Fermilab Theory Group

Christopher T. Hill

DOE Annual Program Review
Fermilab, May 17, 2006

Scale of Effort(s)

Program Review	FY05	FY06	FY07	FY08
Particle Theory (SWF+M&S+G&V)	$3,598	$3,531	$3,731	$3,899
Lattice	$1,451	$2,782	$2,733	$3,035

The support for the Lattice gauge is increasing; some of the funds come from SciDAC, some from the core budget.

Scientists (12)

Bill Bardeen

Marcela Carena

Estia Eichten

Keith Ellis

Walter Giele

Christopher Hill

Andreas Kronfeld

Joe Lykken

Paul Mackenzie

Bogdan Dobrescu*

Stephen Parke

Chris Quigg

*Promoted, 10/01/05

Associate Scientists (1)

Thomas Becher (9/04)

Senior Guest Scientist(1)

Boris Kayser

Emeritus Scientist (1)

Leon M. Lederman

Research Associates (9)

Mu-Chun Chen

Richard Hill

Jay Hubicz

Jim Laiho

Olga Mena

Enrico Lunghi

Jose Santiago

Peter Skands

Ruth van de Water

Regular Users

C. Albright (NIU)

S. Mrenna (Fermilab, Computing)

Y. Keung (UIC)

S.P. Martin (NIU)

Ulrich Baur (Buffalo)

Departures:

Ayres Freitas → Zurich ETH

Giulia Zanderighi → CERN

Uli Haisch → Zurich ETH

Masataka Okamoto → KEK

Ulrich Nierste → Karlsruhe (Professor)

New Postdoc Hires arrived Fall 2005:

Mu-Chun Chen (from BNL),(*)

Richard Hill (from SLAC),

Jay Hubicz (from Cornell)

Enrico Lunghi (from ETH)

Ruth van de Water (from Seattle)

(*) just received Jr. Faculty offer from Irvine

New Postdoc Hires to arrive Fall 2006:

K. Kong (from Gainesville),

R. Mahbubani (from Harvard),

Associate Scientist Search:

Babis Anastasiou (offered and declined)

History of the Post-Docs, Associate Scientists and Frontier Fellows is posted on the web:

http://theory.fnal.gov/people/ellis/alumni.html

http://theory.fnal.gov/people/ellis/Assoc.html

http://theory.fnal.gov/people/ellis/frontier.html

The Fermilab Theory Group Visitors Programs

Frontier Fellows

Senior distinguished visitors spending research time at Fermilab.

Paul Langacker in Fall 05; M. Neubbert Fall 06 (?)

Academic Visitors

Miscellaneous scientific collaborators and workshop participants. (e.g., N. Brambilla, S. Dutta, F. Petriello, A. Vario, in academic year 2005/2006)

Latin American Scholars Program

Two excellent young physicists per year for 6 months come to study/work/collaborate in theory group:

2004: Alejandro Daleo (Argentina), Julian Candia (Argentina)

2005: Roberto Papaqui (Mexico), Alejandro Szynkman (Argentina)

2006: Pablo Barros (Brazil), Maximillianos Rivera (Chile)

Summer Visitors

Approx. 30 visitors spending about 2-3 weeks each during the summer.

Seminar Speakers

Theoretical seminar (44 speakers in 2005);

Joint Experimental-Theoretical Seminar (45 speakers in calendar 2005).

Recent Frontier Fellows and Academic Visitors:

Vernon Barger (10-12/98)

Howard Haber (9-12/98)

Stuart Raby (2-6/99)

Wu-Ki Tung (2-6/00)

Stefan Pokorski (9-12/00)

Jo Anne Hewett (9-12/00)

Mariano Quiros (9-12/01)

Ken Lane (9-2/02)

Eric Braaten (10-12/02)

Aida El-Khadra (7-12/02)

Tao Han (10/04 –12/04)

Edward Boos (10/04 –12/04)

Paul Langacker (9/05 – 2/06)

Thomas Appelquist (10-12/98)

Pierre Ramond (6/99; 5/00)

Steve Ellis (3-6/00)

Moshe Moshe (3-9/00)

Mariano Quiros (9-12/00)

Alexei Yu. Smirnov (4/01)

Steve Gottlieb (9-6/02)

Ulrich Baur (2-4/02)

Scott Willenbrock (7-12/02)

Peter Zerwas (9-11/04)

Manny Paschos (10/04 –12/04)

Sherwin Love (1/05 –04/05)

Frank Petriello (spring 2006)

Publications, Conference Proceedings, Reports

2005 - present

• Senior Staff Scientific Publications:	34	(32 last year)
• Senior Staff Conference Proceedings, Reports, etc.:	30	(24)
• Research Associate Scientific Publications: *	17	(26)
• Research Associate Conference Proceedings:	21	(8)
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	102	(90)

(* not counting newly arrived Research Associates, or papers coauthored and counted for senior members)

The Major Questions of Particle Physics:

What causes Electroweak Symmetry Breaking?

Bardeen, Carena, Dobrescu, Eichten, Hill, Lykken, Quigg, Santiago, Hubicz

Is Supersymmetry associated with the phenomenon?

Bardeen, Carena, Dobrescu, Eichten, Hill, Lykken, Quigg, Santiago, Hubicz

Are extra dimensions to be found near the Electroweak Scale?

Carena, Dobrescu, Hill, Lykken, Santiago, Hubicz

What is the origin and physics of Neutrino Mass?

Kayser, Mena, Parke, Quigg, Chen

What are the indirect signatures in Flavor Physics?

Bardeen, Eichten, Hill, Quigg, Becher, Lunghi

How do we extract new physics within QCD?

Lattice: Bardeen, Eichten, Kronfeld, Mackenzie, Laiho, van de Water

Perturbative: Ellis, Giele, Becher, Skands, Lunghi

Particle physics connections to Cosmology and Astrophysics:

Carena, Hill, Lykken, Quigg, Mena

Staff Research Highlights 2005-2006

Bill Bardeen - continued to study AdS/CFT models relevant for a dual description of QCD. continued the development of a phenomenological chiral string model for heavy-light mesons. studied the divergence structure of Little Higgs models when applied to weak flavor mixing at NLO.

Thomas Becher - Performed a NNLO calculation of the effect of the photon energy cut in B->X_s +gamma. Did an analysis of B->pi form factors with R. Hill. Calculated lattice-to continuum matching relevant for the extraction of epsilon_K.

Marcela Carena - Developed Models of Dark matter direct detection and examined the capability of collider experiments (LHC and ILC) to determine the dark matter density in different SUSY models, and the implications of Direct Dark matter searches at CDMS II for Heavy neutral Higgs searches at the Tevatron and the LHC. Investigated constraints on B and Higgs Physics at the Tevatron and the LHC from present and future measurements of Bs mixing and rare decays, searches for heavy neutral Higgs bosons in inclusive tau decays, effects of radiative corrections on MSSM Higgs boson searches and impact of tau polarization on the study of the MSSM charged Higgs bosons in top quark decays at the ILC. Worked on models of gravity in five dimensional braneworld backgrounds, with the ultimate goal of applying these ideas to cosmology.

Bogdan Dobrescu - Studied the structure of six dimensional gauge theories compactified on the chiral square. Showed that high mass ttbar resonances can appear at the LHC, and potentially at the Tevatron. Explored the types of new macroscopic spin-dependent forces that may be discovered in laboratory experiments and studied implications for Z' searches.

Staff Research Highlights 2005-2006 (cont'd)

Estia Eichten -Continued study of the effects of coupling to decay channels in the charmonium system (with C. Quigg and K. Lane). These effects are particularly important to understand the nature of the a host of new charmonium threshold states (X(3872), X(3940), Y(3940), Z(3930) and Y(4260)) recently observed at the Belle, BaBar and CLEO. Studying (with T. Duncan) of the mechanism of confinement in Coulomb gauge for 2+1 D Lattice QCD.

Keith Ellis -The major effort has been on a semi-numerical method for loop corrections, which is the main bottleneck in developing the NLO Monte Carlo MCFM. Completed the calculation of Higgs->4 partons at one loop, as well as the six-gluon amplitude at one loop. Version 5 of the Monte Carlo MCFM has been released in April 2006, containing many processes at NLO, (see mcfm.fnal.gov).

Walter Giele – Development of dipole shower Monte Carlo, including explicit uncertainty estimates due to approximations and has exact matching to hard scattering matrix elements. Neither feature is included in HERWIG and PYTHIA. Application of a semi-numerical approach (developed last year) to evaluate one-loop matrix elements applied to NLO pp->H+2 jets (through gluon fusion and NLO gg->gggg. Now ready to calculate at NLO many of the Higgs search backgrounds at the LHC (Zanderighi and Ellis).

Christopher Hill – Studied topological properties of Yang-Mills field theories in higher dimensions. Showed that the D=5 Yang-Mills Chern-Simons terms under compactification to D=4 with an A_5 zero mode becomes the exact Wess-Zumino-Witten term of a chiral lagrangian.

Boris Kayser – Studied with de Gouvea and Jenkins how to determine whether the neutrino mass spectrum is normal (quark-like) or inverted even if the mixing angle θ13 is very small. An exploration with de Gouvea and Langacker of how the universe would be qualitatively different if the neutrinos were massless, or else much heavier than they are in fact, is close to completion. An analysis with Jansson, McKeown, Mena, Pascoli, and Quigg of the possibility of producing with the Tevatron a "beta" neutrino beam of great physics reach is underway. Review of neutrino physics published by the Particle Data Group has been revised and updated. With many other members of the APS Multi-Divisional Neutrino Study, a white paper on the theory of neutrinos was completed.

Staff Research Highlights 2005-2006 (cont'd)

Andreas Kronfeld – our numerical lattice QCD calculations of the D^+ and D_s decay constants appeared in June 2005, and were confirmed subsequently by CLEO (f_{D^+}) and BaBar (f_{D_s}). We are extending these calculations to a many topics relevant to B decays and mixing. Doing analytical work to reduce heavy-quark discretization effects in lattice QCD.

Joe Lykken - general analysis of stability issues (ghosts, tachyons) and gauge fixing in warped models of braneworld gravity and braneworld cosmology. LHC phenomenology including new techniques for discoveryin the first physics run. Phenomenology of M-theory analog of the Randall-Sundrum model. Cosmology with multiple inflationary periods. Survey of issues in string phenomenology.

Paul Mackenzie - Completed study of charm meson decay constants in lattice QCD. This was completed prior to the announcement of improved results from CLEO-c (which are in good agreement). Continued work on B meson decay constants and B and D meson semileptonic decays. Studied the use of analyticity constraints in the comparison of semileptonic decay results between lattice QCD and experiment.

Stephen Parke – studied (with Mena) the "Physics Potential of the Fermilab NuMI Beamline"and how a comparison of neutrino running at T2K and NOvA, at the same E/L , can determine the Neutrino Mass Hierarchy for large Theta_13. With Nunokawa and Zukanovich-Funchal calculated the fraction of B8 solar neutrinos that are nu_2 mass eigenstates (90%); developed alternative way to determine the mass hierarchy using disappearance experiments only.

Chris Quigg –With E. Eichten and K. Lane, I am exploring the new states associated with charmonium. Gabriela Barenboim, Olga Mena, and I studied the observational constraints on undulant cosmologies, and explored whether neutrino interactions with relic neutralinos might probe the dark matter. With Mena and Irina Mocioiu, I have looked at gravitational lensing of supernova neutrinos. With Mena, Boris Kayser, and others, we are examining the potential of beta beams for the study of neutrino properties.

Outreach and Policy

M. Carena - Member, Particle Physics Project Prioritization Panel (P5) (2005 - 2007)
CISA (APS Committee on Iternational Scientific Affairs) (2006--2009)
DPF Executuve Committee (2003 --2005)
DPF Nominating Committee (2006 -- 2009)
Fermilab Committee on Hiring and Retention of Scientific Staff (2006)
Aspen Center for Physics Member Nomination Committee (2005--Present)
DPF Outreach Committee (2004--Present)
Fermilab Academic Lecture Series (Chair)
TeV4LHC Workshop (Co-chair) 2004-2005 (Editing proceedings)
Latin American Students Program (2004- Present)

B. Dobrescu - Co-director of the 2006 Joint Fermilab-CERN Hadron Collider Physics Summer School; Convenor at the TeV4LHC Workshop (Fermilab, BNL, CERN, 2004-2006).; URA thesis award committee; Fermilab Colloquium committee .

E. Eichten - Convener (with G. Bali and C. Patrignani) of the "Hadron Spectroscopy and Exotics" Parallel Session for ICHEP 2006 this summer in Moscow.
Coorganized (with Junko Sugemitsu) the phenomology section of the KITP workshop on Modern Challenges for Lattice Field Theory held 1/10-4/01 2005.

C. Hill - Scientist III Promotion Committee (chair);
Head of Fermilab Theoretical Physics Department.

Outreach and Policy

B. Kayser - Member, Particle Physics Project Prioritization Panel (P5);
Neutrino Scientific Assessment Group (NuSAG);
Fermilab Physics Advisory Committee;
Co-Chair, APS Multi-Divisional Neutrino Study;
Editor, Annual Review of Nuclear and Particle Science;
Academic Lectures at Fermilab, Summary talk at International Europhysics Conference on High Energy Physics,
Member, Organizing Committee of Particles and Nuclei International Conference (PANIC 2005), Advisory Committee of Neutrino 2006; Awardee Selection Committee of the Alvin Tollestrup Award for Outstanding Postdoctoral Research.
Editor of Annual Review of Nuclear and Particle Science,

A. Kronfeld - member of the Organizing Committee for the World-Wide Study of Physics and Detectors at Future Linear e+e- Colliders; member of the USQCD Scientific Program Committee; Chair of the Selection Committee for the 2006 J.J. Sakurai Prize (awarded to S. Dimopoulus).

J. Lykken – Chairman DPF, member of HEPAP, co-chair of HEPAP LHC/ILC subpanel (input to EPP2010 process plus the Discovering the Quantum Universe report).
Les Houches convenor, organizer of TeV4LHC and LHC Olympics; Chair of winter conference committee, Aspen Center for Physics. Advisory Board and Steering Committee, KITP Santa Barbara.

Outreach and Policy

P. Mackenzie - Executive Committee of USQCD, the US collaboration organizing lattice QCD computing infrastructure for the DoE; Allocations Committee for the NSF supercomputer centers; NSF panel evaluating high energy theory grant applications. DOE SciDAC, National Committee, Advisor to KEK on Large Scale Simulation; Fermlab Committee for Scientific Appointments.

S. Parke - contributed to the NOvA proposal as well as the study of Physics at the Fermilab Proton Driver.

C. Quigg - Past chair of DPF, HEPAP, Program committee APS ; Albuquerque 2002 (chair), IMSA Board

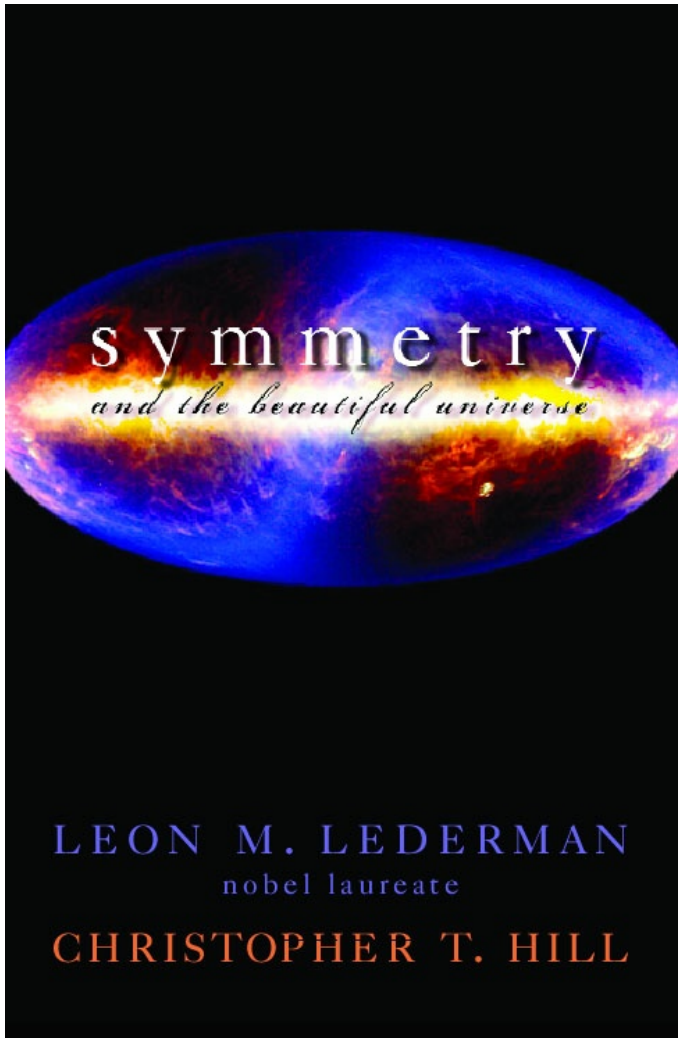
Over 16,000 Sold; To appear in Spanish:

"… In Symmetry and the Beautiful Universe, Leon Lederman and Chris Hill have captured the essence of this simple yet profound concept and conveyed its wonders with art and precision. In accessible and entertaining language, the authors provide readers with a crystal-clear window to physics' most refined theories, allowing us all to appreciate the awe-inspiring beauty of the universe."

—Brian Greene, Author of *The Elegant Universe* and *The Fabric of the Cosmos*; Professor of Physics, Columbia University

"An enigma of twentieth-century physics is the question of symmetry as a guiding principle of nature. Did nature start with the idea of symmetry, or is it an accidental consequence? Is symmetry, with its aesthetic appeal, a fundamental principle? In this penetrating and lucid book the authors, both top physicists, take on symmetry as a basic principle. They succeed in a marvelous way, and consequently this book is a must for the serious student of nature."

—Martinus Veltman, *Nobel Laureate*; Author of *Facts and Mysteries in Elementary Particle Physics*



Initiatives 2005-present

(1) Joint Astrotheory/Theory Pizza Night

(2) Academic Lecture Series

(3) Bardeen Symposium

(4) Monte Carlo Tools for Beyond-the-Standard-Model Physics (MC4BSM), Fermilab, March 20-21,2006

(5) MCFM Monte Carlo program http://mcfm.fnal.gov.

(6) TeV4LHC

(7) Linear e+ e- Collider Physics Study Group http://wwwlc.fnal.gov/.

(8) Lattice Gauge Theory http://lqcd.fnal.gov .

Fermilab Academic Lecture Series

Course 1	The Electroweak Theory and Higgs Physics · Six Lectures Chris Quigg (Fermilab) November 1 – 17, 2005 · Details
Course 2	Tests of the Electroweak Theory · Six Lectures Paul Langacker (Penn & Fermilab) November 29 – December 15, 2005 · Details
Course 3	The New World of Neutrino Physics – Part I · Four Lectures Boris Kayser (Fermilab) February 7 – 16, 2006 · Details
Course 4	The New World of Neutrino Physics – Part II · Four Lectures Stephen Parke (Fermilab) February 21 – March 2, 2006 · Details
Course 5	Exploring the New World of Neutrino Physics · Three Lectures Rob Plunkett (Fermilab) March 9, 14, 16, 2006 · Details
Course 6a	The Smooth Universe · Three Lectures Scott Dodelson (Fermilab) April 3, 5, 10, 2006 · Details

Current:

Course 7

The Search for WIMP Dark Matter around Our Galaxy · Two Lectures
Blas Cabrera (Stanford & Fermilab)
April 17 and 19, 2006 · Details

Course 6b

The Clumpy Universe · Three Lectures
Scott Dodelson (Fermilab)
April 24, 26, May 1, 2006 · Details

Normal lecture days and times: Mondays and Wednesdays at 11:00 am in Curia II.

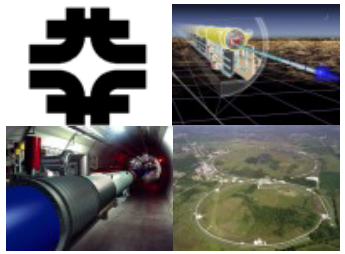
Course 8

High-p_t Hadron Collider Physics · Three Lectures
Dan Green (Fermilab)
May 9, 11, and 16, 2006 · Details

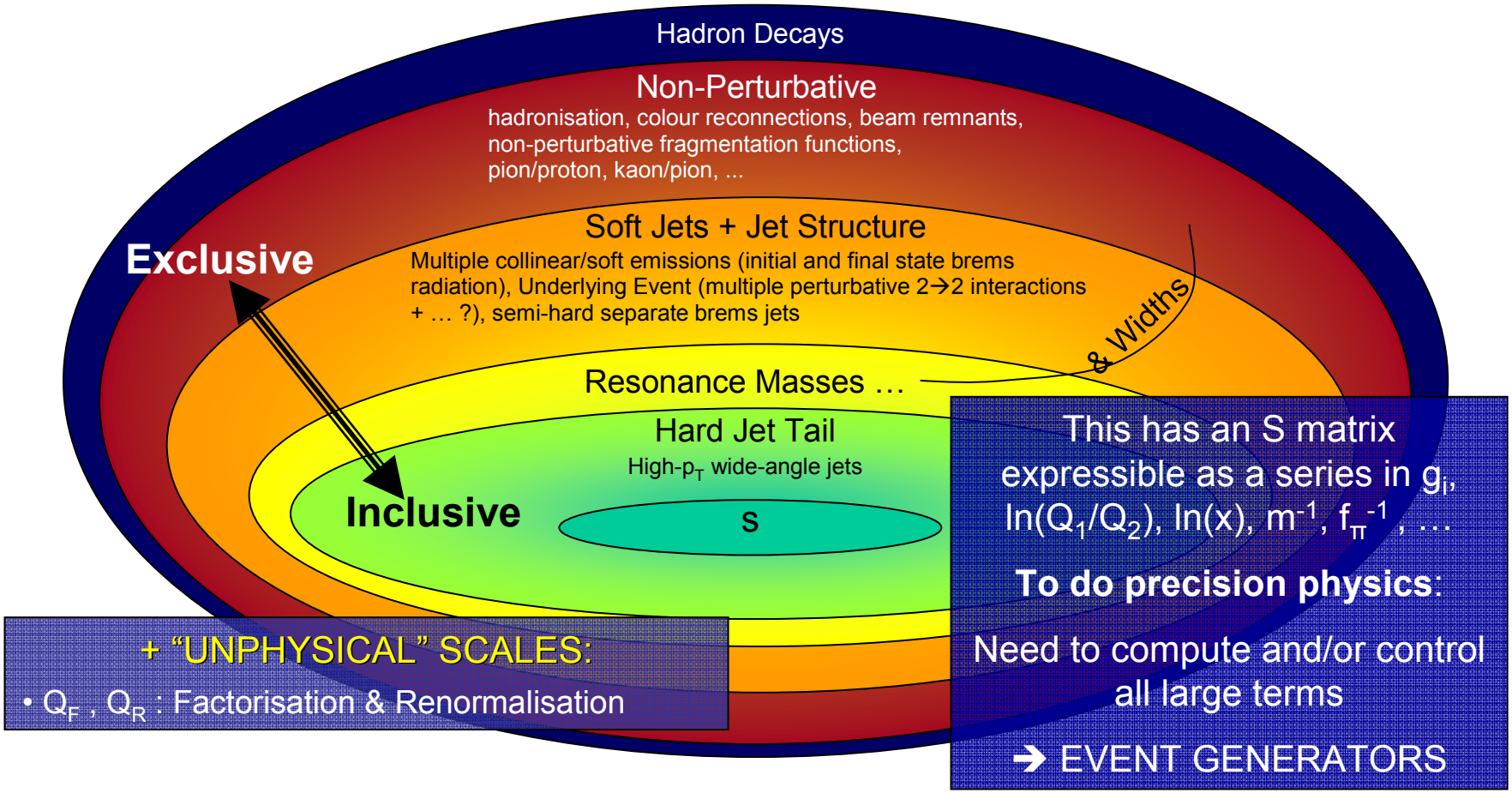
Normal lecture days and times: Tuesdays and Thursdays at 11:00 am in Curia II.

MC4BSM Workshop

Monte Carlo Tools for Beyond-the-Standard-Model Physics. March 20-21 2006. Fermilab

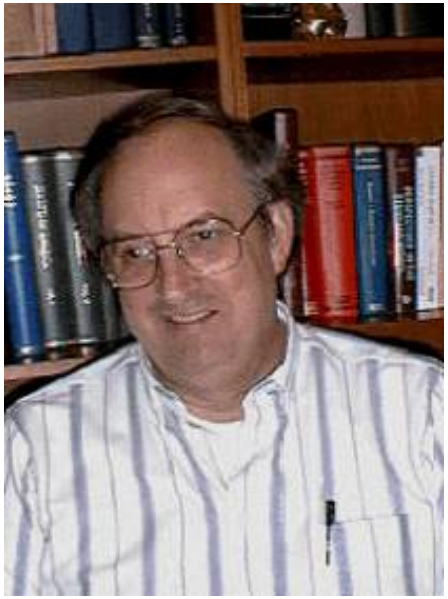


- General problem: how to obtain fully exclusive descriptions of collider final states in arbitrary New Physics models



Bill Bardeen Symposium – Fermilab –

September 23-24, 2005
9:00 am - 5:00 pm



Confirmed Invited Speakers include:

Stephen Adler, Tom Appelquist, Andrzej Buras, Sally Dawson,
Harald Fritzsch, Mary K. Gaillard, Roberto Peccei,
Mike Turner, Henry Tye, Bruno Zumino, …

AGENDA (to appear)
Link to registration (there will be no registration fee)

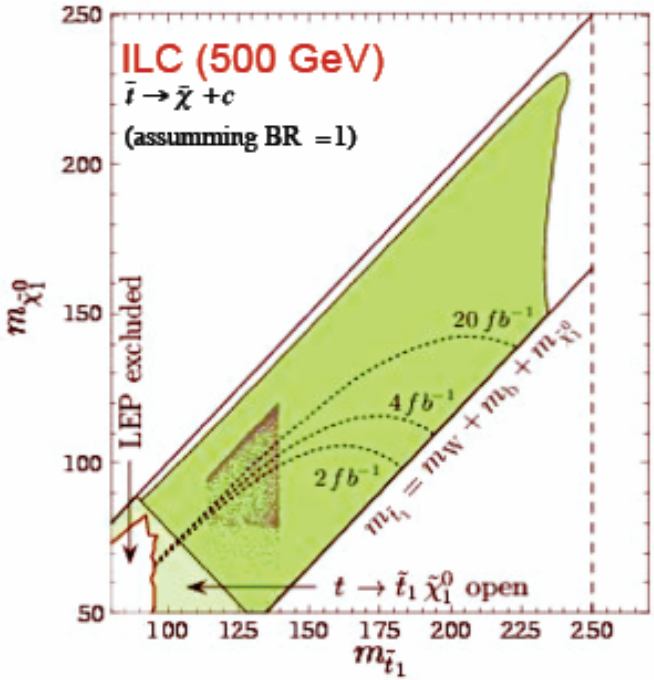
Sample Physics Highlights of the Fermilab Theory Group 2005-present

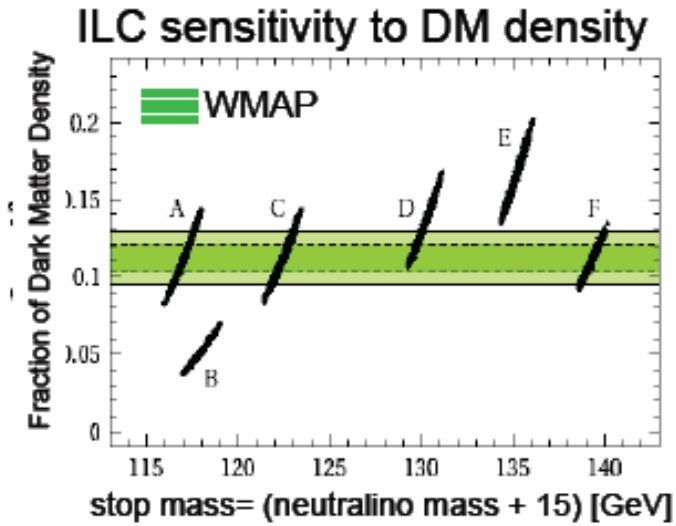
Carena, Freitas, et.al.

Dark Matter at Colliders

The LHC will probably find evidence of DM particles through missing momentum and missing energy analyses

The ILC will determine its properties with extreme detail, allowing to compute which fraction of the total DM density of the universe it makes





SUSY models which explain DM and Matter-Antimatter Asymmetry

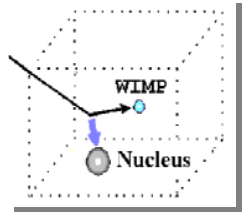
M. Carena et al. hep-ph/0508152

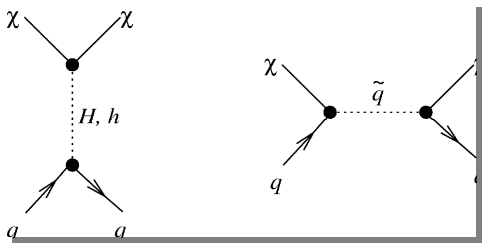
A particle physics understanding of cosmological questions!

Carena, Hooper,* Skands
(*) Fermilab Astrotheory

CDMS/Tevatron Complimentarity

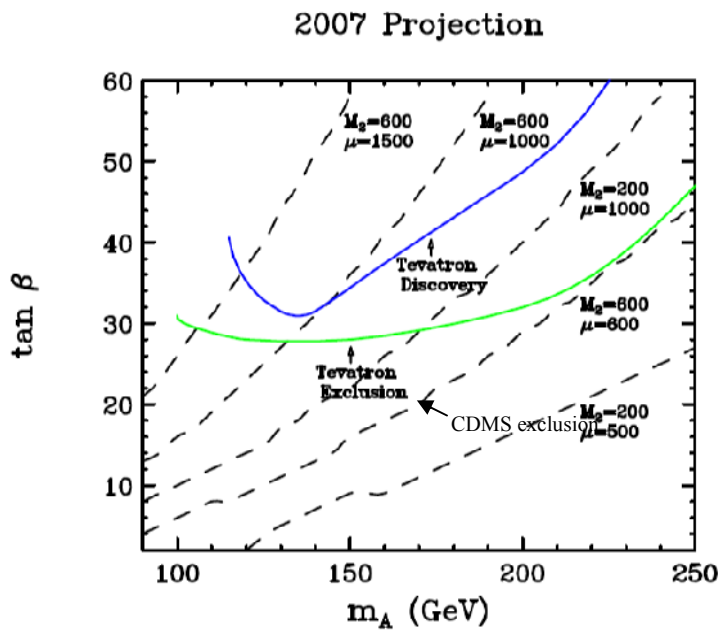
- **CDMS: Cryogenic Dark Matter Search**
  - ”Direct Detection” of Dark Matter by looking for recoils of elastic scattering
  - Prime Candidate: Neutralino from MSSM
  - Scattering process dominated by **t-channel Higgs exchange,** s-channel squark exchange
  - So ”Direct Dark Matter Detection” ~ ”Indirect Higgs Detection”





- **Meanwhile at the Tevatron:**
  - Direct searches for MSSM Higgs through collider production, with H→taus, H→bb

- **➔ Complimentarity**
  - CDMS strong for small mu ~ M2 (large Higgsino component in Neutralino)
  - Tevatron strong for large mu and/or M2 (small Higgsino component in Neutralino)



P. Skands, A. Freitas

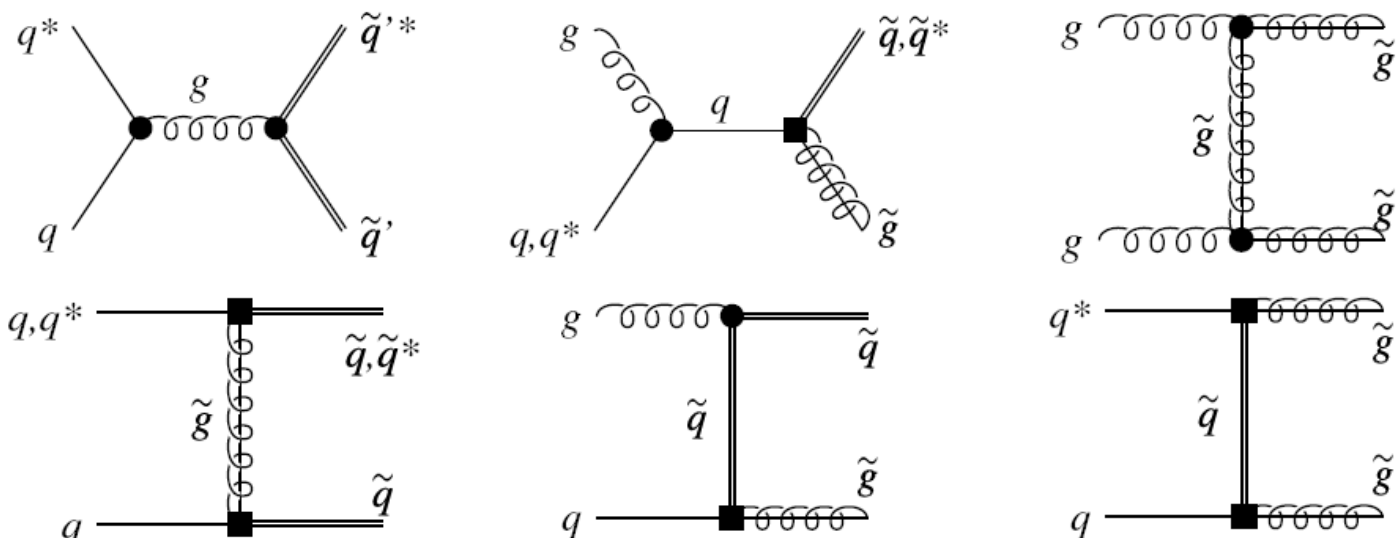
LHC/ILC Complimentarity

Is it Supersymmetry? How to check:

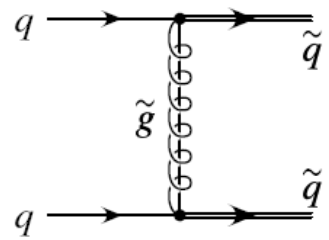
1. Measure spins
2. **Measure dimensionless couplings** and check SUSY relations (vital for SUSY to solve hierarchy problem)

Known: electroweak couplings can be tested with high precision at ILC

But what about the strong gauge -Yukawa coupling relations?



LHC/ILC Complimentarity (cont'd)



- Total cross section for double squark production depends on Yukawa to the fourth:
- To get <u>total</u> cross section at **LHC** ...
  - Measure partial cross section in clean channel: same-sign leptons from

$$\tilde{u}_{\rm L} \xrightarrow{65\%} u\,\tilde{\chi}_1^+ \xrightarrow{100\%} u\,\tau^+\,\nu_\tau\,\tilde{\chi}_1^0 \xrightarrow{35\%} u\,\ell^+ + \not{E}, \qquad \ell = e,\,\mu,$$

  - Measure each of the Branching Ratios in the chain at **ILC**
  - Fold in Branching Ratios from ILC into LHC result → total cross section
- Challenges & Caveats:
  - So far considered only gluino significantly heavier than squarks, so extra jet clearly visible
  - Use 3rd jet veto, b-jet veto, large missing energy, and possibly requiring positive-sign leptons to beat down background
  - Need left-squark branching ratios to be measured at ILC → only works if left-squarks are within mass reach of ILC
- → SUSY-QCD Yukawa coupling can be determined to ~ 5% precision

B. Dobrescu

Gauge theory in 6 dimensions

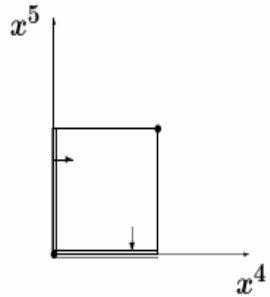
Chiral boundary conditions on a square

G. Burdman, B. Dobrescu, E. Ponton, hep-ph/0506334

Identify pairs of adjacent sides:

$$\mathcal{L}(x^\mu, y, 0) = \mathcal{L}(x^\mu, 0, y)$$

$$\Rightarrow \quad \Phi(y,0) = e^{in\pi/2}\Phi(0,y), \ \ldots$$



Spectrum of Kaluza-Klein modes:

(j,k)	(1,0)	(1,1)	(2,0)	$(2,1)$ $(1,2)$	(2,2)	(3,0)	$(3,1)$ $(1,3)$
$M_{j,k}R$	1	$\sqrt{2}$	2	$\sqrt{5}$	$2\sqrt{2}$	3	$\sqrt{10}$

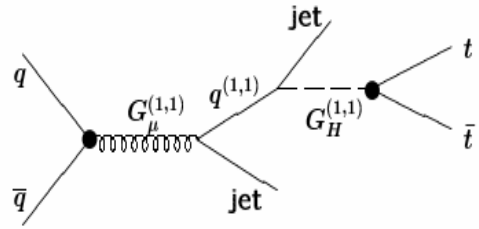
KK parity: invariance under $\Phi^{(j,k)}(x^\mu) \mapsto (-1)^{j+k}\,\Phi^{(j,k)}(x^\mu)$

$t\bar{t}$ resonances from universal extra dimensions

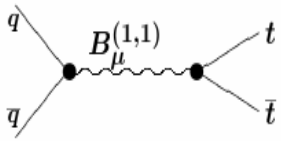
Standard model in 5+1 dimensions *(Burdman, Dobrescu, Ponton, hep-ph/0601186)*

Kaluza-Klein mode of the gluon has cascade decays to gluons polarized along the extra dimensions $G_H^{(1,1)}$.

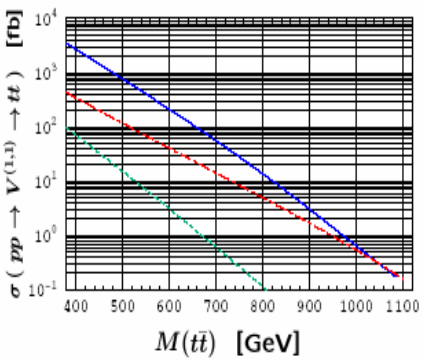
$G_H^{(1,1)}$ (spin-0, color octet) couples to quarks proportional to their mass.



Kaluza-Klein mode of the photon, $B_\mu^{(1,1)}$, has Br$(t\bar{t}) \approx 25\%$



Tevatron:



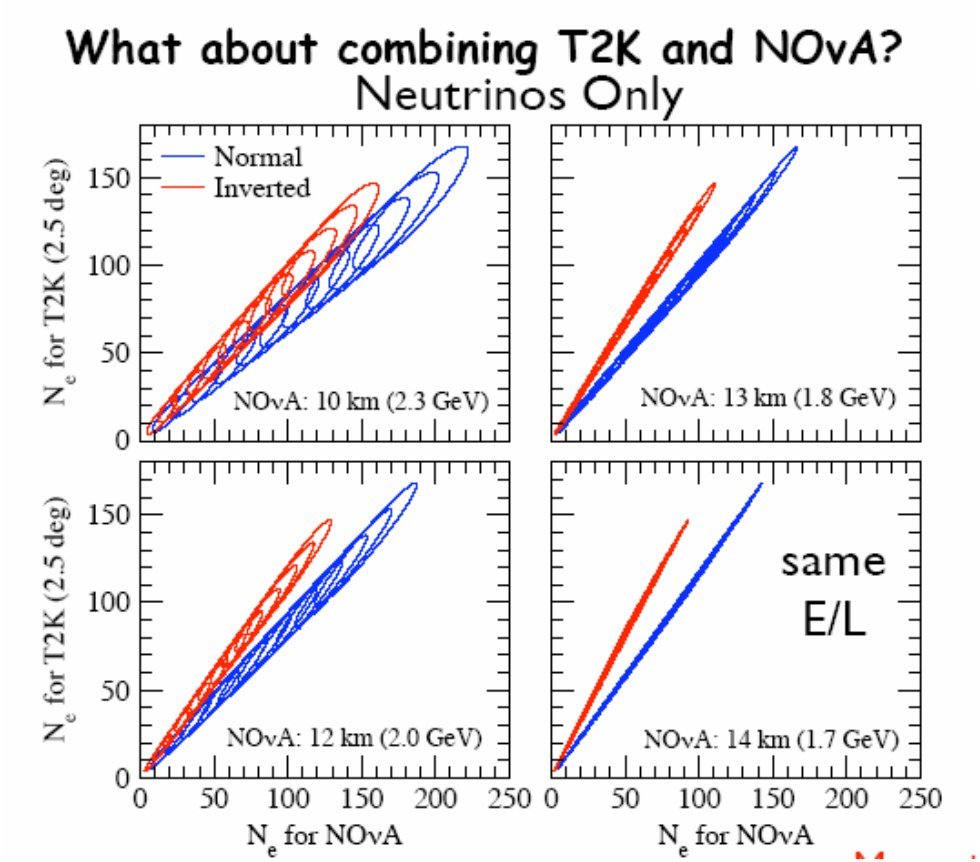
T. Becher and M. Neubert, to appear

Threshold resummation in momentum space

- Traditionally resummation of log's in hard processes is done in *moment* space.
  - Landau pole singularities
  - Mellin inversion to momentum space only numerically
- Solving RG equations in SCET, we have obtained resummed expressions directly in *momentum* space
  - Transparent physical interpretation, no Landau poles, simple analytic expressions for resummed rates.
  - Reproduce moment space expressions.

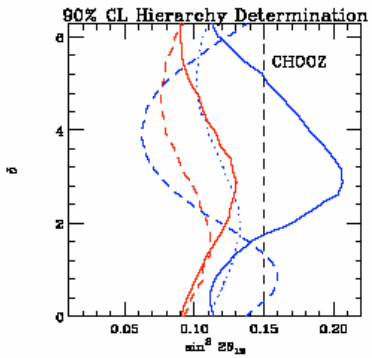
Olga Mena & Stephen Parke

Neutrino Physics

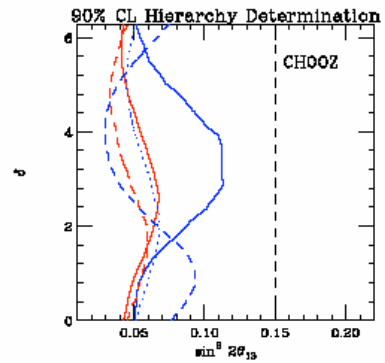


T2K (deg) + NOvA (km)
Off Axis:

phase I



phase II



blue solid 2.5deg/12km
red solid 2.5deg/13km
red dashed 2.5deg/14km
blue dashed 2.5 deg/16km
blue dotted 2.0deg/12km

Lattice Gauge Theory

Fermilab group: Andreas Kronfeld, Paul Mackenzie, Jim Simone (staff), Ruth van de Water, Jack Laiho (post-docs), Elizabeth Freeland (visitor). (and sometimes Bill Bardeen and Estia Eichten.)

Illinois collaborators: Aida El-Khadra (professor), Paco Jain, Todd Evans (grad students).

The Fermilab lattice group is part of USQCD, the national collaboration to establish computational infrastructure for lattice QCD.
Current funded at around $4M/year = $2M/year (DoE/SciDAC, software and hardware R&D) + $2M/year (DoE/HEP program, hardware).

In FY06, Fermilab is installing a $1.5 M cluster for lattice.

Paul Mackenzie serves on the USQCD Executive Committee,
Andreas Kronfeld serves on the Scientific Program Committee.

Main focus of Fermilab lattice group: Standard Model phenomenology

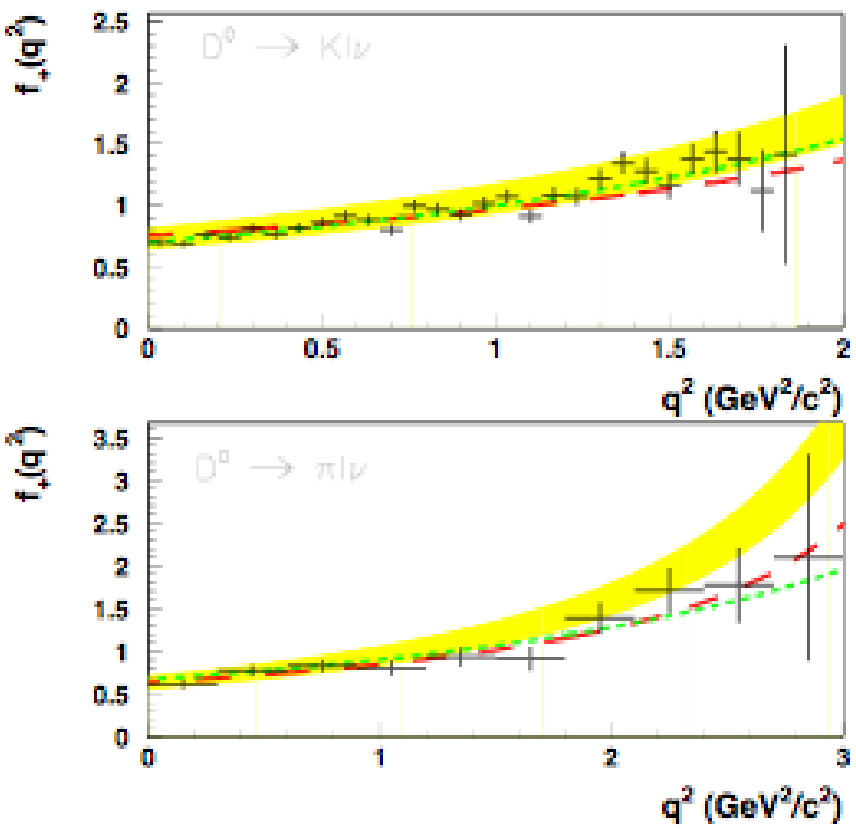
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ \pi \to l\nu & K \to \pi l\nu & B \to \pi l\nu \\ V_{cd} & V_{cs} & V_{cb} \\ D \to \pi l\nu & D \to K l\nu & B \to D^{(*)} l\nu \\ D \to l\nu & D_s \to l\nu & \\ V_{td} & V_{ts} & V_{tb} \\ \langle B_d | \overline{B}_d \rangle & \langle B_s | \overline{B}_s \rangle & \end{pmatrix}$$

Almost all of the Standard Model parameters involving quarks can be obtained from solid lattice calculations.

We are embarked on a broad program of *B* and *D* phenomenology.

Predictions from lattice QCD: *D* semileptonic decay

$f_+^{K,\pi}(q^2)$



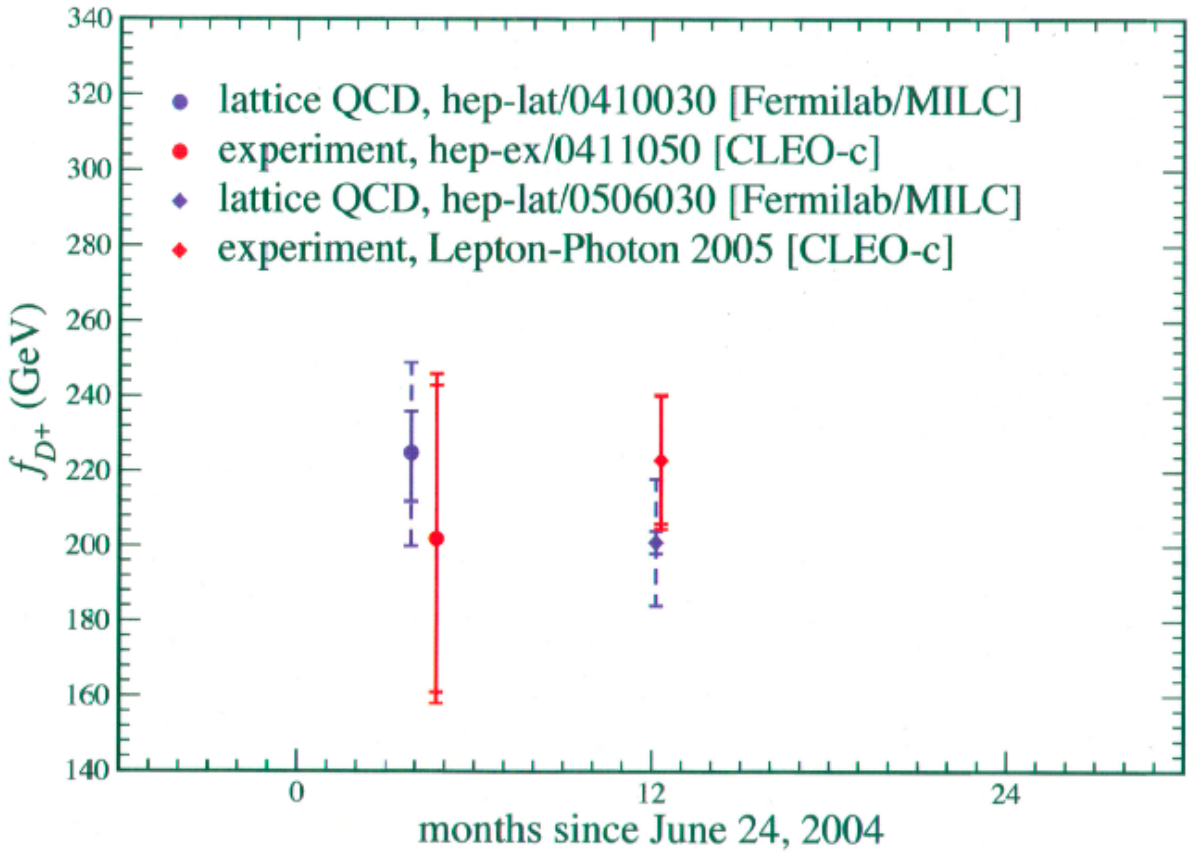
The shape of the *D* semileptonic form factors predicted by the lattice has been confirmed by FOCUS, BaBar, and most recently and most accurately by Belle.

Fermilab/MILC lattice results (yellow) vs. Belle experiment (crosses).

Belle, http://arxiv.org/abs/hep-ex/0604049

Predictions from lattice QCD: f_D

Theory and experiment should each improve by another factor of 2 over the next year.



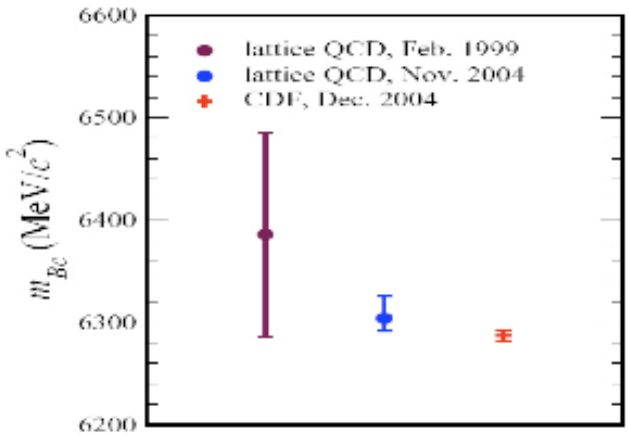
"It became clear that both groups [CLEO-c and Fermilab Lattice & MILC Collaborations] could have substantial results just in time for the Lepton-Photon Symposium in Uppsala at the end of June. Since both communities felt that it was very important for the LQCD result to be a **real prediction**, they agreed to embargo both of their results until the conference... The **two results agree well within the errors of about 8%** for each." CERN Courier **45**, 6 (2005).

Predictions from lattice QCD: The *Bc* mass

"In an unprecedented feat of computation, particle theorists made the most precise prediction yet of the mass of the 'charm-bottom' particle. Days later, experimentalists dramatically confirmed that prediction." Nature **436** (2005)

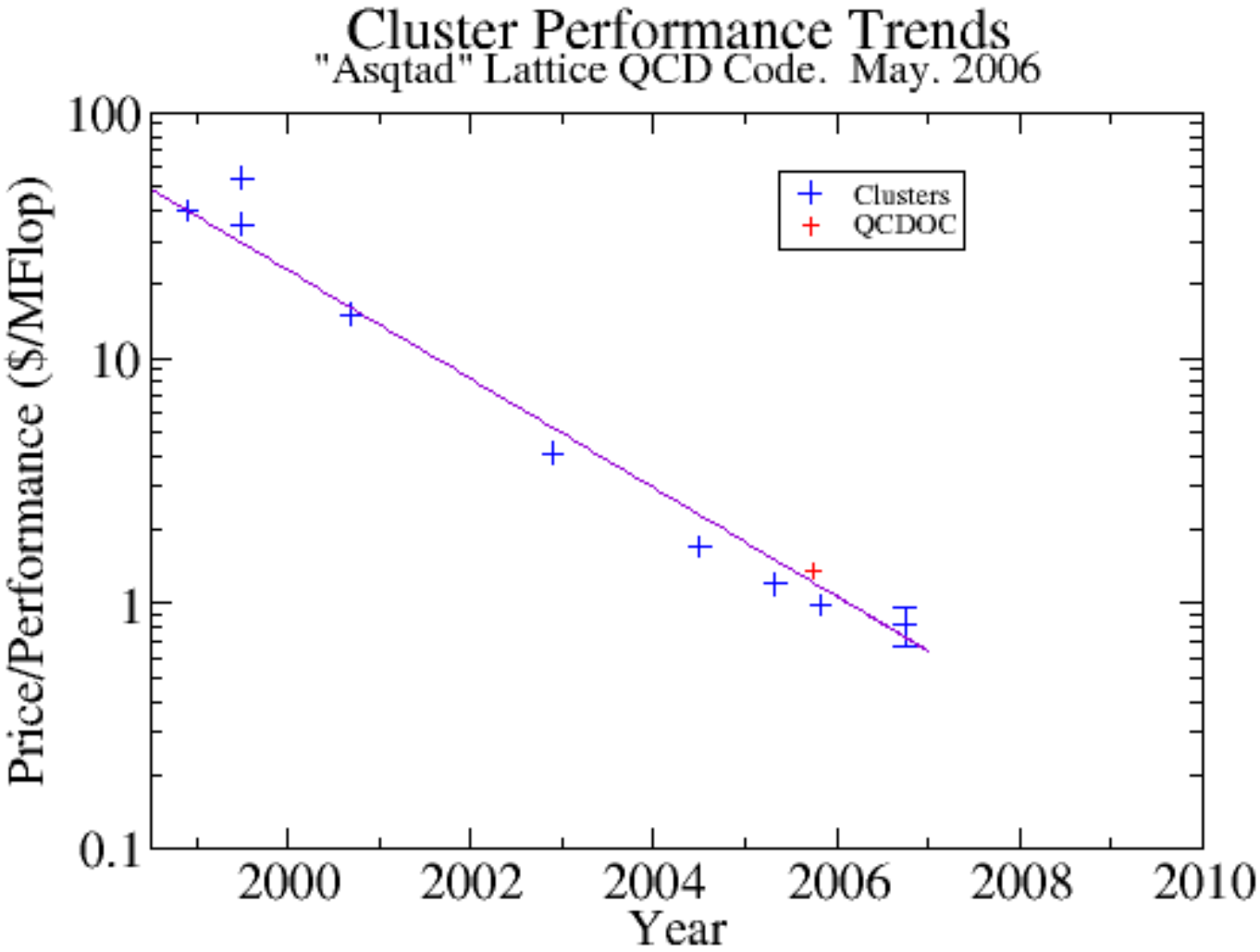
AIP Physics News Update: *Most Precise Mass Calculation For Lattice QCD* among **The Top Physics Stories for 2005**

Mass of the B(c) meson in three-flavor lattice QCD, I. Allison, *et al.*, Phys. Rev. **94** (2005)



Lattice Gauge Theory Future

- Lattice QCD is relevant to experiment as never before, but the need for more progress is still huge.
  E.g., matching the 1% accuracy in *BB* and *BsBs* mixing.
- Needs will still be great in the LHC era.
  - Higher precision flavor physics.
  - Nonperturbative Beyond-The-Standard-Model physics.
- Fermilab is currently the lead US lab in developing computing for lattice gauge theory. It is the natural lab to continue in that role.


Cluster Performance Trends
"Asqtad" Lattice QCD Code. May. 2006
Price/Performance ($/MFlop)
100
10
1
0.1
2000
2002
2004
2006
2008
2010
Year
Clusters
QCDOC

Future Goals of Theory Group

- We seek a stronger identification with the ILC physics program capabilities through our research efforts
  - e.g. Precision perturbative QCD;
  - SUSY LHC/ILC complementarity;
  - Dynamical models: e.g. search for the Wess-Zumino-Witten term in Little Higgs Theories? ...
- Seek to become *the* center for next generation perturbative QCD in the U.S. for LHC/ILC (Giele, Ellis, Becher, ...)
- Continue leadership in Lattice Gauge Theory
- The Fermilab Theory Group will play a stronger central role in the intellectual life and vitality of the U.S. HEP program as it strives to host the ILC:
  - expanded visitors program,
  - more workshops.

Summary

- The Fermilab Theory Group now plays a leading role in the international phenomenological High Energy Physics program.
- Its members are world-class scientists and leaders of the field through their research, and their policy and outreach activities.
- The Fermilab Theory Group plays a central role in the intellectual life and vitality of the laboratory.
- The Theory Group's Visitors programs play a key role in the intellectual commerce of the international HEP program.