FLAVOR QUESTIONS FOR THE LHC

J. Rosner – University of Chicago – 6/1/09 at FPCP 2009

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Flavor is perhaps **the** most poorly understood aspect of the Standard Model.

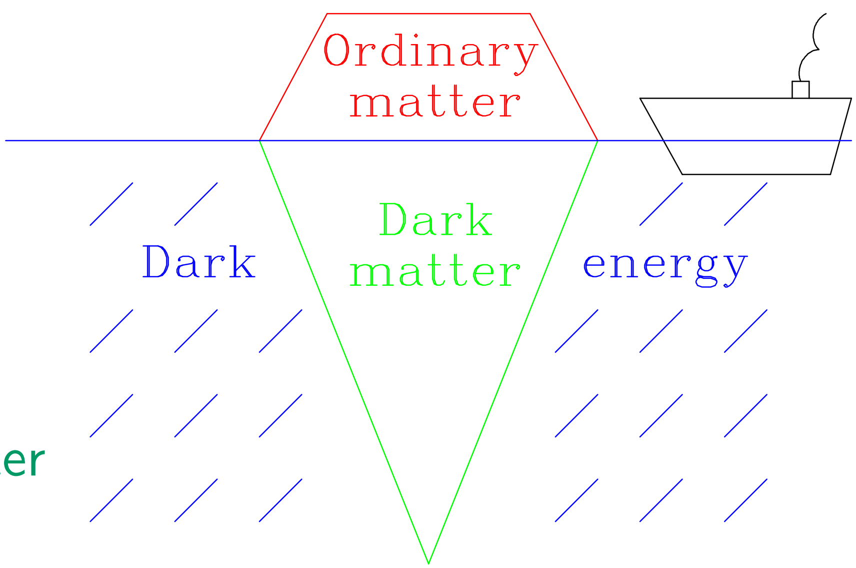
Ordinary matter makes up 4% of known energy density of Universe

Dark matter comprises another 23% and we have little clue as to its nature.

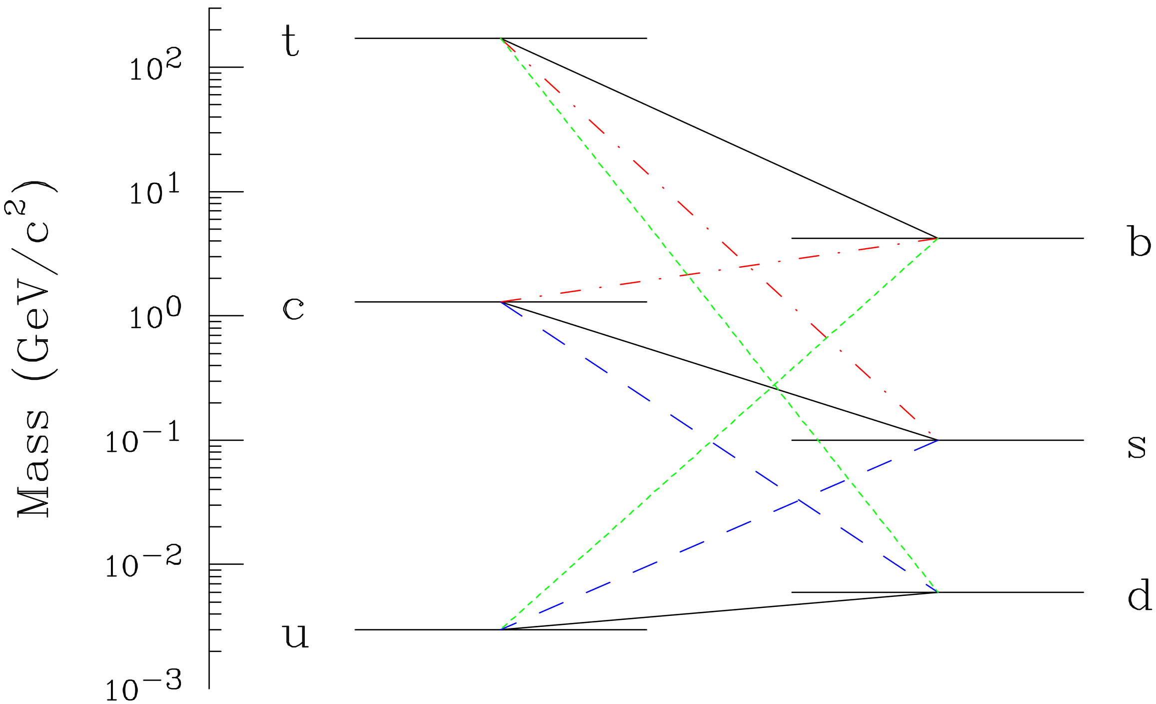
Dark energy accounts for the remaining 73%; we know even less about it.

Tip of the iceberg:
ordinary quarks and leptons ⇒

Unseen part of the iceberg: ⇒
could be clue to nature of ordinary matter



QUARKS: MASSES, COUPLINGS



Black transitions $\mathcal{O}(1)$

Blue transitions $\mathcal{O}(0.23) \equiv \lambda$

Red transitions $\mathcal{O}(0.04) \sim \lambda^2$

Green trans. $< \mathcal{O}(0.001) \sim \lambda^3$

Phases (Kobayashi-Maskawa) give CP violation

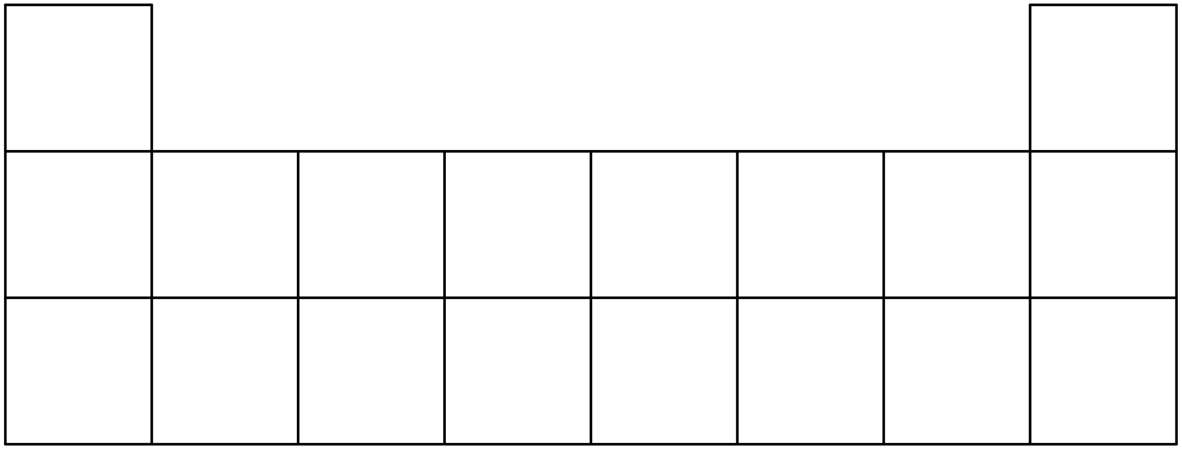
Standard Model: coupling pattern arises from same physics giving quark masses

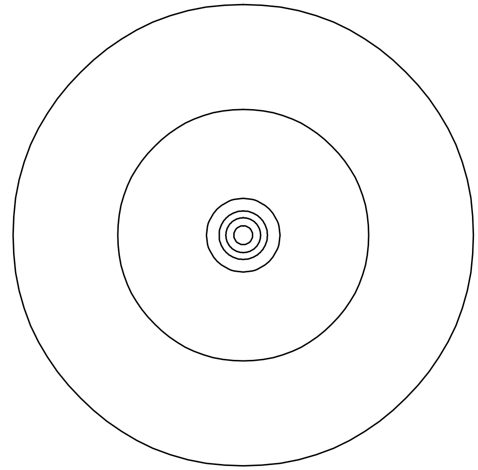
Leptons: differ by having very small neutrino masses, large mixings

What kind of physics is giving rise to this pattern? It is likely we will understand it much more fully if we know **how much of the pattern we are already seeing.**

Two familar examples give conflicting prospects for understanding the pattern

TWO FAMILIAR PATTERNS





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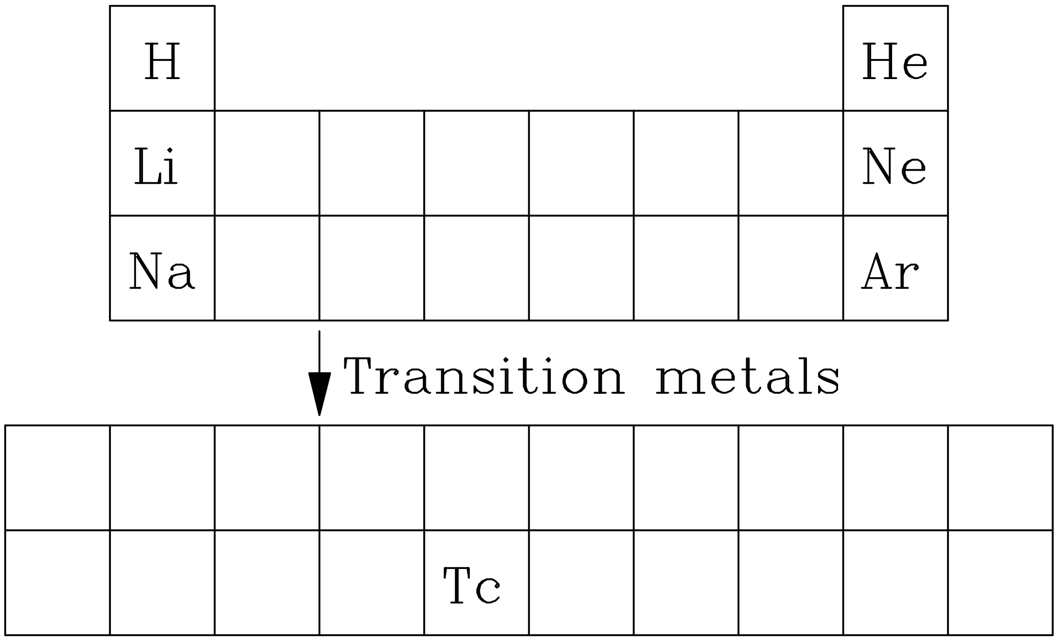
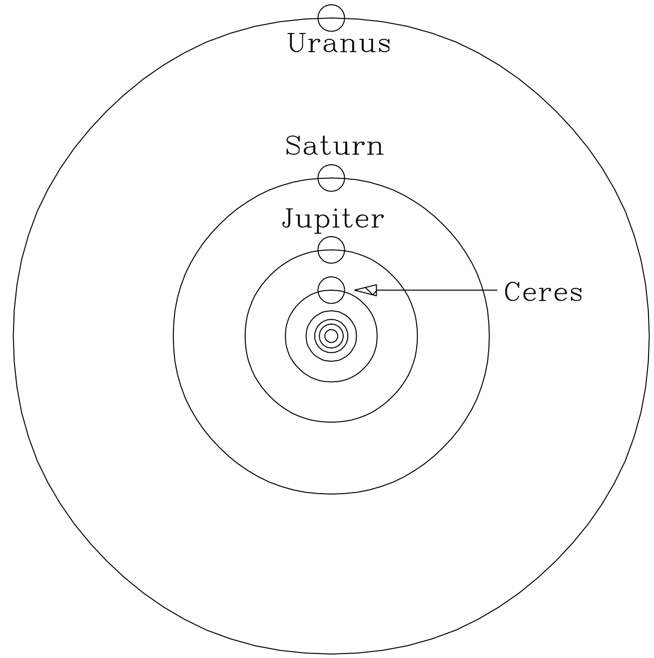


Periodic Table of the Elements



Planetary orbits

Each element has a different nuclear charge; electron shell structure governs chemistry; existience of Technetium predicted

Titius/Bode: $a(\mathrm{AU}) = 0.4 + 0.3k$ where $k = 0, 1, 2, 4, 8, \ldots$ predicted orbits of Ceres, Uranus

Titius/Bode law failed to predict orbit of Neptune; Pluto approximately where Neptune should have been; other dwarf planets don't fit; no dynamical explanation

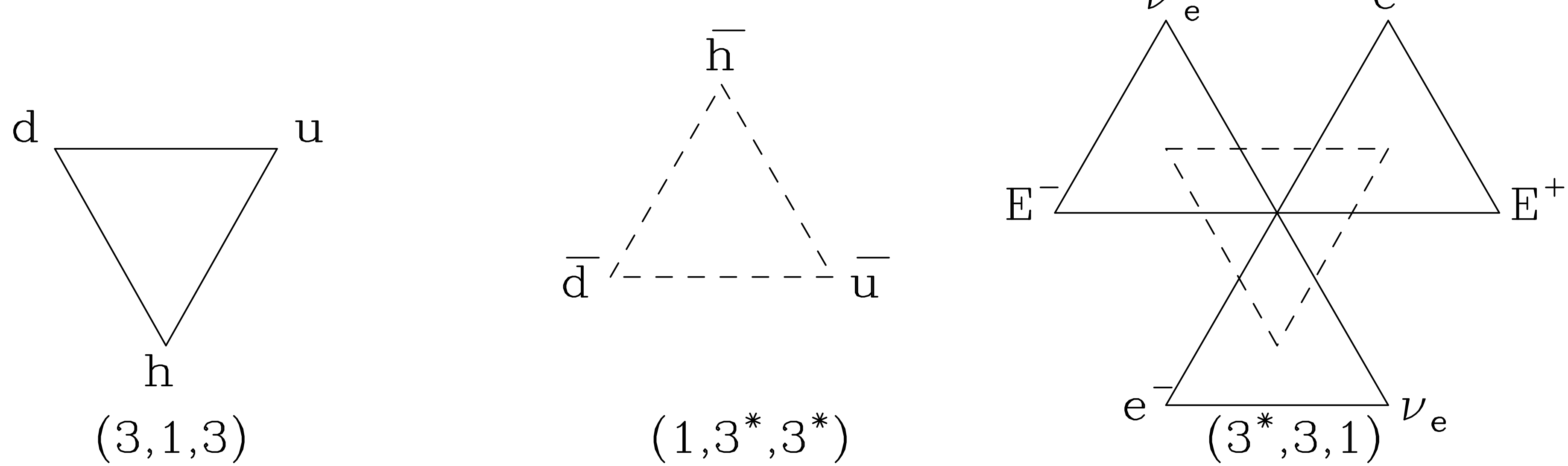
Simulations can give similar relations; ⇔ "anarchy" in quark-lepton masses.

MORE QUARKS?

Examples: fourth family, extended GUTs, Kaluza-Klein excitations

GUTs: SU(5) ($5^* + 10$ account for all known left-handed quarks and leptons)
SO(10) Add left-handed antineutrino (large Majorana mass?) to make a 16-plet
E_6: Add SO(10) 10-plet and singlet to 16-plet; gives a 27-plet

E_6 has subgroup $SU(3)_L \otimes SU(3)_R \otimes SU(3)_{color}$: 27-plet is



New isosinglet $Q = -1/3$ quarks h; new vector-like leptons $E^\pm$ and their neutrinos $\nu_E, \bar{\nu}_E$ (center); new sterile neutrino n (center). The h could mix with b and be responsible for $m_b \ll m_t$; searches at Fermilab exclude masses up to ~ 300 GeV.

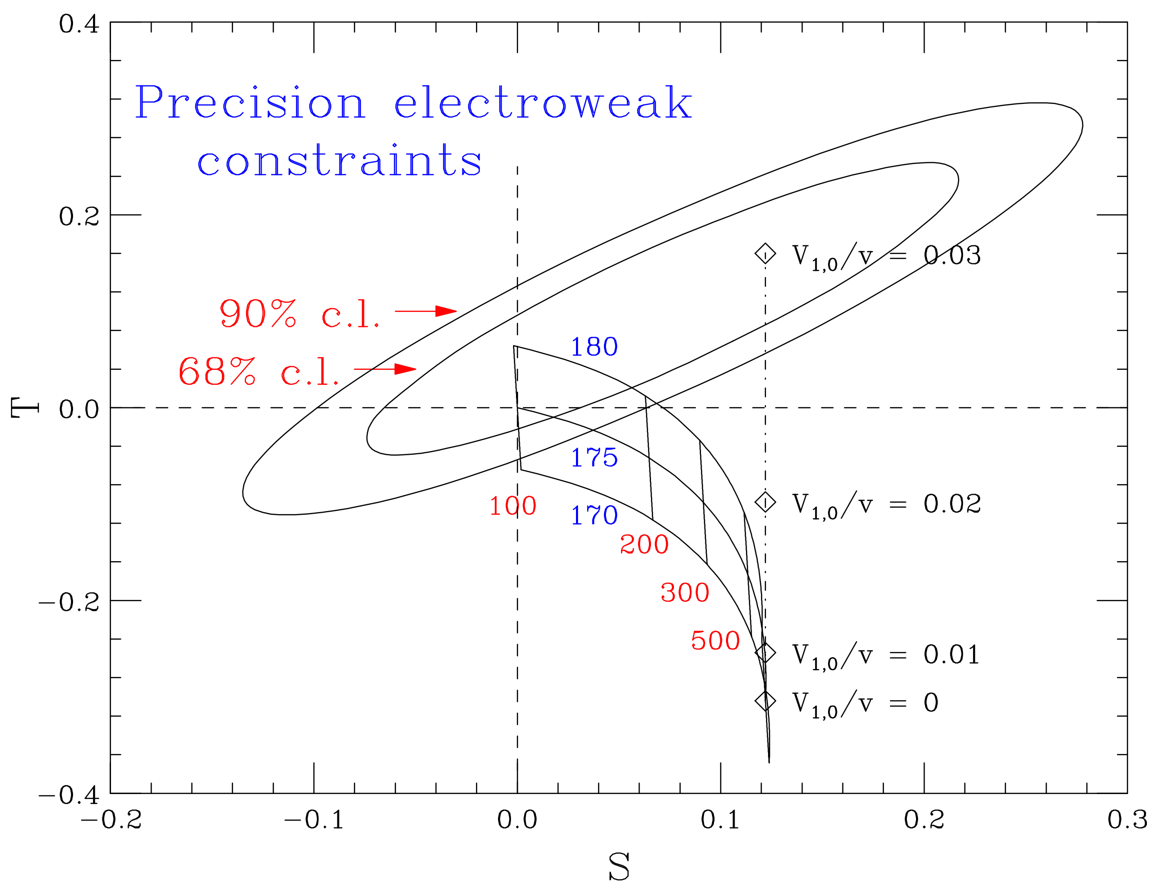
FOURTH FAMILY

If a fourth quark-lepton family exists, its neutrino must be heavier than $\sim M_Z/2$

Particles in loops affect W, Z, γ propagators and SM coupling relations:

$$\frac{G_F}{\sqrt{2}} = \left(1 + \frac{\alpha S}{4\sin^2\theta}\right)\frac{g^2}{8M_W^2}\ , \quad \frac{G_F\rho}{\sqrt{2}} = \frac{g^2+g'^2}{8M_Z^2}\ , \quad \rho \equiv 1 + \alpha T\ , \quad \alpha \simeq 1/129$$

New quark-lepton family: $\Delta S = 2/(3\pi) \simeq 0.2$, $\Delta T \simeq 0.4(m_{t'}^2 - m_{b'}^2)/(100\ \text{GeV})^2$



Labels: Higgs, top masses (GeV)

Vertical dot-dashed line shows effect of small triplet-Higgs VEV $V_{1,0}$ (up to 0.03 of Standard Model VEV v)

Here $\Delta\rho = 4(V_{1,0}/v)^2$

Large t'–b' mass splitting behaves like triplet Higgs, causing positive $\Delta\rho = \alpha\Delta T$

B. Holdom *et al.*, arXiv:0904.4698: also can relax M_H constraint

CHARM AND BOTTOM

Decays of mesons containing c, b quarks can give information on new physics.

Large menu of possibilities: supersymmetry, extra dimensions, new sectors associated with electroweak symmetry breaking or dark matter.

However, must distinguish genuine signatures of new physics from incompletely understood Standard Model effects such as arise in low-energy strong interactions.

Today: Some Standard Model and experimental questions raised by recent experiments on charm and B decays.

Cabibbo-Kobayashi-Maskawa (CKM) matrix; parameters

B_s–$\bar{B}_s$ mixing and CP violation in $B_s \to J/\psi\phi$

CP asymmetries and rates in $B \to (K\pi, \pi\pi)$

Progress on decay constants (beauty and charm)

Inclusive $D_s \to \omega X$: puzzle for strong dynamics?

Comments on models, dark matter scenarios, LHCb topics

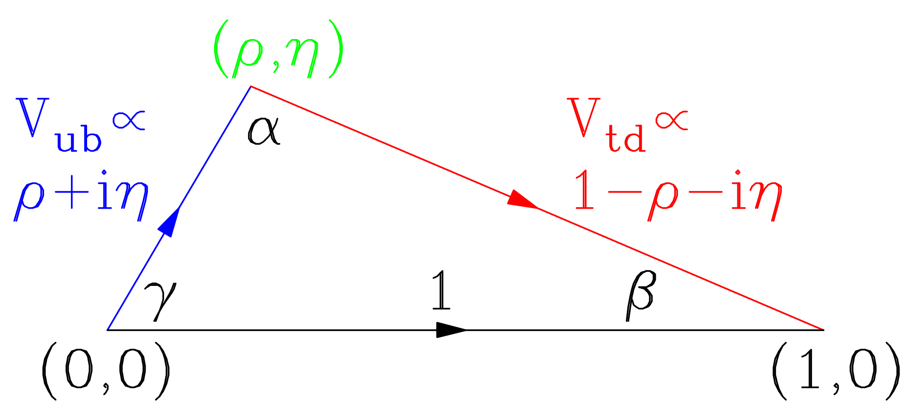
CKM MATRIX PARAMETERS

A convenient parametrization suggested by Wolfenstein:

$$V = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \simeq \begin{bmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{bmatrix}$$

Here $\lambda \simeq 0.2255$, $A \simeq 0.81$, $\rho \simeq 0.14$–0.18, $\eta \simeq 0.34$–0.36. (Two groups, UTfit and CKMfitter, slightly different parameters)

Unitarity ($V^\dagger V = 1$) implies (e.g.) $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$ or dividing by the middle term, $(\rho + i\eta) + (1 - \rho - i\eta) = 1$. This generates the *unitarity triangle*:



Learn shape from:

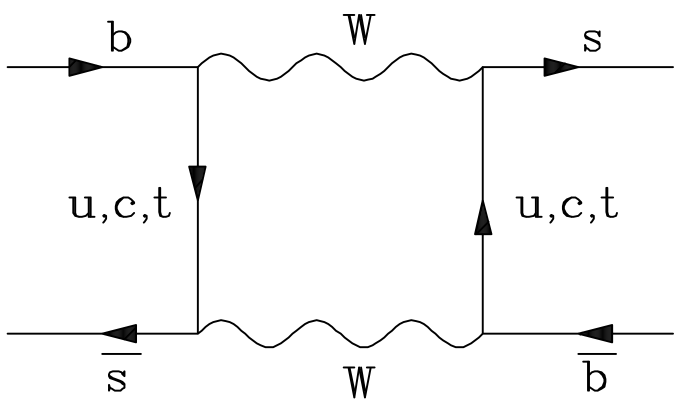
Kaon CP violation $\Rightarrow \eta(1-\rho)$

B–$\overline{B}$ mixing $\Rightarrow |1-\rho-i\eta|$

Charmless B decays $\Rightarrow |\rho + i\eta|$

Direct measurements satisfy $\alpha + \beta + \gamma = \pi$ (Trabelsi, 2009 Moriond EW):
$\alpha = (89.0^{+4.4}_{-4.2})^\circ$, $\beta = (21.0 \pm 0.9)^\circ$, $\gamma = (70^{+27}_{-29})^\circ$. Sides more constraining.

MIXING OF STRANGE B'S



Mixing is stronger than for B^0–$\overline{B}^0$ because $|V_{ts}/V_{td}| \simeq 5$

Unitarity implies $|V_{ts}| \simeq |V_{cb}| \simeq 0.041$ so B_s–$\overline{B}_s$ mixing probes hadron physics

Matrix element between B_s and $\overline{B}_s$ involves a combination $f_{B_s}^2 B_{B_s}$: f_{B_s} is the "B_s decay constant" (matrix element of $b\bar{s}$ operator between B_s and vacuum); $B_{B_s} \simeq 1$ parametrizes degree to which W exchange graphs dominate mixing.

Lattice QCD (arXiv:0902.1815): $f_{B_s}\sqrt{B_{B_s}}/[f_B\sqrt{B_B}] = 1.258 \pm 0.033$.

B^0–$\overline{B}^0$ mixing amplitude well-measured: $\Delta m_d = (0.507 \pm 0.005)$ ps^{-1}.

Consequently, B_s mixing measurement implies a value of $|V_{td}/V_{ts}|$

CDF measurement at Fermilab $\Delta m_s = (17.77 \pm 0.10 \pm 0.07)$ ps^{-1} gives $|V_{td}/V_{ts}| = 0.214 \pm 0.005$ and hence $|1 - \rho - i\eta| = 0.950 \pm 0.026$

Implies $\gamma \simeq (72 \pm 5)^\circ$, great improvement over value based on Δm_d.
$B^+ \to D^0\ (\bar{D}^0)K^+$ may improve this (CLEO $K_S\pi^+\pi^-$ Dalitz plot, arXiv:0903.1681)

B_s–$\bar{B}_s$ MIXING AND CP VIOLATION

$B_s \to J/\psi\phi$ expected in SM to have small CP asymmetry: governed by B_s–$\bar{B}_s$ mixing phase $\phi_M = -2\beta_s$

$\beta_s \equiv \mathrm{Arg}(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*) = \lambda^2\eta \simeq 0.02$ with $\lambda = 0.2255 \pm 0.0019, \eta \simeq 0.36$

Extract three independent partial waves $(L = 0, 1, 2)$ or three independent amplitudes $A_0, A_\|, A_\perp$ using fits to angular and time distributions

CDF and D0 at Fermilab Tevatron favor mixing phase differing from $-2\beta_s$. Defining $\phi_{B_s} = \beta_s + \phi_M/2$, HFAG average (A. Chandra, 2009 Moriond EW): $\phi_{B_s} \in [-163, -95]^\circ$, $[-84, -17]^\circ$, 2.2σ away from SM ($\Delta\Gamma_s \simeq 0.1$ $\surd$ SM).

Discrete ambiguity $\phi_M \to \pi - \phi_M$ associated with uncertainty in strong phases $\delta_\| \equiv \mathrm{Arg}(A_\| A_0^*)$, $\delta_\perp \equiv \mathrm{Arg}(A_\perp A_0^*)$ can be eliminated by comparison with $B^0 \to J/\psi K^{*0}$ as most contributions are similar [M. Gronau and JLR, Phys. Lett. B **669**, 321 (2008)]; phases equal within 10°

Advocate showing an explicit time-dependence which exhibits CP violation; not an easy task as oscillations are quite rapid (recall large Δm_s)

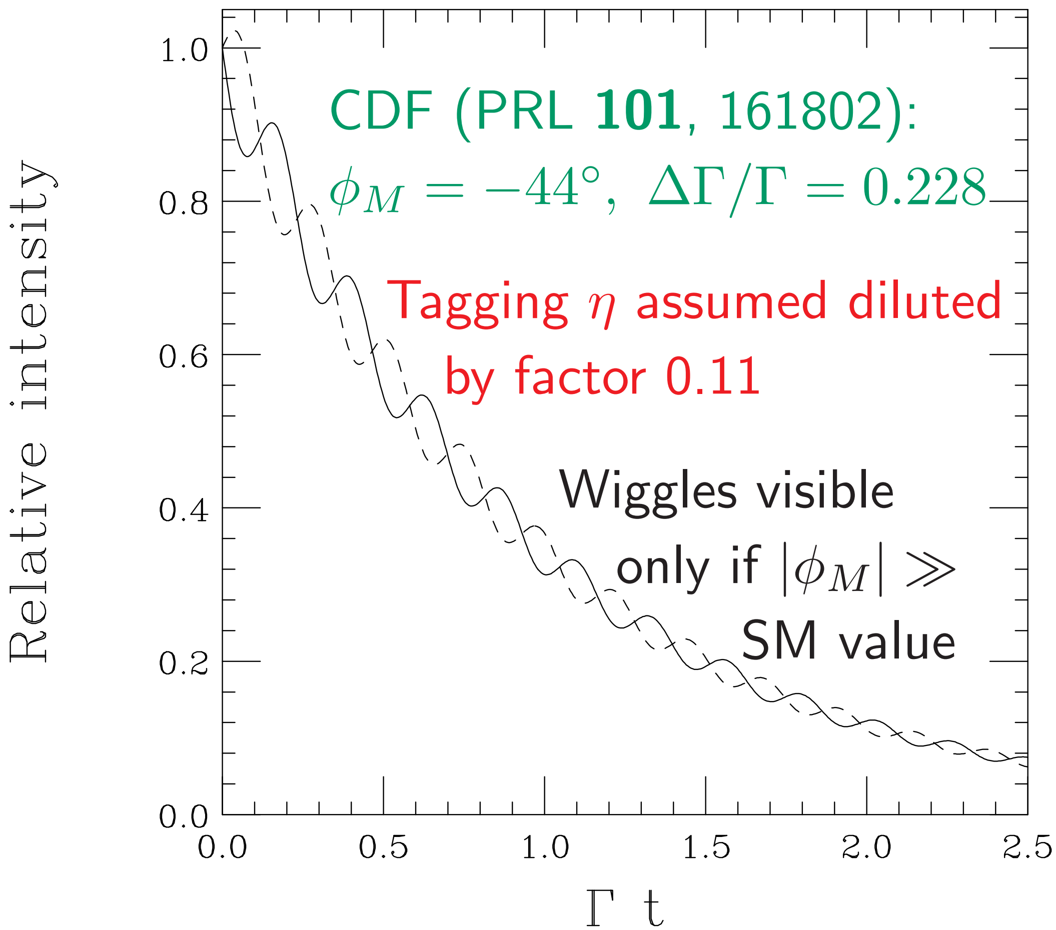
See A. Buras, arXiv:0902.0501 for mixing models, e.g., "littlest Higgs," extra dim.

B_s DECAYS: TIME-DEPENDENCES

Isolate CP violation by tagging at $t = 0$: $\eta = \pm 1$ for tagged $(B_s, \bar{B}_s)$

Functions $\mathcal{T}_+$, $\mathcal{T}_-$ associated with $|A_\parallel|^2$, $|A_\perp|^2$ (different angular dependences)

$$\mathcal{T}_\pm \equiv e^{-\Gamma t}[\cosh(\Delta\Gamma t)/2 \mp \cos(\phi_M)\sinh(\Delta\Gamma t)/2) \pm \eta \sin(\phi_M) \sin(\Delta m_s t)]$$



Time-dependence of $\mathcal{T}_\pm$ based on best-fit CDF parameters for $B_s \to J/\psi\phi$ decays

Solid: $\mathcal{T}_+$, B_s tag;

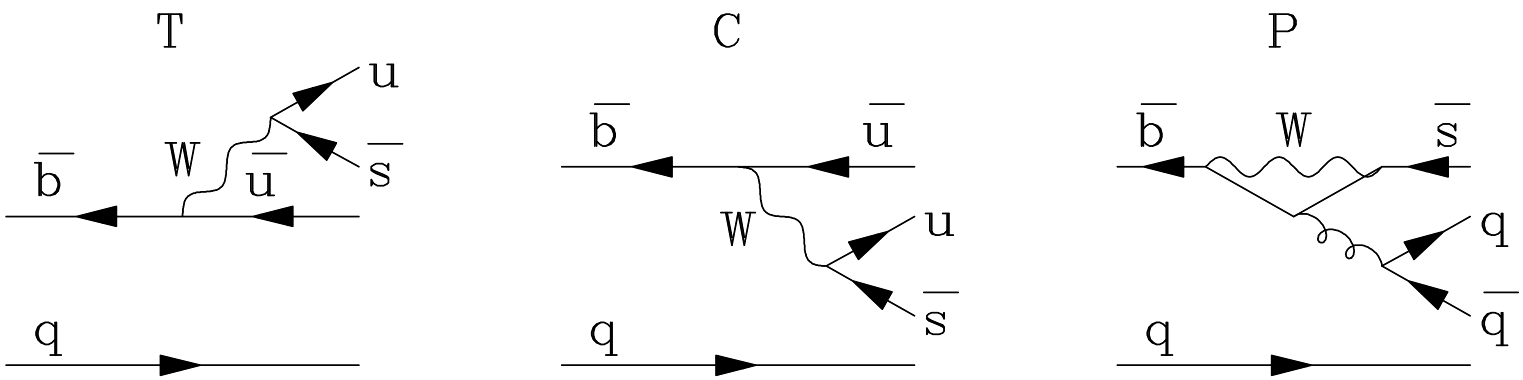
Dashed: $\mathcal{T}_+$, $\bar{B}_s$ tag;

Similar curves for $\mathcal{T}_-$

Such a plot would be clearer evidence for CP violation in $B_s \to J/\psi\phi$ at a level beyond the Standard Model

$B \to (K\pi, \pi\pi)$

CP asymmetries in $B^0 \to K^+\pi^-$ and $B^+ \to K^+\pi^0$ predicted equal if color-suppressed amplitude neglected: M. Gronau and JLR, PR D **59**, 113002 (1999)



Decay	Amplitude	BR (10^{-6})	A_{CP}
$B^0 \to K^+\pi^-$	$-(t+p)$	19.4 ± 0.6	-0.097 ± 0.012
$B^+ \to K^+\pi^0$	$-(t+p+c+A)/\sqrt{2}$	12.9 ± 0.6	0.050 ± 0.025
$B^0 \to K^0\pi^0$	$(p-c)/\sqrt{2}$	9.8 ± 0.6	0.00 ± 0.10
$B^+ \to K^0\pi^+$	$p+A$	23.1 ± 1.0	0.009 ± 0.025

$$t \equiv T + P^C_{\rm EW}\ , \quad c \equiv C + P_{\rm EW}, \quad p \equiv P - (1/3)P^C_{\rm EW}$$

SU(3) fit to $B \to (K\pi, \pi\pi)$ [Chiang *et al.*, PR D 70, 034020 (2004)]: $|C/T| = 0.46^{+0.43}_{-0.30}$, Arg$(C/T) = (-119 \pm 15)^\circ$; confirmed by Li-Mishima (arXiv:0901.1272).

WHAT'S THE PROBLEM?

Large C also needed for $\mathcal{B}(B^0 \to \pi^0\pi^0) = (1.55 \pm 0.19) \times 10^{-6}$

$A\ priori$ calculations: color-suppressed amplitude too small; no similar enhancement in $B \to \rho\rho$. Li-Mishima: special role for pseudoscalars

Kaidalov-Vysotsky (PL B **652**, 203 (2007): $\mathcal{B}(B \to \rho\rho) \gg \mathcal{B}(B \to \pi\pi)$; rescattering $(\rho\rho \to \pi\pi) \gg (\pi\pi \to \rho\rho) \Rightarrow$ more C in $\pi\pi$ than in $\rho\rho$

Rescattering via $\bar{b} \to \bar{c}c\bar{s}$ also a likely source of enhanced $\bar{b} \to \bar{s}$ "charming" penguin

Consistency tested by A_{CP} sum rule [M. Gronau, PL B **627**, 82 (2005)]:

$$\Delta(K^+\pi^-) + \Delta(K^0\pi^+) = 2\Delta(K^+\pi^0) + 2\Delta(K^0\pi^0),\ \Delta(f) \equiv \Gamma(\bar{B} \to \bar{f}) - \Gamma(B \to f).$$

Predicts $A_{CP}(B^0 \to K^0\pi^0) = -0.148 \pm 0.044$ vs. expt. -0.01 ± 0.10

Standard Model seems to be able to accommodate large C; no need for new-physics scenarios involving $P_{\rm EW}$ contribution to $c = C + P_{\rm EW}$

A_{CP} sum rule provides diagnostic for $\Delta I = 1$ new physics: S. Baek *et al.*, arXiv:0905.1495. Measure $A_{CP}(B^0 \to K^0\pi^0)$ to 0.03 or better.

DECAY CONSTANTS

$B^+ \to \tau^+\nu_\tau$ probes B meson decay constant f_B, CKM element V_{ub}, new physics such as charged Higgs (H) exchange:

$$\Gamma(B^+ \to \tau^+\nu_\tau) = \frac{G_F^2}{8\pi}|V_{ub}|^2 f_B^2 m_B m_\tau^2 \left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 \left[1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right]^2 ,$$

where $\tan\beta \equiv v_2/v_1$, with $v_{1,2}$ v.e.v.'s of two neutral Higgs bosons

Since review by JLR and S. Stone for PDG, arXiv:0802.1043:

(1) New (Belle,BaBar) measurements (arXiv:0809.3834,4027):
$\mathcal{B}(B^+ \to \tau^+\nu_\tau) = [(1.65^{+0.38+0.35}_{-0.37-0.37}), (1.8 \pm 0.8 \pm 0.1)] \times 10^{-4} \Rightarrow$
New average (Artuso *et al.*, arXiv:0902.3743) $(1.73 \pm 0.35) \times 10^{-4}$;

(2) New calculation by HPQCD group (arXiv:0902.1815) of $f_B = 190(13)$ MeV

Taken with $|V_{ub}| = (3.9 \pm 0.5) \times 10^{-3}$, (2) implies

$$\mathcal{B}(B^+ \to \tau^+\nu_\tau) = (0.97 \pm 0.28) \left[1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right]^2 \times 10^{-4}$$

so the coefficient of $[\ldots]^2$ is 1.7σ below experiment

With $B \to D\tau\nu$: constrains (arXiv:0902.3743) $(m_B \tan\beta/m_H)^2$ to be very small

OTHER DECAY CONSTANTS

HPQCD finds $f_{B_s}/f_B = 1.226(26)$, in agreement with [JLR, PR D **42**, 3732 (1990)] $(m_s/m_d)^{1/2} = 1.25$ for quark masses $m_s = 485$ MeV, $m_d = 310$ MeV

CLEO: $f_D = (205.8 \pm 8.5 \pm 2.5)$ MeV [PR D **78**, 052003 (2008)] vs. lattice [HPQCD, PRL **100**, 062002 (2008)] $f_D = (207 \pm 4)$ MeV, or [Fermilab/MILC, arXiv:0904.1895] (207 ± 11) MeV

CLEO's $f_{D_s} = (259.5 \pm 6.6 \pm 3.1)$ MeV (J. P. Alexander *et al.*, PR D **79**, 052001) is 2.3σ above HPQCD prediction $f_{D_s} = (241 \pm 3)$ MeV but consistent with Fermilab/MILC prediction (249 ± 11) MeV

CLEO ratio $f_{D_s}/f_D = 1.268 \pm 0.064$ consistent with quark model estimate 1.25

A. G. Akeroyd and F. Mahmoudi (arXiv:0902.2393): constraints on charged Higgs

$\Gamma(D_s^+ \to \ell^+ \nu_\ell) = \frac{G_F^2}{8\pi} f_{D_s}^2 m_\ell^2 M_{D_s} \left(1 - \frac{m_\ell^2}{M_{D_s}^2}\right)^2 |V_{cs}|^2 r_s^2$, where

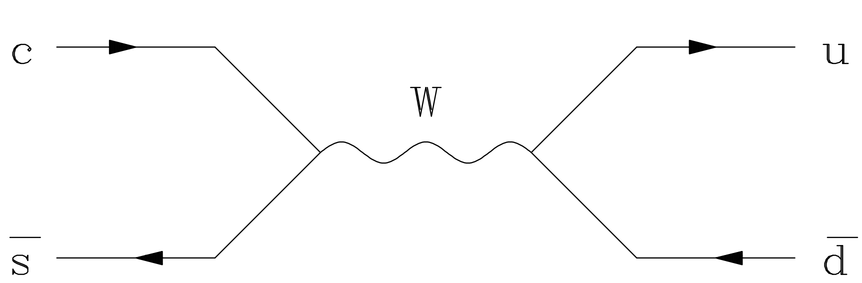
$r_s \equiv 1 + \left(\frac{1}{m_c + m_s}\right)\left(\frac{m_{D_s}}{m_{H^+}}\right)^2 (m_c - m_s \tan^2\beta)$ in Type II 2-Higgs-doublet model

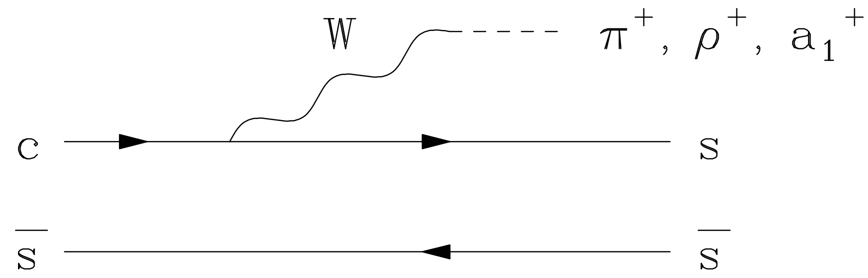
B. Dobrescu + A. Kronfeld [PRL **100**, 241802 (2008)]: New-physics scenarios including leptoquarks or unconventional charged Higgs

INCLUSIVE $D_s \to \omega X$

CLEO's $\mathcal{B}(D_s^+ \to \omega X) = (6.1 \pm 1.4)\%$ was a surprise: knew only $\mathcal{B}(D_s^+ \to \pi^+\omega) = (0.25 \pm 0.09\%)$ but now have accounted for $(5.4 \pm 1.0)\%$ (preliminary)

Mechanisms for $D_s^+ \to \omega X^+$ are not so obvious: often have to get rid of an $s\bar{s}$ pair.





$D_s^+ \to (\text{virtual } W^+) \to u\bar{d}$
is helicity-suppressed

G-parity forbids
$\pi^+\omega$, $(3\pi)^+\omega$

[1] PR D **79**, 074022 (2009)

$c \to u\bar{d}s$ with spectator s
could give $\omega\pi^+\eta$ [1]

Could get $\omega(\pi^+, \rho^+, a_1^+)$
if $s\bar{s} \to \omega$ (OZI-suppressed [2])

[2] PR D **79**, 074006 (2009)

If right-hand graph is important might expect $D_s \to \omega\ell^+\nu_\ell$ to be observable

Helicity-suppression also not apparent in CLEO's result [PRL **100**, 181802 (2008)]:
$\mathcal{B}(D_s \to p\bar{n}) = (1.30 \pm 0.36^{+0.12}_{-0.16}) \times 10^{-3}$ (reasonable form factor)

SOME MODELS

Extra Z bosons arise in many extensions of SM; not guaranteed to have flavor-diagonal couplings if SM fermions also mix with new fermions in such extensions

Example: Grand Unified Theories based on the exceptional group E_6 have two extra Z bosons Z_χ, Z_ψ (only one linear combination of which may be relatively light) and extra isoscalar quarks with $Q = -1/3$ which can mix with d, s, b

Many grand unified theories have $\mathrm{SU}(4)_{\mathrm{color}} \times \mathrm{SU}(2)_{\mathrm{L}} \times \mathrm{SU}(2)_{\mathrm{R}}$ subgroup. $\mathrm{SU}(4)_{\mathrm{color}}$ unifies quarks and leptons and contains $\mathrm{U}(1)_{\mathrm{B-L}}$ and leptoquarks; $\mathrm{SU}(2)_{\mathrm{R}}$ has right-handed W's and $\mathrm{U}(1)_{\mathrm{R}}$ such that EM charge is $Q = I_{3\mathrm{L}} + I_{3\mathrm{R}} + (B - L)/2$

Leptoquarks can contribute to leptonic meson decays; right-handed W's contribute to mixing; strong constraints on W_L–W_R box diagrams

Supersymmetry: box diagrams can change flavor unless specifically forbidden

Electroweak-symmetry-breaking schemes (Littlest Higgs [Nambu-Goldstone] with T-parity, Technicolor, . . .) generically have flavor-changing interactions

Theories with extra dimensions [Fitzpatrick-Perez-Randall, PRL **100**, 171604 (2008)]: top sector flavor violation (ILC!), 2 TeV scale Kaluza-Klein excitations

DARK MATTER SCENARIOS

Imagine a TeV-scale effective symmetry SU(3) ⊗ SU(2) ⊗ U(1) ⊗ G, where G could be SUSY with R-parity, extra-dimensional excitations with Kaluza-Klein parity, little Higgs models with T-parity, Technicolor, or some other group.

Possible types of matter (JLR, Snowmass 2005, astro-ph/0509196):

Type of matter	Std. Model	G	Example(s)
Ordinary	Non-singlet	Singlet	Quarks, leptons
Mixed	Non-singlet	Non-singlet	Superpartners
Shadow	Singlet	Non-singlet	E_8' of $E_8 \otimes E_8'$

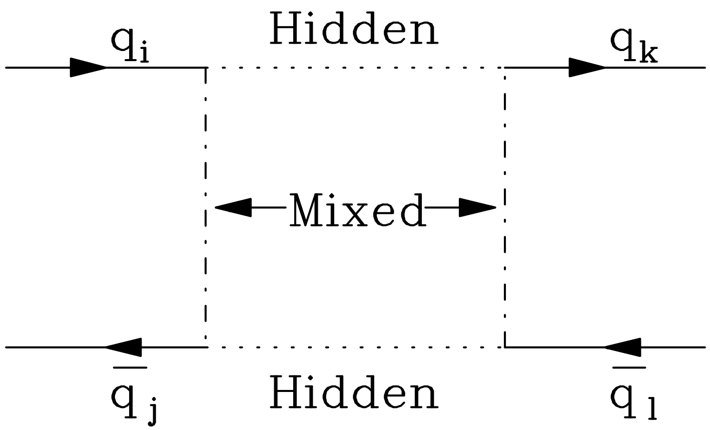
Ordinary matter could be singlets under G even if subconstituents were non-singlets (e.g., in composite-Higgs models). Loops could involve G-nonsinglets.

Many dark matter scenarios involve mixed matter, such as superpartners or particles with odd KK- or T-parity. Flavor-changing loops can occur.

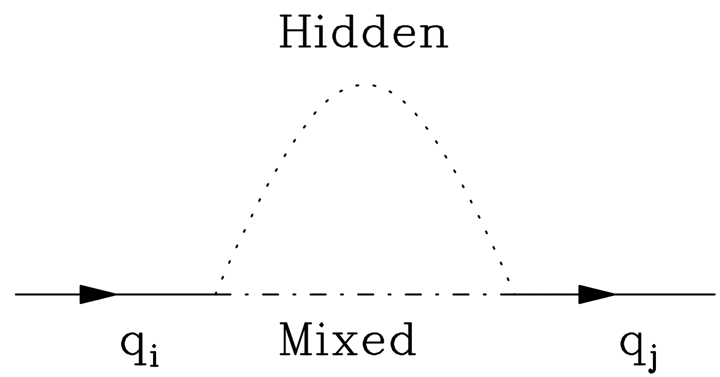
Mixed-matter scenarios may be different if G is more general than a "parity."

Shadow matter may not interact with ordinary matter *at all* except gravitationally.

HIDDEN SECTOR IN LOOPS



Box diagram

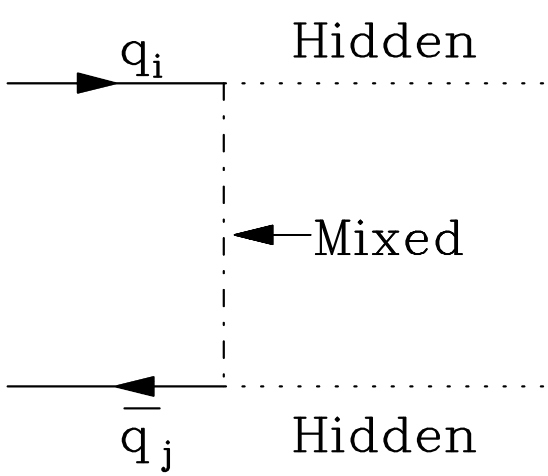


Penguin diagram

Mixed particles must have same SU(3) $\otimes$ SU(2) $\otimes$ U(1) quantum numbers as the quarks to which they couple, but off-diagonal flavor couplings are allowed

Flavor-diagonal couplings still can affect muon anomalous moment a_μ

For coupling $\mathcal{O}(\alpha)$, mass scale to explain 3σ discrepancy in a_μ is ~ 50 GeV



D. McKeen [arXiv:0903.4982 $\Rightarrow$ PRD] suggests looking for light "hidden" states in quarkonium decay

Example: $\Upsilon(2S) \to \gamma\chi_{b0} \to \gamma XX$, where X could be a light dark matter candidate

WIMPless DM: Feng + Kumar, PRL **101**, 231301 (2008)

SOME LHCb TOPICS

Unique window to B_s decays:

Better $J/\psi\phi$ studies, with explicit time dependence plots

$B_s \to J/\psi(\eta,\ f_0)$: $\mathcal{B}$ less (1/3 for η) but no helicity analysis needed.
L. Zhang (poster): $\mathcal{B}(B_s \to J/\psi f_0)/\mathcal{B}(B_s \to J/\psi\phi) = (42 \pm 11)\%$

$A(B_s \to D_s^+ K^-) \sim V_{ub}^* V_{cs}$; $A(\bar{B}_s \to D_s^+ K^-) \sim V_{us}^* V_{cb}$

$(B,\ B_s) \to (\pi\pi, K\pi)$ [Fleischer; Gronau + JLR] $\Rightarrow \gamma$

Many tests of flavor SU(3) by comparison with B decays

Hidden valley scenario suggests energy threshold (TeV?) for production of new matter; some may end up in new light (few GeV?) states. M. Kuharczyk & S. Stone, "Status of Hidden Valley in LHCb," Exotica Workshop, LHCb week, May 26, 2009: examples of 3 TeV Z', 35 GeV "v-pion," SM Higgs $\to \Pi_v^0 \Pi_v^0$

Charm studies: virgin territory. Large production cross sections; small Standard Model CP violation; probes loop/penguin diagrams involving mixed/hidden sector

LOOKING FORWARD

Belle, Fermilab Tevatron still running; Babar and CLEO analyzing data. (CLEO capable of searching for light scalars or pseudoscalars in bottomonium decay.)

Nearest future: LHCb (whenever LHC begins operation) and some b physics capabilities at ATLAS and CMS. Questions include many on the strange B system, e.g., pinning down the mixing and/or CP-violating phase in B_s–$\bar{B}_s$ system

Other LHCb questions: (a) flavor symmetry and departures from it in B_s decays provide reality checks for schemes seeking to calculate strong-interaction properties (e.g., non-factorizable amplitudes); (b) effects of any new sector on loops and direct production of new particles

KEK-B/Belle upgrade: initially 10 ab^{-1}; eventually > 5 times that; super-B more

Simplest motivation: Anything studied previously with single-B decays now can be studied with double-tagged events if tagging efficiency approaches 1%.

ILC to explore Higgs, SUSY, top sector

Rich program of understanding strong-interaction and nonperturbative effects will be needed to complement searches for rare processes in order to interpret apparent departures from SM as genuine signs of new physics

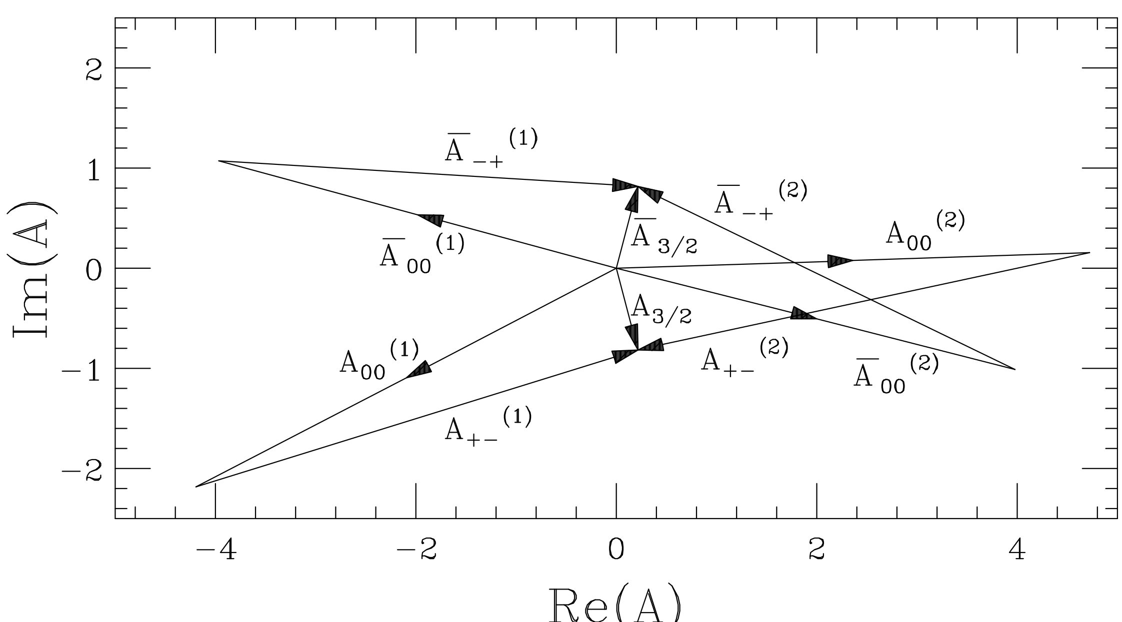
S PARAMETER IN $B^0 \to K^0\pi^0$

M. Gronau + JLR, PL B **666**, 467 (2008): $B^0 \to K^0\pi^0$ dominated by $\bar{b} \to \bar{s}$; expect small $C_{K\pi} = -A_{CP}(B^0 \to K^0\pi^0)$, $S_{K\pi} = \sin(2\phi_1) = 0.67 \pm 0.02$ ($c\bar{c}$ value)

Time-dependent asymmetry $A(t) = -C_{K\pi}\cos(\Delta m t) + S_{K\pi}\sin(\Delta m t)$

Small deviations from $S_{K\pi} = \sin(2\phi_1)$ predicted in SU(3) fits and most other approaches; Fleischer *et al.* (arXiv:0806.2900) found $S_{K\pi} = 0.99$. We asked why.

Took $I_{K\pi} = 3/2$ amplitude from $I_{\pi\pi} = 2$ amplitude from $B^+ \to \pi^+\pi^0$ using SU(3)



Found large relative phase of $A_{00} \equiv A(B^0 \to K^0\pi^0)$ vs. $\bar{A}_{00} = A(\bar{B}^0 \to \bar{K}^0\pi^0)$ [sol. (1)]

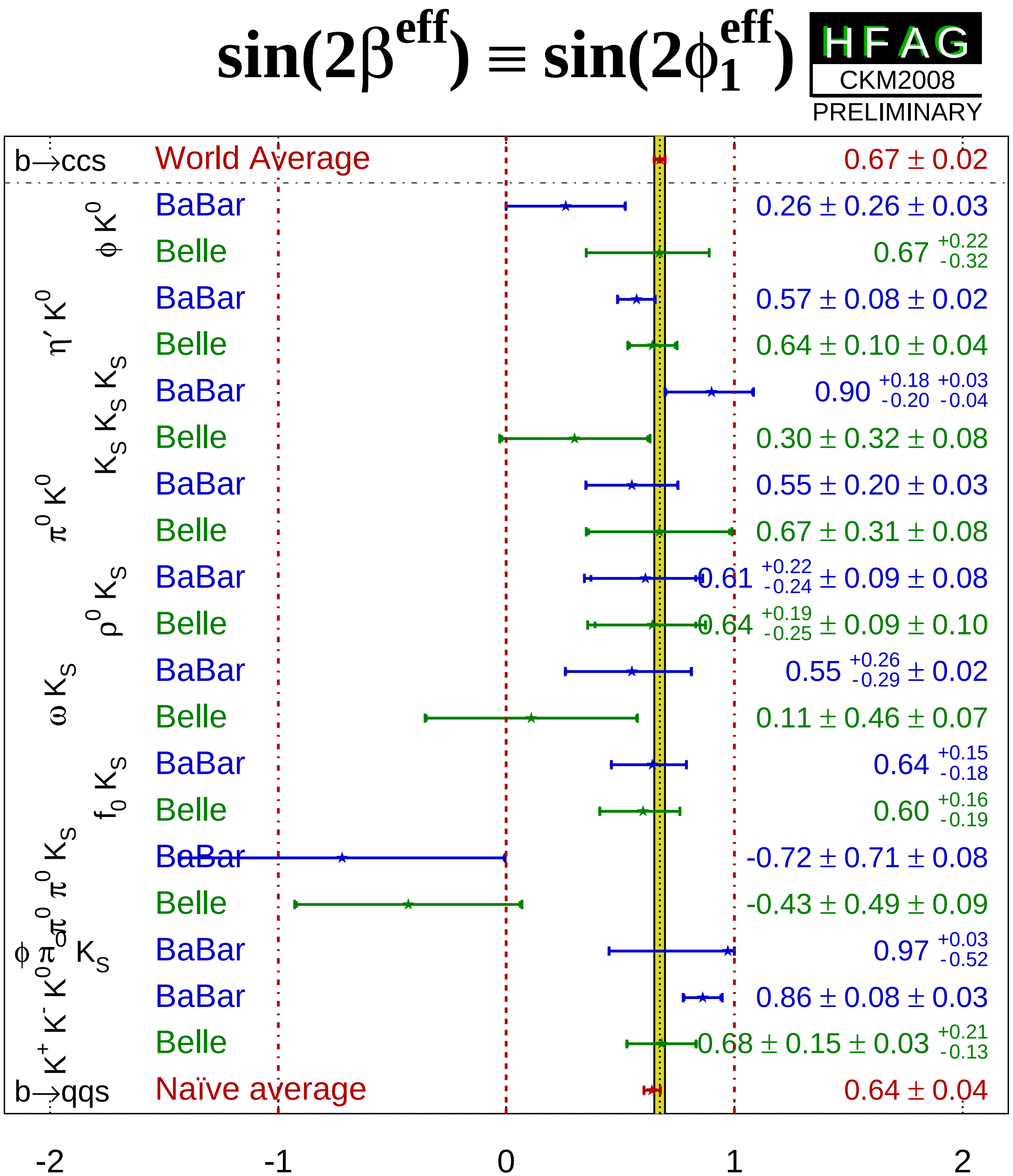
Results sensitive to $K^0\pi^0$ BR and weak phase ϕ_3 (65° here)

Ciuchini *et al.* (arXiv:0811.0341): Implies too small $\mathcal{B}(K^0\pi^+)$

If ϕ_3, $\mathcal{B}(B^0 \to K^0\pi^0)$ lowered by 1σ, $S_{K\pi}$ prediction more in line with SU(3) fit

STRANGE PENGUINS

As quoted by K. Trabelsi, 2009 Moriond EW



Several B decays involving K's in final state seem to be dominated by the $b \to s$ penguin.

Expect coefficient of $\sin \Delta mt$ decay rate modulation to be $\sin 2\phi_1 = 0.67 \pm 0.02$ as for $B^0 \to J/\psi K_S$.

$b \to s$ penguin-dominated decays can provide information on new physics [Y. Grossman and M. Worah, PL B**395**, 241 (1997)] but no such evidence at present

$B^0 \to J/\psi K_S$: $b \to u\bar{u}s$ PENGUINS?

Time-dependence in $B^0 \to J/\psi K_S$ and related $b \to c\bar{c}s$ states yields $\sin(2\phi_1) = 0.67 \pm 0.02$; could several-percent corrections be due to rescattering from $b \to u\bar{u}s$? [M. Ciuchini *et al.*, PRL **95**, 221804 (2005); S. Faller *et al.*, arXiv:0809.0842]

M. Gronau and JLR, arXiv:0812.4796, $\Rightarrow$ PL B: using measured BRs for charmless $|\Delta S| = 1$ B^0 decays, place an upper bound of order 10^{-3} on these corrections

Ratio ξ of $b \to u\bar{u}s$ penguin to $b \to c\bar{c}s$ color-suppressed amplitudes is small because (1) $|V_{ub}V^*_{us}/V_{cb}V^*_{cs}| \simeq 0.02$; (2) Wilson coefficients for penguin operators are small; and (3) final state must be produced by Okubo-Zweig-Iizuka (OZI) rule violation

Perturbative estimates indicated $\xi < 10^{-3}$ but if $b \to c\bar{c}s$ processes could enhance $b \to s$ penguins, why not $b \to u\bar{u}s$ as well?

Rescattering from charmless final states was compared with rescattering from charm-anticharm, using detailed balance and accounting for contributions from several charmless modes; $r_f \equiv |\langle f|T^u|B^0\rangle / \langle f|T^c|B^0\rangle$

Example: Compare "tree" amplitude contribution in $B^0 \to K^{*+}\pi^- \to J/\psi K^0$ with $B^0 \to D_s^+ D^{*-} \to K^{*+}\pi^-$

u-PENGUIN CONTRIBUTIONS

Vector-pseudoscalar modes:

Mode f	$\mathcal{B}$ (10^{-6})	p^* (MeV)	r_f	Upper bound on ξ_f (10^{-4})
$K^{*+}\pi^-$	10.3±1.1	2563	0.31±0.03	7.9±1.1
$\rho^- K^+$	8.6±1.0	2559	0.26±0.03	5.6±1.0
$K^{*0}\pi^0$	2.4±0.7	2562	0.09±0.04	0.6±0.3
$\rho^0 K^0$	5.4±1.0	2558	0.04±0.03	0.5±0.4
ωK^0	5.0±0.6	2557	0.04±0.03	0.5±0.4
$K^{*0}\eta$	15.9±1.0	2534	0.04±0.02	1.6±0.7
$K^{*0}\eta'$	3.8±1.2	2471	0.08±0.04	0.8±0.4

Large branching ratio: $\mathcal{B}[B^0 \to K_0^*(1430)^+\pi^-] = (50^{+8}_{-9}) \times 10^{-6}$

Nevertheless, u-quark tree amplitude contribution to this process is small and one finds $r_f = 0.015 \pm 0.013$, leading to $\xi_f < (1.9 \pm 0.4) \times 10^{-4}$

Inter alia, the estimate of the tree contribution depends on knowing $f_{K_0^*}$, for which theoretical estimates give 40 ± 6 MeV

Measure in τ decays: $\mathcal{B}(\tau \to K_0^*\nu) < 5 \times 10^{-4}$ vs. prediction $\sim 8 \times 10^{-5}$

V_{ub} AND "WEAK ANNIHILATION"

Extract $|V_{ub}|$ from charmless semileptonic B decays

$|V_{ub}/V_{cb}|^2 = 1\%$; phase space favors u over c by factor of 2. Need strategies to extract 2% charmless semileptonic decay signature; e.g., higher E_ℓ endpoint

"Weak annihilation" (WA) (M. Gronau + JLR, arXiv:0902.1363 for references) can contaminate E_ℓ endpoint signal: B^+ turns into a soft $I = 0$ hadronic system plus a vector $\bar{b}u$ which then can annihilate freely into $\ell\nu$ (pseudoscalar: helicity suppressed)

CLEO [PRL **96**, 121801 (2006)] and BaBar (arXiv:0708.1753) place upper limit for WA of few % of charmless semileptonic b decays; Gambino *et al.* [JHEP **0710**, 058 (2007)] estimate couple of %

Process is supposed to be of order $1/m_b^3$ so it should be more visible in charm decays

$D_s \to \omega\ell\nu$ probes WA: semileptonic D_s decay $\to s\bar{s}$ but ω mostly nonstrange

$s\bar{s}$ admixture in $\omega \Rightarrow \mathcal{B}(D_s \to \omega\ell\nu) < 2 \times 10^{-4}$, vs. $\mathcal{B}(D_s \to \phi\ell\nu) \simeq 2\%$

If $D_s^+ \to \omega\pi^+$ is due to WA, estimate $\mathcal{B}(D_s \to \omega\ell\nu) \simeq [\mathcal{B}(D_s \to \omega\pi^+)/\mathcal{B}(D_s \to \phi\pi^+)]\mathcal{B}(D_s \to \phi\ell^+\nu) \simeq (1.3 \pm 0.5) \times 10^{-3}$, nearly order of magnitude larger