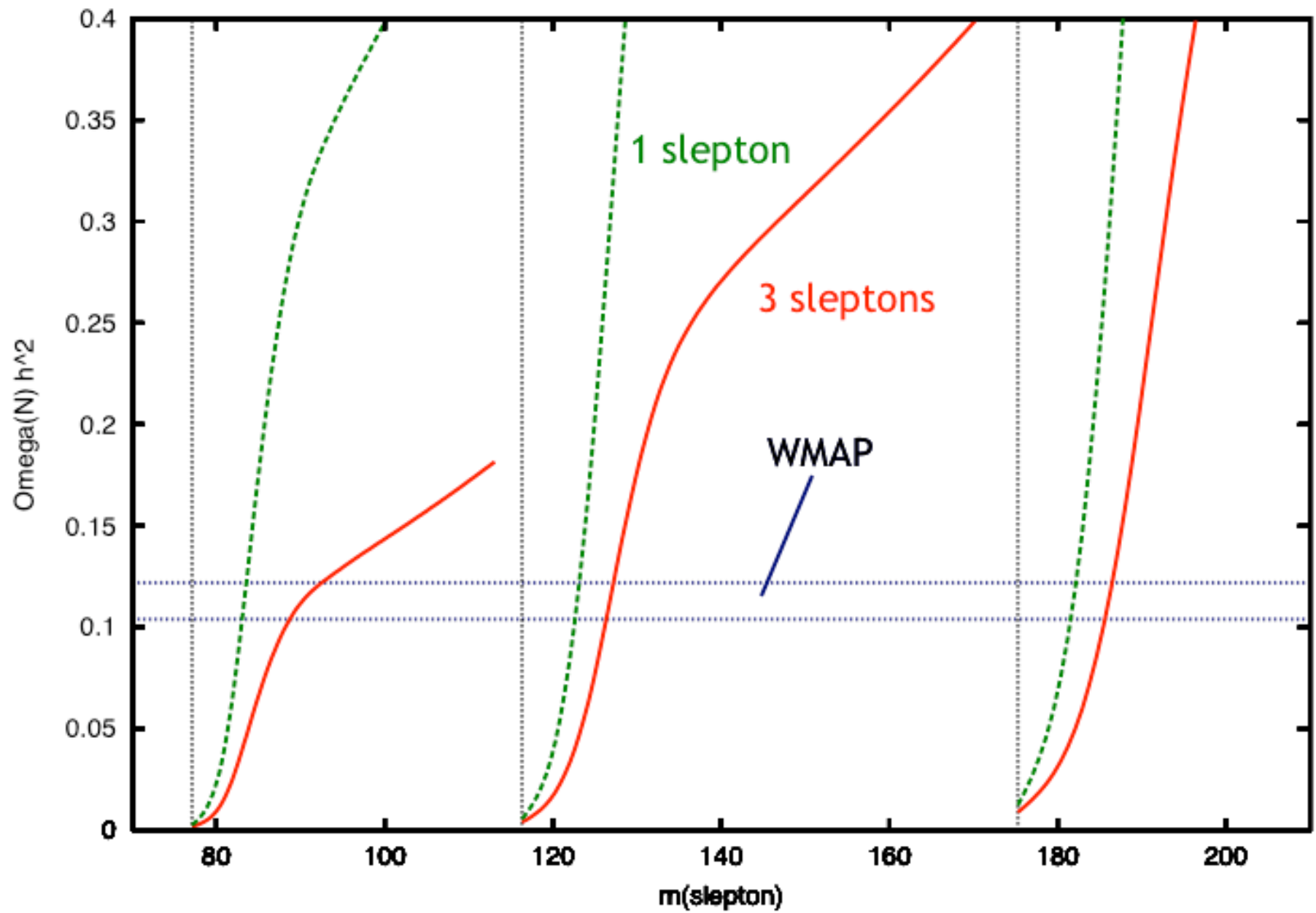
$m(A) \sim 2m_N$: use **resonant annihilation** $NN \rightarrow A \rightarrow \tau^+\tau^-, b\bar{b}$

To the extent that these requirements are sharp, we need **very accurate SUSY spectrum measurements** to test the concordance with cosmology.

Here is an example with slepton coannihilation:

The density of sleptons varies as

$$\frac{n(\tilde{\ell})}{n(N)} \sim \exp\left(-\frac{m_{\tilde{\ell}} - m_N}{T}\right) \sim \exp\left(-20\frac{m_{\tilde{\ell}} - m_N}{m_N}\right)$$



In this example, $m_{\tilde{\ell}}$ or $m_{\tilde{\ell}} - m_N$ must be measured to about **200 MeV** to predict Ω at the percent level.

Wu-Yen Chuang and I are working out these sensitivities and the corresponding experimental requirements for the various SUSY scenarios.

Birkedal-Hansen and **Matchev** and **Belanger** are carrying out similar studies, as part of the LC/Cosmology working group study.

3. D-celeration - a new model of inflation

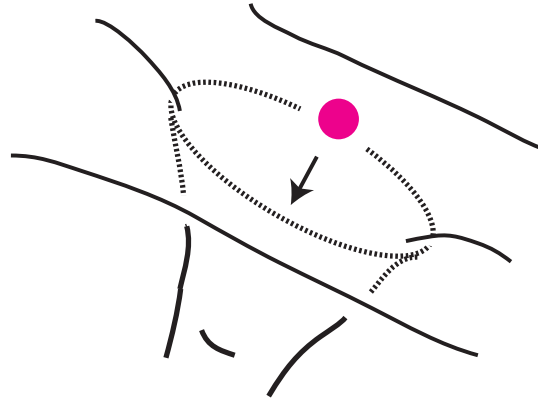
Over the past several years, Kachru and Silverstein have been studying string compactifications with $N=1$ supersymmetry in backgrounds with **D-branes**, **antisymmetry tensor fluxes**, and other nonperturbative elements. These ingredients have the potential to solve many of the old problems of weak coupling heterotic string compactifications. In particular, most moduli, often including the overall size of the compactification, are stabilized at the tree level.

Last year, I presented the discovery by Kachru and collaborators, based on this formalism, of **the first string compactifications with de Sitter space as the background space-time**.

String compactification on 5-d anti-de Sitter space are related by Maldacena's famous duality to conformal quantum field theories in 4-d space-time. So the methods just discussed can also be used to discover new 4-d field theories - or to appreciate old ones better.

Here is an example. A big D-brane in anti-de Sitter space has a local geometry with an extended "throat". The throat is infinitely deep in the field theory limit and is smoothed only by non-perturbative string effects.

If a small D-0 brane falls down the throat, it takes a long time to reach the bottom.



From the 4-d field theory viewpoint, this looks like a nontrivial modification of the kinetic terms of the field dual to the brane position. This field is described by a Born-Infeld action.

$$S = \int \sqrt{-g} \left[-\frac{1}{2} \frac{m_{\text{Pl}}^2}{g_s} \frac{\phi^4}{\lambda} \sqrt{1 + \lambda g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi / \phi^4} \right]$$

As $\phi \rightarrow 0$, the higher derivative terms in the action slow the rolling of this field.

Silverstein and David Tong have studied this phenomenon and found it to be an attractive alternative description of the slowly rolling field in inflation. With Alishahiha, they computed the effects of the higher-derivative terms in creation non-Gaussian scalar perturbations that are (in principle) visible in the CMB fluctuations. The pattern of these perturbations is characteristic, peaking for equilateral-triangle 3-point configurations.

As these three examples illustrate, we are trying to push the boundaries of theory and to find, at these boundaries, new theoretical viewpoints to inform current and future experimental programs.