향물리 국제학회
(香物理)

H. Fritzsch
Munich

Summary - TH

Flavor Physics

Konfuzius: rigid laws and
simple structures

Laotse: world of complexity
swing between Yin and Yang

Flavor Physics: field of highest
complexity and richest phenomenology

1971 G.M. / F. : Baskin - Robins in Pasadena
32 flavors
→ physics of flavor

Quarks: 6 masses 4 mixing pm.

Leptons: 6 masses 6 " "

Total: 30 p.m., 22 pm. → flavor
problem

S. M. + LEP:

$$m_H = 91^{+58}_{-37} \text{ GeV}$$

$$m_H < 211 \text{ GeV } (95\% \text{ c.l.})$$

L. C.: $E_{cm} = 800$ GeV

$M_H = 120$ GeV 160 000 events / yr.

$H \to \bar{b}b$, $H \to W^+W^-$ about equal at $M_H = 130$ GeV

MSSM: 2 Higgs doublets

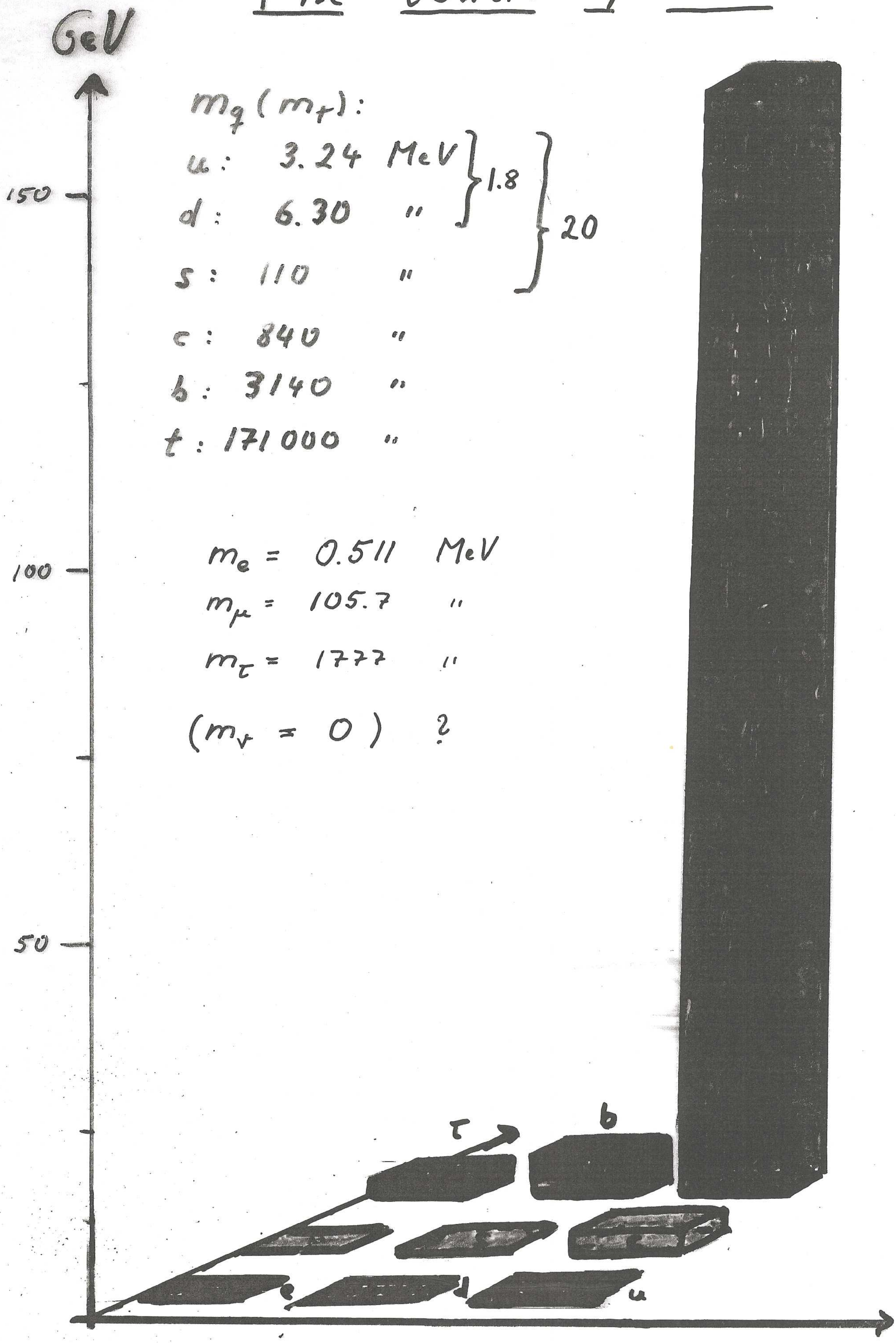
$m_h < 135$ GeV (incl. rad. corr.)

Rich phenomenology for

LHC <u>and</u> LC

(Tesla?)

The towers of mass



→ Mass hierarchy

Fermion masses: $\longrightarrow$ H-field (?)

Coupling of H to quarks / leptons might be different from S.M.

$H \not\rightarrow \bar{b}b \qquad H \rightarrow gg, \gamma\gamma, \ldots$

Phen.: $m_c : m_t \cong m_u : m_c$

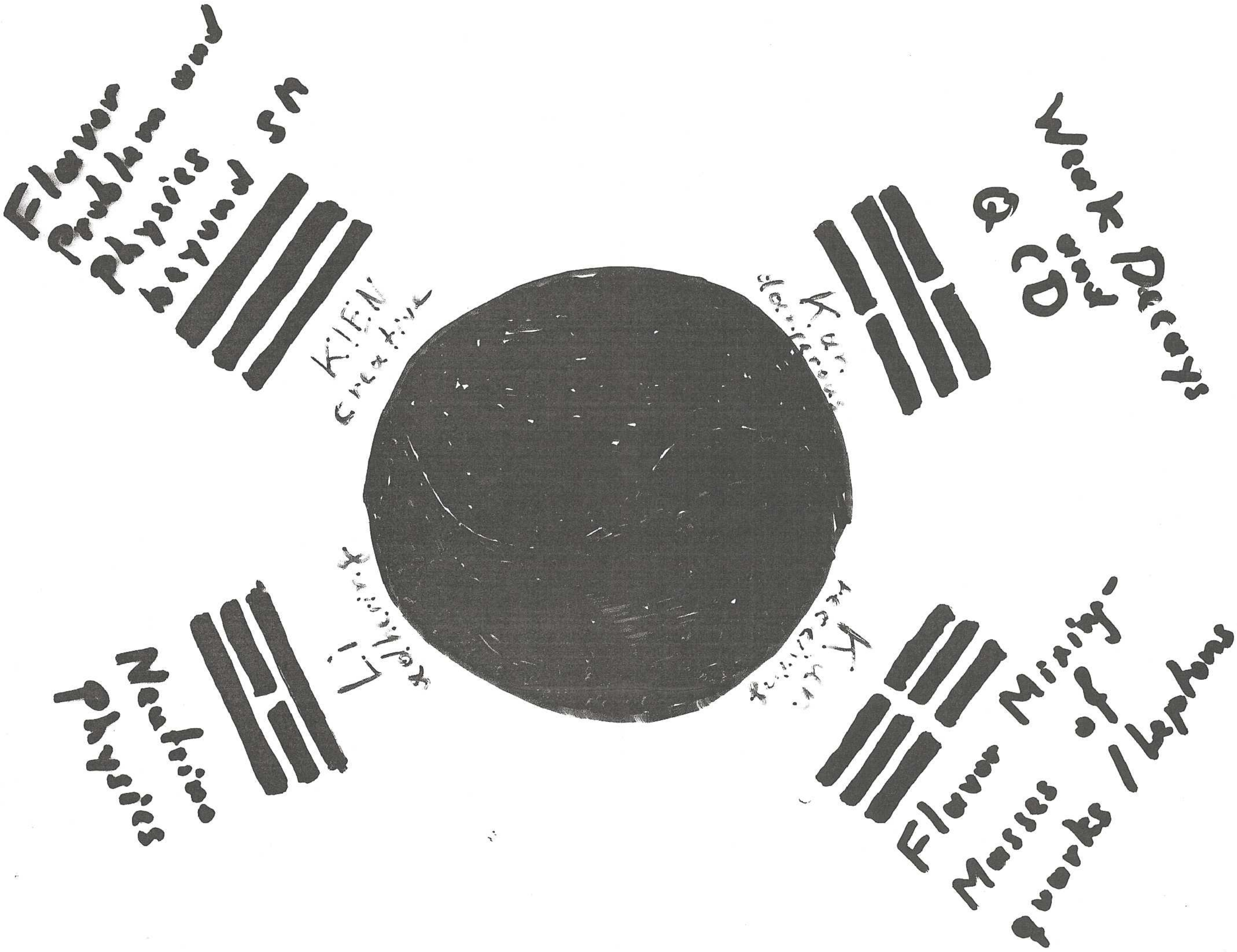
$m_s : m_b \cong m_d : m_s$

1987:
$m_t = \underline{170}$
(S.L.)

$m_t \sim \langle 0|H|0\rangle = v = 246$ GeV

$\frac{v}{\sqrt{2}} \cong 174$ GeV $(\rightarrow m_t!)$

(accident?, symmetry?)



Yin — Yang

Theory — Exp.

Wolfenstein:

$$V \cong \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

[illegible]

Useful representation:

adopted by Berk

$$V = \underbrace{\begin{pmatrix} c_u & s_u & 0 \\ -s_u & c_u & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\theta_u} \underbrace{\begin{pmatrix} e^{-i\varphi} & 0 & 0 \\ 0 & c & s \\ 0 & -s & c \end{pmatrix}}_{\theta,\ \varphi} \underbrace{\begin{pmatrix} c_d & -s_d & 0 \\ s_d & c_d & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\theta_d}$$

(like Euler matrix, but with $e^{-i\varphi}$)

$$S(3) \longrightarrow S(2) \longrightarrow Y.$$

Texture: $\begin{pmatrix} 0 & \sim & 0 \\ \sim & \sim & \sim \\ 0 & \sim & \sim \end{pmatrix}$

$$\theta_u = \arctan\sqrt{\frac{m_u}{m_c}}$$

$$\theta_d = \arctan\sqrt{\frac{m_d}{m_s}}$$

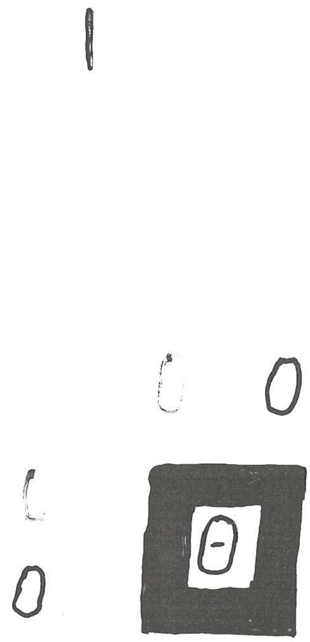
$$\varphi = 90^\circ$$

3 steps towards CKM

$$m_{II} = 0$$

$m_u = 0$ $m_d = 0$

(u, c, t) $\begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix}$ $\begin{pmatrix} d \\ s \\ b \end{pmatrix}$



$$\begin{pmatrix} \Theta_d & \begin{matrix} 0 \\ 0 \end{matrix} \\ \begin{matrix} 0 & 0 \end{matrix} & 1 \end{pmatrix}$$

!

$$\begin{pmatrix} \boxed{\theta_u} & & 0 \\ & & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad e^{-i\varphi}$$

$$\cong \begin{pmatrix} e^{-i\varphi} & s_u - s_d e^{-i\varphi} & s_u s \\ s_d - s_u e^{-i\varphi} & 1 & s \\ -s_d s & -s & 1 \end{pmatrix}$$

$s_u = \sin\theta_u$

$s_d = \sin\theta_d$

$s = \sin\theta$

→ L. Euler

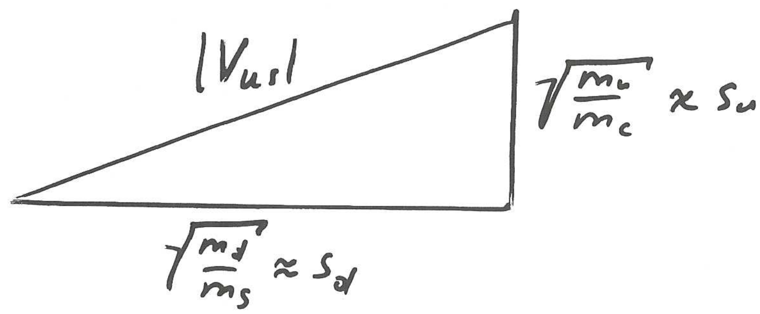
H. F. (N.P. 79)

Froggatt / Nielsen (N.P. 79)

Dim., Hall, Raby (92)

Lehmann, Wu. (94)

F., Xing (97)



Ex.: $m_u(1\,GeV) = 6.8\ MeV$

$m_d(1\,GeV = 8.1\ MeV$

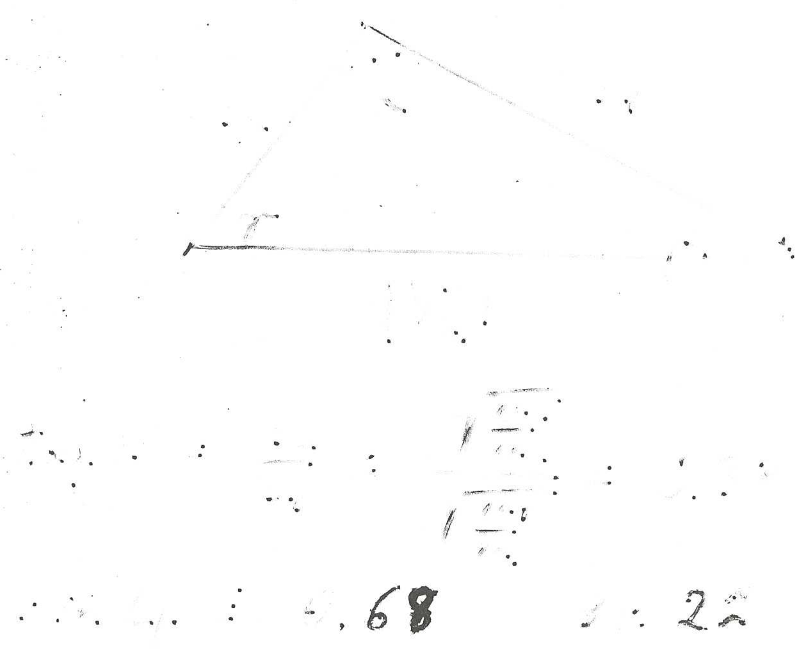
$m_s(1\,GeV) = 190\ MeV$

$m_c(1\,GeV) = 1050\ MeV$

$$|V_{us}|^2 \cong \frac{m_d}{m_s} + \frac{m_u}{m_c} \cong 0.2207$$

$$\tan\theta_u = \sqrt{\frac{m_u}{m_c}} = \left|\frac{V_{ub}}{V_{cb}}\right| \approx 0.081 \qquad \tan\theta_d = \left|\frac{V_{td}}{V_{ts}}\right| \approx 0.207$$

U.T.: $\alpha \cong 90^\circ$



$\alpha \cong 90^\circ$

$\beta \cong 22^\circ$

$\gamma \cong 68^\circ$

$\cancel{CP}$ and β:

$$\sin 2\beta = 0.736 \pm 0.049 \qquad \text{(exp.)}$$

$\rightarrow$ [illegible]

$$|V_{cb}| = (4.02 \pm 0.14 \pm 0.13_{th}) \cdot 10^{-2}$$

Chamless B-decay

isospin ok
SU(3) careful [illegible]
[illegible]

[illegible] effect [illegible] phase
[illegible] possibly [illegible]
[illegible] and [illegible]

$B \rightarrow PP,\ PV$

Factorization (?)

$\gamma \sim 79^\circ$ (but large error)

S. M. under pressure?

$B \to J/\psi + K_S$

$B \to \phi + K_S$ $\longrightarrow$ ratio ≈ 1 expected

Exp.: large, but opposite sign (Belle)

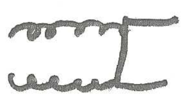
3.5σ away from S. M.

($\to$ measure again, might disappear)

$B^+ \to \eta' K^+$ $\quad (79 \pm 12) \cdot 10^{-6}$ $\quad$ Sanda

$B^+ \to \pi^0 K^+$ $\quad (22 \dots) \cdot 10^{-6}$

η': can be produced out of glue

 η' $\quad$ glue ball resonances?

No need for new physics!

Won

Look for leptonic decays of B

$B^+ \to \mu^+ \nu$ $\quad 4 \cdot 10^{-7}$

$B^+ \to \tau^+ \nu$ $\quad 5 \cdot 10^{-5}$

Search for new physics!

Calculating CKM:

Kang

Fermion masses $\longleftrightarrow$ CKM

Fundamental theory lacking.

NNI - texture as a possibility

(non-hermitean (?))

String Theory $\longleftrightarrow$ Flavour structure ...

[illegible]

(still rather obscure)

Connection between Gravity and

L - Q - Masses ? (unlikely or very indirect)

Large ew. penguins?

Yoshikawa

Points towards new physics?

$\sigma(e^+e^- \to J/\psi + \eta_c, \eta_c', \chi_{c0}$

Bodwin

$\sigma(\text{Belle}) \sim 10 \times \sigma_{QCD}$

Lee

Problem for S.M. (?)

Glue Ball production?

Need for checking by Babar

Neutrinos

Do ν's oscillate? Yes.

Why? How? MSW?

Super-Kam. ...; KamLAND...; SNO...

Needed: Direct observation

$\nu_\mu \dots \longrightarrow \nu_\tau \longrightarrow \tau^-$

Minos, G. Sasso

Further "must-do"'s:

$\nu_\mu \xrightarrow[\Delta m^2_{atm}]{} \nu_e \quad (\sim 1\%)$

$\bar{\nu}_\mu \longrightarrow \bar{\nu}_e$

~ Test for U_{e3} (non-zero?)

Test for $\cancel{CP}$

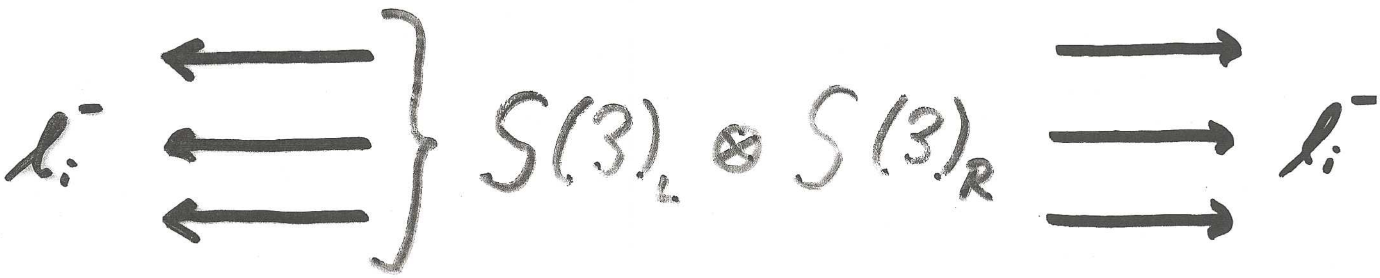
Why difference between quark sector and lepton sector?

($\Rightarrow$ S.M.: ν massless)

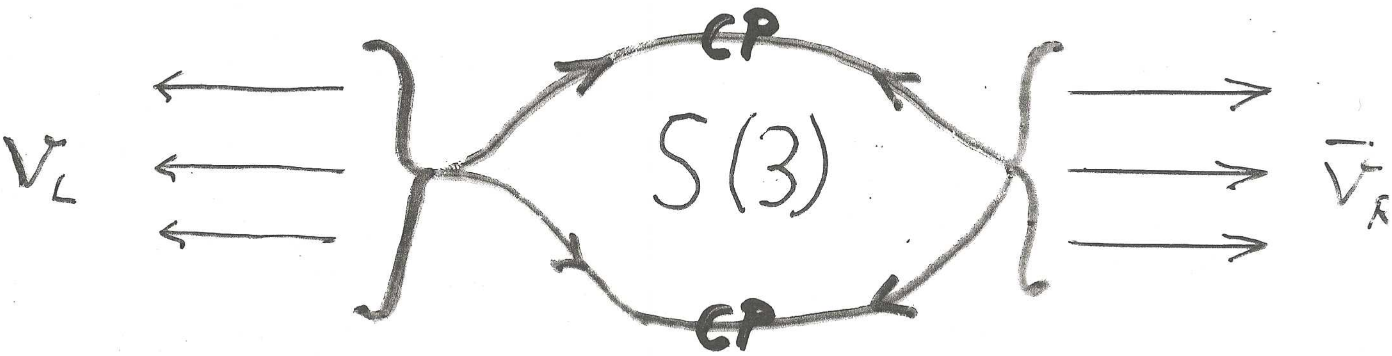
Large angles expected in theory (F., Xing. 96)

Majorana Masses

Talk Kamioka (97')



$$\begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}$$



$$S(3)_L \otimes S(3)_R \to S(3)_{L,R}$$

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Misalignment between L^- and ν

(↳F., Xing 95')

Quarks

$$U: \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix} \qquad D: \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}$$

Leptons

$$\nu: \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \qquad L^-: \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}$$

$$\frac{1}{3}\begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix} \xrightarrow{\quad U \quad} \begin{pmatrix} 0 & & \\ & 0 & \\ & & 1 \end{pmatrix}$$

$$\begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix} \longrightarrow \begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix}$$

$$U = \begin{pmatrix} 1/\sqrt{2} & -\frac{1}{\sqrt{2}} & 0 \\ 1/\sqrt{6} & 1/\sqrt{6} & -2/\sqrt{6} \\ 1/\sqrt{3} & 1/\sqrt{3} & 1/\sqrt{3} \end{pmatrix}$$

"Start-up matrices for flavor mixing"

Quarks

$$V = \begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix} + O(\varepsilon) + \dots$$

Leptons:

$$V = \begin{pmatrix} \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & \boxed{0} \\ \frac{1}{\sqrt{6}} & \frac{1}{\sqrt{6}} & \frac{-2}{\sqrt{6}} \\ \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \end{pmatrix} + O(\varepsilon)$$

$$\begin{pmatrix} \frac{1}{\sqrt{2}}(\nu_1 - \nu_2) \\ e^- \end{pmatrix} \quad \begin{pmatrix} \frac{1}{\sqrt{6}}(\nu_1 + \nu_2 - 2\nu_3) \\ \mu^- \end{pmatrix} \quad \begin{pmatrix} \frac{1}{\sqrt{3}}(\nu_1 + \nu_2 + \nu_3) \\ \tau^- \end{pmatrix}$$

Qualitative difference between quarks / leptons

Flavor mixing small for quarks

" " large for leptons

Symmetry Breaking

$S(3) \longrightarrow S(2) \longrightarrow$ %

L^-: S.B. analogous to quarks.

$$\nu_e = \frac{1}{\sqrt{2}}(\nu_1 - \nu_2)$$ + corrections

$$\nu_\mu = \frac{1}{\sqrt{6}}(\nu_1 + \nu_2 - 2\nu_3)$$ + corr..

$\Delta m^2 \cong 0.005\ eV^2$

$$\nu_\tau = \frac{1}{\sqrt{3}}(\nu_1 + \nu_2 + \nu_3)$$ + c...

Are corrections [illegible]

$\nu_e \longleftrightarrow (\nu_\mu, \nu_\tau)$ solar

$\nu_\mu \longleftrightarrow \nu_\tau$ atm.

$\pi_0 \xleftrightarrow[\Delta I]{} (\eta, \eta')$

$\eta \xleftrightarrow[\Delta SU(3)]{} \eta'$

Search for

θ_{13} ($\theta_{\mu e}$):

1) See θ_{13}

2) ~~CP~~, if phase $\neq 0$

Nishikawa

Para

Expected from S(3)-violation:

$$\theta_{13} \simeq \frac{2}{16}\sqrt{\frac{m_e}{m_\mu}} \qquad \sin^2 2\theta_{13} \equiv 0.013$$

Itow

Atmosph. ν's:

$$\sin^2 2\theta > 0.92 \qquad 90\%\text{ c.l.}$$

$\sin^2 2\theta = 0.94$ (ex.) might still be ok.

$\rightarrow \theta = 38^\circ$ (not 45°!)

Ex.: Democratic symm.:

$$\sin^2 2\theta = \frac{8}{9} + \text{corr} \quad (\nearrow 0.94?)$$

Solar angle: $45^\circ - \sim 10^\circ$ (from corrections).

$SO(10) \times SU(3)$

King (A.: 74) McNamara

natural for massless ν's

flavour (?)

Mixing, ~~CP~~

cosmology

M...

Lepton Flavour Violation

Okada

$\mu \to e\gamma$ ...

$\mu^- A \to e^- A$ 6.1×10^{-13}

$\tau \to \mu\gamma$ $3.2 \cdot 10^{-7}$

ν's ~ extra dimensions

Ng

$\mu \to 3e$

$\beta\beta_{0\nu}$ - decay

Are ν's really so special ?

~~CP~~ ~ leptogenesis

baryon genesis via

leptons (Maj. ν's)

Sphaleron process?

Still many unknowns!

Kang

$U(1) \times SU(2)_L \times SU(2)_R \times SU(3)$ Brachmachari

$\subset SO(10)$

Fermion masses

$\longleftrightarrow$ Leptogenesis

Gauge Coupling Unification: $2 \cdot 10^{15}$ GeV

(MSSM)

Unlike SU(5): SO(10)

allows also unification

without Supersymmetry!

Kane

Flavor Physics ⟷ string theory

¿ Much of flavor physics may only be understood from <u>string theory.</u> ?

(who knows [illegible] physics)

Light b-squark?

<u>Unlikely</u>!

Berger

Extra dimensions:

¿ natural framework to understand flavor and fermion masses ?

Choi

Strong CP-Problem

Chang. g.

Is it really a problem?

Perhaps not:
no problem, if u or d are massless.
→ Related to mass generation.

MSSM and FCNC

Kolda

Observed at Tevatron, LHC, e^+e^-?

$B^0 \longrightarrow \phi K_s$

Oh

$B^0 \longrightarrow \eta' K$

Probably no room for new physics –

$B \to \phi K_s$

Back

vs.

Park

$B \to (J/\psi) K$

Presumably ok with S. M. (Supersymm.?)

Masiero

Kong

$N_f = N_c$

little Higgs (?)

K.O.

Large SuSy-effects in B-physics?

$B \to X_{d,s} \gamma$,

$B \to \phi K$ ...

Which way to go in F.P.?

New physics already there:

quark-lepton mass spectrum

transitions between families.

Supersymmetry

[illegible]

[illegible] (126?)

Supergravity -

S-Strings

[illegible]ons?

[illegible]bes?

[illegible] gun?)

New dimensions?

Substructure and/or

New Forces (~TeV)

(Why S.M. so good?)

Perhaps signals around

corner: g-2, $t \to c$ + gluon, γ

..., B-decays

t-physics!

Problem of mass:

$M_p \cong const. \cdot \Lambda_c$

(confined field energy)

$m_c = g_Y \cdot \Lambda_W = g_Y \cdot 246$ GeV.

pointlike in S.M.?

Only exps. can tell.

Needed: Predictive specific theories

SM, [illegible]

But: Strong Ints. as ex.

Nuclear Forces

50'↗ Hadronic Spectrum

50'° π - N - Models

60'. Symmetries ⟷ EW-Dynamics

(→ 1960')

62 Current Algebra

64 Quarks

72 QCD ? (Chicago)

2003 QCD !

LOC

J. Chay, K. Choi, S. Y. Choi,

E. J. Chun, D. K. Hong, C. S. Kim,

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Y. Kwon, S. K. Oh

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Supp. staff:

J. Park, J. E. Lee, S. Y. Kim

Prof. Kim from Kias

(→ many years in office)

More definite answers:

JCFP 05

Taiwan ?

URC:

Adoption of mainland

→ 05:

China (Urumchi?)

Taiwan

Vietnam

JCTP

Munich, (near Munich)

Bon voyage!