Hadrons

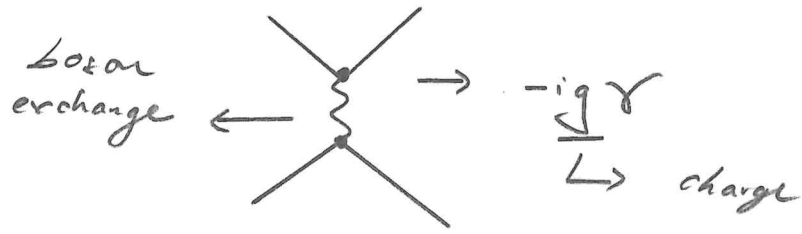
10. 2025

lecture 1

4 force laws

strong	$\begin{pmatrix} R \\ G \\ B \end{pmatrix}$	$SU(3)$
weak	$\begin{pmatrix} n \\ p \end{pmatrix}$ or $\begin{pmatrix} u \\ d \end{pmatrix}$; $\begin{pmatrix} e^- \\ \nu_e \end{pmatrix}$	$SU(2)$
E & M	e^-	$U(1)$
gravity	?	

Gauge Theory → gauge symmetry → conservation law
gauge charge
gauge bosons



$$\mathcal{L} = \bar{\psi}(i\partial\!\!\!/ - m)\psi - g\bar{\psi}A\!\!\!/\psi - \frac{1}{4}F_{\mu\nu}F^{\mu\nu}$$

Group theory → dim. of fundamental repr. (N_c column vec.)

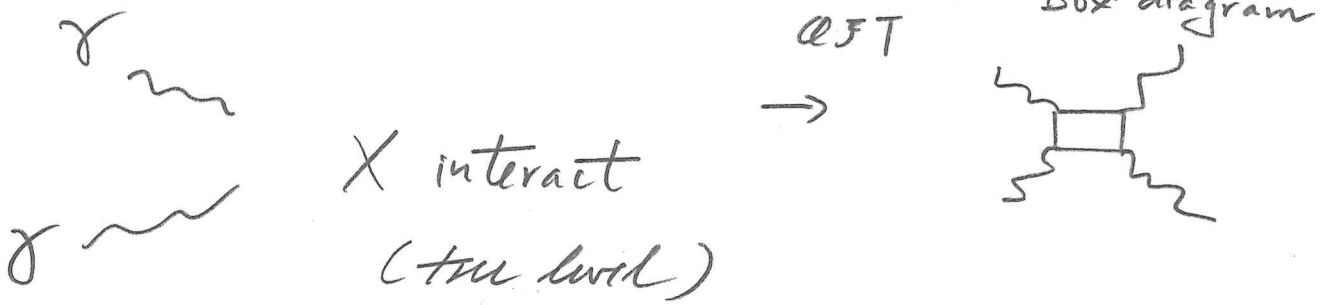
→ adjoint repr.

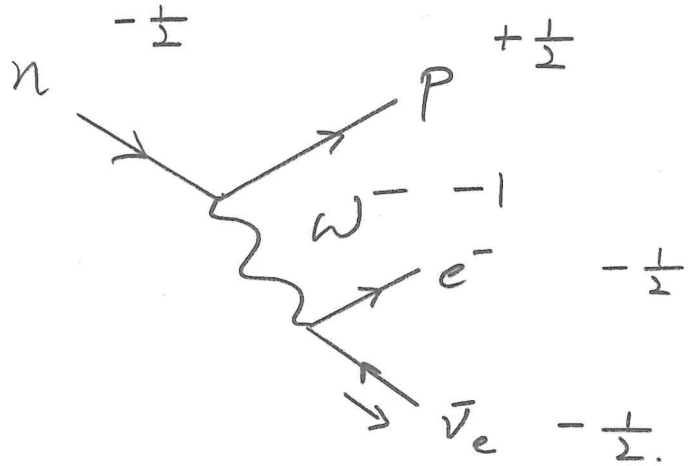
$N_c^2 - 1$

$N_c \times N_c$ matrices.

charge ⟷ interaction

γ is chargeless.

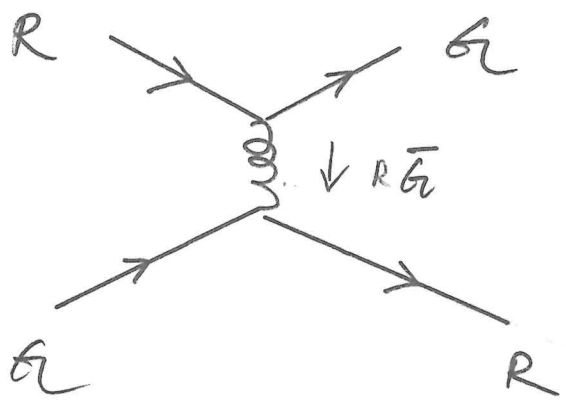




W^- has isospin charge -1

What about the Gluons?

Gluons $R\bar{G}$

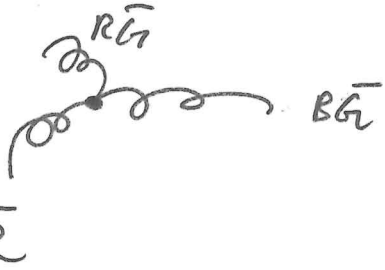


abelian Vs non-abelian

U(1)

?

SU(2)
SU(3)



World Domination

DoFs

quarks & gluons

π's

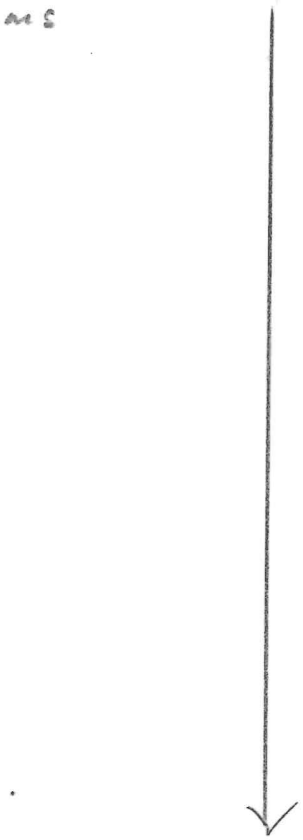
N

π, σ, ω

A, Z α, β, γ

hadrons +
stat. mech.

quarks + stat. mech.



Universe life time

LQCD → Spectroscopy ~ Monte Carlo
LQCD → FTQCD Sign problem
Pure Gauge

QCD → Schwinger Dyson Eqn. ~ Continuum
functional

pQCD ~ asymptotic freedom.
resummation.
NP phy.

χ_{pt} EFTs (un)linear σ model
LECs Sym.

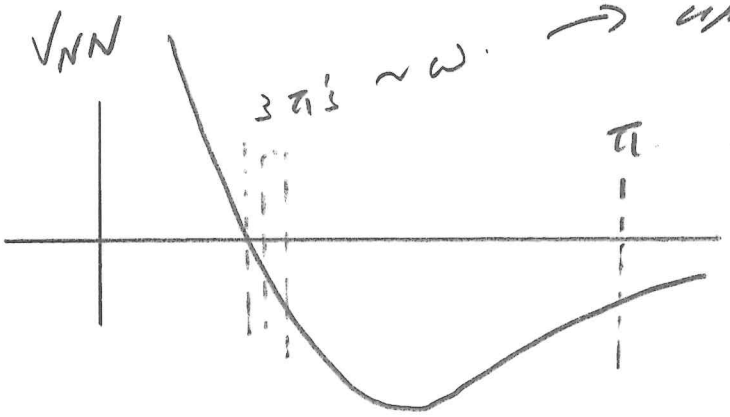
V_{NN} pot. model Wallecka
Schrödinger eqn. model
scattering theory $\pi, \sigma, \omega, \rho, a_1 \ldots$

Atomic Nucleus Brückner HF GFS.
Liquid Drop Model
Shell Model

Nuclear Matter
HICs Wallecka den. functional
HRG Fermi Gas.

Quark Matter NJL
Functional approach.

Astrophysics. NS PNJL
BHC EoSs composition.



→ repulsive

→ attractive

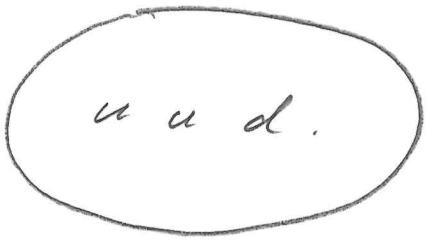
VdW of QCD (residual)

how to understand short range repulsion in nuclear force?

Why $\omega \to$ repulsive?

$\pi \sim 0 \leftrightarrow$ attractive?

SCSB



$M_p \sim 938$ MeV

m_u
$m_d \sim$ few MeV ← how do we know? (Higgs)

$m_\pi \sim 140$ MeV

what if $m_{u,d} \to 0$.

$M_p \to ?$

$m_\pi \to ?$

macroscopic ; phenomenologues

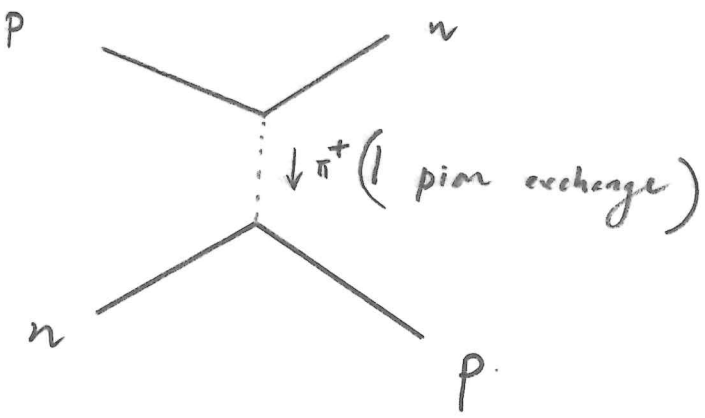
eff. theories : how to build things up ?

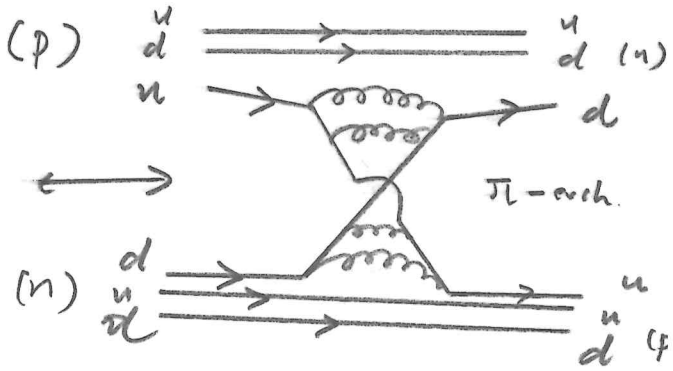
microscopic ; fundamental

QCD — χ_{pt} (π as dof) — hadron forces ~ π; σ, ω exch

$\sigma \sim \pi\pi$

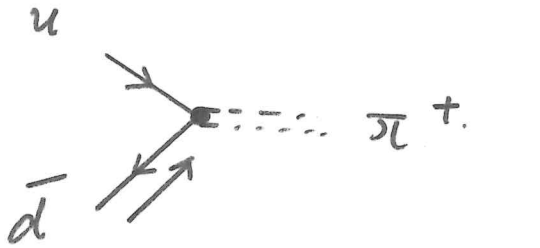
$\omega \sim \pi\pi\pi$





how to generate a Bound State is a hard physics problem.

cc P. Hoyer.



BSE.