SLAC Particle Theory Group

High quality science

-- place where any particle theorist wants to spend some time

-- people experimentalists look to, to help make sense of their data and plan for future

Our Goals

- First Rate, leading edge research
-
- Service to the Lab
-
- Service to the broader HEP agenda
-
- Training students and postdocs

Research

- Broad Range ---from most abstract theory to close linkage to current data
-
- Recognized leaders in our subfields
-
- Freedom to choose what we work on, with strong value on usefulness and impact for larger community

Depth and Breadth

String theory
Stringy cosmology
Stringy phenomenology
No strings attached -beyond Standard Model models and their phenomenology
QCD – various approaches
Heavy quarks and QCD
Heavy quarks and CP violation
Collider Physics
…… and more

Synergy

The combined theory strength of SLAC Particle theory, KIPAC, Stanford’s Physics and Applied Physics departments and UC Santa Cruz Physics Department makes this one of the broadest and strongest concentrations of theorists anywhere

Faculty hiring

- First criteria is excellence
-
- Maintain breadth of science
-
- Build on new strengths
-
- Hire jointly with Stanford Physics where interests merge

Post doctoral researchers

- We want and get the best!
-
- We typically have a few extra postdocs, visitors with support from elsewhere
-
- Enable postdocs to function as independent scientists

Atmosphere (Sid's legacy)

- Keep the doors open
-
- Ask questions
-
- Hallway conversations-blackboards
-
- Be sure everyone is engaged

The future

- SLAC is changing
-
- Will maintain a strong HEP Theory presence
-
- There’s theory in other parts of SLAC
- Accelerator, KIPAC, SSRL, photon science
-
- Build new synergies as science overlaps

Role of SLAC Theory in Broader HEP Community

- Involvement in SLAC/Stanford Programs
- ILC
- Studies for Future Projects
- Summer Schools
- Other Community Roles
- Research Lays the Groundwork for Future Experiments

Will be used for Luminosity Monitor & PDFs

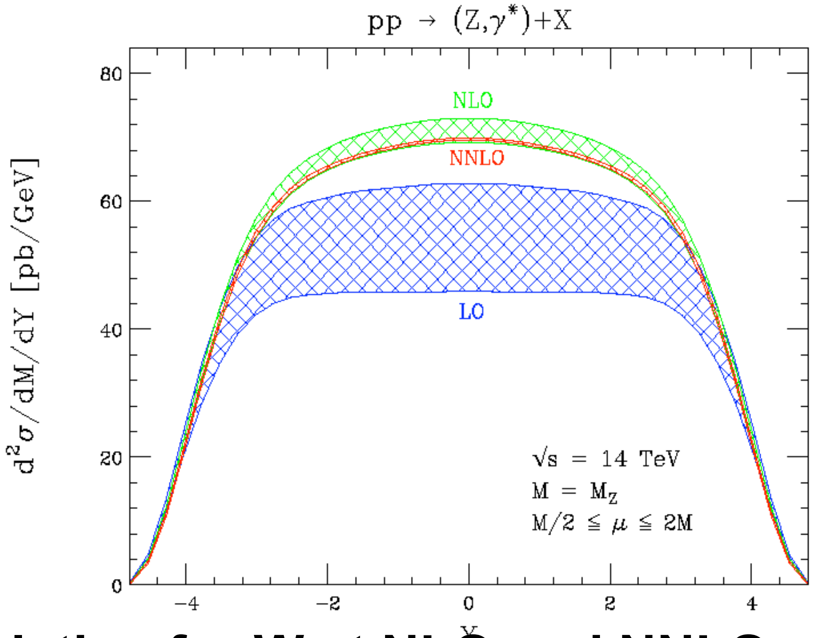
NNLO Calculations & PDFs

- Bands indicate the uncertainty from varying the renormalization (μ_R) and factorization (μ_F) scales in the range:

$$M_Z/2 < (\mu_R = \mu_F) < 2M_Z$$

- Ø At LO: ~ 25 - 30 % x-s error
- Ø At NLO: ~ 6 % x-s error
- Ø At NNLO: < 1 % x-s error

Anastasiou et al., Phys.Rev. D69:094008, 2004



Similar improvement in calculation for W at NLO and NNLO

VRAP code at http://www.slac.stanford.edu/~lance/Vrap/

• PDFs - See talk from A. Tricoli from the Standard Model session for some estimated PDF uncertainties upon measured $W \rightarrow l\nu$ η distributions. Currently PDFs contribute several percent to the errors.

Exotic Physics @ Rome
ATLAS Physics Week
June 2005. S. Ferrag

- **Extended gauge symmetries:**
  - Heavy Gauge bosons: Z',W'
  - Little Higgs
  - LRSM: H++, Z', W', Majorana N…
  - **Heavy fermions**
  - **Isosinglet quarks (E6 down, Top)**
- Flavour Changing Neutral Current
- Compositeness:
  - **Excited fermions (electrons, quarks)**
- Leptoquarks
- **Extra dimensions**
  - Large extra dimensions:
    - direct Graviton production
    - **Virtual exchange of gravitons**
    - Black Holes
  - Small extra dimensions:
    - KK excitations of gauge bosons: W, Z and g
    - **Universal extra dimensions**
    - Coupling unification
  - Warped extra dimensions:
    - RS radion
    - Narrow Graviton resonance

SLAC Theorist referenced for almost every topic

…Many Atlfast studies being validated with full simulation.

Involvement in SLAC/Stanford Programs

- Joint position with Stanford ITP
  - Kachru, Silverstein
- Joint position with ILC Detector Group
  - Rizzo
- SLAC Scenarios Study
  - Dixon, co-chair
  - Hewett, member
- SLUO Executive Cmtte
  - Dixon
- Strong Interaction with SLAC/SLUO experimenters
  - Brodsky, Dixon, Hewett, Peskin, Quinn, Rizzo, Pierce, Hill
- Phenomenology Wine & Cheese

International Linear Collider

- Physics Interplay of the LHC and ILC: hep-ph/0410364
  - Hewett: editor, Rizzo
- Role of Polarized Positrons and Electrons at the ILC
  - Rizzo:editor
- Connections to Astrophysics and Cosmology
  - Peskin: editor
- Worldwide Detector Benchmark Cmtte
  - Peskin
- American Linear Collider Physics Group
  - Executive Cmtte: Hewett
  - Working Group Leader: Hewett, Peskin
  - Snowmass Physics Working Groups: Peskin, co-chair
  - ALCPG Meetings Org Cmtte's: Hewett, Peskin
- LCWS 2005 @ Stanford, March 18-22
  - Hewett: chair, Peskin, Rizzo

Studies for Future Projects

- Fermilab Proton Driver Advisory Group
  - Dixon
- Physics at CLIC Multi-TeV Linear Collider: hep-ph/0412251
  - Hewett, Rizzo
- Discovery Potential of a Super-B Factory: hep-ph/0503261
  - Hewett, editor
  - Hill, Lillie, Quinn, Rizzo
- Physics program of the JLAB 12 GeV Upgrade
  - Brodsky
- Physics program of GSI anti-proton facility
  - Brodsky

Summer Schools

- TASI 2005 - `The Many Dimensions of String Theory'
  - Kachru, Silverstein: Program Director
  - Dixon, Hewett: Lecturer
- SLAC Summer Institute - `Gravity in the Quantum World and the Cosmos'
  - Hewett: Program Director
  - Kachru, Peskin, Rizzo, Silverstein: Lecturer 2004/2005
- Princeton PiTP - `Introduction to Collider Physics'
  - Peskin: Program Director
  - Dixon: Lecturer
- International Schools:
  - Brodsky: St. Andrews 2004, Italy Enrico Fermi 2004
  - Dixon: Taiwan 2005
  - Hewett: Les Houches 2005
  - Kachru: Trieste 2004, Vancouver 2005
  - Peskin: Germany Maria Laach 2004
  - Silverstein: Iran 2005/2006, China 2005

Other Community Roles

- APS
  - Quinn: 2004 President/2005 Past President
  - Dixon, Hewett, Peskin, Quinn: cmtte members
- National Academy Studies
  - Quinn: EPP2010, Science Learning, Quarks to Cosmos
- HEPAP
  - Hewett + RSVP, LHC/ILC, P5 Subpanels
- Program Advisory Cmtte's
  - Brodsky: BNL, GSI, Int Light-Cone
  - Dixon: US node coordinator EU Network
  - Hewett: LHC theory initiative
  - Peskin: Sloan research fellowships
  - Quinn: Fine Institute for Theoretical Physics (Minnesota)
  - Silverstein: Aspen, KITP

Cont…

- Journal Editorial Boards
  - Brodsky: Nucl Phys B, Progress in Particle & Nucl Phys
  - Kachru: JHEP
- Joint Research Grants
  - Brodsky: CRDF (ITEP Moscow), Bi-National (Tel Aviv)
- Numerous Workshop/Conf organizing cmtte's
- A semi-infinite number of conference talks

SLAC Theory and the HEP Community: Summary

- Large and diverse involvement
- Large impact on broad HEP community
- Help to shape the future HEP program

And we do research too…

SLAC HEP Theory Postdocs and Students

M. E. Peskin
DOE site visit -- 2005

One of the primary goals of the SLAC HEP Theory Group is to provide an environment in which the top young theorists in the field can develop their ideas. We believe that this is one of the most important ways in which we serve the HEP community.

We are budgeted for 7 Research Associate (postdoctoral) positions. We have been able to attract some of the top young people in the community to fill these positions.

Since we are a part of Stanford University, we have access to outstanding graduate students.

The breadth of our group and our traditional of open discussion and criticism, plays an important role in the development ofyoung scientists in both of these groups.

We take the selection of postdoctoral fellows extremely seriously. Each winter, we systematically read and discuss our 200-250 applications.

While we try to offer positions to candidates with a range of interests, our first criterion is outstanding work. We give some preference to new Ph. D.'s.

We consider our role as supporting our postdocs rather than directing them in our own projects. One of the main attractions of our group is the intellectual freedom that we offer.

SLAC was one of the first groups to offer a 3-year, rather than a 2-year, postdoctoral appointment. We encourage postdoctoral fellows to follow their interests into new subjects.

A measure of our success is:

the extent to which our postdoctoral fellows have won faculty positions based on their work at SLAC.

the extent to which it is our postdoctoral fellows, rather than the senior staff, that receive credit for this work.

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:

Gudrun Hiller > Munich
Albion Lawrence > Brandeis
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

Historically, the quality of our graduate student thesis work has also been very high, especially in the period 1971-73.

In addition, for two generations, we have written the book on quantum field theory.

Here is a table of our recent graduates:

Recent Ph. D. graduates of our group:

95	Jonathan Feng	Peskin	asst. prof., U C Irvine
	Don Finnell	Peskin	(strategic consulting)
	Yael Shadmi	Dixon	asst. prof., Technion
99	Chih-Lung Chou	Peskin	asst. prof., Chung-Yuan Chr. U
00	Eugene Mirabelli	Peskin	(computer games)
01	Maxim Perelstein	Dixon	asst. prof., Cornell
	Yun Song	Silverstein	postdoc, math, Cambridge ?
02	Allan Adams	Silverstein	Jr. Fellow, Harvard
	John McGreevy	Kachru	postdoc, Stanford
	Michael Schultz	Kachru	postdoc, Caltech
03	Yue Chen	Peskin	(financial modelling)
	Frank Petriello	Hewett	asst. prof., Wisconsin
04	Michal Fabinger	Silverstein	postdoc, Harvard/IAS
05	Ben Lillie	Hewett	postdoc, Chicago
	Liam McAllister	Kachru	postdoc, Princeton

In both of these roles, the members of the SLAC HEP Theory Group have an important impact in training young theoretical physicists.

Current Research of the SLAC HEP Theory Group

DOE site visit 2005

New Physics at the TeV Scale

Little Higgs

Pierce, Peskin, Perelstein, Conley, Le, Hewett, Katz

Split Supersymmetry

Dimopoulos, Pierce, Wacker, ... , Lillie, Hewett, Masip, Rizzo

Higgsless Models and Randall-Sundrum Compactifications

Lillie, Hewett, Rizzo ~ LC/LHC study

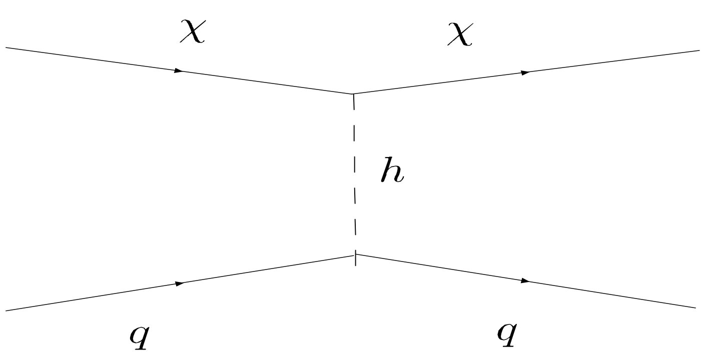
Black Holes at the LHC

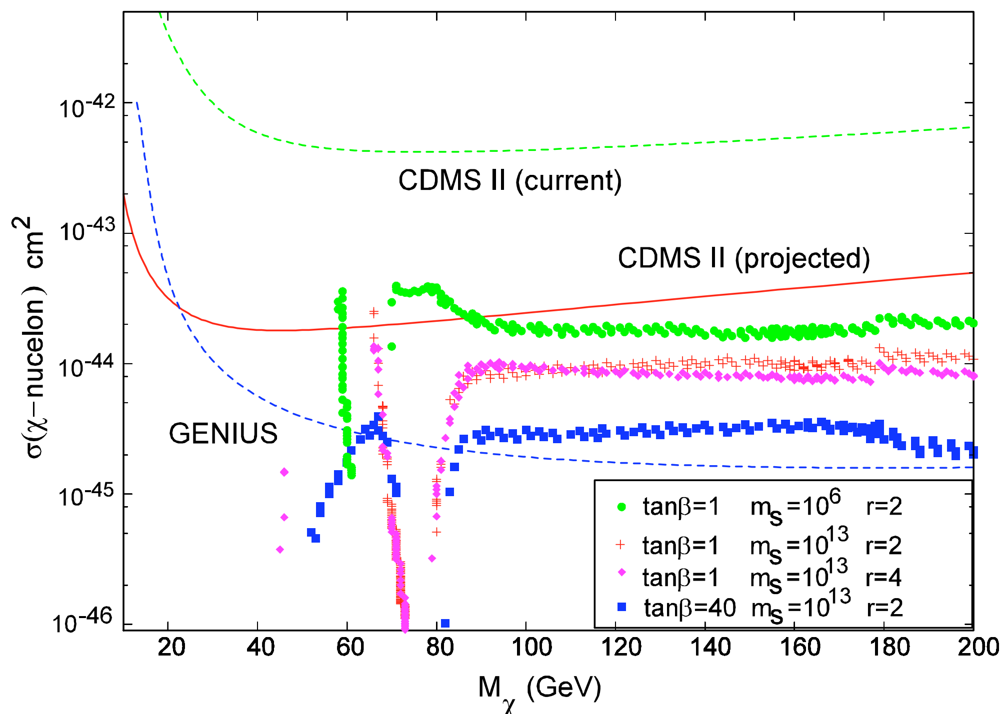
Lillie, Hewett, Rizzo

Dark Matter

Baltz, Battaglia, Peskin, Wizansky ~ LC/Cosmology study

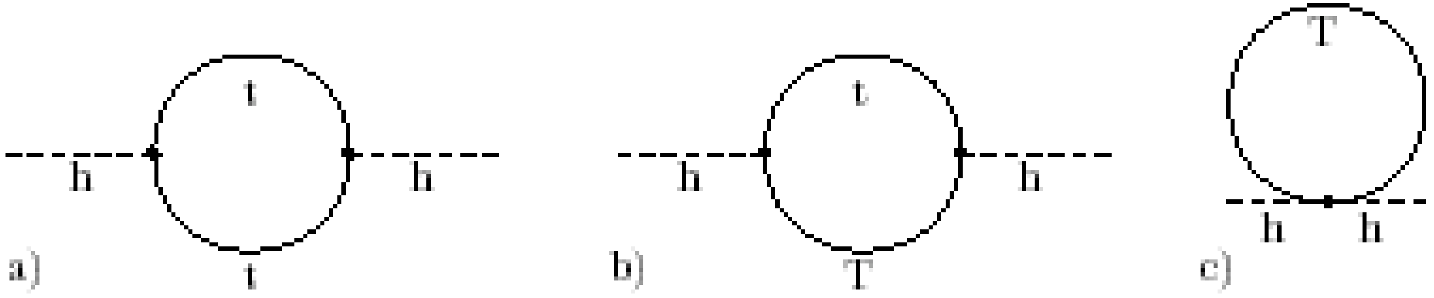
- Phenomenological studies of physics beyond the standard model can point experimenters to new strategies and observables.
- Split Supersymmetry:
  - Stable Gluinos: What do they look like? Can LHC detectors trigger on such events?
  - Dark Matter Mediated by Higgs Boson Exchange





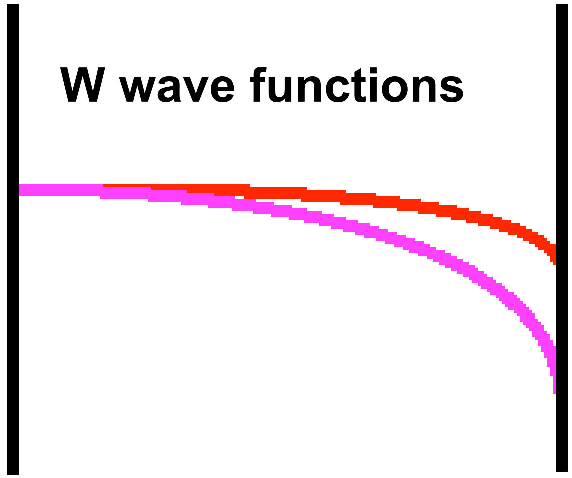
- Little Higgs

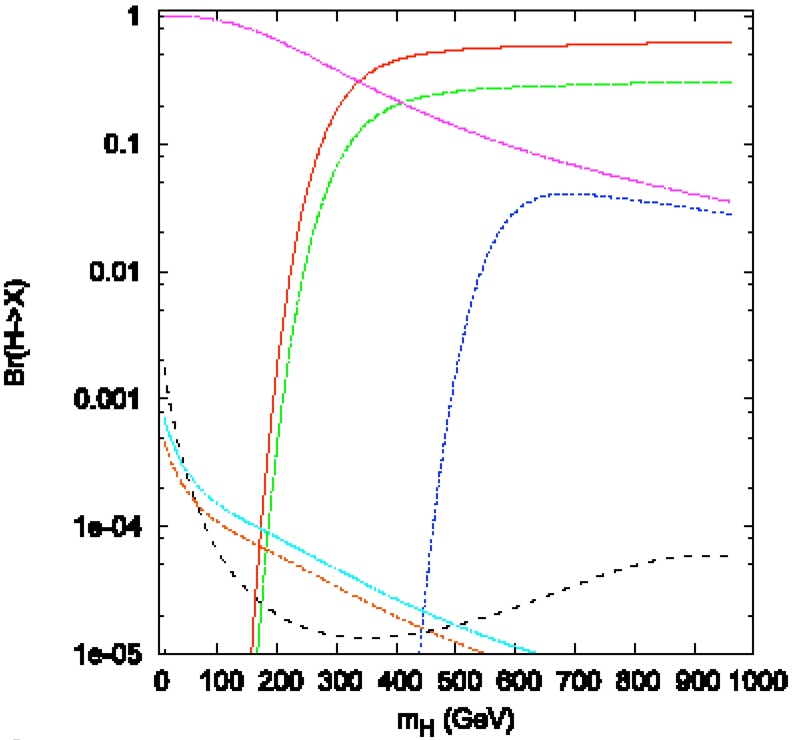
Measurements of masses and couplings at colliders can test the mechanism of electroweak symmetry breaking.



Higgs bosons in RS Models

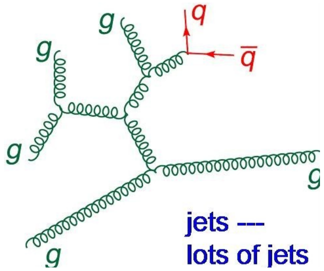
Predict a pattern of deviations from the Standard Model pattern of couplings:

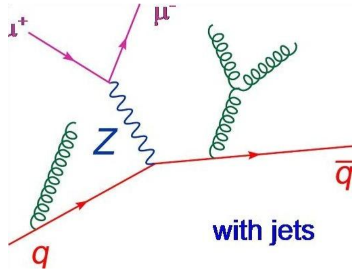


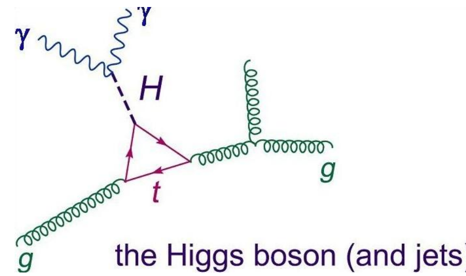


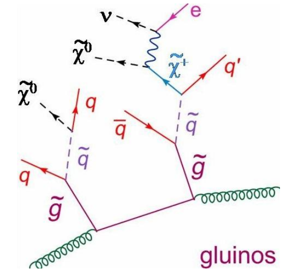
cf: "Higgs -radion mixing" with deviations in the h → 2 g, h→ 2 γ couplings

Multileg (Loop) Amplitudes for LHC Physics

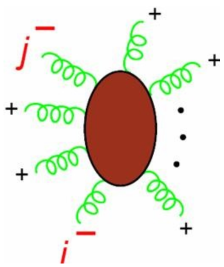








- **Parke-Taylor (1986) ⇒ Twistor space** – Witten (2003)



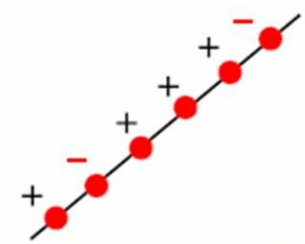
$$\frac{\langle ij\rangle^4}{\langle 12\rangle\langle 23\rangle\ldots\langle n1\rangle}\delta\left(\sum_i k_i\right)$$

$$\langle ij\rangle = \bar{u}_-(k_i)u_+(k_j)$$

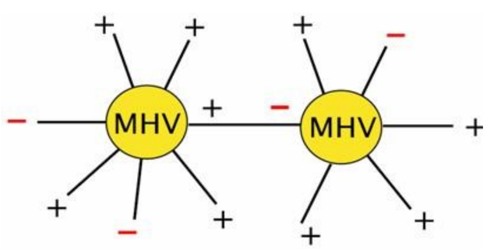
$$u_+(k_i) = (\lambda_i)_\alpha;\, u_-(k_i) = (\tilde{\lambda}_i)_{\dot{\alpha}}$$

$$\Rightarrow$$

$$\int d\tilde{\lambda} e^{i\mu\tilde{\lambda}}$$



- **MHV rules** – Cachazo, Svrcek, Witten (2004)



Off-shell Parke-Taylor amplitudes connected by **scalar propagator**

More efficient than Feynman rules for QCD (and SUSY) tree amplitudes. Lagrangian connection ?

C. F. Berger (SLAC), Z. Bern (UCLA), D. Forde, D. A. Kosower (Saclay), P. Mastrolia (UCLA), in progress

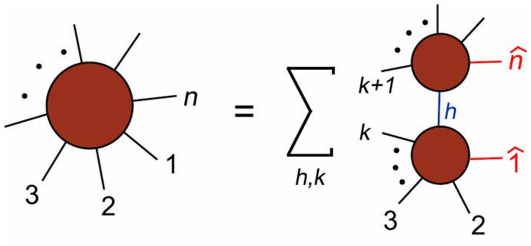
Multileg (Loop) Amplitudes and Twistor Space

- **Extension to Higgs bosons**

  L. Dixon (SLAC), E. W. N. Glover, V. Khoze (Durham U., IPPP), JHEP 0412:015, 2004

  and vector bosons.

- **On-shell recursion relations** – Britto, Cachazo, Feng, and Witten (2004-05)



- **Extension to one loop SUSY and QCD amplitudes** ...

  Z. Bern (UCLA), V. Del Duca (INFN, Turin), L. J. Dixon (SLAC), D. A. Kosower (Saclay), Phys. Rev. D 71, 045006 (2005)

  S. J. Bidder, N. Bjerrum-Bohr (Swansea U.), L. J. Dixon (SLAC), D. Dunbar (Swansea U.), Phys. Lett. B 606, 189 (2005)

  Z. Bern (UCLA), L. J. Dixon (SLAC), D. A. Kosower (Saclay), hep-th/0412210

  Z. Bern (UCLA), L. J. Dixon (SLAC), D. A. Kosower (Saclay), Phys. Rev. D 71, 105013 (2005)

  Z. Bern (UCLA), L. J. Dixon (SLAC), D. A. Kosower (Saclay), hep-ph/0505055.

- ... **and including Higgs bosons**

  C. F. Berger (SLAC), V. Del Duca (INFN, Turin), L. J. Dixon (SLAC), in progress

Phenomenology

- **Dijets, event shapes (LEP)**

  C. F. Berger (SLAC), Mod. Phys. Lett. A 20, 1187 (2005)

  C. F. Berger (INFN, Turin), L. Magnea (Turin U), Phys. Rev. D70, 094010 (2004)

- **Transversely polarized Moller scattering (E158)**

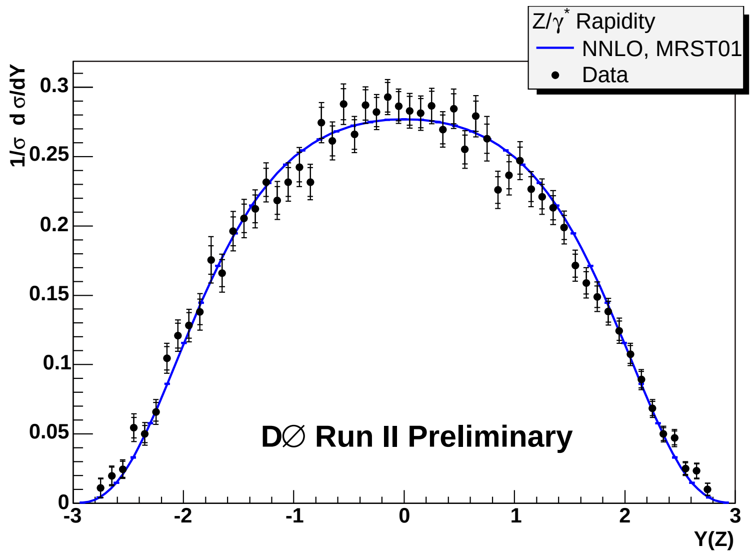
  L. J. Dixon, M. Schreiber (SLAC), Phys. Rev. D 69, 113001 (2004)

- **Corrections to $\gamma\gamma \to H \to b\bar{b}$**

  L. J. Dixon, Y. Sofianatos (SLAC), in progress

- **NNLO electroweak gauge boson rapidity distributions**

  C. Anastasiou, L. J. Dixon (SLAC), K. Melnikov (Hawaii), F. Petriello (SLAC), Phys. Rev. D 69, 094008 (2004)



Heavy quark physics at SLAC

Implications for physics beyond the Standard Model
Joanne Hewett

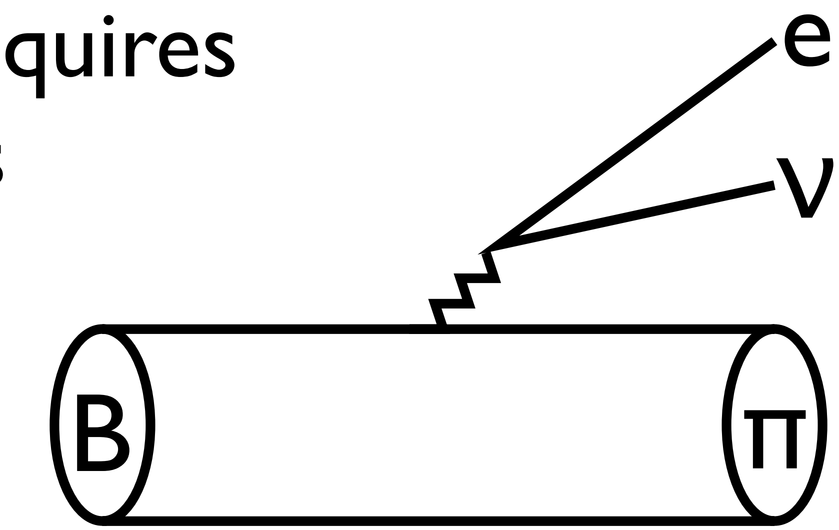
Phenomenology of B decays
Helen Quinn
- $B \to \rho\rho$, $B \to \rho\pi$, isospin and SU(3) analysis

QCD and effective field theory
Stan Brodsky,
Richard Hill, Thomas Becher (FNAL), Matthias Neubert (Cornell)
- hard exclusive processes involving heavy quarks

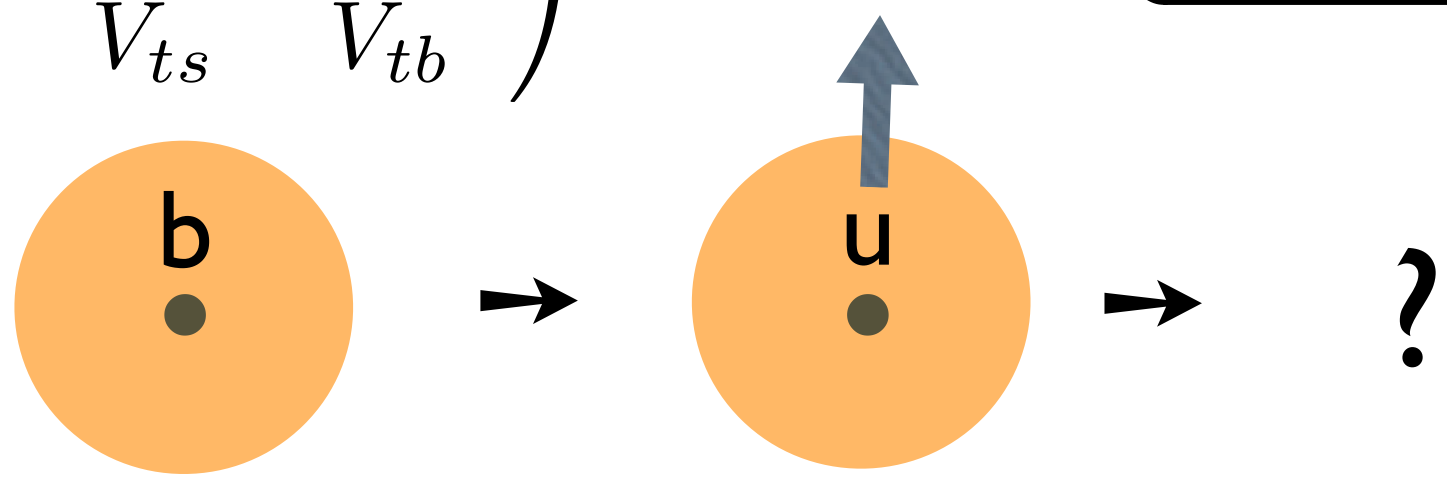
→ Input to experimentalists

Measuring *weak interaction* parameters requires understanding of *strong interaction* physics

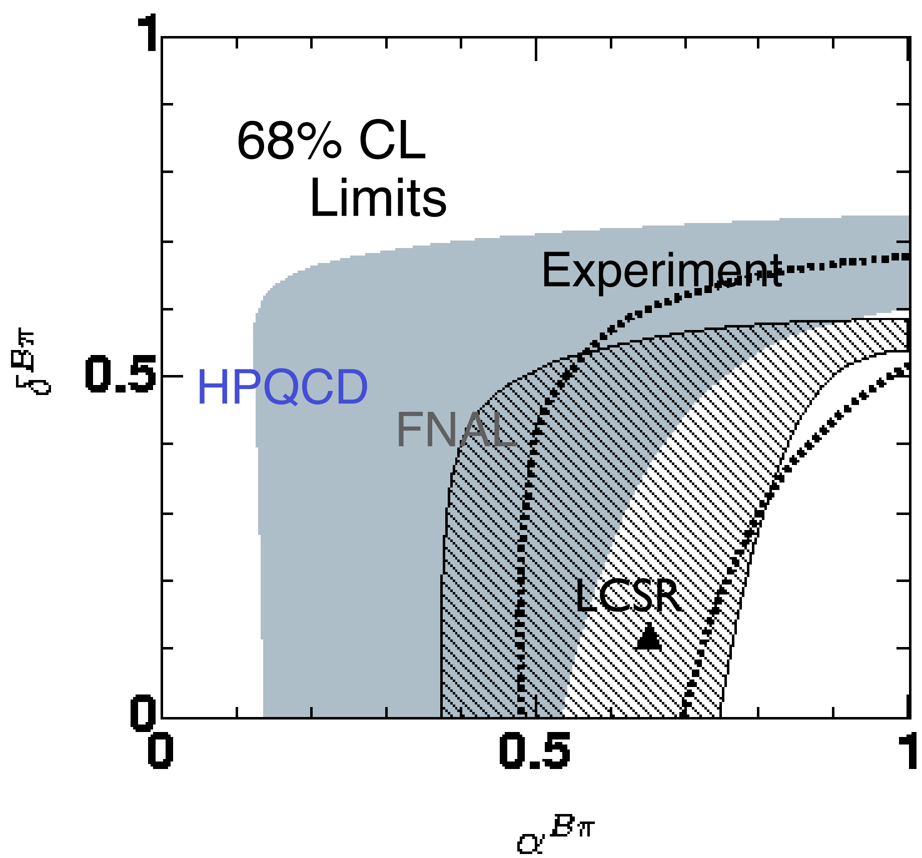
$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



Q:



A: hard-scattering mechanism and soft-overlap mechanism



$$\begin{aligned} F(q^2) &= \zeta(E) + \left(\frac{4E}{m_B} - 1\right) H(E) \\ &= \frac{f(0)}{1-\alpha}\left(\frac{1}{1-q^2/m_{B^*}^2} - \frac{\alpha}{1-q^2/\gamma m_{B^*}^2}\right) \\ &= \frac{f(0)\left(1-\delta q^2/m_{B^*}^2\right)}{\left(1-q^2/m_{B^*}^2\right)\left(1-[\alpha+\delta(1-\alpha)]q^2/m_{B^*}^2\right)} \end{aligned}$$

$$\rightarrow \quad \delta = \frac{2H}{\zeta+H} = ?$$

AdS/CFT and AdS/QCD at SLAC

- AdS/CFT: duality between string theory on $AdS_5 \times S^5$ and conformal N=4 Super Yang-Mills.
- AdS string theory can be approximately understood as a field theory on AdS.
- AdS extra-dimensional theories can solve the hierarchy problem by introducing a nearly conformal structure above the TeV scale
  - Dual to a strongly coupled theory like walking technicolor.
- QCD theory may have a string like dual.
  - Can we understand AdS as a model for QCD?

Developments at SLAC

- AdS as a model for the low lying hadron spectrum.
  - Guy F. de Teramond and Stanley J. Brodsky, hep-th/0409192: accepted in Phys. Rev. Lett.
  - Fit the low lying hadron spectrum with the eigenmodes of fields on a slice of AdS.

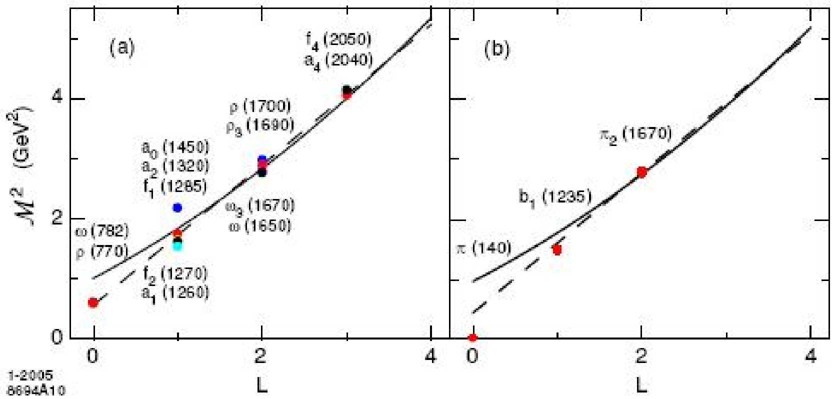


Fig: Light meson orbital spectrum: 4-dim states dual to vector fields in the bulk, $\Lambda_{QCD} = 0.26\ \mathrm{GeV}$

- Modeling low lying hadron masses and widths.
  - Joshua Erlich, Emmanuel Katz, Dam T. Son, Mikhail A. Stephanov, hep-ph/0501128
  - By matching to perturbative QCD in the UV, predict the widths and masses of pions, ρ, a_1.
  - Fit 8 observables with three model parameters and RMS error of 9%.

- Modeling the strange mesons - Joshua Erlich, Emmanuel Katz, Dam T. Son, Mikhail A. Stephanov

- Modeling f_2 using graviton modes - Emmanuel Katz, Adam Lewandowski, Matthew Schwartz

- The renormalization group in AdS
  - Adam Lewandowski, Phys. Rev. D71:024006, (2005).
  - Understanding fixed point structure, RG flows and their connection to CFT

String Theory and Fluxes

- Renewed interest in anthropic principle, notion of landscape of vacua
  → KKLT construction

- fix moduli by turning on fluxes and by non-perturbative effects
  - size and shape of compactification manifold
  - generalization of electromagnetic flux
  - fluxes don't always finish the job: brane instantons

- break SUSY by small amount to obtain de Sitter vacua
  - use anti-D3 brane
  - warped metric: contribution of brane to action depends on position in internal space.
  - cosmology!

Projects

- Study of flux compactifications
  - construction: Kachru, Denef, Douglas, Florea, Kallosh, Kashani-Poor, Linde, Trivedi
  - non-perturbative aspects: Kachru, Kallosh, Kashani-Poor, Tomasiello, Tripathy, Trivedi
  - counting solutions: DeWolfe, Giryavets, Kachru, Taylor, Tripathy
- Cosmology in flux compactification setting: Dasgupta, Hsu, Kachru, Kallosh, Linde, Maldacena, McAllister, Zagermann
- Phenomenology inspired by flux compactifications: Arkani-Hamed, Dimopoulos, Kachru, McGreevy, Wacker
- Formal developments (N=2): Kashani-Poor, Tomasiello

String Cosmology on the Landscape

- Study Distribution of Vacua: (Kachru, Kashani-Poor, Giryavets, Liu, McAllister, ...)
  - Peaked around certain Features
  - Regions with Slow Roll Inflation
- Study Dynamics on Landscape: (Silverstein, Maloney, Liu, McAllister, Saltman, Linde, Koffman, Tong)
  - Dynamical Attraction to certain Vacua
- Study Initial Conditions: (Silverstein, Maloney, McGreevy)
  - Wave Function of the Universe

String Theory and Gravity

- Strings Near Singularities (Silverstein, Maloney, Liu, Saltman, Kallosh, McGreevy, Adams, Dabholkar)
  - Resolution of Black Hole and Cosmological Singularities
  - Topology Change & Tachyon Condensation
- Strings in Inflating Backgrounds (Silverstein, Maloney, Frievogel, Saltman, Shenker, Alishahiha, Jones, Karch, Karczmarek, Strominger, Tong)
  - Holographic Description (Gauge/Gravity Duality)
  - Possible Observational Consequences