An Outlook

In 10 years the written laws of physics will be different than they are now.

What is the biggest unsolved problem in physics?

"I do not like this question... Galileo was surrounded by great professors of theology, Aristotelian philosophy, and so forth, who addressed all the 'greatest' questions about the nature of the universe, the meaning of life, and so on, in long treatises. But Galileo made a more lasting contribution by studying and figuring out precisely how balls roll down inclined planes."

Frank Wilczek, in Physics World, Dec. 1999

Sarcophilis harrisii
(Tasman devil)

“The devil is in the details.”

How Will It Emerge?

- The energy frontier
- The quark flavor frontier
- The neutrino frontier
- The theory frontier
- The cosmic frontier

How Will It Emerge?

- The energy frontier
- The quark flavor frontier
- The neutrino frontier
- The theory frontier
- The cosmic frontier

- CDF & D-Zero; LHC;
- B-TeV
- K-physics
- NUMI & off-axis
- Symmetries & Lattice
- Sloan, SNAP, …

Quark Flavor Physics

Cabbibo-Kobayashi Maskawa Theory

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$= \begin{pmatrix} 0.9741 \text{ to } 0.9756 & 0.219 \text{ to } 0.226 & 0.0025 \text{ to } 0.0048 \\ 0.219 \text{ to } 0.226 & 0.9732 \text{ to } 0.9748 & 0.038 \text{ to } 0.044 \\ 0.004 \text{ to } 0.014 & 0.037 \text{ to } 0.044 & 0.9990 \text{ to } 0.9993 \end{pmatrix}$$

$$\hat{V} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\varrho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\varrho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

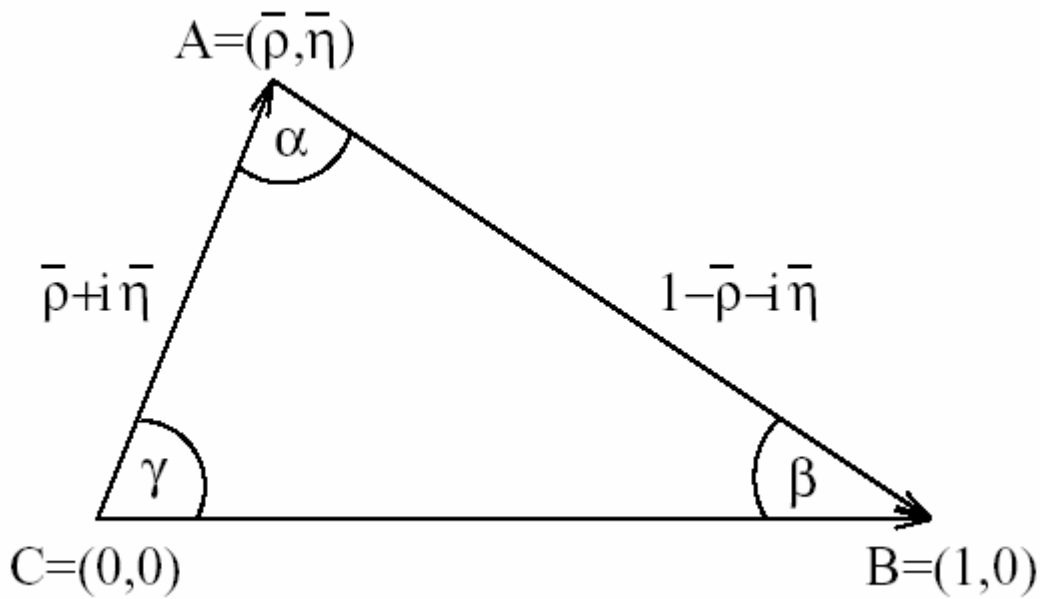
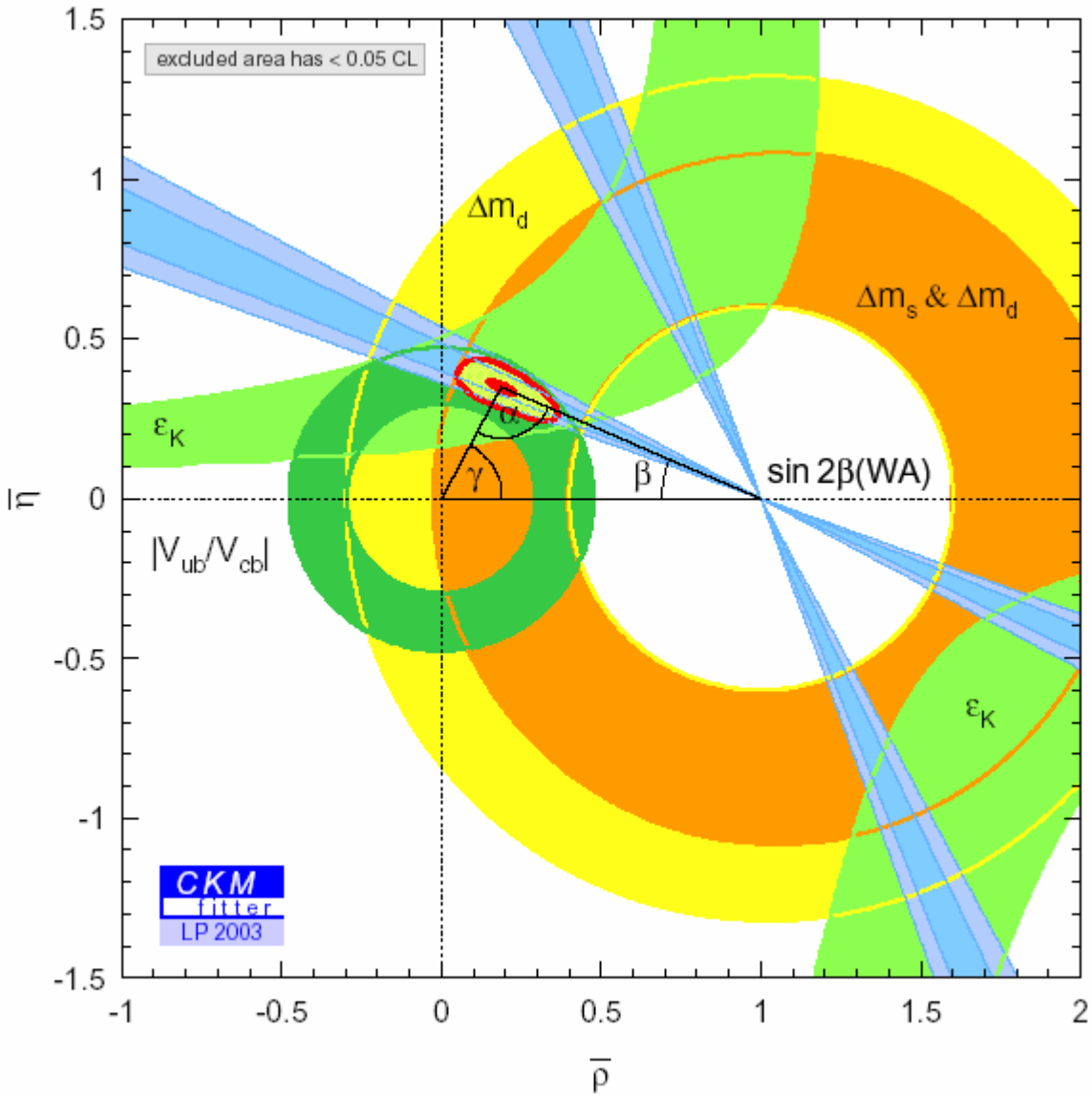


Fig. 1.1: *Unitarity Triangle.*

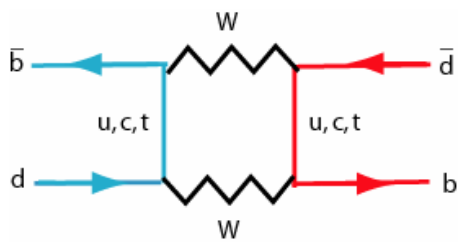


Hocker et.al., Grossman

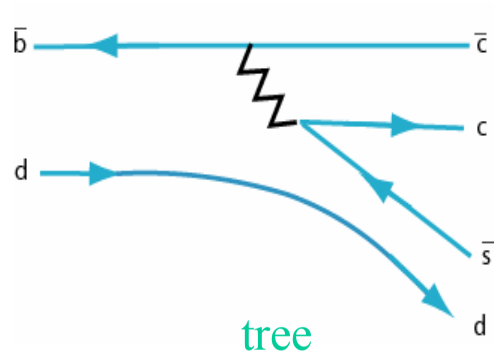
Incorporates:

V_{cb}, V_{ub}/V_{cb}, ε_K, Δm_d , Δm_s, $a_{\rm CP}(B \to \psi K_S)$

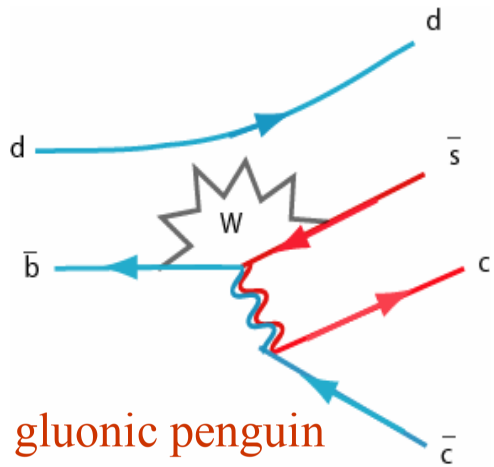
Golden Mode $B_d \to \psi K_S$ measures CP-violation in $B^0 \leftrightarrow \overline{B}^0$ Mixing:



box



tree



gluonic penguin

$\sin 2\beta_{\psi KS} = +0.79 \pm 0.39 \pm 0.16$ CDF Run-I 400 events (2000)

$\sin 2\beta_{\psi KS} = +0.91 \pm 0.32 \pm 0.18$ CDF Run-I 60 events $\Psi(2S)K_S$ (2000)

$\sin 2\beta_{\psi KS} = +0.84 \pm 0.94 \pm 0.16$ Aleph + Opal Z-pole (2000)

$\sin 2\beta_{\psi KS} = +0.719 \pm 0.074 \pm 0.035$ Belle (2002)

$\sin 2\beta_{\psi KS} = +0.741 \pm 0.067 \pm 0.034$ Babar (2002)

$\sin 2\beta_{\psi KS} = +0.73 \pm 0.05$ PDG average

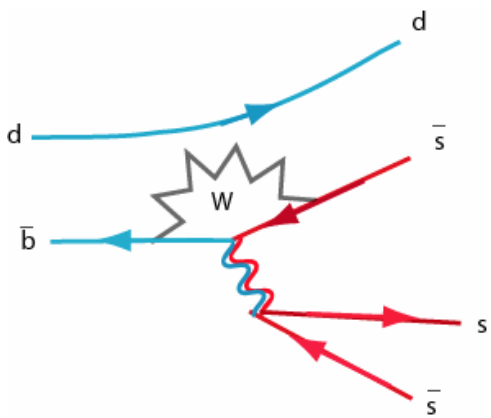
Apparent discrepancies between CP-violation parameters measured in $B_d \rightarrow \psi K_S, \varphi K_S, \eta' K_S$:

$\sin 2\beta_{\psi KS} = +0.73 \pm 0.05$ (Golden Mode)

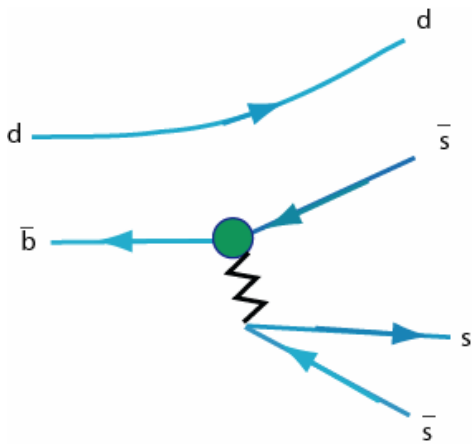
$\sin 2\beta_{\Phi KS} = +0.47 \pm 0.34$ (Babar)
$\sin 2\beta_{\Phi KS} = -0.96 \pm 0.50$ (Belle)
$\sin 2\beta_{\eta' KS} = +0.43 \pm 0.28$ (Belle)
$\sin 2\beta_{\eta' KS} = +0.02 \pm 0.35$ (Babar)

$\sin 2\beta_{XKS} = +0.17 \pm 0.16$ 3σ discrepancy

Modes like $B_d \to \phi K_S$ and $B_d \to \eta' K_S$ are sensitive to CP-violation in a penguin process:



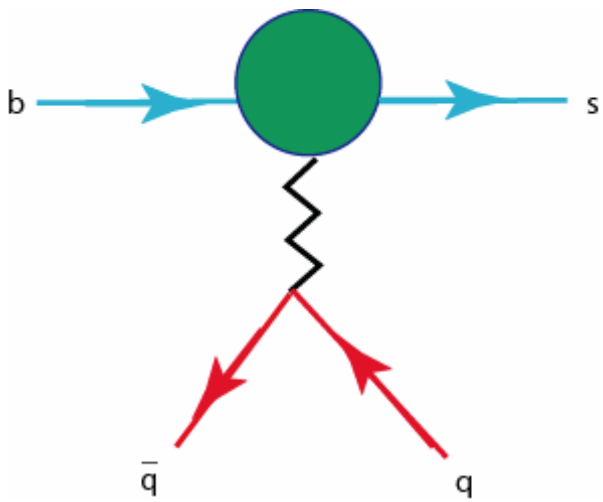
gluonic penguin

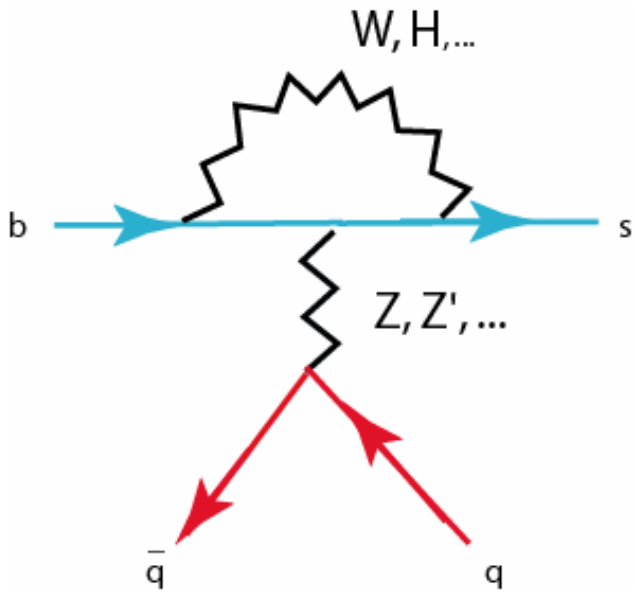


New physics?
FCNC "Z" vertex?
"Trojan Penguins"

$\sin 2\beta_{\psi KS} = +0.17 \pm 0.16$

Electroweak (or "Trojan") Penguins





The $B \to K\pi$ Puzzle

Grossman, Neubert, Kagan hep-ph/9909297
Buras, Fleischer, Recksiegel, Schwab
hep-ph/0309012

Cleo, BaBar and Belle have measured branching ratios (these are CP-averaged):

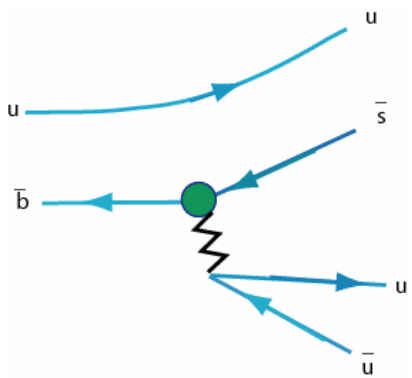
$$R_c \equiv 2\left[\frac{Br(B^\pm \to \pi^0 K^\pm)}{Br(B^\pm \to \pi^\pm K^0)}\right] = 1.17 \pm 0.12$$

$$R_n \equiv \frac{1}{2}\left[\frac{Br(B_d \to \pi^\mp K^\pm)}{Br(B_d \to \pi^0 K)}\right] = 0.76 \pm 0.10$$

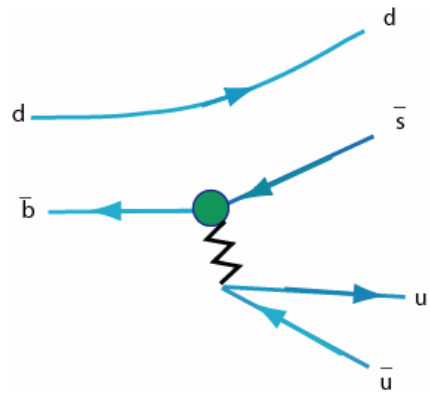
Color allowed
"Trojan Penguins"

$$R \equiv \left[\frac{Br(B_d \to \pi^\mp K^\pm)}{Br(B^\pm \to \pi^\pm K)}\right]\frac{\tau_{B^+}}{\tau_{B_d^0}} = 0.91 \pm 0.07$$

Standard

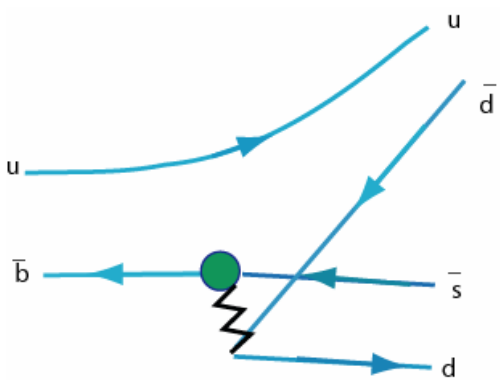


$$B_d^{\,+} \to \pi^0 K^+$$

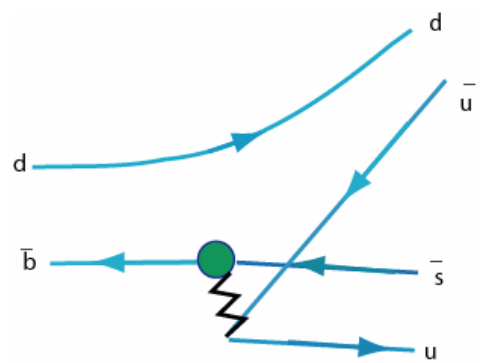


$$B^0 \to \pi^0 K^0$$

Color Allowed
Trojan Penguins

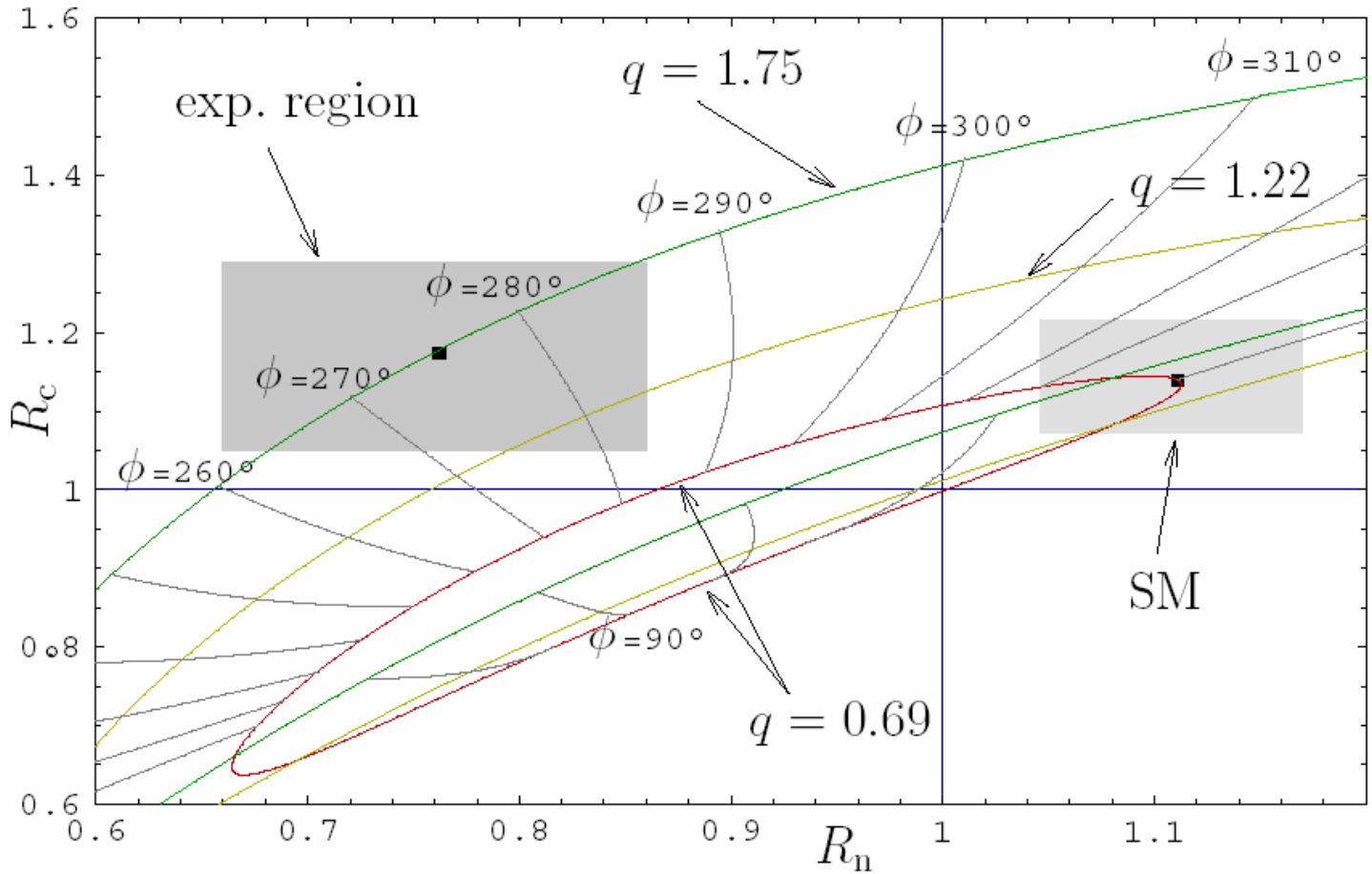


$$B^+ \to \pi^+ K^0$$



$$B_d^{\,0} \to \pi^- K^+$$

Color Suppressed
Trojan Penguins



Buras, Fleischer, Recksiegel, Schwab hep-ph/0309012

(q, ϕ) parameterized EW penguin: Standard Model $q = 0.69 \quad \phi = 0$

Experimental fit: $q = 1.75^{+1.27}_{-0.99} \quad \phi = -85^{+11}_{-14}$

Other anomalies in two-body charmless branching ratios:

Channel	Class	SM			TC2			$\delta\mathcal{B}$ [%]			Data
		2	3	∞	2	3	∞	2	3	∞	
$B^0 \to \pi^+\pi^-$	I	9.10	10.3	13.0	9.27	10.5	13.2	1.9	1.8	1.6	$4.3^{+1.6}_{-1.5} \pm 0.5$
$B^0 \to \pi^0\pi^0$	II	0.28	0.15	0.92	0.28	0.16	0.94	1.0	6.3	2.8	< 9.3
$B^+ \to \pi^+\pi^0$	III	6.41	5.06	2.85	6.41	5.07	2.85	0.1	0.1	0.1	< 12.7
$B^0 \to \eta\eta$	II	0.14	0.10	0.29	0.20	0.17	0.38	40	64	30	< 18
$B^0 \to \eta\eta'$	II	0.14	0.08	0.38	0.19	0.13	0.45	30	67	19	< 27
$B^0 \to \eta'\eta'$	II	0.05	0.01	0.13	0.04	0.02	0.14	13	73	7.8	< 47
$B^+ \to \pi^+\eta$	III	3.51	2.78	1.75	3.85	3.17	2.25	10	14	28	< 5.7
$B^+ \to \pi^+\eta'$	III	2.49	1.88	1.02	2.59	1.99	1.16	3.8	5.8	13	< 12
$B^0 \to \pi^0\eta$	V	0.26	0.29	0.39	0.36	0.42	0.57	42	44	46	< 2.9
$B^0 \to \pi^0\eta'$	V	0.06	0.08	0.14	0.08	0.10	0.18	37	35	26	< 5.7
$B^+ \to K^+\pi^0$	IV	12.0	13.5	16.7	19.6	21.8	26.5	63	61	59	$11.6^{+3.0+1.4}_{-2.7-1.3}$
$B^0 \to K^+\pi^-$	IV	17.8	19.8	24.0	24.4	26.9	32.2	37	36	35	$17.2^{+2.5}_{-2.4} \pm 1.2$
$B^+ \to K^0\pi^+$	IV	19.9	23.2	30.6	27.7	32.7	44.0	39	41	44	$18.2^{+4.6}_{-4.0} \pm 1.6$
$B^0 \to K^0\pi^0$	IV	7.27	8.31	10.7	7.95	9.36	12.6	9.3	13	18	$14.6^{+5.9\ +2.4}_{-5.1\ -3.3}$
$B^+ \to K^+\eta$	IV	3.91	4.56	6.07	4.09	5.08	7.45	4.6	11	23	< 6.9
$B^+ \to K^+\eta'$	IV	22.6	28.5	42.4	33.8	41.6	59.5	50	46	40	$80^{+10}_{-9} \pm 7$
$B^0 \to K^0\eta$	IV	3.22	3.63	4.58	3.33	3.90	5.23	3.6	7.5	14	< 9.3
$B^0 \to K^0\eta'$	IV	21.9	28.2	43.0	32.9	41.3	61.2	50	47	43	$89^{+18}_{-16} \pm 9$
$B^+ \to K^+\bar{K}^0$	IV	1.16	1.35	1.78	1.61	1.90	2.55	38	40	43	< 5.1
$B^0 \to K^0\bar{K}^0$	IV	1.10	1.28	1.68	1.52	1.80	2.41	38	40	43	< 17

Z. Xiao et.al., hep-ph/0011175

Data mostly CLEO,

These are most sensitive channels to the trojan penguin

Implications for Kaon Physics:

Special "clean" Golden Modes:

$$K^+ \longrightarrow \pi^+ \nu\bar{\nu} \qquad Br(K^+ \to \pi^+\nu\bar{\nu})_{\rm SM} = (7.8 \pm 1.2) \cdot 10^{-11}$$

(3 events, AGS 787 + AGS 949) $\quad Br(K^+ \to \pi^+\nu\bar{\nu}) = (14.7^{+13.0}_{-8.9}) \cdot 10^{-11}$

$$K_{\rm L} \longrightarrow \pi^0 \nu\bar{\nu} \qquad Br(K_{\rm L} \to \pi^0\nu\bar{\nu})_{\rm SM} = (3.0 \pm 0.6) \cdot 10^{-11}$$

Test the "Golden Relation" :

$$(\sin 2\beta)_{\pi\nu\bar{\nu}} = (\sin 2\beta)_{\psi K_S} \quad ???$$

Corollary processes :

Buras hep-ph/0402191

(1)

Branching Ratios	MFV	SM
$Br(K^+ \to \pi^+ \nu\bar{\nu}) \times 10^{11}$	19.1	8.0
$Br(K_L \to \pi^0 \nu\bar{\nu}) \times 10^{11}$	9.9	3.2
$Br(K_L \to \mu^+\mu^-)_{SD} \times 10^9$	3.5	0.9
$Br(K_L \to \pi^0 e^+ e^-)_{CPV} \times 10^{11}$	4.9	3.2
$Br(B \to X_s \nu\bar{\nu}) \times 10^5$	11.1	3.6
$Br(B \to X_d \nu\bar{\nu}) \times 10^6$	4.9	1.6
$Br(B_s \to \mu^+\mu^-) \times 10^9$	19.4	3.9
$Br(B_d \to \mu^+\mu^-) \times 10^{10}$	6.1	1.2

(2)

BaBar:

$$Br(B^\pm \to \phi\pi^\pm) < 0.41 \times 10^{-6}$$
$$Br(B^0 \to \phi\pi^0) = (0.2 \pm 0.4) \times 10^{-6}$$

Standard Model

$$Br(B^\pm \to \phi\pi^\pm) = 5.5 \times 10^{-9}$$
$$Br(B^0 \to \phi\pi^0) = 2.5 \times 10^{-9}$$

Giri and Mohanta, hep-ph/0404091

(3) $B_s \leftrightarrow \overline{B}_s$ Mixing: $x_s >> 26$??

(4) Nierste's Process: $B_s \to \phi\rho$

Quark Flavor Physics will remain profoundly important:

- Hints of new physics, perhaps associated with a vertex $s \to d + (Z, Z')$ arising from new dynamics may be emerging in the world data sets.
- B_s physics must be fully developed;
- Much for CDF and D-Zero to do now, B-TeV later!
- Highly synergistic with Kaon physics!
- B-TeV and CKM(2) should be aggressively pursued.

The Energy Frontier

The Devil May Soon Appear

- CDF & D-Zero have excellent chances at catching the devil!
- Intriguing new hints of "something"
  - (Edward Teller, "If only you knew what I know!")
- Possible dramatic results within 1 fb^{-1}

The Energy Frontier will move to CERN in 5 years

- Fermilab and CMS
- LHC Physics analysis center
- Develop the Next Generation of QCD Monte Carlos (Ellis, Giele, …)!

The Energy/Theory Frontier

The Energy Frontier will reveal new organizing principles of nature

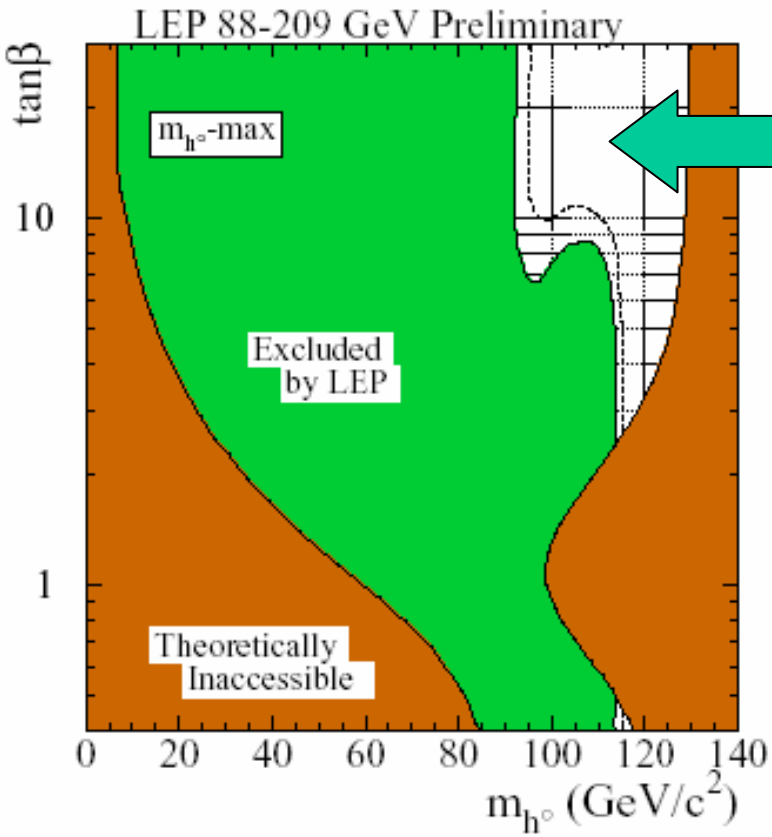
- Supersymmetry
  - Fermionic extra dimensions
  - SUSY particles = KK-modes
- Classical Extra Dimensions
- New Strong Dynamics and Interactions
- Something Else?

What kind of devil lives at the energy frontier?

- How is $SU(2)\times U(1)$ symmetry broken?
- Is there weak scale SUSY?
- Are there w.s. compact extra dimensions?
- Are there new w.s. interactions, including possible strong forces?
- What new organizing principle is required at the weak scale?

Trouble with SUSY?

The MSSM is being squeezed:



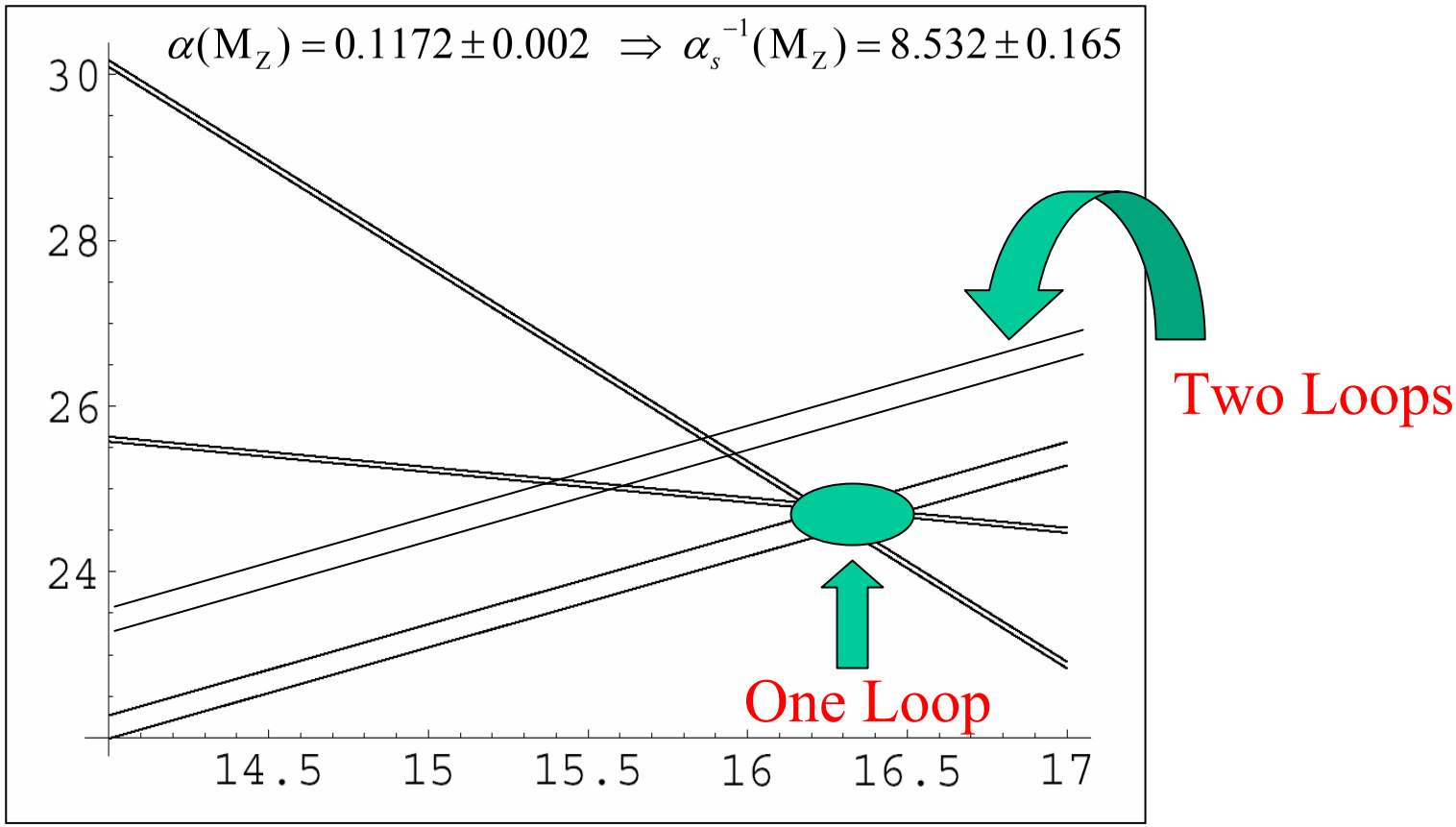
Fine Tuning
< 10% precision

What we mean by weak scale SUSY:

- Must provide a *custodial symmetry* for the "weak scale" via SUSY.
- Must have *unification* in a simple and compelling way (consistent with String).
- Must **not be** "*fine-tuned*." (This is supposed to be *the* fundamental theory!)

Does SUSY Unify?

S. Raby PDG



4% discrepancy > 3 sigma discrepancy predicting $\alpha(M_Z)$

$$-m_H{}^2 H^* H + \frac{\lambda}{2}(H^* H)^2$$

Fixed = 175 GeV

$$\mathrm{v}_{weak} = m_H / \sqrt{\lambda}$$

Increased by experimental limit

forced to increase

Compute Higgs mass from Quartic coupling:

$$m_H{}^2 \approx M_Z{}^2 + \frac{3}{8\pi^2 \mathrm{v}_{weak}{}^2} m_{top}{}^4 \ln(m_{\tilde{t}}{}^2 / m_{top}{}^2)$$

Tree approximation, large tan β

Top-stop loop

(2) Top-stop loop

Compute Higgs mass
from underlying parameters:

$$m_H{}^2 \approx -\mu^2 f(\ldots) + \frac{3}{8\pi^2}(m_{\tilde{t}}{}^2 - m_t{}^2)$$

(1) Tree approximation

Must arrange a cancellation between (1) and (2)

Fine tuning < 10% The "Little Hierarchy Problem"

Barbieri; Gaillard, Birkedal,Chako; Kribs; . . .

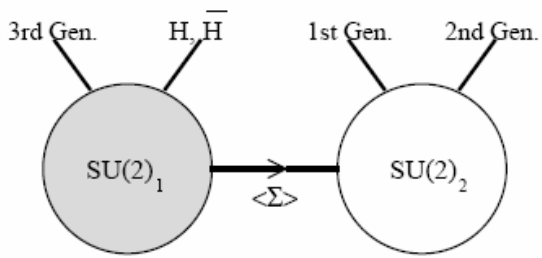
How to fix it?

e.g., Batra, Delgado,Kaplan,Tait
JHEP **0402**, 043 (2004) and *hep-ph/0404251*

NMSSM: Modify the tree relationship: $m_h \leq |\cos 2\beta| m_Z$

(1) Replace μ-term by gauge singlet

(2) Topflavor gauge structure is now $SU(2)_1 \times SU(2)_2 \times U(1)_Y$

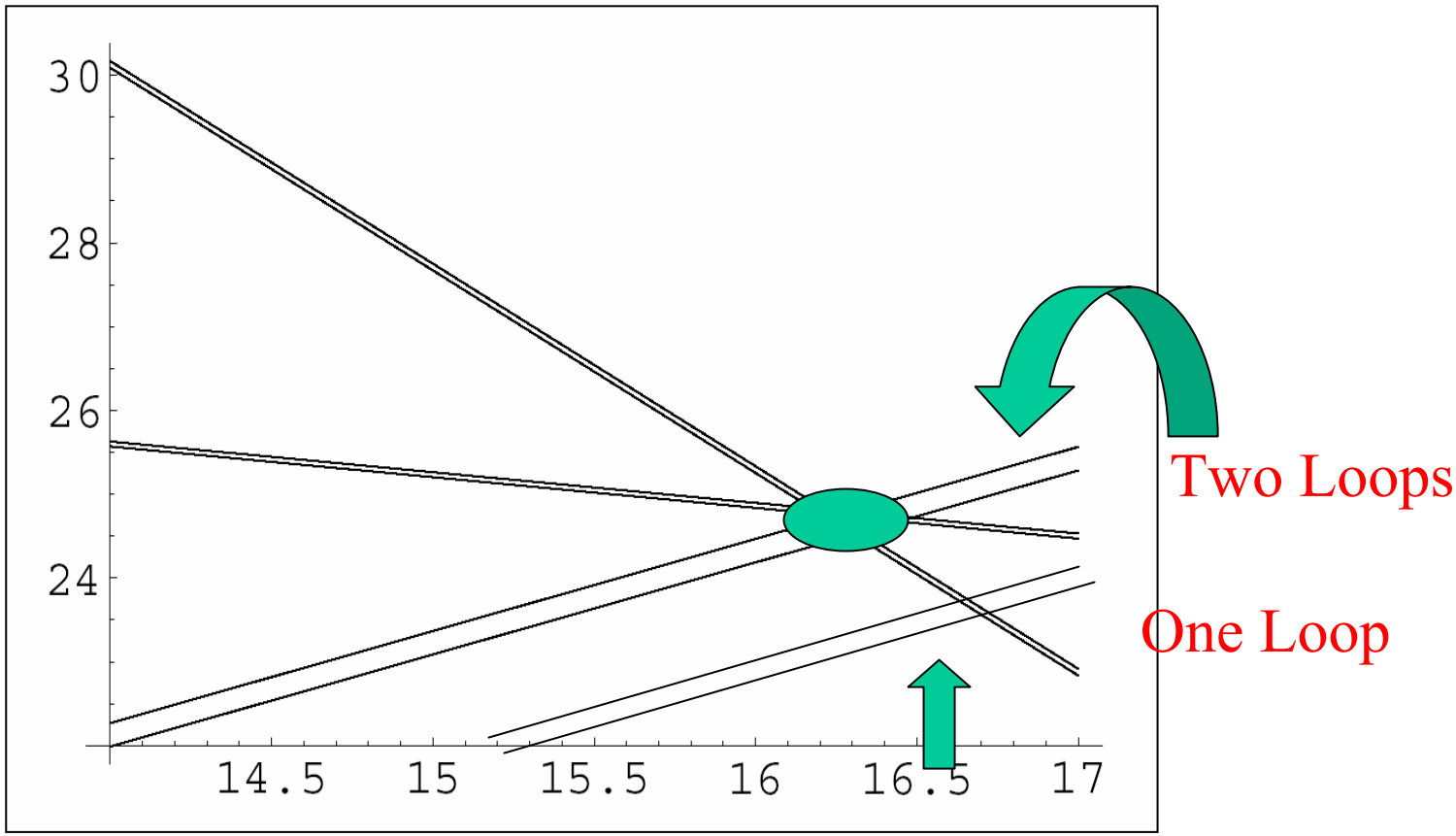


$$m_{h^o}^2 < \frac{1}{2}\left(g^2\Delta + g_Y^2\right) v^2 \cos^2 2\beta$$

$$\Delta = \frac{1 + \frac{2m^2}{u^2}\frac{1}{g_2^2}}{1 + \frac{2m^2}{u^2}\frac{1}{g_1^2+g_2^2}} \quad \text{and} \quad \frac{1}{g^2} = \frac{1}{g_1^2} + \frac{1}{g_2^2}$$

Make SUSY Unify!

Dimopoulos
Arkani-Hamed



Raise m_{stop} to 10^{10} GeV; invoke "anthropic principle."

Or, perhaps something else:

Solutions pull away from SU(5) unification
and toward a strongly interacting theory

Non-SUSY solutions to EWSB exist and are natural.

Strong Dynamics: TC2, or the Top Seesaw

Eichten, Lane;
Dobrescu, CTH,
Chivukula, Georgi,
Arkani-Hamed, Cohen…

Deconstruction and the Little Higgs

Neutrino Frontier

The Devils in Neutrino Physics

- Majorana vs Dirac Masses?
- Relationship to electroweak scale?
- Relationship to GUT/Planck scale?
- Dynamical aspects of neutrino masses?
- The global strategy.

Weinberg 1968: $$g\overline{\psi}_L \cdot H\psi_R$$

Gell-Mann, Ramond, Slansky; Yanagida; Weinberg 1977: $$\frac{g\overline{\psi}_L \cdot H\psi^c \cdot H}{\Lambda}$$

The GUT Scale?!

Mixing Overview:

flavor mass

$$|\nu_\alpha\rangle = U_{\alpha i}|\nu_i\rangle.$$

(using $s_{ij} = \sin\theta_{ij}$ and $c_{ij} = \cos\theta_{ij}$)

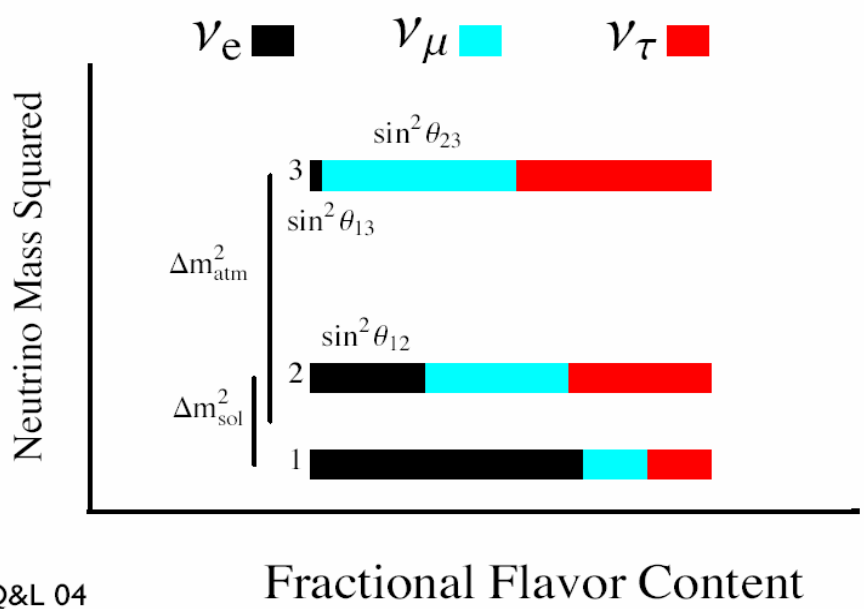
$$U_{\alpha i} = \begin{pmatrix} 1 & & \\ & c_{23} & s_{23} \\ & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & & s_{13}e^{-i\delta} \\ & 1 & \\ -s_{13}e^{i\delta} & & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & \\ -s_{12} & c_{12} & \\ & & 1 \end{pmatrix} \begin{pmatrix} 1 & & \\ & e^{i\alpha_2} & \\ & & e^{i\alpha_3} \end{pmatrix}$$

Atmos. L/E $\mu \to \tau$ ~500 km/GeV

Atmos. L/E $\mu \leftrightarrow e$

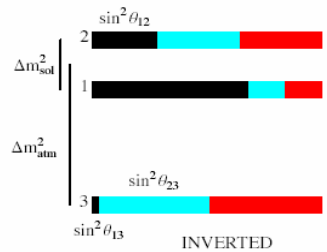
Solar L/E $e \to \mu, \tau$ ~18 km/MeV

Majorana $0\nu\beta\beta$



central values θ_{12}, θ_{23} max. for θ_{13} and $|\sin\delta| = 1$

or



Selected $SO(10)$ Models and θ_{13} Predictions

Model	(Level) Flavor Sym.	Texture	$\tan\beta$	$\sin^2 2\theta_{13}$
AB	(4) $U(1) \times Z_2 \times Z_2$	Lopsided	~ 5	0.0008-0.003
ABMSV	(1) Min. eff. ops.	Sym (II)	?	0.10
BO	(1) Min. eff. ops.	Sym	?	0.004-0.008
BKOT	(1) Min. eff. ops.	Sym	?	0.0004-0.01
BPW	(3) $U(1)$ eff. ops.	Sym (II)	low	?
CM	(4) $U(2) \times (Z_2)^3$	Sym	10	0.09
FKO	(1) Min. eff. ops.	Sym	45	0.16
GMN	(1) Min. eff. ops.	Sym(II)	10	0.10
KM	(2) $SU(3) \times U(1)$	Lopsided	small	~ 0.19
KRV-S	(4) $SU(3) \times Z_2 \times U(1)_A$	Sym/Asym	?	0.02
M	(2) $U(1)_A \times Z_2$	Lopsided	5	~ 0.19

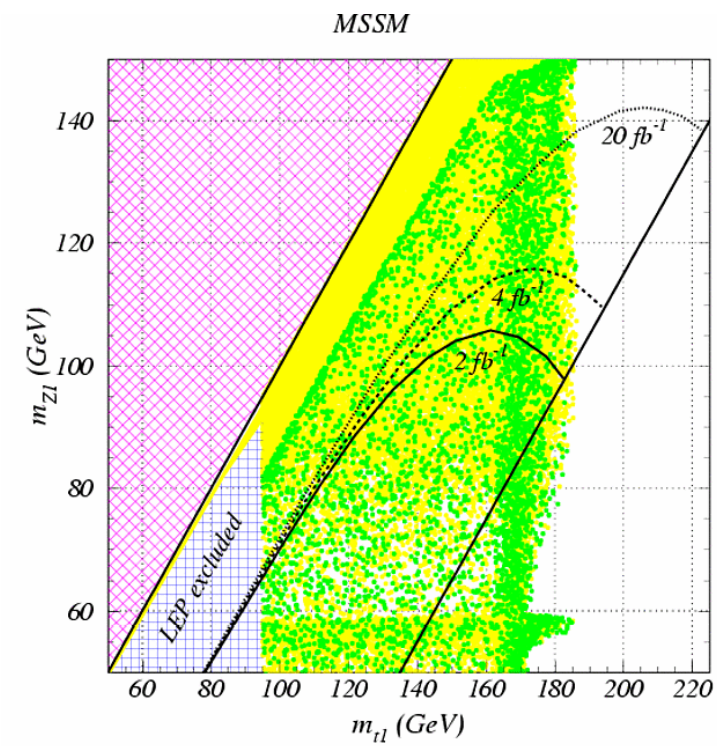
AB	Albright, Barr	$\sin^2 2\theta_{atm} \simeq 0.99$
ABMSV	Aulakh, Bajc, Melfo, Senjanovic, Vissani	not spelled out
BO	Bando, Obara	
BKOT	Bando, Kaneko, Obaro, Tanimoto	
BPW	Babu, Pati, Wilczek	
CM	Chen, Mahanthappa	$\sin 2\beta = 0.74$, $\delta_{CKM} \sim 35°$
FKO	Fukuyama, Kikuchi, Okada	$\Delta m^2_{sol}/\Delta m^2_{atm} = 0.188$
GMN	Goh, Mohapatra, Ng	$\sin^2 2\theta_{atm} \leq 0.92$, $\sin^2 2\theta_{12} \geq 0.9$
KM	Kitano, Mimura	satisfies LMA mixing?
KRV-S	King, Ross, Velasco-Sevilla	
M	Maekawa	satisfies LMA mixing?

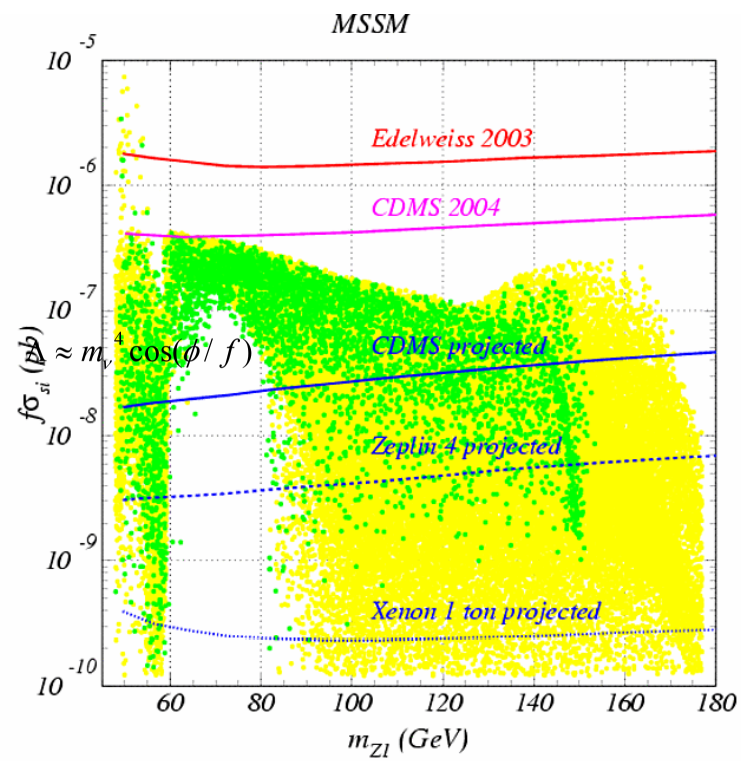
Cosmic Devils

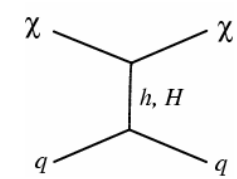
- The Cosmological Constant Problem
  - The Big Problem
  - The Little Problem
- The Dark Matter Problem
  - Cosmic coincidences? SUSY? Neutrinos?
- The Matter-Antimatter asymmetry
  - Which CP-violation? SUSY? Neutrinos?
  - Leptogenesis?

(1) SUSY Light-stop models with neutralino LSP dark matter $\not{E}_T$ signal

Balazs, Carena, Wagner; Lykken, Demina







(2) Dark Matter and Dark Energy from Neutrinos: $\Lambda \approx m_\nu^4 \cos(\phi / f)$ $\rho \approx m_\nu T^3$

Neutrino "pseudo-gravity"

CTH, Schramm, Fry; Frieman, Stebbins, Waga; Kolb; Nelson, Kaplan, Weiner

Cosmic Devils

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The Role of Scale Symmetry?

- We live in 1+3 dimensions
- The big cosmological constant conundrum
- The Higgs Boson mass scale
- How QCD solves the problem of hierarchy
- New Strong Dynamics?

$$\partial_\mu S^\mu = T_\mu{}^\mu = \Lambda_{\text{cosmological}} + \frac{\beta(g)}{2g} Tr(G_{\mu\nu} G^{\mu\nu}) + m_H{}^2 \overset{?}{H^* H} + \ldots$$

$$\approx 0 \quad ?$$

Inspiration?

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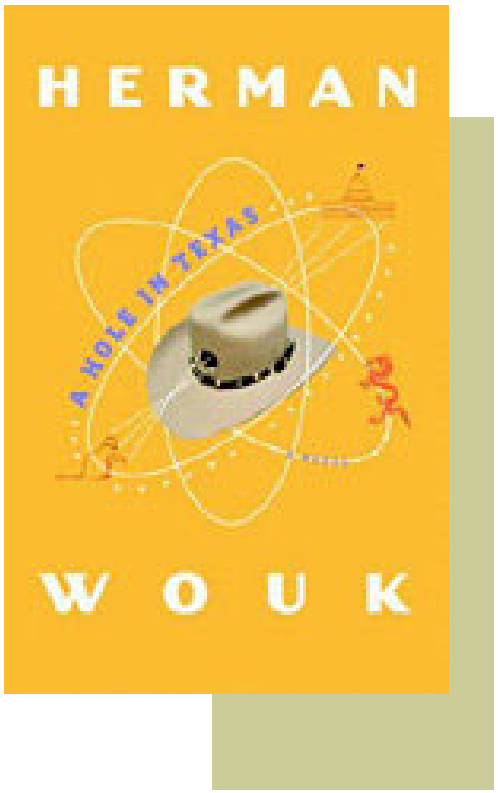
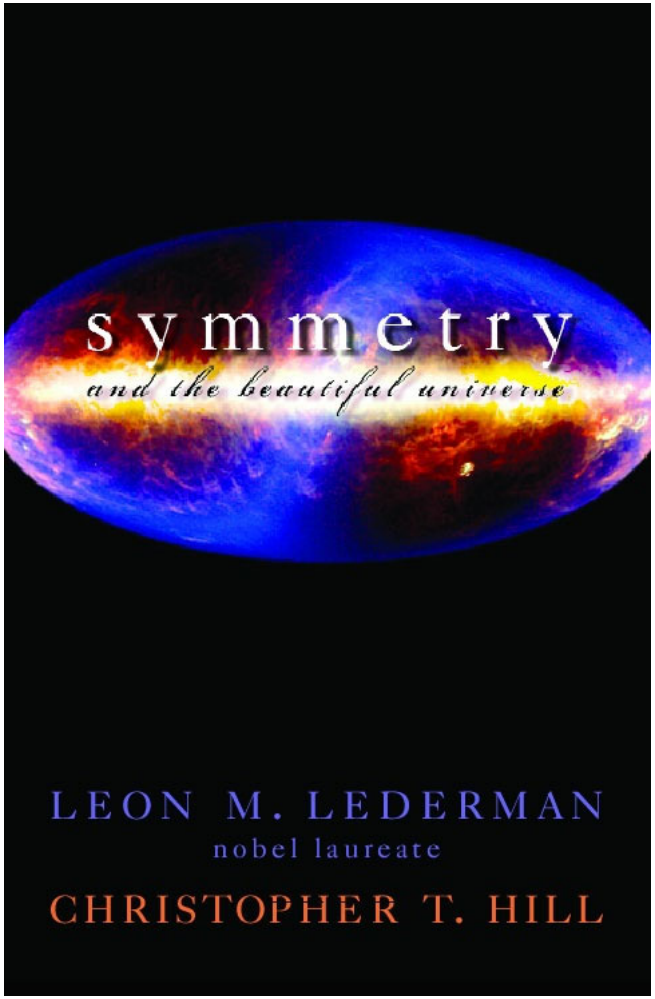
HALF DOME, WINTER · YOSEMITE NATIONAL PARK



Love, Politics and Subatomic Particles

Reviewed by Linda Richards

In reviewing *A Hole In Texas,* it seems significant to note that Herman Wouk's first novel, *Aurora Dawn,* was published in 1947: 56 years ago. Also significant: he was 32 years old at the time. Wouk received the Pulitzer Prize for *The Caine Mutiny,* which was published in 1951. As I write this, Wouk is just days shy of his 89th birthday. (He was born on May 27th, 1915.)



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Symmetry and the Beautiful Universe

Prometheus Books, expected release in Fall, 2004