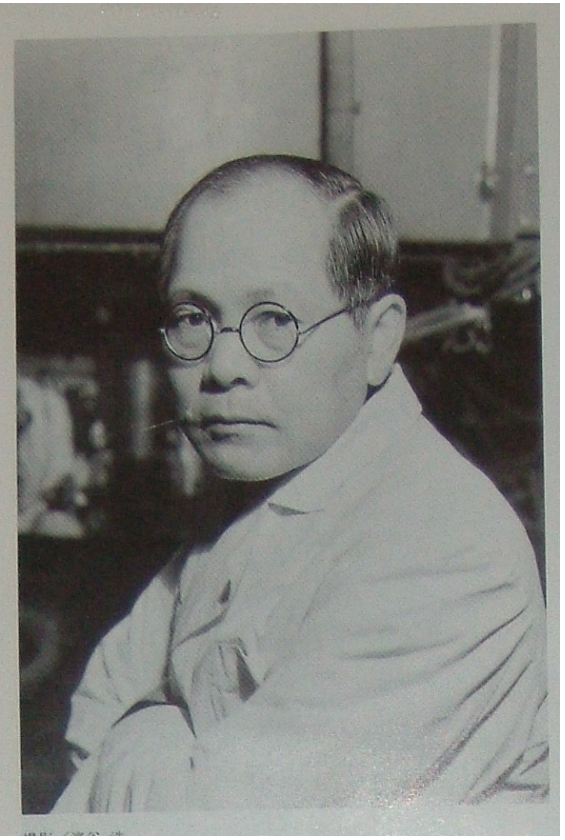
1908--1991



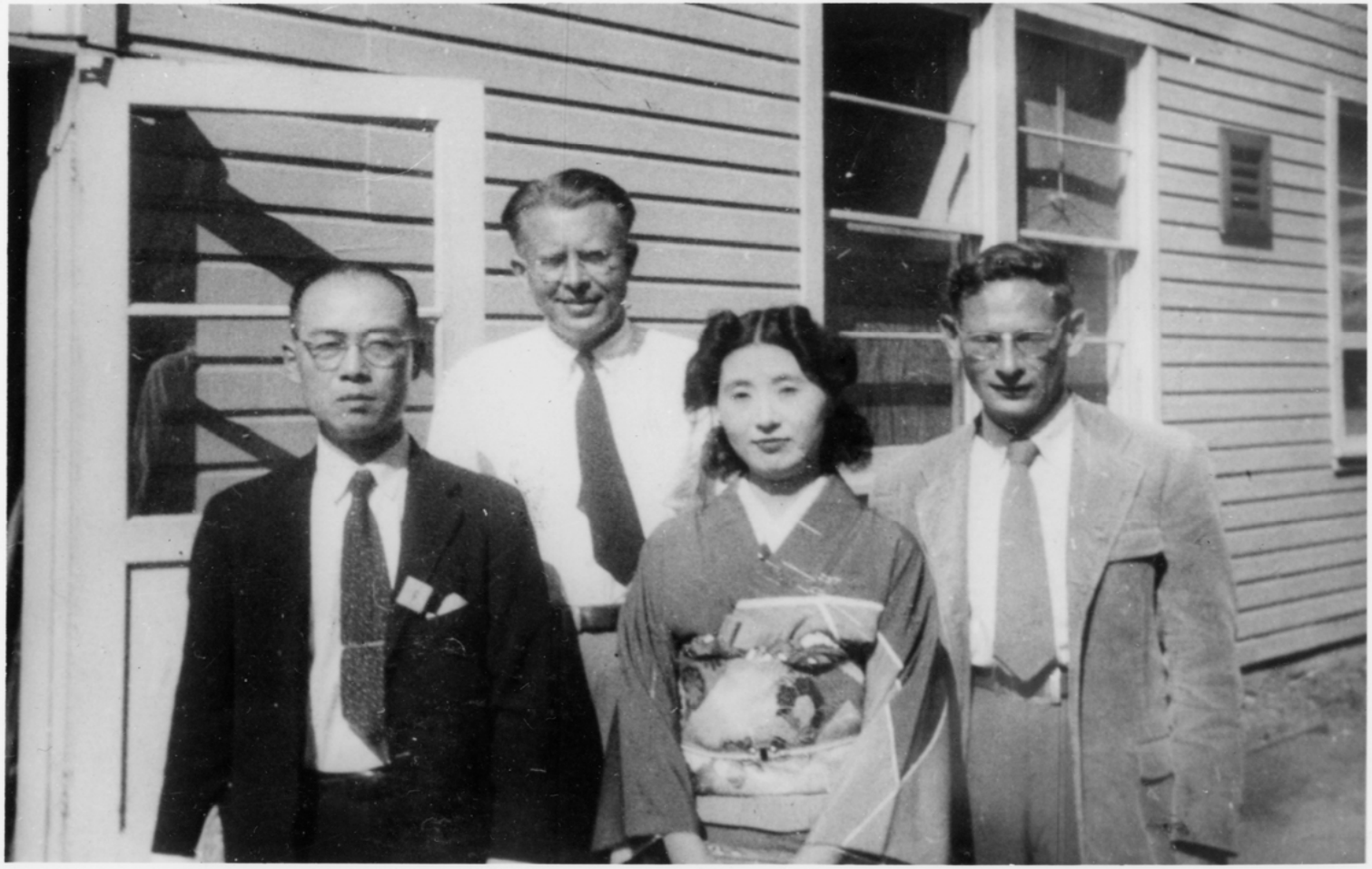
Yoshio Nishina
1890-1951

Hideki Yukawa
1907-1981

Sin-itiro Tomonaga
1906-1979

Ryogo Kubo 1920 - 1995

At Berkeley
Yukawa,Lawrence, Mrs. Yukawa, Serber



Brief history of particle physics since the 1930s

Neutron, positron
Cyclotron (Lawrence)
Beta decay theory
Meson theory (Yukawa)
Muon (second lepton)
*Pion (first meson)
QED and renormalization
*Non-Abelian gauge fields
*Various hadrons (ρ,ω, etc.) and flavor symmetry
*Parity violation with V - A weak interaction
*Chiral symmetry
*Spontaneous symmetry breaking and mass generation
*Quark model
Regge trajectories of hadrons
*Electroweak unification
Quark color and QCD
The standard model
SU(3)xSU(2)xU(1) gauge fields,
3 generations of quarks and leptons

Gregor Wentzel 1898-1978

Search for hadron internal symmetries

Flavor symmetry
- Isotopic spin SU(2) for (p,n),($\pi^{\pm}$, π^{0})
- SU(3) octet hadrons

Chiral symmetry (handedness)
- V - A weak interaction
- symmetry broken by fermion mass
- almost conserved axial vector current
- (PCAC, σ model)

Vector meson (ρ,ω) dominance ansatz

Colored quarks and color SU(3) gauge field (QCD)

The collective modes

Langmuir plasma

$\omega_P^2 = e^2\rho/m$

Debye sceening

$e^{-\mu r}/r$, $\mu=\omega_P/v_T$

Bohm and Pines

longitudinal and transverse collective modes

Tomonaga effective theory for 1-D fermionic systems

London theory of superconductivity

$\boldsymbol{j} = (1/\Lambda)\mathbf{A}$, $1/\Lambda = \omega_P$

Simple transcription

$$H = \int \psi^\dagger p^2/(2m)\psi + 1/2 \int\int' (\psi^\dagger\psi)V(\psi^\dagger\psi)'$$

$$\psi, \psi^\dagger \rightarrow \rho^{1/2} \exp(\pm i\theta), \quad [\theta,\rho] = i$$

BCS theory

Cooper pairing and gap formation around the Fermi surface

Bogoliubov-Valatin quasiparticles

$$\Psi = \alpha\psi_{\uparrow} + \beta\psi_{\downarrow}^{\dagger}$$

$$H_{BV} = \Psi^{\dagger}(\tau_3\varepsilon + \tau_1\Delta)\Psi, \quad \Psi = (\psi_{\uparrow}, \psi_{\downarrow}^{\dagger})$$

Collective modes

$$\pi \sim \Psi^{\dagger}\tau_2\Psi, \quad m = 0 \qquad \text{(NG)}$$

$$\sigma \sim \Psi^{\dagger}\tau_1\Psi, \quad m = 2\Delta \quad \text{(Higgs)}$$

London relation

$$\mathbf{J} = \mathbf{A}/\Lambda$$

Conserved current

$$\mathbf{J} = \Psi^{\dagger}(p - \tau_3 eA)\Psi - \nabla\pi$$

$$\rho = \Psi^{\dagger}\tau_3\Psi - (1/v^2)\,\pi$$

$$v^2 = v_F^2/3$$

$$\partial\rho/\partial t + \nabla\cdot\mathbf{J} = 0$$

Chiral problem and nucleon mass generation

Chiral invariants

vector, axial vector, (scalar, pseudoscalar)

→ SSB of chiral symmetry by mass scalar

$H_N = \Psi^\dagger(\rho_1 \boldsymbol{\sigma}\cdot\mathbf{p} + \rho_3 M + g\rho_2\pi)\Psi$

Chiral (axial) current

$j_{A\mu}=\Psi^\dagger(\rho_1, \boldsymbol{\sigma})\Psi$,

$\partial \cdot j_A = -2M\Psi^\dagger\rho_2\Psi$,

$J_{A\mu} = j_{A\mu} - f\,\partial_\mu\pi$

$f = 2M/g$ (Goldberger-Treiman)

$\partial\cdot J = f m_\pi^2$ PCAC

Collective modes (mesons)

π mass ~ 0

σ mass 2M

Quark model $M_N \rightarrow M_q$ (~ $M_N/3$)

General mass relations

	NG	fermion	“Higgs”	
	0	1	2	
BCS	0	1	2	
hadrons	0	1	2	
^{3}He B				
$\sigma\cdot p$	0	1	2	J=0
$\sigma\times p$	0	1	2	J=1
$\sigma_i p_k$	$2(2/5)^{1/2}$	1	$2(3/5)^{1/2}$	J=2

$$m_1^2 + m_3^2 = 4m_2^2$$

Quarks and Higgs mass relations?