Theoretical Physics

DOE Annual Program Review

September 24–27, 2007

Andreas Kronfeld

Theoretical Physics Group

- Scientists I–III
  - William Bardeen
  - Marcela Carena
  - Bogdan Dobrescu
  - Estia Eichten
  - R. Keith Ellis
  - Walter Giele
  - Christopher Hill
  - Boris Kayser
  - Andreas Kronfeld
  - Joseph Lykken
  - Paul Mackenzie
  - Stephen Parke
  - Chris Quigg
- Associate Scientists
  - Thomas Becher (9/2004)
  - Peter Skands (2/2007)
  - Patrick Fox (10/2007)
- Research Associates
  - Richard Hill ('05)
  - Jay Hubisz ('05)
  - Kyoungchul Kong ('06)
  - Jack Laiho ('04)
  - Enrico Lunghi ('05)
  - Rakhi Mahbubani ('06)
  - José Santiago ('04)
  - Peter Skands ('04)
  - Ruth Van de Water ('05)

Theoretical Physics Group

- **Associated colleagues:**
  - Carl Albright (ex-NIU)
  - André de Gouvêa (NU)
  - Elizabeth Freeland (SAIC)
  - Wai-Yee Keung (UIC)
  - Stephen Martin (NIU)
  - Stephen Mrenna (CD)
  - Jim Simone (CD)
  - Tim Tait (ANL)
- **Visitors:**
  - Frank Petriello (1–5/06)
  - JoAnne Hewett (3–4/07)
  - Matthias Neubert (7-9/07)
  - Mariano Quirós (10-11/07)
- **Alumni:**
  - Mu-Chun Chen » UCI
  - Olga Mena » Roma I
- **Outgoing postdocs:**
  - Hubisz » Argonne/Chicago
  - Laiho » Washington U.
  - Santiago » ETH Zürich
- **Incoming postdocs:**
  - Anupama Atre « Wisconsin
  - Yang Bai « Yale
  - Jon Bailey « Wash. U.
  - Jan Winter « Dresden
- **Latin American Students:**
  - Boris Panes (Chile)
  - Juan Racker (Argentina)

Community Service

- American Physical Society
  - DPF: Lykken (Past Chair), Kayser (Chair-Elect), Kronfeld (ExecCom), Carena (NomCom, Outreach)
  - APS: Carena (CISA, General Council), Quigg (APS April meeting task force)
- Agency advisory committees
  - HEPAP: Lykken
  - P5: Carena, Kayser
  - Other subpanels: Kayser, Lykken, …
- Institutional advisory committees
  - Aspen Center for Physics: Carena, Lykken
  - TASI Summer School: Lykken
  - Fermilab PAC: Kayser (ex Ellis, Kronfeld, Lykken)
- Particle Data Group
  - Dobrescu, Kayser

Community Service (2)

- ILC Policy
  - Kronfeld (WWS-OC, Fermilab ILC Task Force, …)
- Neutrino Physics Policy
  - Kayser (all possible panels), Parke, Mena
- Lattice QCD Policy
  - USQCD: Mackenzie (ExecCom), Kronfeld (SPC Chair)
  - DOE SciDAC, US NSF, KEK (Japan): Mackenzie
- Education
  - IMSA Board: Quigg
- Editorial
  - Annual Review of Nuclear and Particle Science: Kayser
- DOE/NSF LHC Communications Task Force
  - Lykken

Laboratory Service

- **Academic Lectures**
  - **Organization: Carena, Becher, Kronfeld, Quigg; Eichten**
  - **Lectures: Quigg, Kayser, Parke, Ellis, Giele, Lunghi, Becher, Kronfeld; Langacker, Plunkett, Dodelson, Cabrera, Green, Berryhill, Herndon**
- **Fermilab Seminars**
  - **Colloquium: Dobrescu (w/ many others)**
  - **Joint Experimental-Theoretical Physics: Becher, Giele**
  - **Theoretical Physics: Kronfeld, Skands, R. Hill**

Laboratory Service (2)

- Scientific Committees at Fermilab
  - FCSA: Eichten
  - Scientist III committee: Bardeen
  - Wilson Fellows: Kronfeld
  - URA thesis award: Dobrescu
  - Tollestrup postdoc award: Carena
  - Awards: Quigg
- Joint Appointments with universities
  - Lab policy: Hill
  - Search with UChicago: Lykken, Ellis, Kronfeld

Fermilab Steering Group

- Precision physics subgroup
  - Hill
- Neutrino physics subgroup
  - Kayser
- Production editor
  - Lykken
- Editorial consultants
  - above + Carena, Kronfeld, Parke; de Gouvêa

Conferences, etc. (@ Fermilab)

- Monte Carlo Tools for Beyond-the-Standard Model Physics
  - Skands
- USQCD Collaboration Meeting
  - Kronfeld
- Joint Fermilab-CERN Hadron Collider Physics Summer School
  - Dobrescu (2006); Carena (2008)
- LHC Early Phase for the ILC Workshop
  - Carena

Conferences, etc. (2)

- LoopFest VI: Radiative Corrections for LHC & ILC
  - Ellis, Giele
- Neutrino Physics Summer School 2007
  - Kayser (OC); de Gouvêa, Kayser, Parke, Quigg
- ALCPG/GDE meeting
  - Carena (PC), Kronfeld (OC, PC)
- Hadron Collider Physics Conference 2008
  - Ellis
- International conferences elsewhere
  - All & too numerous to mention

Neutrino 2008

May 26–31, 2008

Jenni Adams (Univ.of Canterbury)
Francis Halzen (Univ. of Wisconsin)
Stephen Parke (Fermilab)

Cosmological Connections

- **Scientific collaboration:**
  - Classics: Hill & Schramm; Frieman, Hill, Stebbins, Waga
  - Neutrino astrophysics: Gandhi, Quigg, Reno, Sarcevic
  - Neutrino cosmology: Barenboim, Mena, Quigg
  - Modified gravity: Mena, Santiago, Weller
  - WIMPs at colliders: Carena, Hooper, Skands
  - Dark UED matter: Dobrescu, Hooper, Kong, Mahbubani
- **Pizza nights**
- **Grudge matches (3-1)**
  - Soccer, (American) football, softball, basketball (Bardeen was unavailable)
- **Computational Cosmology Task Force**
  - Included lattice theorist and lattice computing experts

Level of Effort (Summary)

- The Theoretical Physics Group has
  - 13 tenured staff
  - 1 → 3 tenure-track staff
  - 9 ± 1 postdocs
  - (1 administrative assistant)
- Additional costs (travel, computers, etc.)
  - $450,000 per annum + 15% for M&S and G&V
  - ~30% to top travelers (on HEPAP, P5)

Science: Past, Present & Future

- **Fermilab's Theoretical Physics Group has been productive and influential throughout its history:**
  - **Original research papers**
  - **Review articles**
  - **Policy documents**
  - **Books**
    - ***Gauge Theories*, Chris Quigg**
    - ***QCD and Collider Physics*, R. Keith Ellis, James Stirling, and Brian Webber**
    - ***Symmetry and the Beautiful Universe*, Leon Lederman and Chris Hill**

Science Greatest Hits

- **Many landmarks:**
  - Discovery of the supersymmetric string
  - Elucidation of the role of the Higgs boson
  - Development and application of pQCD
  - The case for the SSC and LHC
  - Discovery of MHV amplitudes
  - Invention of heavy-quark effective theory
  - Elucidation of and predictions with lattice QCD
  - Proposals of TeV strings & extra dimensions
- **Our productivity and influence in these fields, as well as neutrino and susy phenomenology (see breakout sessions).**

Research Highlights 2006-2007

- In the past 18 months, the theorists have been active in many areas (59 papers)
  - Cosmology
  - Lattice QCD (here; Mackenzie breakout)
  - Higgs and other agents of EWSB (Lykken)
    - Exotic Kaluza-Klein states (Carena *et al.*)
  - Neutrinos (Kayser/Parke)
  - Lepton and quark flavor physics
    - BR($b \to s\gamma$) at NNLO (Becher, Neubert)
    - Anomaly-mediated $\nu\gamma$ interactions (Harvey, Hill, Hill)
  - Perturbative QCD (Ellis/Giele)

ILC Work

- Spin correlations of *Zh* vs. *ZA* (Parke)
  - hep-ph/0606052
- Colliders and susy dark matter (Carena)
  - hep-ph/0608255, 0705.0431
- Top partners @ ILC (Kong)
  - hep-ph/0703057
- Bhabha scattering (Becher)
  - 0704.3582
- ILC, LHC and quintessence (Kong)
  - 0706.2375

Lattice QCD

- **Major theoretical and computational effort**
  - Three senior scientists: Kronfeld, Mackenzie, Simone (CD);
  - Typically two postdocs: Van de Water and Laiho → Bailey;
  - Fermilab Lattice Collaboration at Fermilab, UIUC, DePaul, SAIC:
    - Collaboration of Collaborations with MILC,
    - Cooperation with HPQCD Collaboration;
  - Computing design & support from Holmgren, Singh, …;
  - Management from Holmgren, Boroski, ….

USQCD Hardware Project

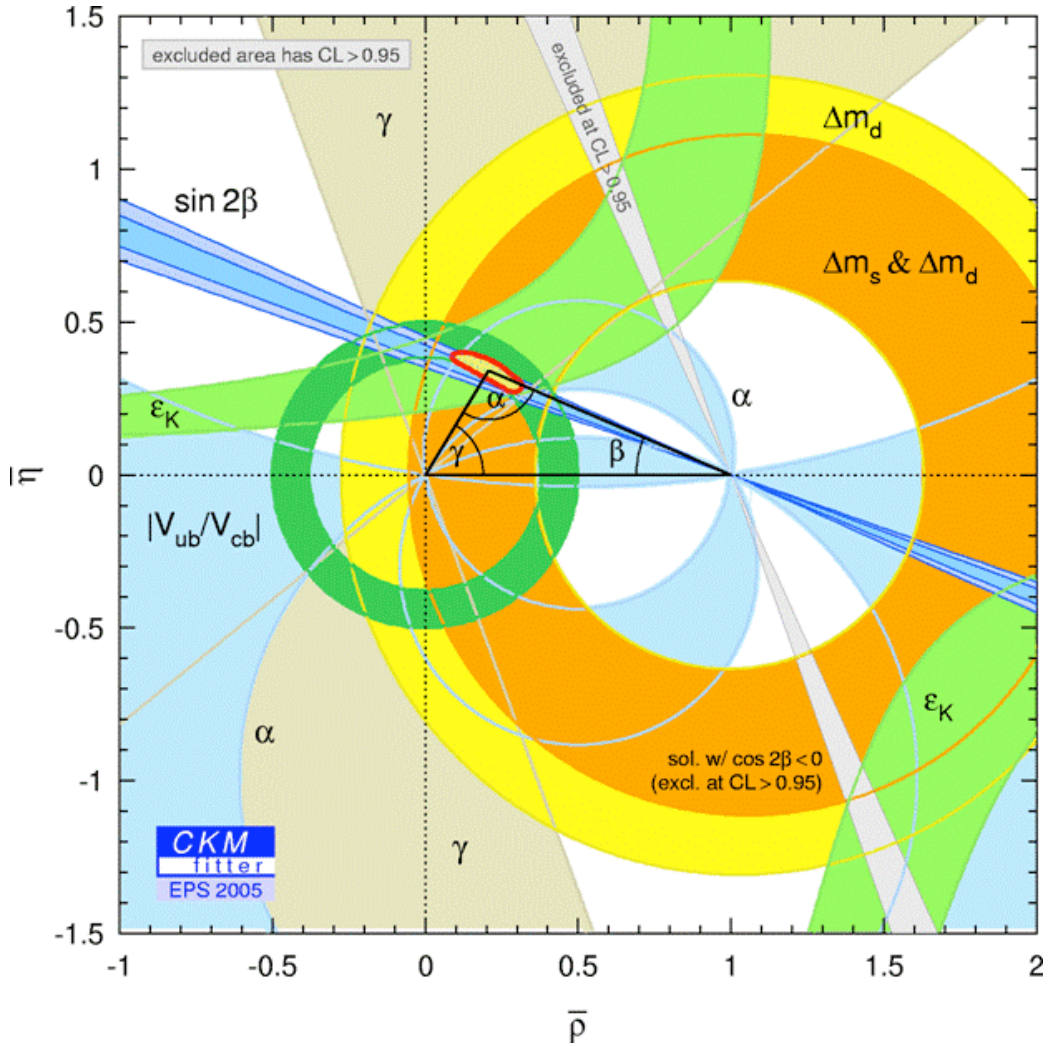
- PC clusters, funded by DOE-HEP and DOE-NP
  - Project = $9.2 M over FYs ’06–’09 (details: Mackenzie)
  - ~ $450K to Fermilab from SciDAC for software (salaries)
- Operate earlier DOE-funded QCDOC (acquired in FYs ’04, ’05; HEP, NP, SciDAC, ASCR).
- Lab infrastructure from Fermilab, JLab, BNL:
  - Fermilab provides $400K +$200K/year as support
  - Fermilab provides $600K/year (on average) for buildings
- Fermilab physics projects within USQCD:
  - *B* and *D* Meson Decays: 10% → 13% of USQCD resource
  - Quarkonium Physics: 3.2% → 4.5%
  - B_K with mixed action (Laiho, Van de Water): 2.9% → 6.0%
- More ambitious plans for FYs ’10–’14 under discussion.

Lattice Status

- B. Grinstein at CKM 2006 (December in Nagoya):
  - "I'll believe a 3% lattice [QCD] theory error when the lattice has produced one successful **pre**diction and several 3% **post**dictions."
- Nine postdictions in March 2003 from HPQCD, MILC, and Fermilab Lattice Collab'ns: accuracy 1–3%; published in PRL.
- Predictions (all PRL)
  - *D* meson semileptonic decays in August 2004;
  - mass of B_c meson in November 2004;
  - *D* meson leptonic decay in June 2005.
- Verified by FOCUS, Belle, CLEO; CDF; CLEO, BaBar….

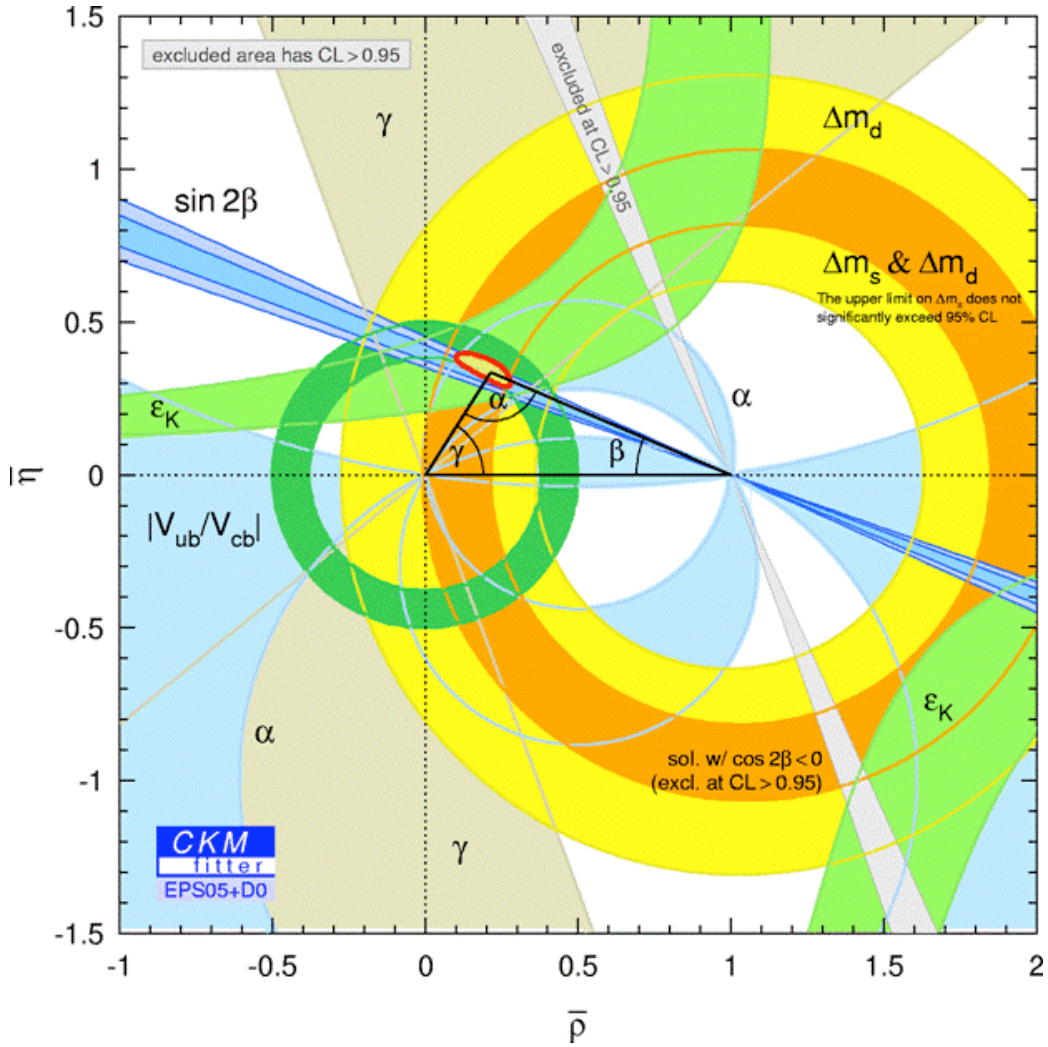
Lattice Flavor Physics

Pre-Tevatron



Lattice Flavor Physics

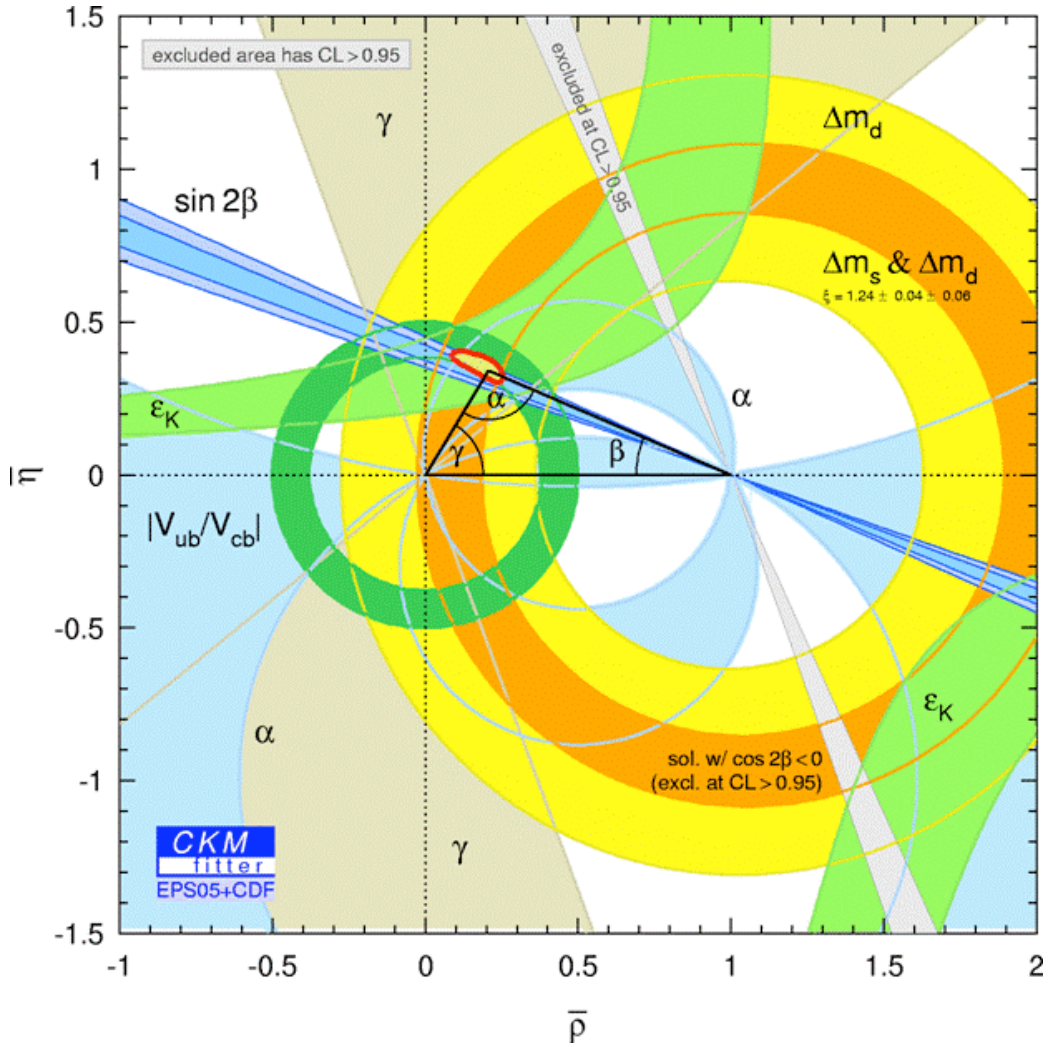
DØ: 10%



Lattice Flavor Physics

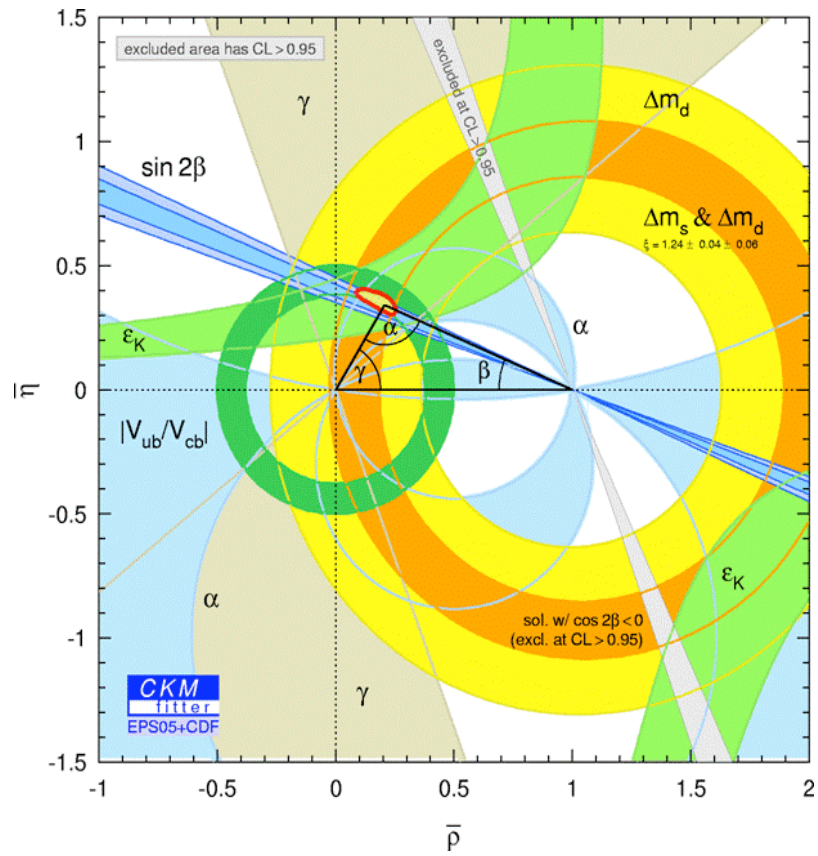
CDF: 1%

Okamoto ξ



Fermilab Lattice Flavor Physics

- Unitarity triangle
  - V_{cb} units
  - B decays, K & B mixing
- After success with the D mesons, we simply change the quark mass.
- $B \to D^{(*)} l\nu$ yields V_{cb}
  - Laiho, Kronfeld
- $B \to \pi l\nu$ yields V_{ub}
  - Van de Water, Mackenzie
- SM B mixing yields V_{td}
  - Simone, UIUC, DePaul
- SM K mixing constrains apex
  - Laiho, Van de Water



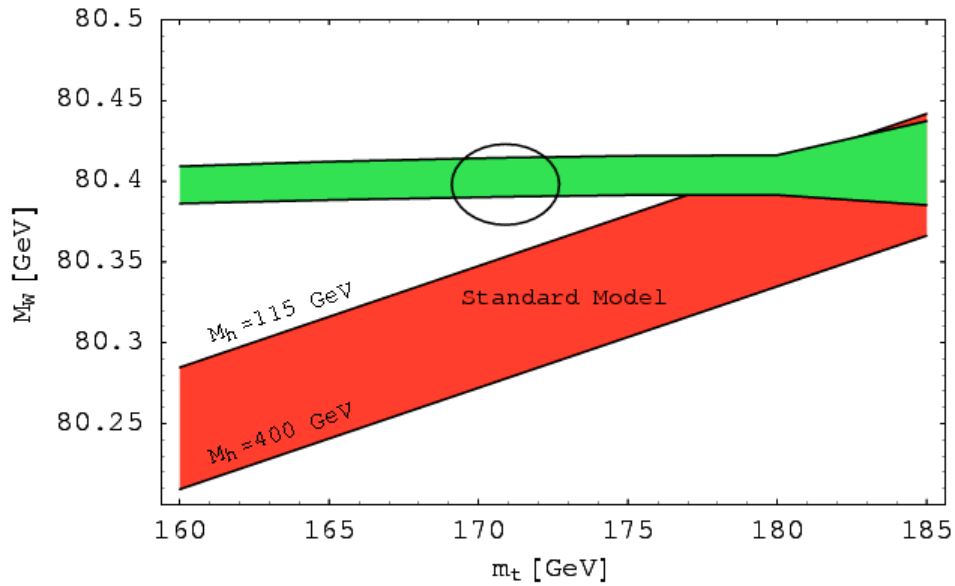
Fermilab Lattice Redux

- **Fermilab's theory group**
  - **provides leadership to the USQCD Collab'n;**
  - **participated in the first realistic calculations with sea quarks;**
  - **made several predictions that were later confirmed by *many* experiments;**
  - **poised to contribute crucial results to flavor physics, such as the reduction in the exclusive determination of V_{cb} from 4% → 2% (Laiho).**
- **Fermilab was the key to the success of the '06–'09 Project; we are asking the lab to continue to play the same role in '10–'14.**

Carena, Pontón, Santiago, Wagner,
hep-ph/0610067

- New Signatures from Warped Extra Dimensions
- Original model (Randall-Sundrum)
  - Solves hierarchy problem
  - Suggests theory of flavor
  - Towers of copies of SM particles
  - Out of LHC reach
- New ideas
  - Compatible with current data
  - Accessible at Tevatron and LHC
- Symmetries: custodial and LR
  - Custodial protects m_W/m_Z
  - Both together protect *Zbb* coupling

Carena, Pontón, Santiago, Wagner (2)



- **Model agrees with recent measurements of m_t, m_W**
- **Masses:**

$$M_{KK}^{gauge} \sim 2.5 - 3.5\,\text{TeV}$$

$$M_{KK}^{fermions} \geq 300\,\text{GeV}$$

- **Exotically charged quarks, $Q_{5/3} \to W^+W^+b_{-1/3}$**

Becher & Neubert, hep-ph/0610067

- $B \to X_s\gamma$ is a sensitive probe of New Physics. After large effort by several groups, the first NNLO calculation of the BR is now available.
- Experimental cut $E_\gamma > E_0$ complicates theoretical analysis: low scale
  - $\Delta = m_b - 2E_\gamma \sim 1$ GeV

  becomes relevant.
- Separate low-scale effects using renormalization group in SCET, leading to NNLO accuracy.
- Comparison with experiment:

$$\mathrm{BR}_{E>1.6\ \mathrm{GeV}}(\bar{B} \to X_s\gamma) = \begin{cases} (2.98 \pm 0.26) \times 10^{-4} & \text{NNLO} \\ (3.55 \pm 0.26) \times 10^{-4} & \text{HFAG} \end{cases}$$

Harvey, Hill, Hill, arXiv:0708.2398 [hep-ph]

- **Anomaly-mediated ν-γ interactions with non-zero baryon density**
  - Treat vector mesons as background fields coupled to hadronic currents (standard)
  - Use Wess-Zumino-Witten term to represent QCD anomalies (standard)
  - Introduce SU(2)×U(1) SM gauging
  - Physical pseudo-Chern-Simons terms:

$$\frac{N_c}{48\pi^2}\frac{e g_\omega g_2}{\cos\theta_W}\epsilon_{\mu\nu\rho\sigma}\omega^\mu Z^\nu F^{\rho\sigma}$$

- **Could explain low-energy MiniBooNE spectrum through $\nu N \to \nu\gamma N$**
- **Could cool neutron stars**

Summary

- **Fermilab's Theoretical Physics Group**
  - **plays a leading international role in particle physics;**
  - **consists of world-class scientists active in research, outreach, and policy;**
  - **plays an central role in the intellectual life of the laboratory;**
  - **attracts future leaders as postdocs;**
  - **attracts visitors from students to famous profs on sabbatical;**
  - **would be a bargain at twice the price!**

Web Site, etc

- Main URL is http://theory.fnal.gov/
- Former postdocs, Associate Scientists, Frontier Fellows, Latin American students:
  - http://theory.fnal.gov/people/ellis/alumni.html
  - http://theory.fnal.gov/people/ellis/Assoc.html
  - http://theory.fnal.gov/people/ellis/frontier.html
  - http://theory.fnal.gov/people/ellis/LAstudents.html
- Lattice QCD portal is http://lqcd.fnal.gov/
- Backup documents
  - Publication list
  - List of all-time highly cited papers