SLAC
High-Energy
Theory Group

M. E. Peskin
2005 DOE Program Review

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

95% of our budget 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 (1/2)
Michael Peskin
Helen Quinn
Tom Rizzo
Eva Silverstein (1/2)
Marvin Weinstein

emeritus

James Bjorken
Richard Blankenbecler
Sid Drell
Pierre Noyes
Yung-Su Tsai

Postdoctoral Fellows

Stephon Alexander
Carola Berger
Richard Hill
Amir Kashani-Poor
Emmanuel Katz
Adam Lewandowski
Alex Maloney
Aaron Pierce

next year:

Bogdan Florea
Roni Harnik
Ryuichiro Kitano
Petr Svrcek

last 6 years:
23 offers, 19 accepted

Long-Term Visitors

Paul Aspinwall
Antonio Dobado
James Lindesay
Felipe Llanes-Estrada
Petr Vogel
Peter Zerwas

Graduate Students

Michael Binger	Brodsky
Wu-Yen Chuang	Peskin/Kachru
John Conley	Hewett
Alex Giryavets	Kachru
My Phong Le	Hewett
Benjamin Lillie	Hewett
Xiao Liu	Kachru
Liam McAllister	Kachru
Alex Saltman	Silverstein
Stewart Siu	Weinstein/Peskin
Navin Sivanadam	Silverstein
Georgios Sofianatos	Dixon
David Starr	Silverstein
Tommer Wizansky	Peskin

plus 1st -year rotators

Kachru-Silverstein students are supported jointly w. campus

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

Theorists from KIPAC attend our seminars and vice versa. Ted Baltz and Andrei Frolov interact closely with our group.

senior staff planning:

In the steady-state, the group has 7 postdoctoral fellows. Of these, 2 were obtained by replacing retiring senior staff (Tsai, Bjorken) by postdoctoral fellows.

In response to recent faculty retirements (Noyes, Blankenbecler):

One billet was given to KIPAC.

We have offered the other postion to Georgi Dvali.

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

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
Hooman Davoudiasl > (postdoc)
Martin Schmaltz > Boston

1999:
Gundrun Hiller > Munich
Albion Lawrence > Brandies
Kirill Melnikov > Hawaii
2000:
Simeon Hellerman > (postdoc)
2001:
Babis Anastasiou > (postdoc)
Thomas Becher > Fermilab
David E. Kaplan > Johns Hopkins
2002:
Stephon Alexander > Penn State
Richard Hill > (postdoc)
Amir Kashani-Poor > (postdoc)
Aaron Pierce > Michigan
2003:
Adam Lewandowski > Annapolis
2004:
Emmanuel Katz > Boston

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

Thomas, Pierce, Wells / Feng, Strassler

1995-8: New physics contributions to CP violating B decays

Atwood, Grossman, Worah (and Nir)

1998-2005: Effects of extra space dimensions in particle physics

Arkani-Hamed, Schmaltz, Davoudiasl / Perelstein, Lille

2001-5: Computational perturbative QCD

Anastasiou, Melnikov, Thomas, Berger / Petriello

2003-5: String compactifications w. R-R fluxes, and their lessons

Kashani-Poor / Schultz, McAllister, Giryavets

How are we theorists connected to the experimental program ?

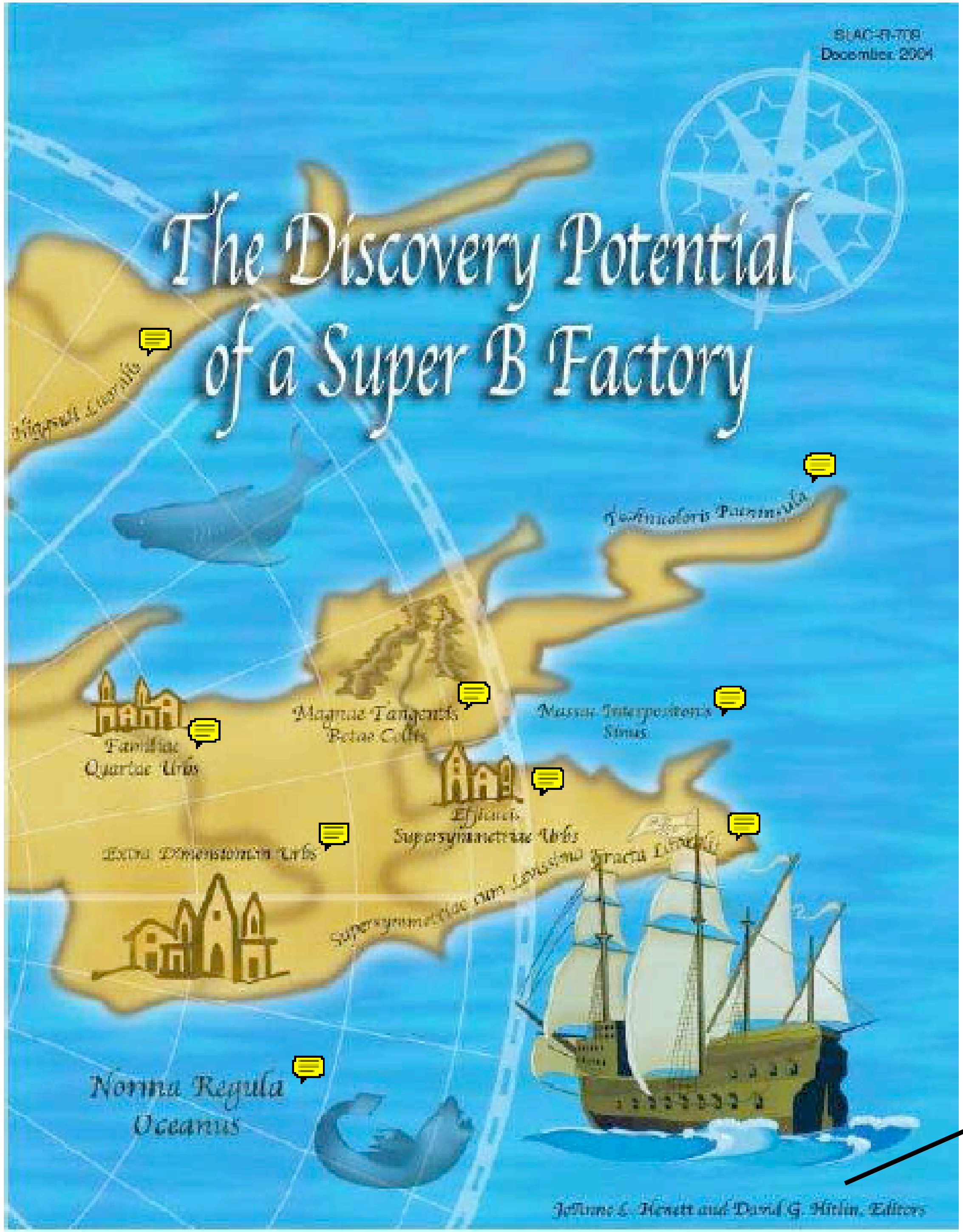
We have a continuing day-to-day connection to experimenters on site.

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 ...

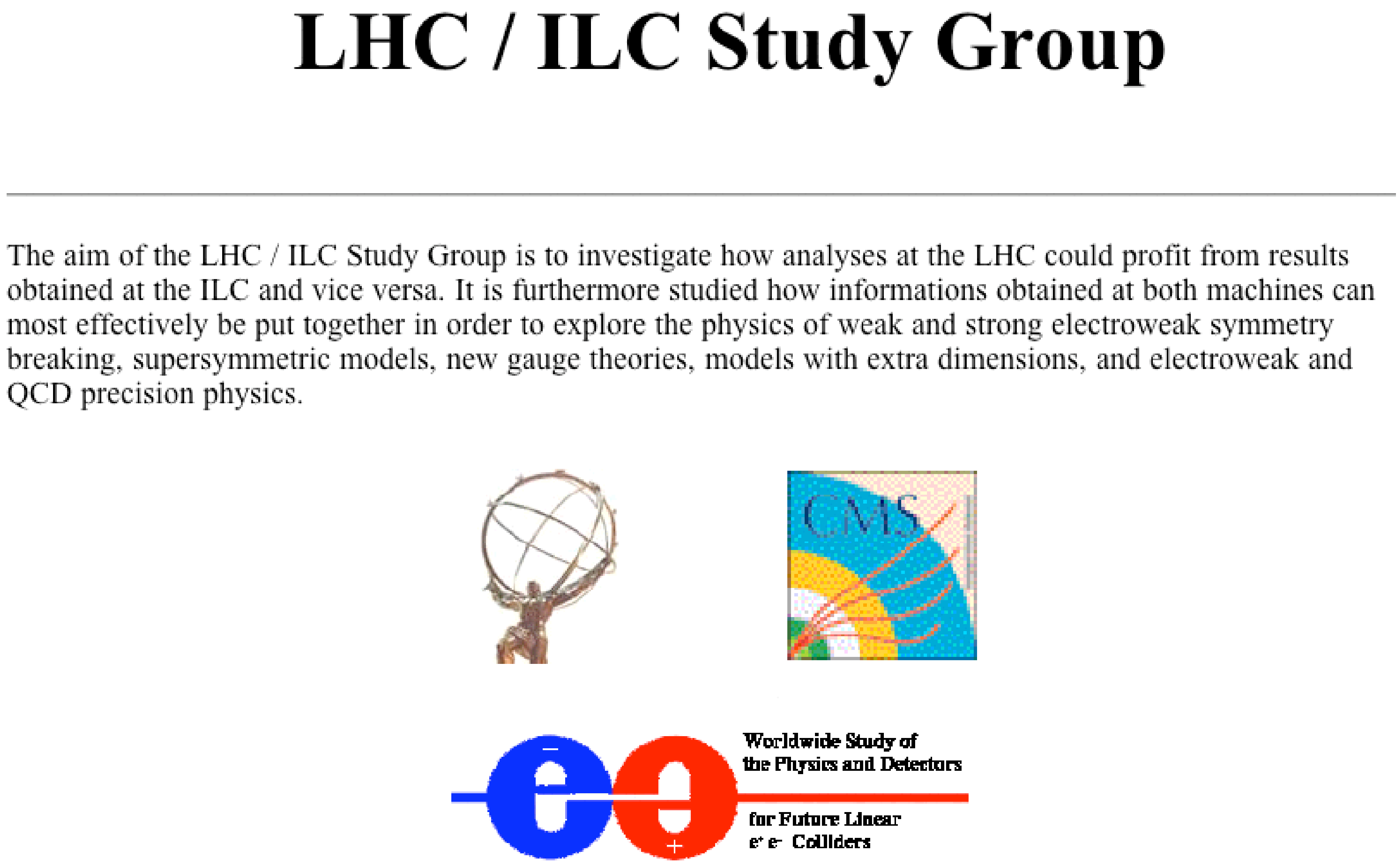


SLAC-R-709
December 2004

The Discovery Potential of a Super B Factory

JoAnne L. Hewett and David G. Hitlin, Editors

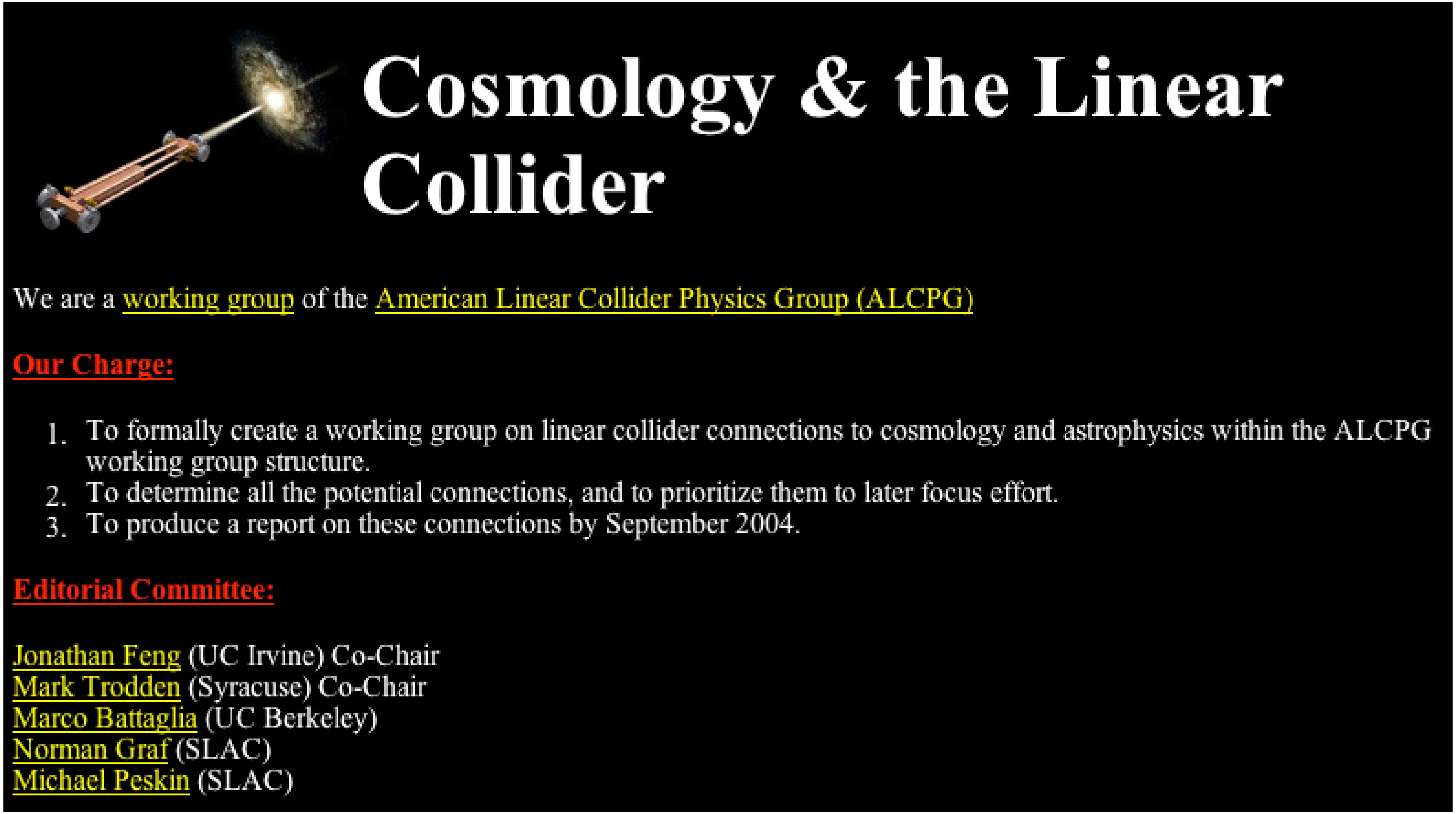
JoAnne L. Hewett
and
David G. Hitlin, eds.



LHC / ILC Study Group

The aim of the LHC / ILC Study Group is to investigate how analyses at the LHC could profit from results obtained at the ILC 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.

Hewett and Rizzo played major roles in preparing this group’s report.



Cosmology & the Linear Collider

We are a working group of the American Linear Collider Physics Group (ALCPG)

Our Charge:

1. To formally create a working group on linear collider connections to cosmology and astrophysics within the ALCPG working group structure.
2. To determine all the potential connections, and to prioritize them to later focus effort.
3. To produce a report on these connections by September 2004.

Editorial Committee:

Jonathan Feng (UC Irvine) Co-Chair
Mark Trodden (Syracuse) Co-Chair
Marco Battaglia (UC Berkeley)
Norman Graf (SLAC)
Michael Peskin (SLAC)

Peskin is spending much of his time on this report.

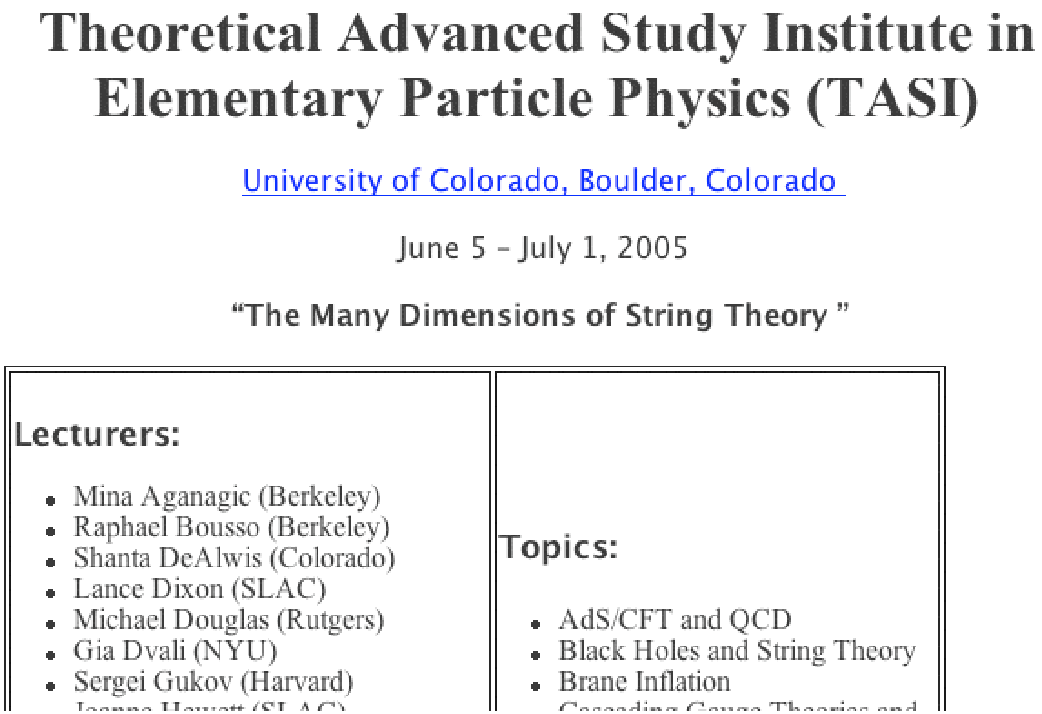
and in a related collaboration with Baltz (KIPAC), Battaglia (UC Berkeley), Wizansky (SLAC grad student).

summer schools:

TASI 05 - Kachru and Silverstein

PiTP 05 - Peskin

SLAC SI - Hewett et al.



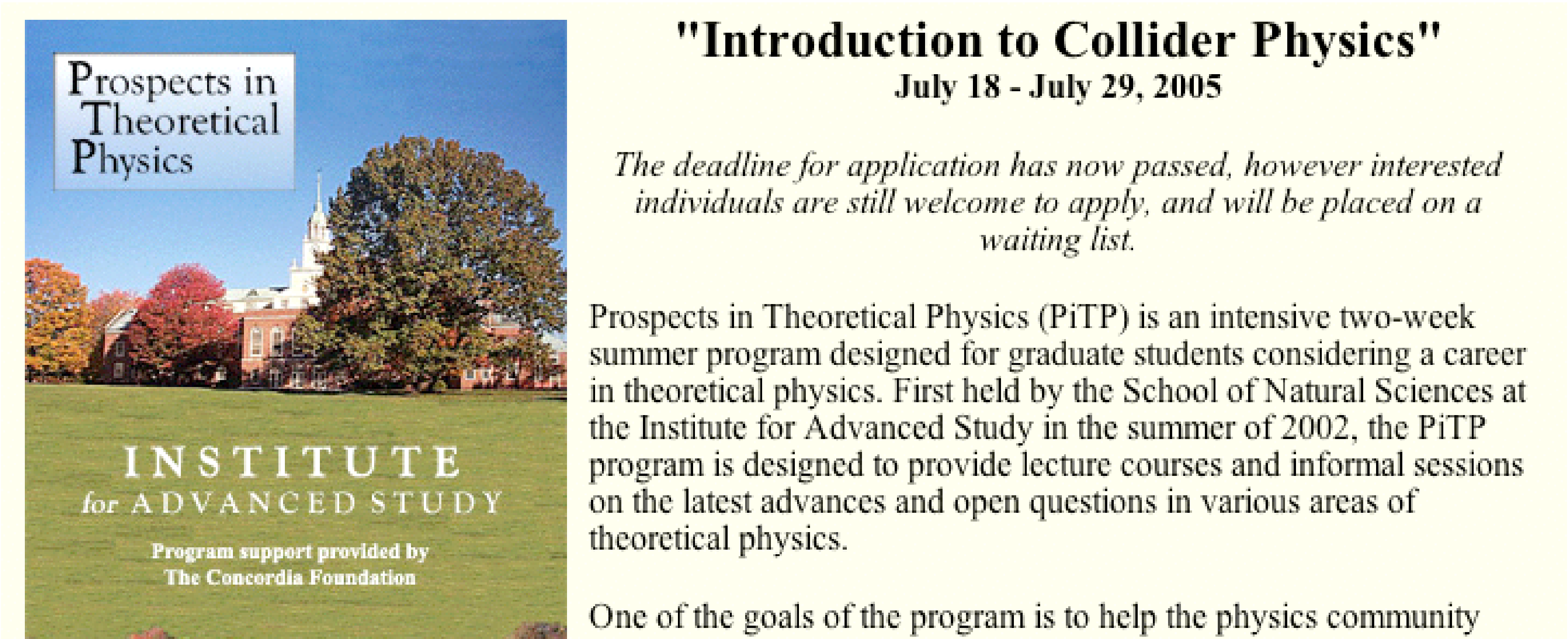
Theoretical Advanced Study Institute in Elementary Particle Physics (TASI)

University of Colorado, Boulder, Colorado

June 5 – July 1, 2005

"The Many Dimensions of String Theory"

Lecturers:	Topics:
• Mina Aganagic (Berkeley) • Raphael Bousso (Berkeley) • Shanta DeAlwis (Colorado) • Lance Dixon (SLAC) • Michael Douglas (Rutgers) • Gia Dvali (NYU) • Sergei Gukov (Harvard)	• AdS/CFT and QCD • Black Holes and String Theory • Brane Inflation



"Introduction to Collider Physics"

July 18 - July 29, 2005

The deadline for application has now passed, however interested individuals are still welcome to apply, and will be placed on a waiting list.

Prospects in Theoretical Physics (PiTP) is an intensive two-week summer program designed for graduate students considering a career in theoretical physics. First held by the School of Natural Sciences at the Institute for Advanced Study in the summer of 2002, the PiTP program is designed to provide lecture courses and informal sessions on the latest advances and open questions in various areas of theoretical physics.

One of the goals of the program is to help the physics community

I would like to pause for a moment to discuss some aspects of the question of cosmic dark matter.

Today, the existence of dark matter is established, and we know that it accounts for 20% of the energy content of the universe. We know that this matter is NOT baryons or leptons; beyond this, there are many theories.

However, one class of theories is should have pride of place, theories in which dark matter is a WIMP, a stable , neutral particle with weak-interaction-scale cross sections

WIMPs are preferred theoretically, because WIMPs arise in all nontrivial models of electroweak symmetry breaking.

WIMPs are preferred experimentally, because detection experiments for dark matter particles work only if they are WIMPs.

So let us assume that dark matter is made of WIMPs. Here are some provocative but correct * consequences:

1. The problem of determining the WIMP identity and the WIMP density purely from astrophysical measurements is ill-posed.

2. WIMP signatures at the LHC are huge and cannot be missed.

3. It is not possible to learn the identity of the WIMP at the LHC.

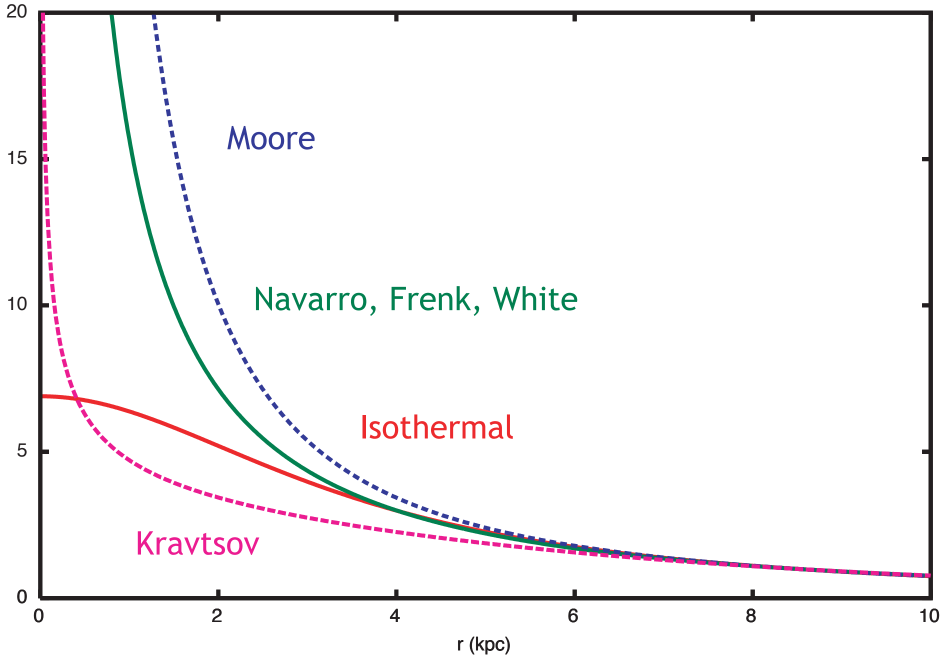
4. The ILC can identify the WIMP as an elementary particle.

5. The ILC can also determine the WIMP cross sections needed for comparison with astrophysics.

Dark matter is necessarily "Physics Beyond the Standard Model". If dark matter is a WIMP, we will have the opportunity to explore this physics. Particle accelerators (LHC and ILC) and astrophysical experiments all have a role to play.

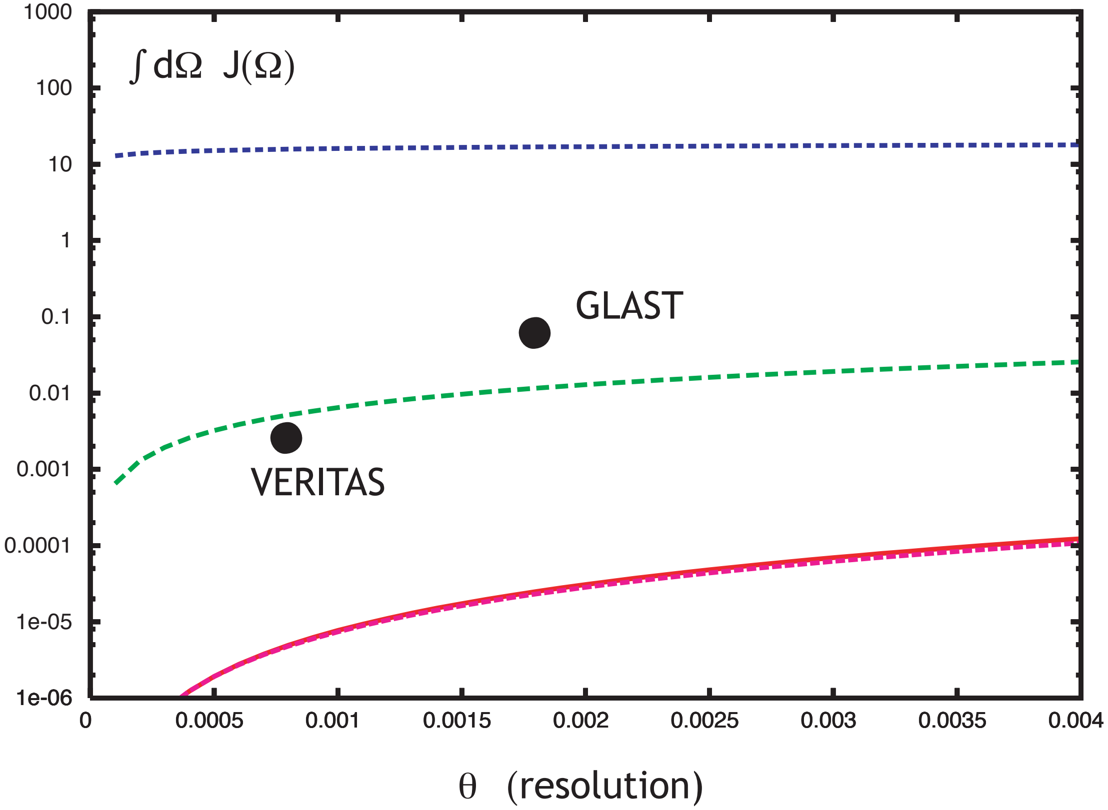
* yes, there are footnotes. Ask me.

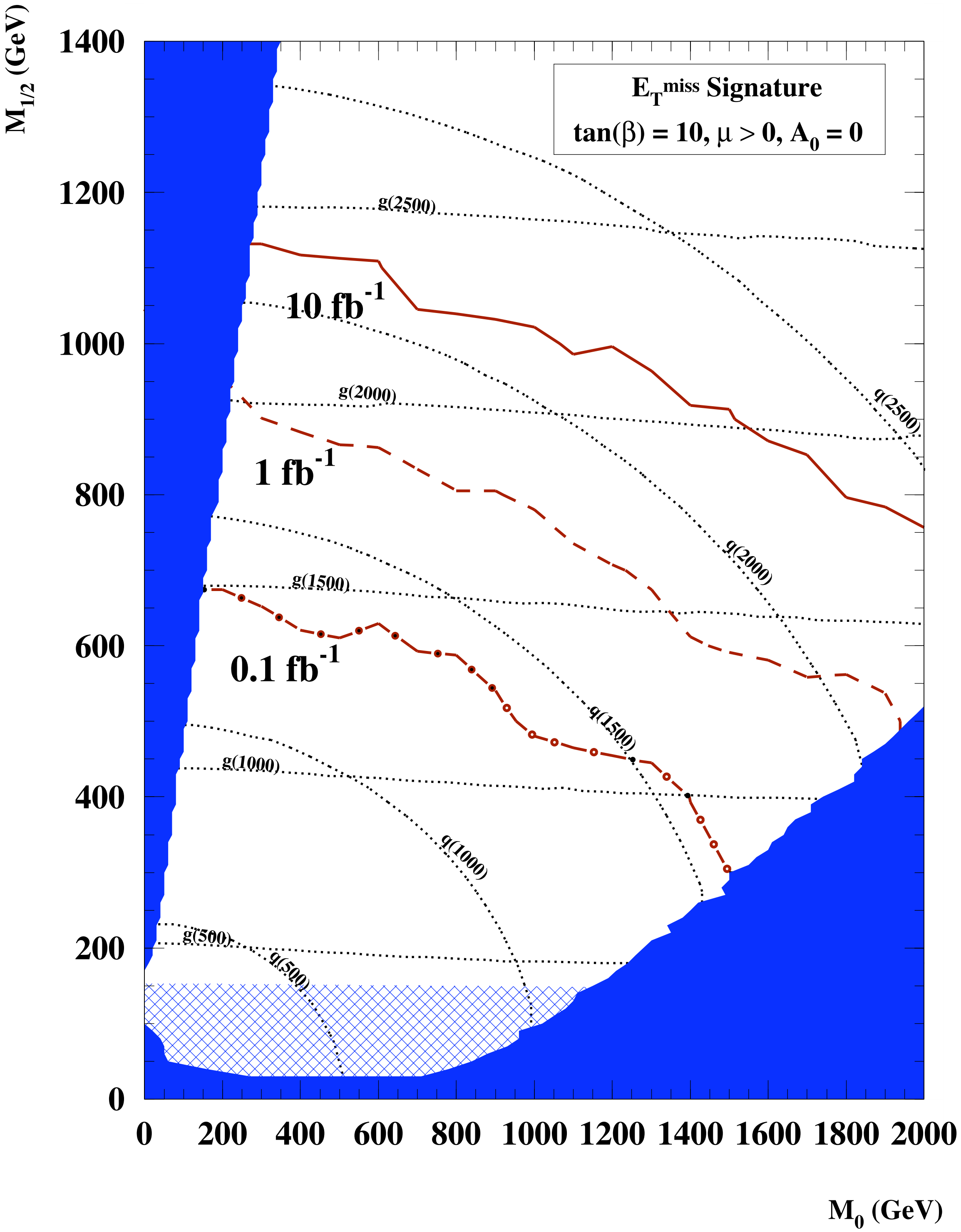
Models of the dark matter distribution near the galactic center vary widely:



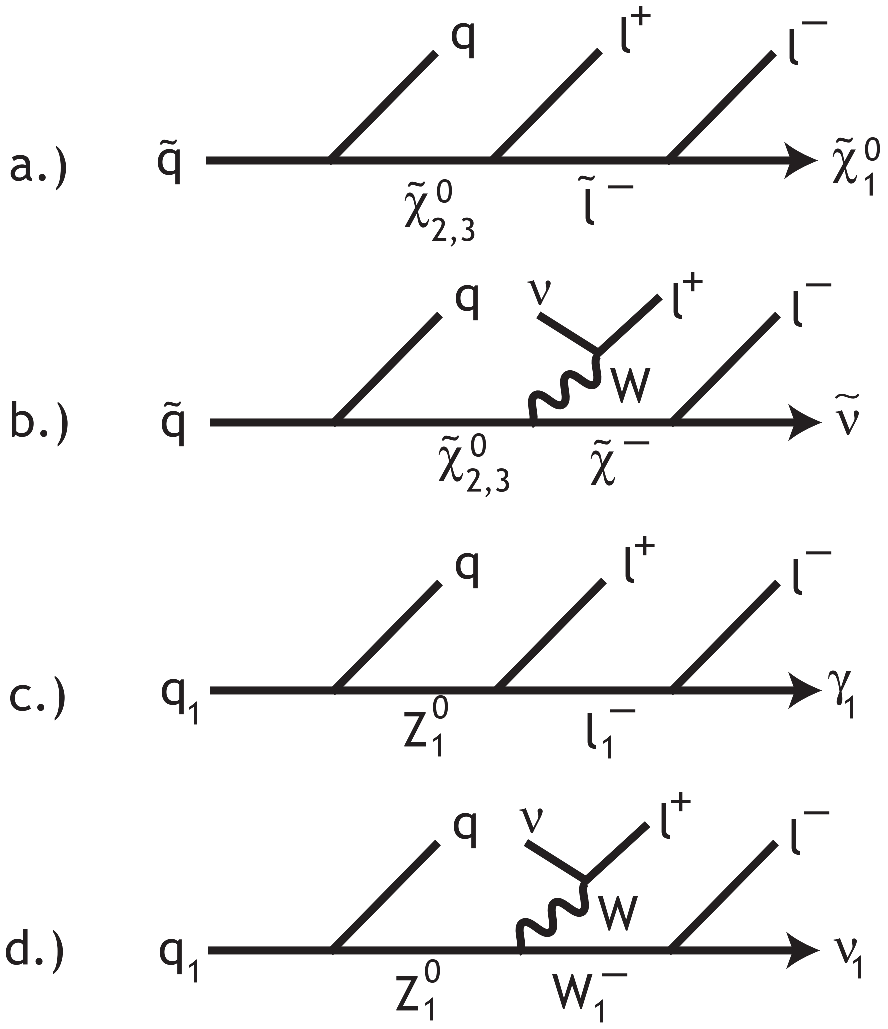
For the canonical cross section,

$$m_\chi = 100\ \mathrm{GeV}$$



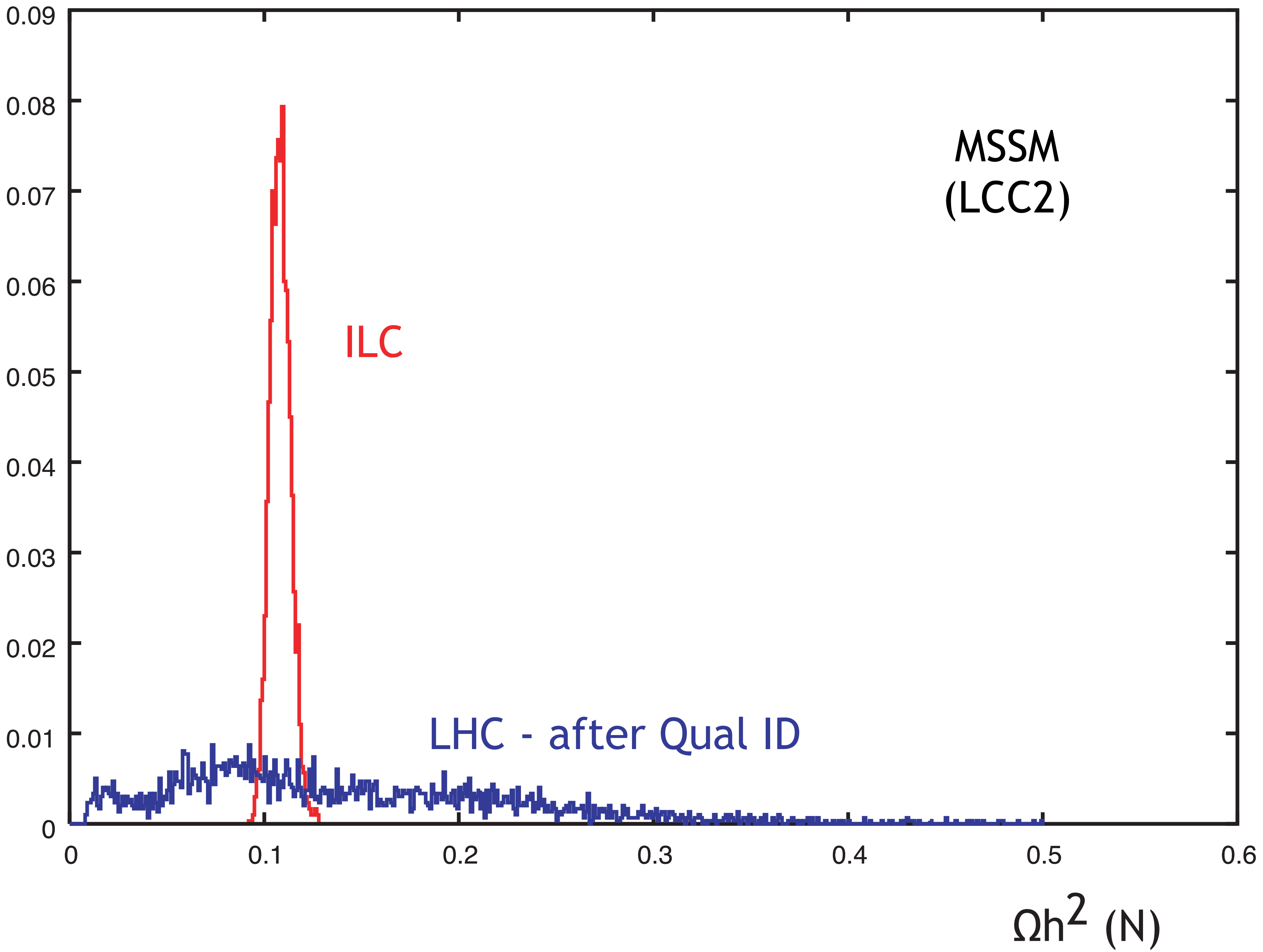

E_T^{miss} Signature
$\tan(\beta) = 10, \mu > 0, A_0 = 0$
10 fb^{-1}
1 fb^{-1}
0.1 fb^{-1}
g(2500)
g(2000)
g(1500)
g(1000)
g(500)
q(2500)
q(2000)
q(1500)
q(1000)
q(500)
$M_{1/2}$ (GeV)
M_0 (GeV)
0
200
400
600
800
1000
1200
1400
1600
1800
2000

ATLAS

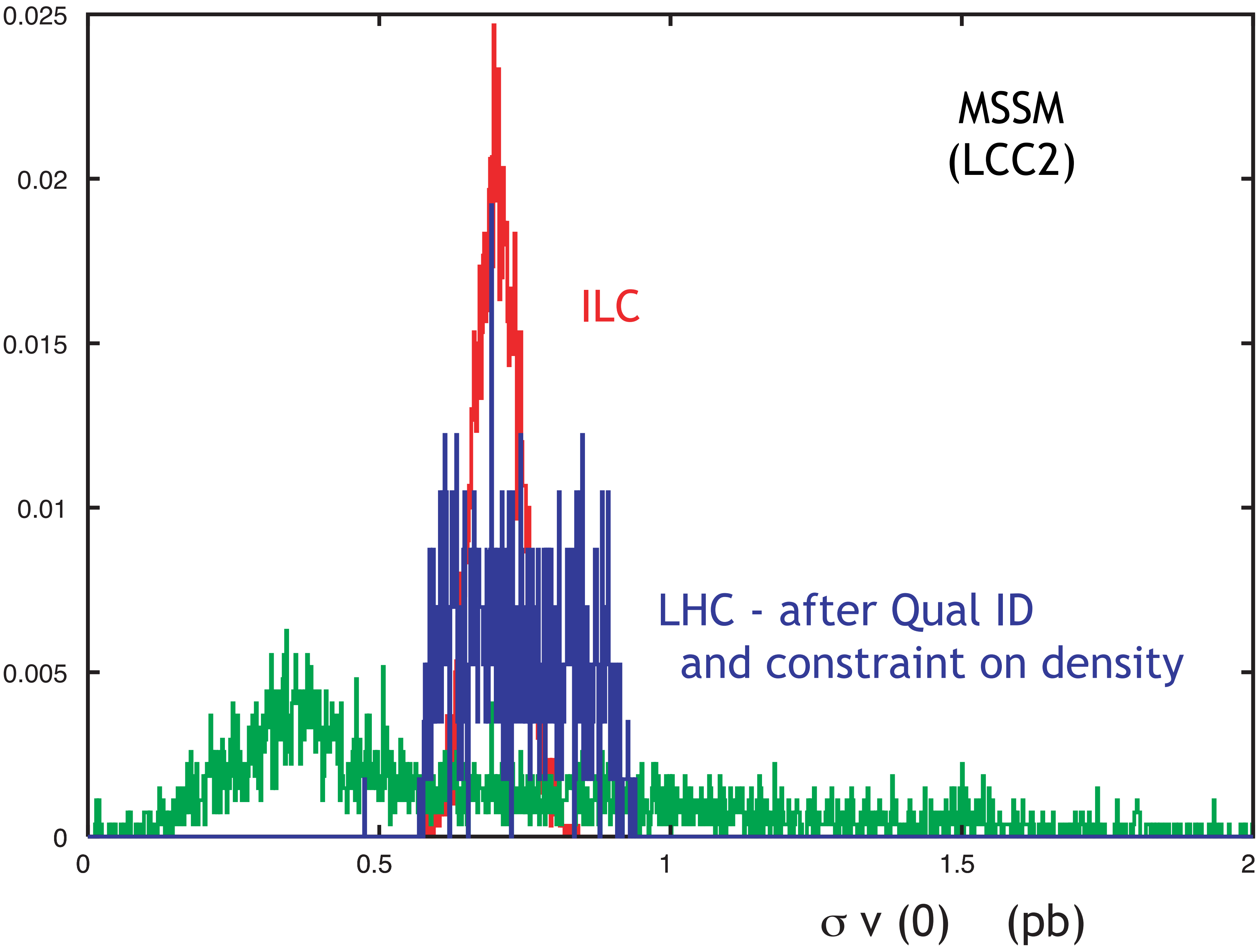


SUSY models

UED models



ILC simulations by J. Alexander et al.


0.025
0.02
0.015
0.01
0.005
0
0
0.5
1
1.5
2
MSSM
(LCC2)
ILC
LHC - after Qual ID
and constraint on density
σ v (0) (pb)

Now I would like to discuss two more 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.

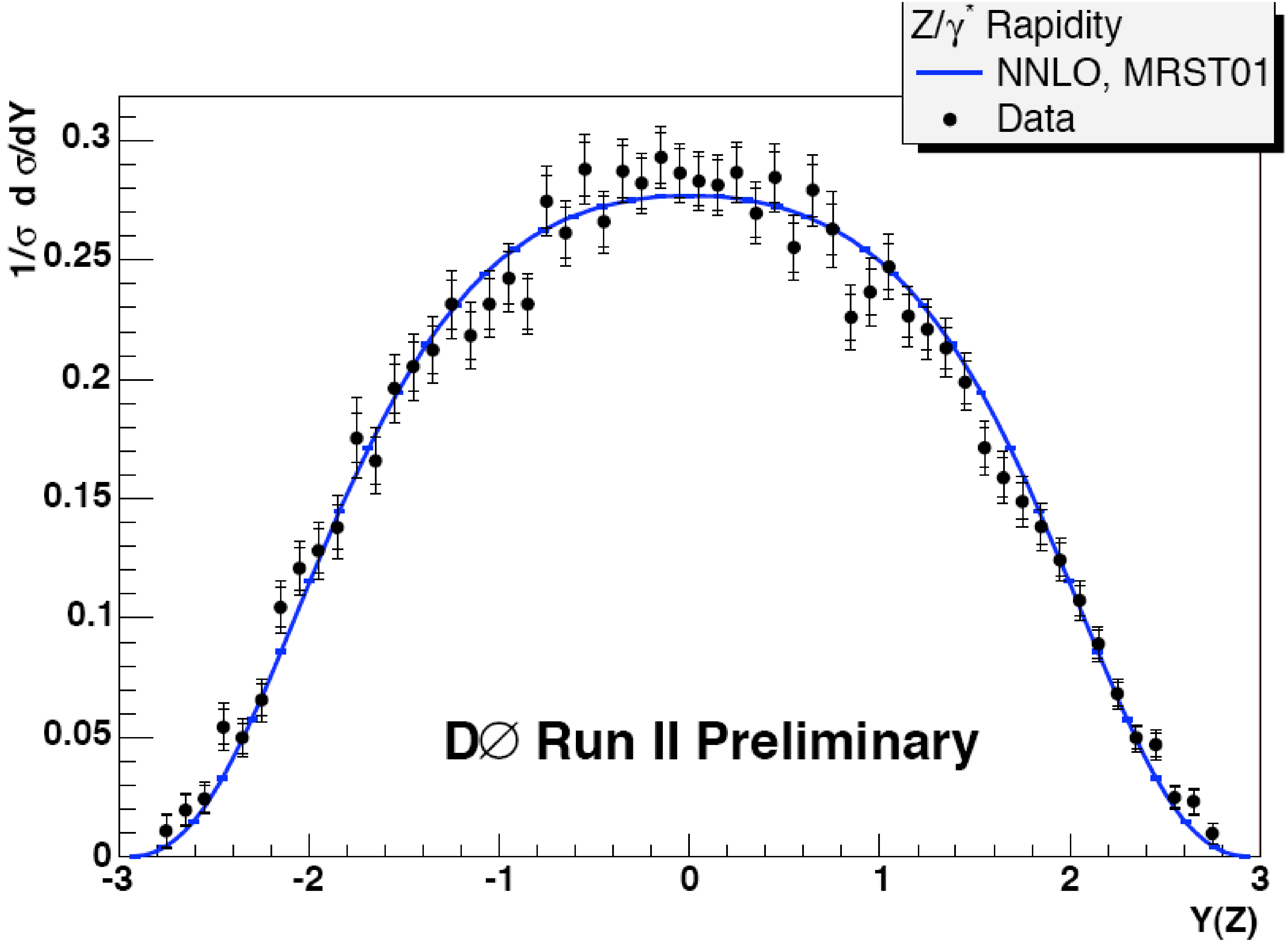
Over the last 13 years, Lance Dixon and his collaborators have been trying to improve the art of QCD perturbation theory.

The goal of this program is to produce high-precision theoretical expressions for comparison with cross ections measured at LHC,

and to determine α_s to better than 1% accuracy.

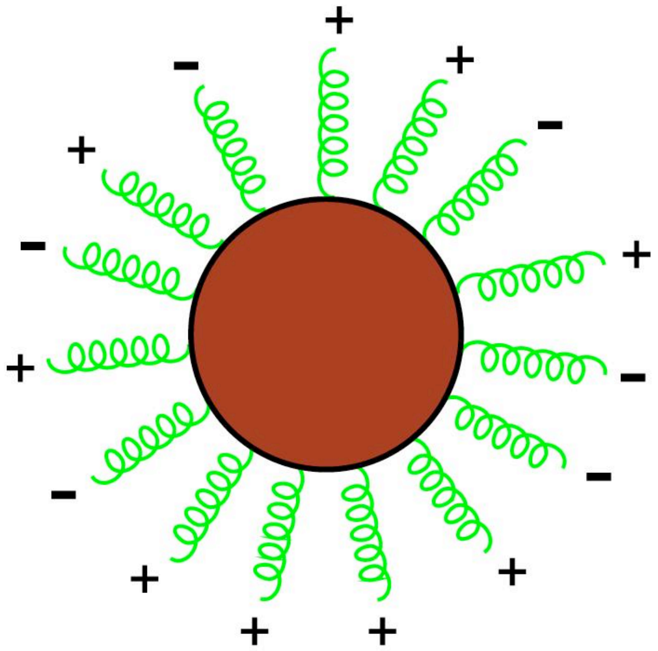
Brute-force Feynman diagram calculation requires thousands of diagram, millions of terms, for typical processes. To improve on this, one needs deep insight into QCD perturbation theory.

A major activity of the past few years has been the development of methods for NNLO QCD calculations for colliders. The rapidity distribution in Drell-Yan is now available at NNLO (Anastasiou, Dixon, Melnikov, Petriello).


Z/γ^* Rapidity
NNLO, MRST01
Data
1/σ dσ/dY
0
0.05
0.1
0.15
0.2
0.25
0.3
-3
-2
-1
0
1
2
3
Y(Z)
DØ Run II Preliminary

Our latest work pursues a new insight into perturbative QCD by Witten:

Massless QCD tree amplitudes are holomorphic functions with support on lines in twistor space.



Amplitudes are characterized by gluon/quark helicities. The simplest case has two negative (or positive) helicities (MHV) (Parke-Taylor).

Cachazo, Svrcek, and Witten showed that general tree amplitudes can be built up from MHV amplitudes using simple rules !

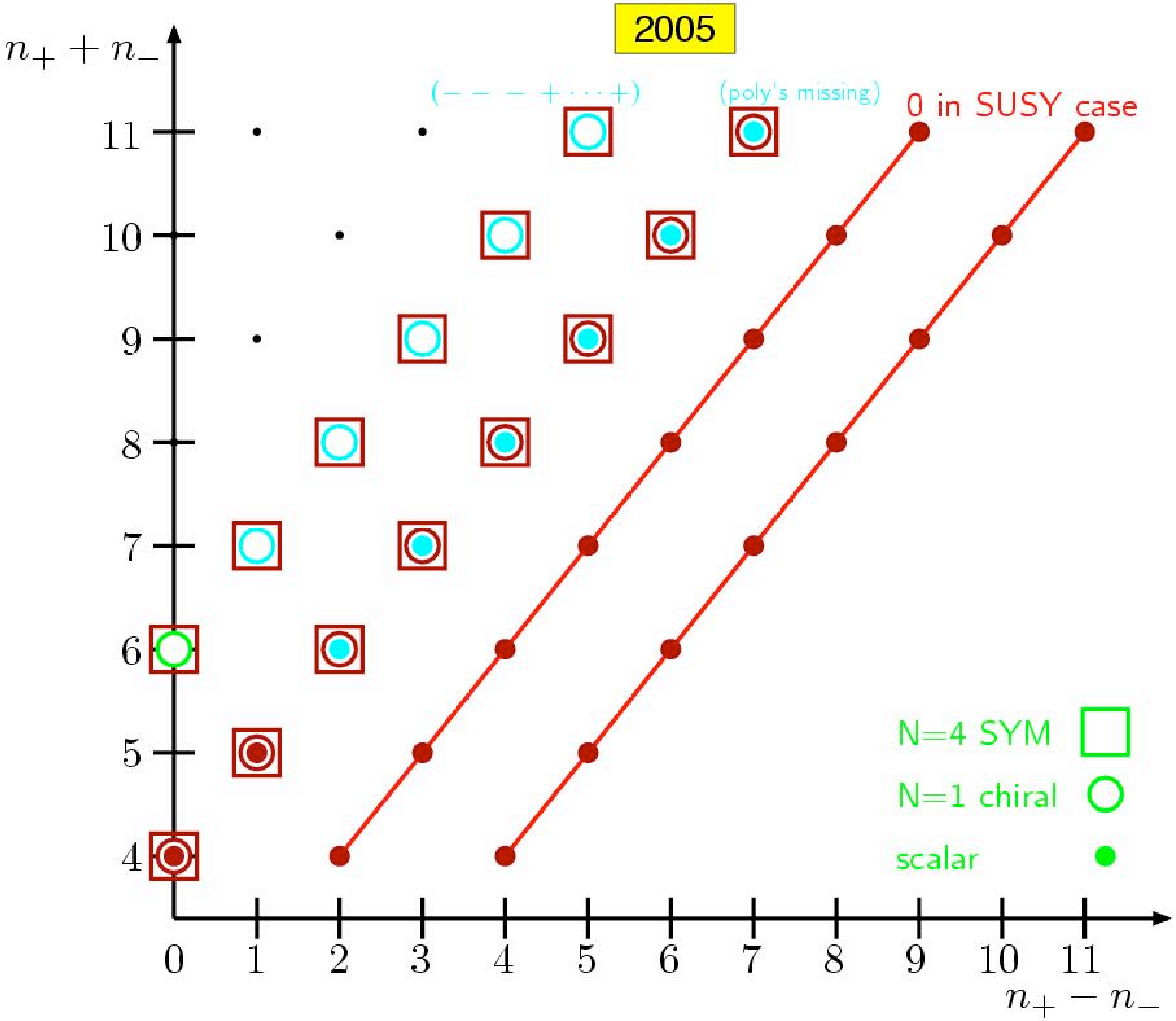
The method generalizes to diagrams for Higgs boson production; Dixon, Glover, and Khoze computed all h + n g tree amplitudes up to n(-) = 4.

The new methods allow calculation of families of QCD 1-loop amplitudes.

In 1993, Bern, Dixon, and Kosower computed QCD 1-loop 5-point amplitudes. In 1994, they showed that 1-loop amplitudes in supersymmetric QCD can be constructed from tree amplitudes using unitarity cuts.

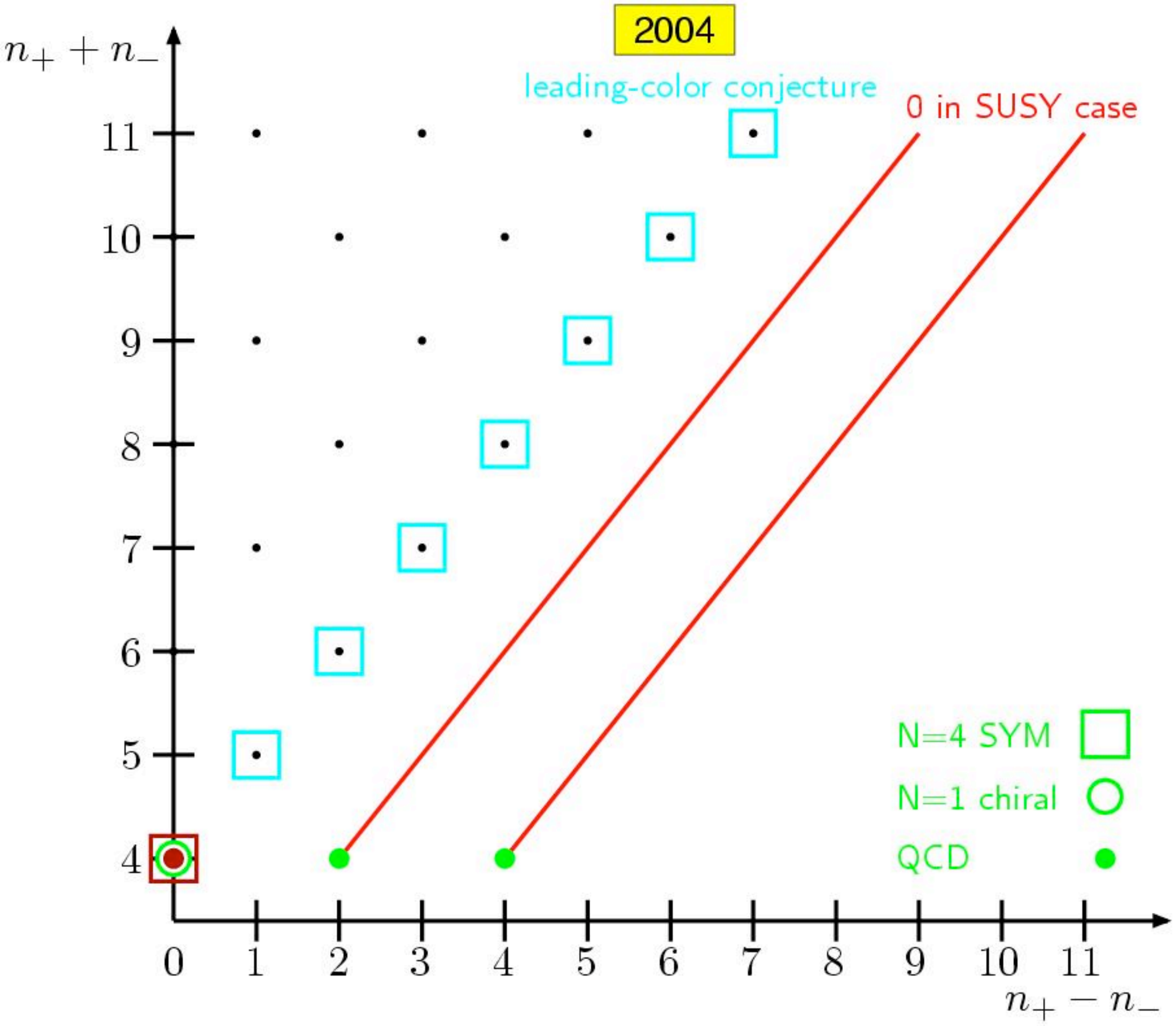
The new results build on these methods and allow explicit calculation of infinite families of 1-loop N=4 SUSY QCD amplitudes, so far up to n(-) = 3 (Bern, Dixon, Del Duca, Kosower). The resulting expressions are relatively simple in twistor variables, with support on polygons in twistor space.

2005



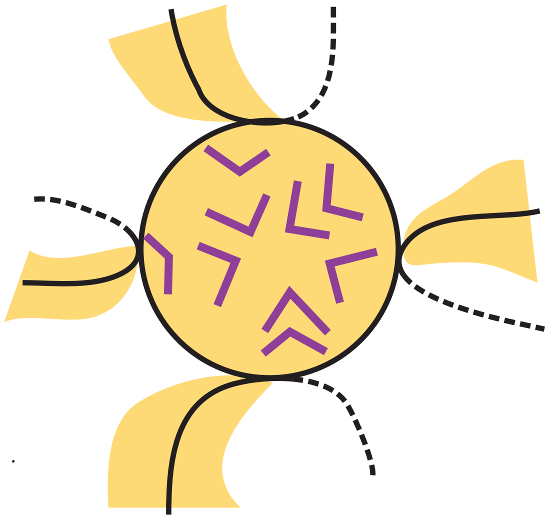
$n_+ + n_-$
11
10
9
8
7
6
5
4
$(- - - + \cdots +)$
(poly's missing)
0 in SUSY case
N=4 SYM
N=1 chiral
scalar
0
1
2
3
4
5
6
7
8
9
10
11
$n_+ - n_-$

A conjecture is suggested for the 2-loop MHV amplitudes, and for a 3-loop generalization. We look forward to much more progress in the next year.



Turn now to another problem that I have discussed in previous years, string theory compactifications with Ramond-Ramond fluxes.

R-R fields are the antisymmetric tensor gauge fields found in higher-dimensional supergravity theories. The associated field strengths can wind in a topologically nontrivial way around cycles in the Calabi-Yau manifold of a string compactification.



These fields can form superpotentials that can fix the Kahler (size) moduli and the dilaton, leading to discrete solutions.

Kachru, Kallosh, Linde, and Trivedi (KKLT) showed that this strategy can be used to construct string theories in de Sitter space, with positive background cosmological constant.

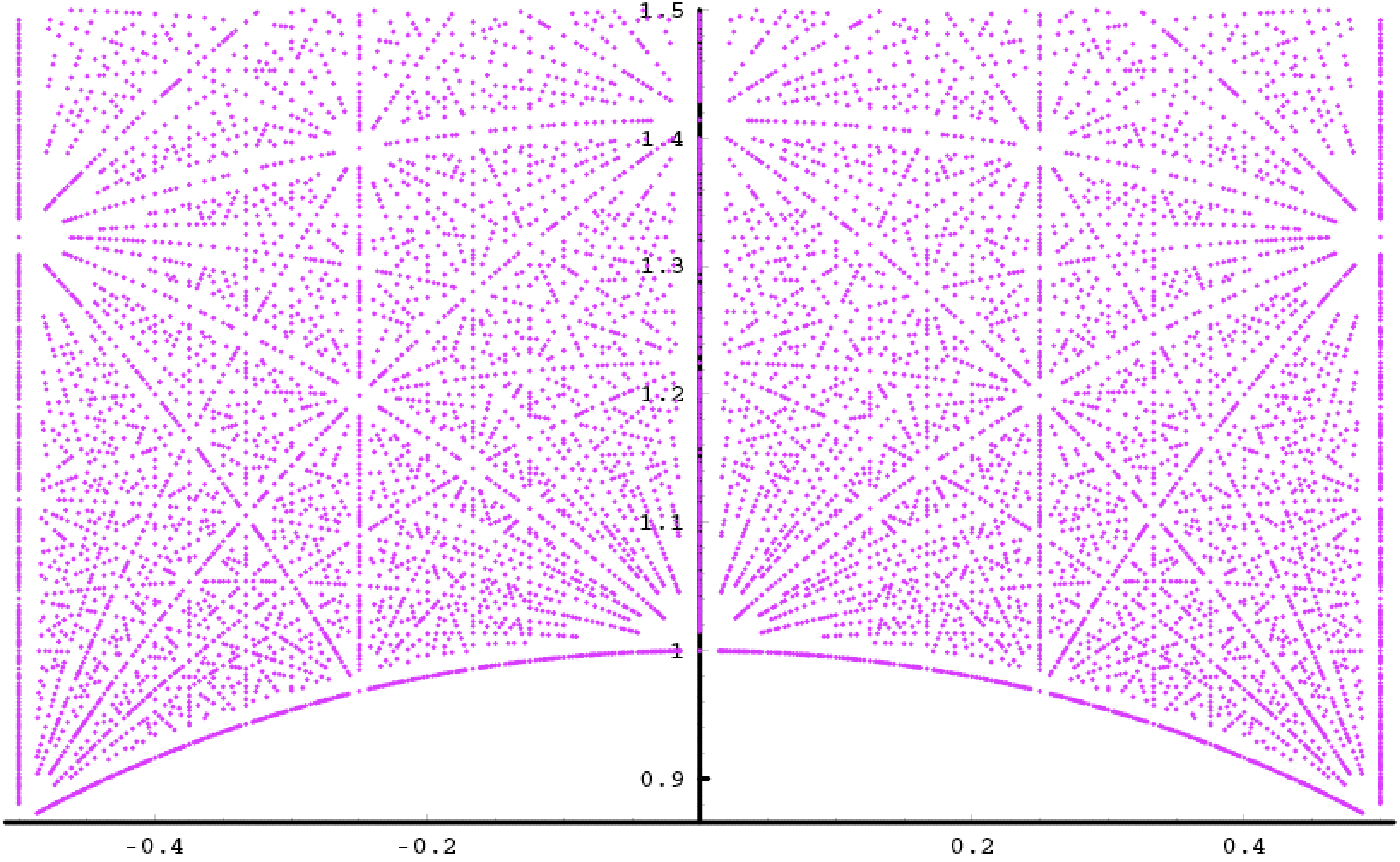
These theories are models for inflating vacuum states, and for our real universe.

However, it turns out that there are huge numbers of such solutions to string theory. In the past year, there has been progress in enumerating families of solutions and studying their properties.

R-R fluxes are quantized. The equations for minimizing the potentials are linear equations, to be solved over the integers. Techniques from number theory are useful in confronting this problem.

This year, de Wolfe, Giryavets, Kachru, and Taylor have enumerated vauum states in a number of schemes, some with the constraint of possessing discrete symmetries.

Here is a map of solutions that respect a continuous R symmetry, as a functions of a complex structure modulus.



What is the significance of this multiplicity of vacuum states?

It is certainly a real property of string theory, as we currently understand it. It must have some implications for models of inflation and for ‘theories of everything’.

To some people, it indicates that the theory of everything is not unique, so that the underlying parameters of the Standard Model are determined anthropically.

Dvali has conjectured that these solutions accumulate where they produce light particles, giving a probabilistic explanation of the hierarchy problem. This behavior is seen in some string examples.

We need more data on the pattern of these solutions. This requires detailed, and clever, analyses.

These examples illustrate the variety of problems under investigation in the theory group.   We are happy to choose problems requiring tough mathematical analysis, but we happier when the results can bring back new insights into elementary particles and fundamental physics.