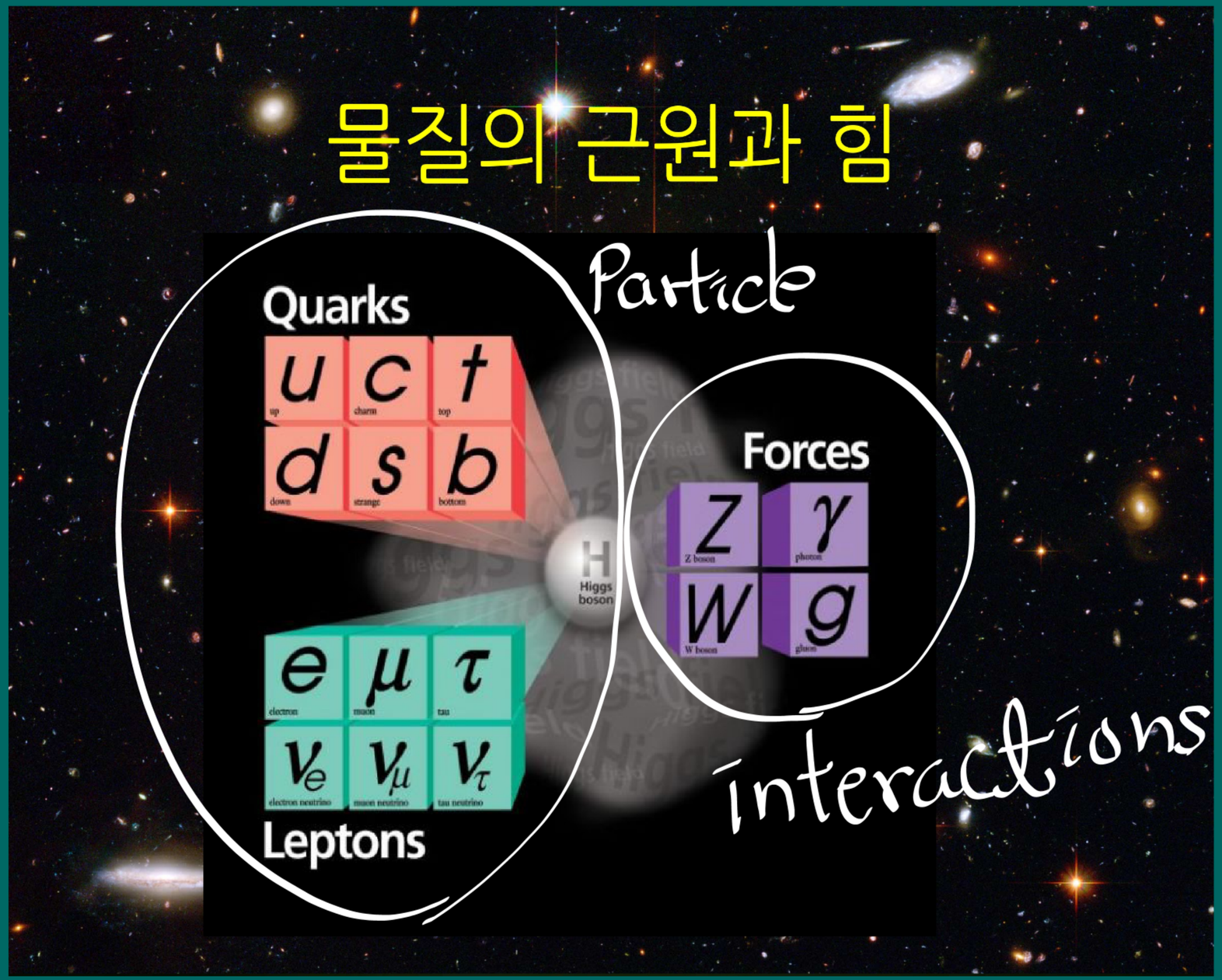
물질의 근원과 힘



거시 → 미시

D.H.

빛 (입자)

e (파동)

光子(γ): Maxwell eq. → $m=0$

↳ k-G eq

↳ e^- (mass problem)

↳ e^+ (anti-particle)

↳ Vacuum: $\Delta E \cdot \Delta t \geq \hbar$

Virtual World: $\Delta E < \hbar/\Delta t$

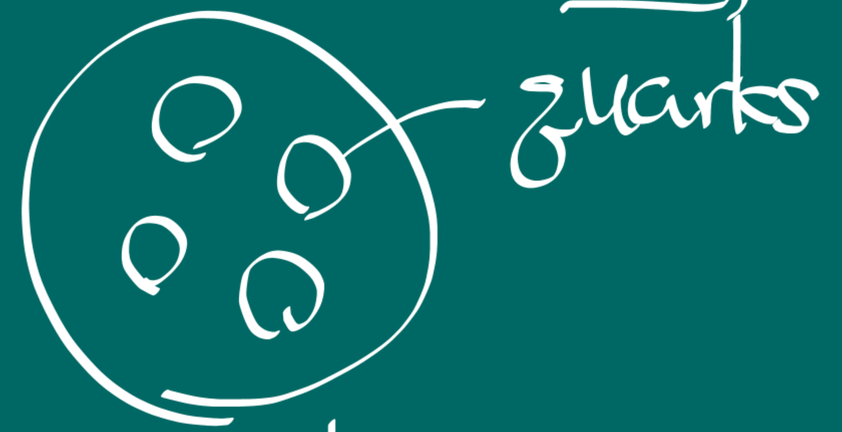
1MeV $\sim 10^{-21}$s

$n \to p e^- + \bar{\nu}$

3^{rd} H $\Rightarrow$ LN cons.

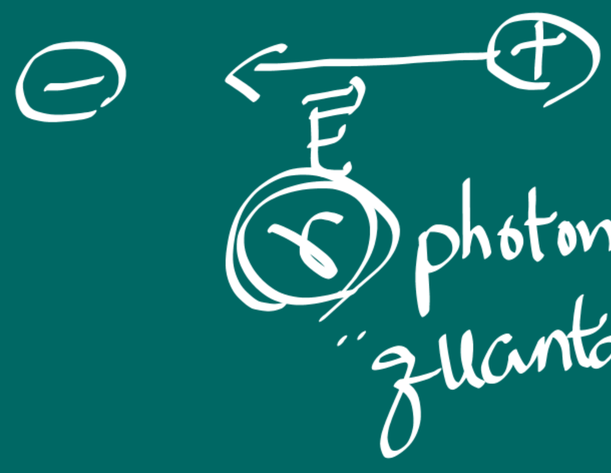
$m_\nu = 0$ ($\vec{\sigma}\cdot\vec{p}$: ant; "Left-H")

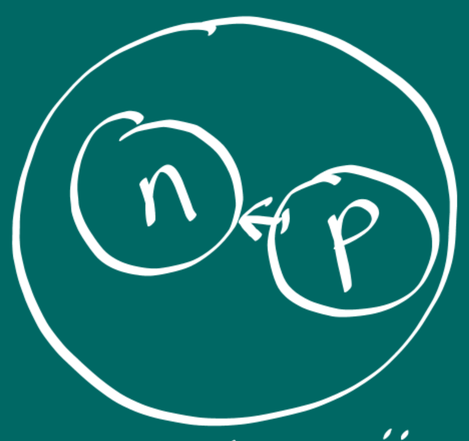
↳ Inelastic e-p



3: u.d.s

+(3)





"핵력"

Pion discovery.

$m_\pi = 140\ MeV/c^2$.

$\Delta p \cdot \Delta x \geq \hbar$

e.m.

$\Delta p c \sim \frac{\hbar c}{\Delta x} = \frac{1.24\ keV \cdot nm}{6\pi \cdot 10^{-15} m}$

mc^2 $\quad$ $10^{-15} m$

$\sim$ "200 MeV" =

$\nabla^2\psi - \frac{1}{c^2}\frac{\partial^2\psi}{\partial t^2} = \left(\frac{mc}{\hbar}\right)^2 \psi$; K-G

$m(r) = 0$

↳ Time-Ind. ψ

$\psi = U(r) = \frac{g_0}{4\pi r} e^{-r/R}$, $R = \frac{\hbar}{mc}$

$10^{-15} m \Leftrightarrow m = 200 MeV$

$\Leftrightarrow \frac{e}{4\pi\varepsilon_0 r}$

e.m.

e.m. self interaction.

$\int^{e^-} \ldots\ldots \left(e^- \frac{e^2}{4\pi\varepsilon_0 r} \right.$

α_{em} (strength) $= \frac{e^2}{4\pi\varepsilon_0}\frac{1}{\hbar c} = \frac{1}{137}$

"$\alpha_{em} \sim 0.01$"

Weak interaction.

$n \to p e^- \bar{\nu}_e$

Contact Int: $10^{-5}\,\alpha_{em}$

+ Quarks

n: dd**u**

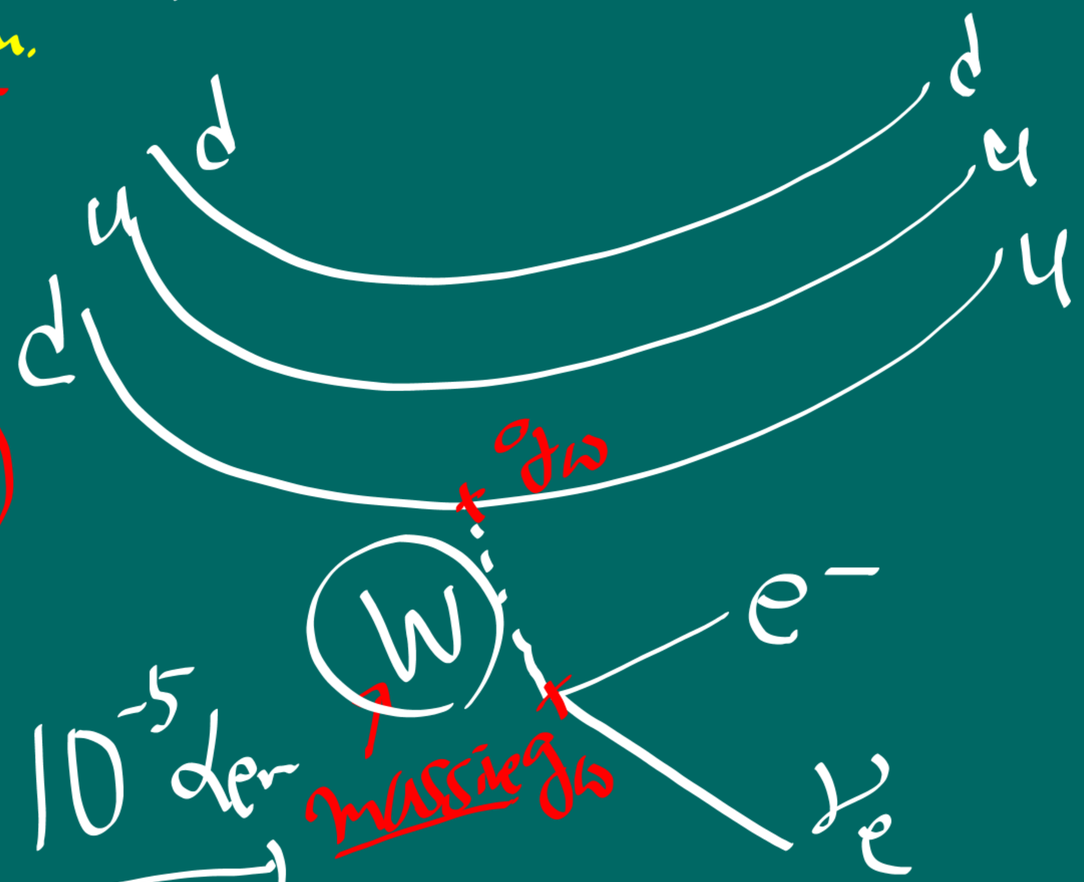
p: uu**d**

$\alpha_{weak} \sim \frac{g_W^2}{4\pi}$ (X)

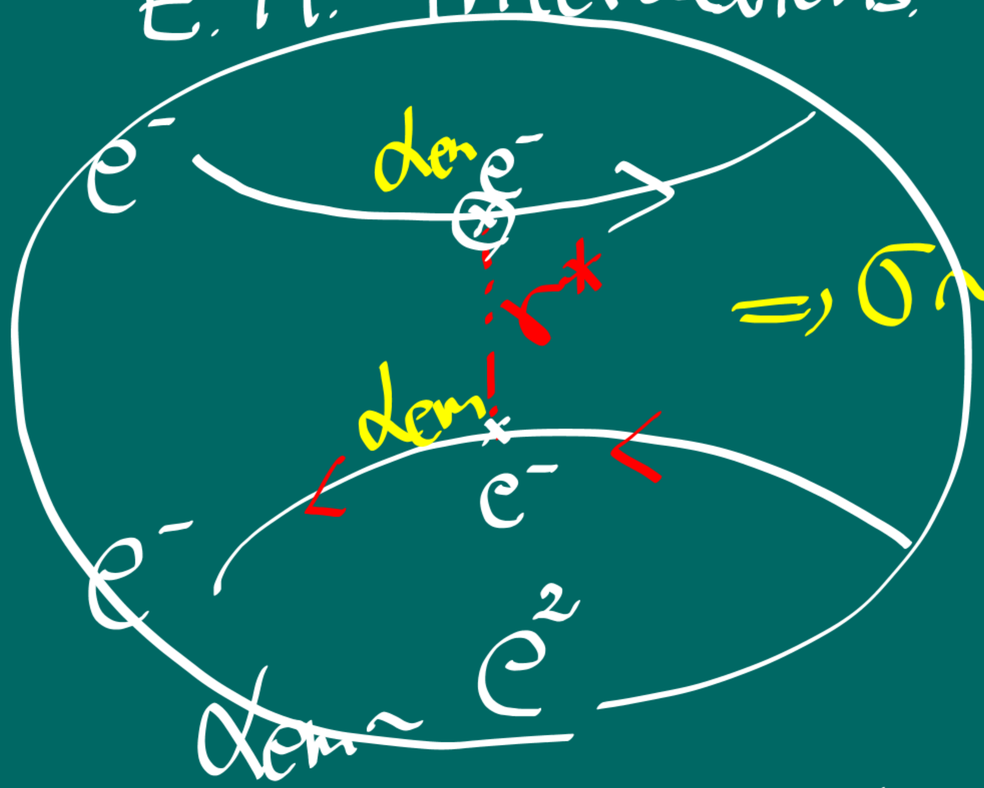
$\sim \frac{g_W^2}{M_W^2} \sim 10^{-5}\,\alpha_{em}$

$\Delta p \cdot \Delta x \sim \hbar$

$\Delta x \sim 10^{-18}\,m \Leftarrow \Delta p \cdot c \sim$ "200 GeV"



E.M. Interactions



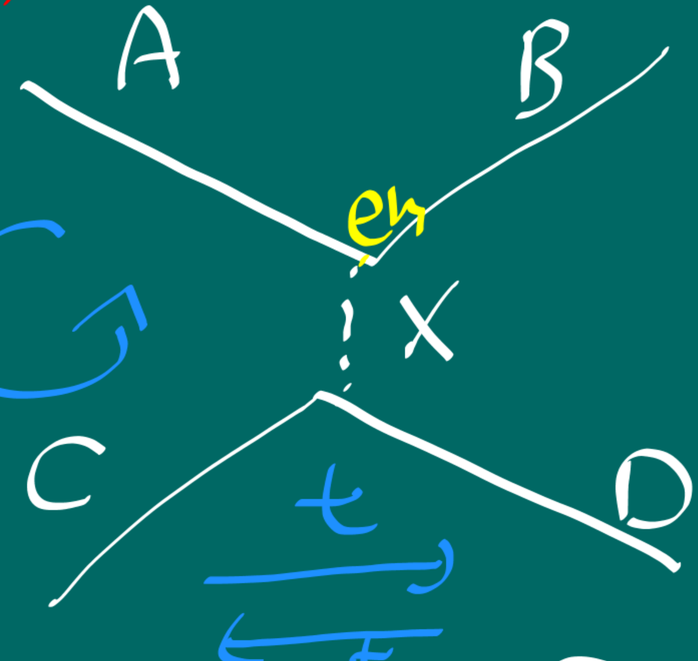
$\Rightarrow \sigma \sim \alpha_{em}^2$

$e^{-i(pz-Et)/\hbar}$

$(-\vec{p})(-t)$

$e^-e^- \to e^-e^-$

$e^-e^+ \to e^-e^+$

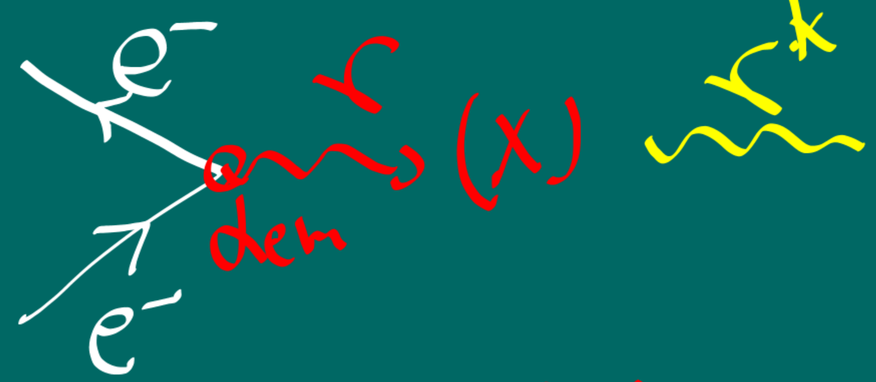


$A + C \to B + D$

(Dynamics: all possible if kinematics are allowed.

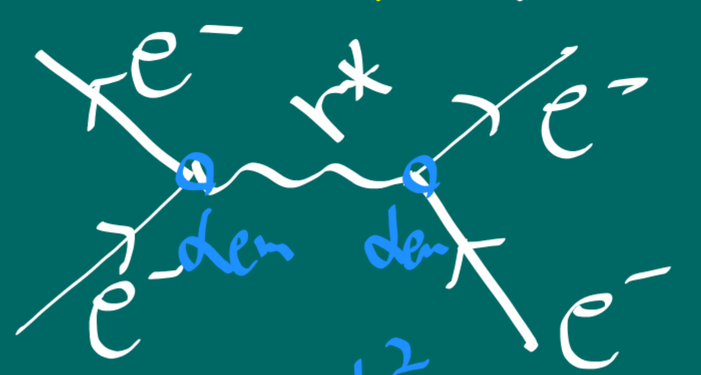
Scattering amp $= M = \frac{\alpha_{em}}{q^2 + m^2} = M$

$\sigma(\text{prob}) \sim |M|^2 = \alpha_{em}^2 / q^4$

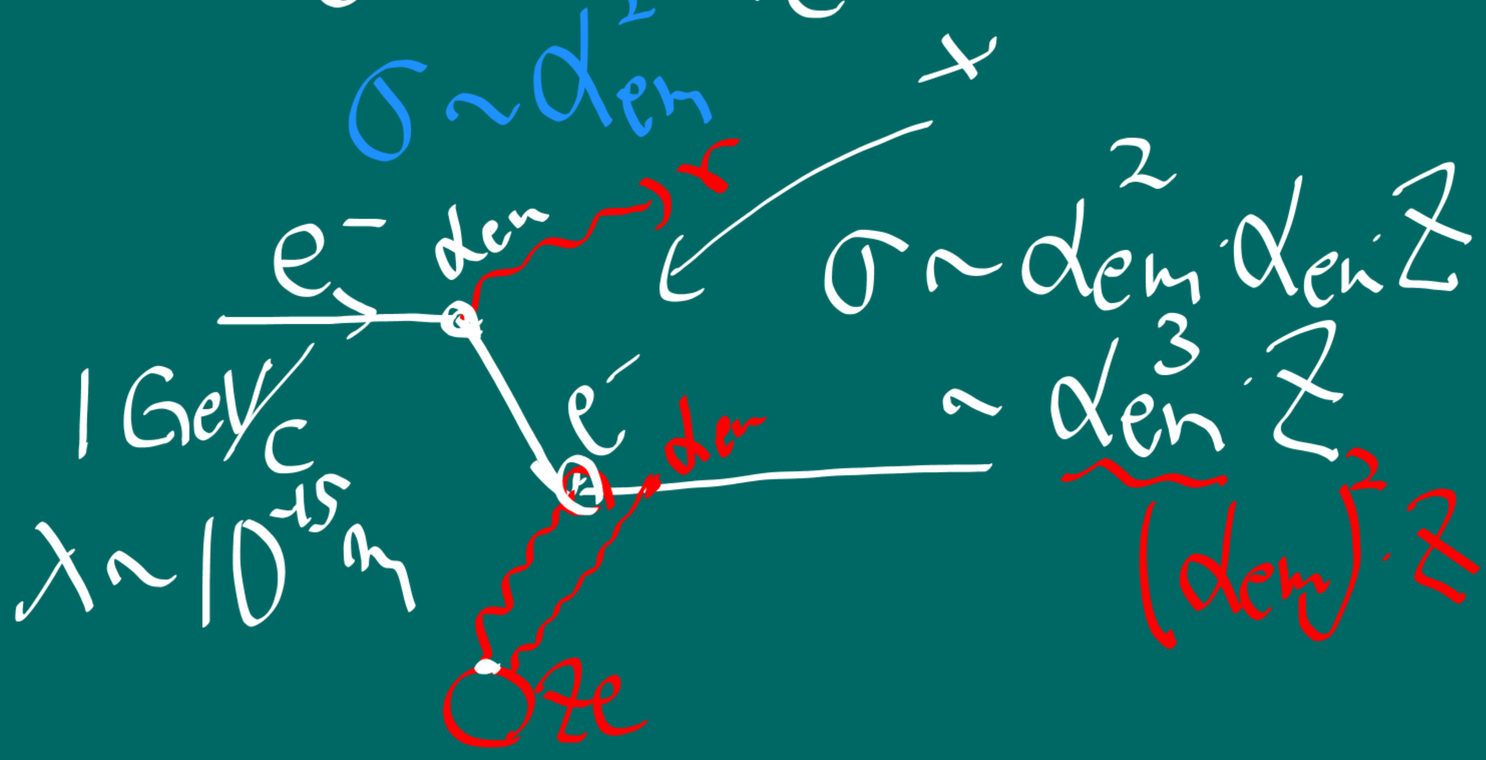


$e^-e^+ \to r(x)\, r\, r(0)$

$\to r^*$ $(m_{r^*} \neq 0)$ L (T)



$\sigma \sim \alpha_{em}^2$

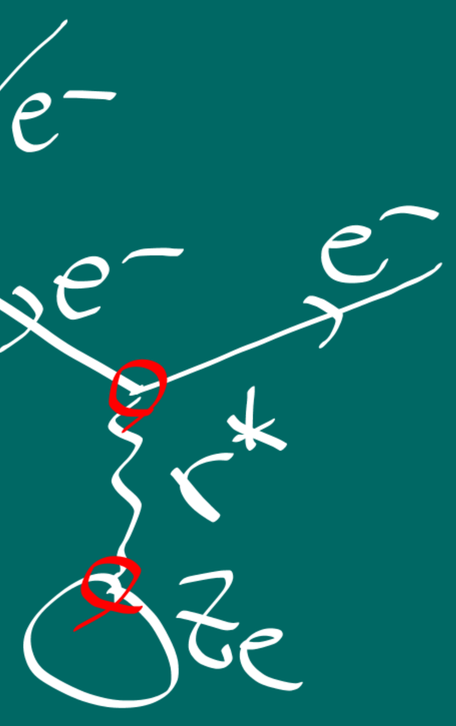


$\sigma \sim \alpha_{em}^2 \cdot \alpha_{em} Z$

$\sim \alpha_{em}^3 \cdot Z$

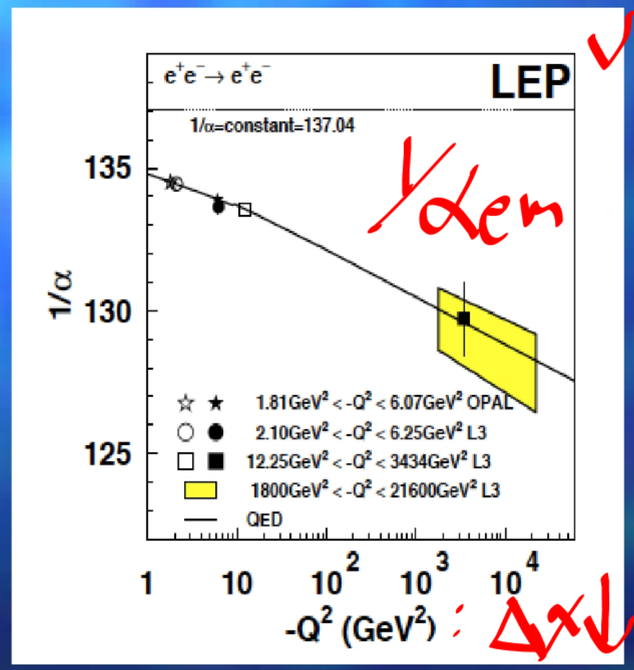
$(\alpha_{em})^2 \cdot Z$

$\alpha_{em} \sim \frac{e^2}{4\pi\varepsilon_0 \hbar c}$



Electromagnetic Coupling

- Electromagnetic constant is increased as λ is decreased.
- Coupling constant is running



$\alpha_{em} \sim \frac{1}{137} \sim g_e^2/4\pi\varepsilon_0 \hbar c$

$\alpha_{weak} \sim G_F \sim 10^{-5} \cdot \alpha_{em}$

$\sim \frac{g_W}{4\pi}$ / $M_W^2 \sim 6400\,GeV^2$

$g_W \sim 0.6$

$n \to p e^- \bar{\nu}_e$ (weak)

W^*

$\bar{\nu}_e + e^- \to \bar{\nu}_e + e^-$

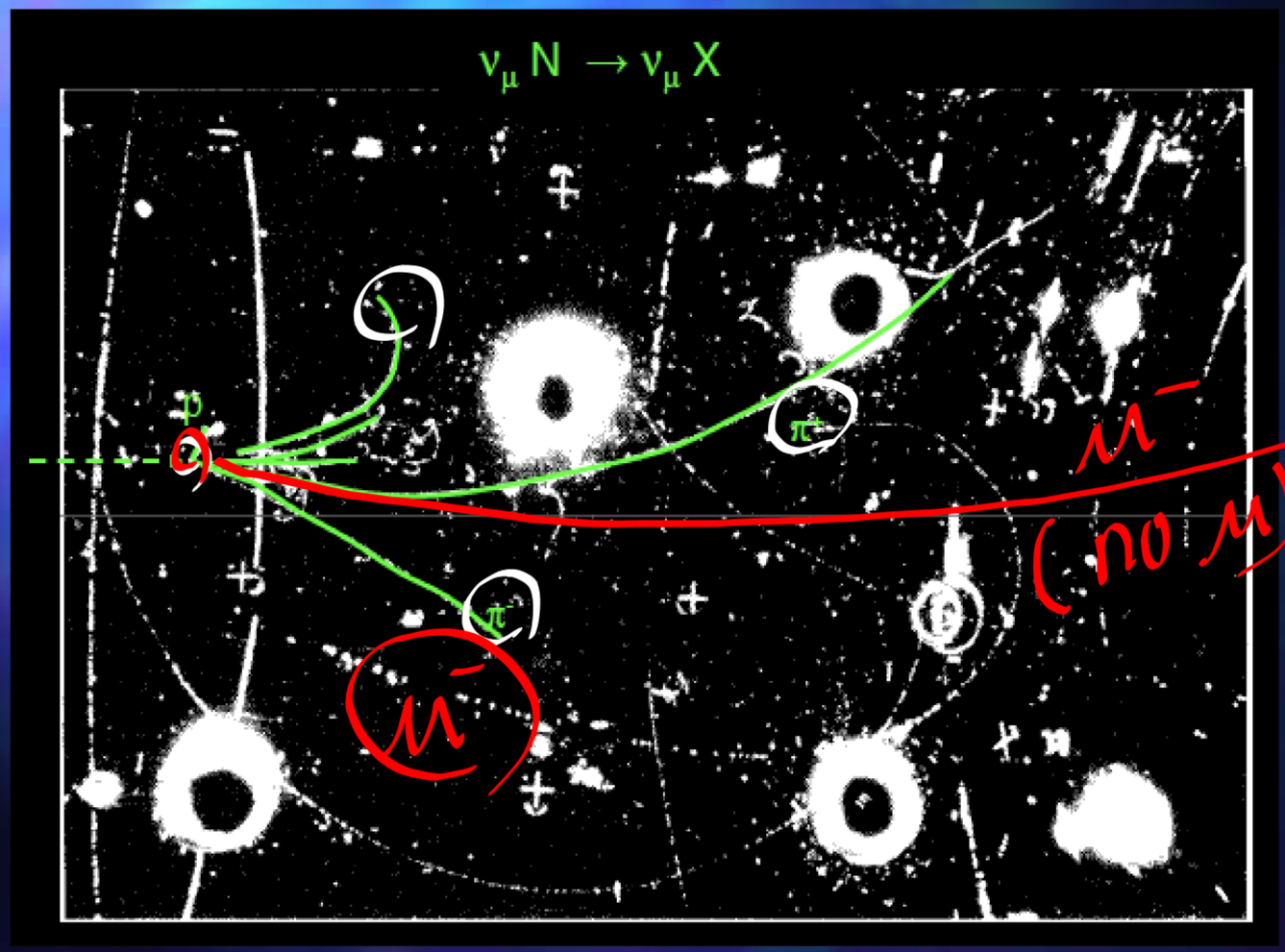
$\nu_\mu + N(n/p) \to \mu^- + X$

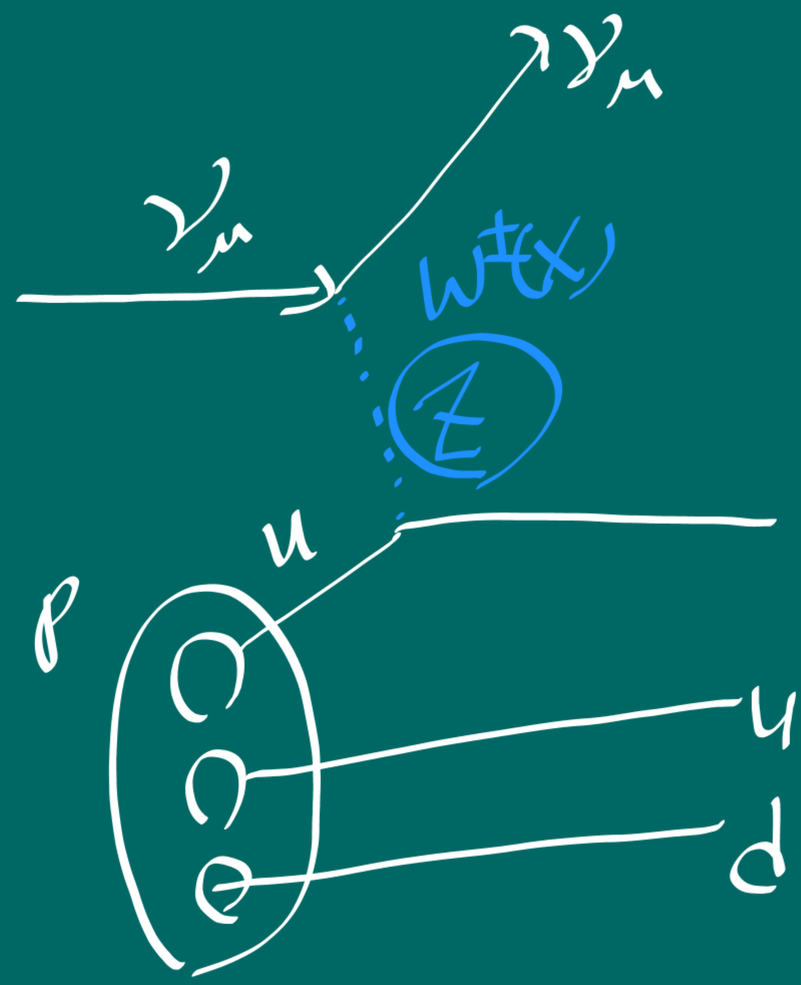
$\to$ Nothing (ν_μ)

$+ X$

$\vdots$

Neutral Current (1971)



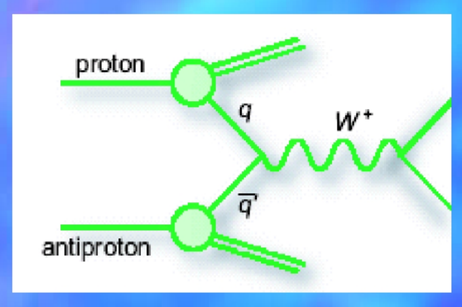


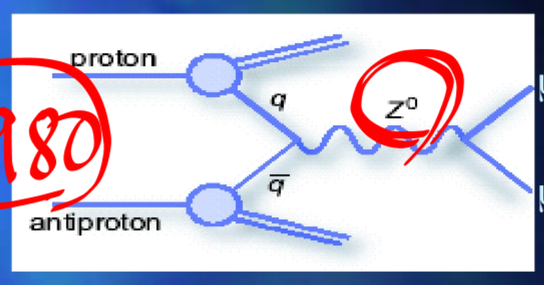
$G_F \sim \frac{g_W^2}{M_W^2}$ ~ NC event rate. (M_Z)

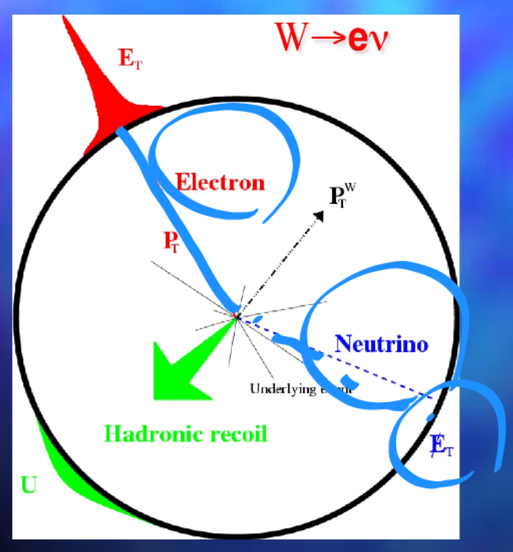
"$M_W = M_Z \cdot \cos\theta_W$" $\theta_W \sim 30^\circ$

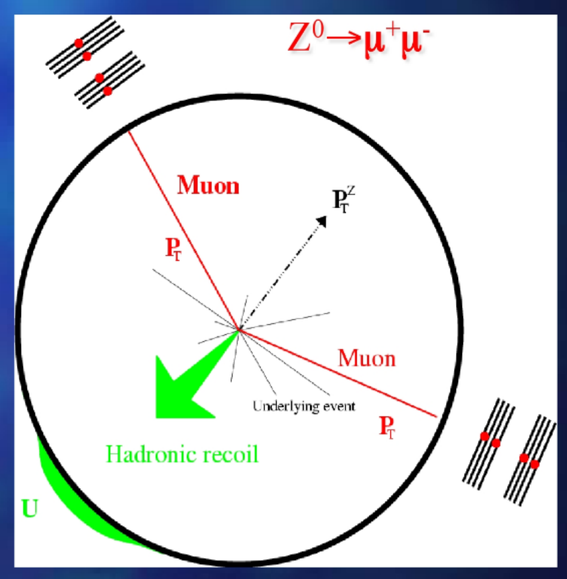
C. Rubia: $p\bar{p}$ (CERN)

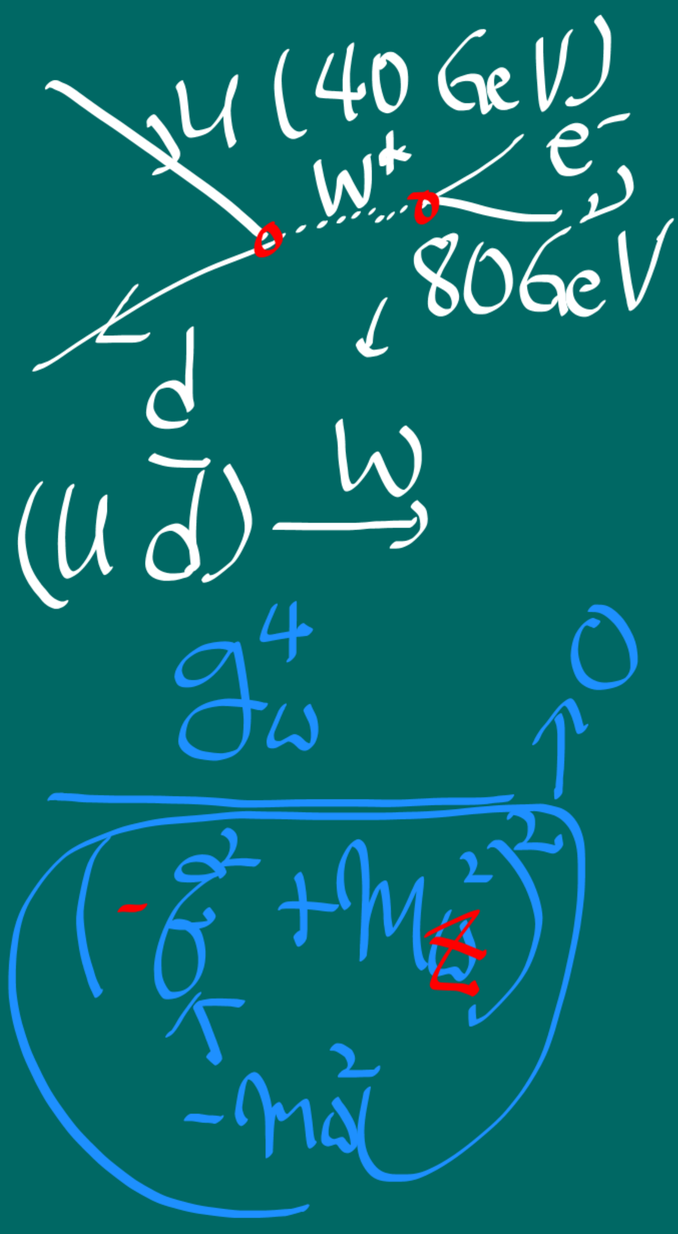
W and Z events







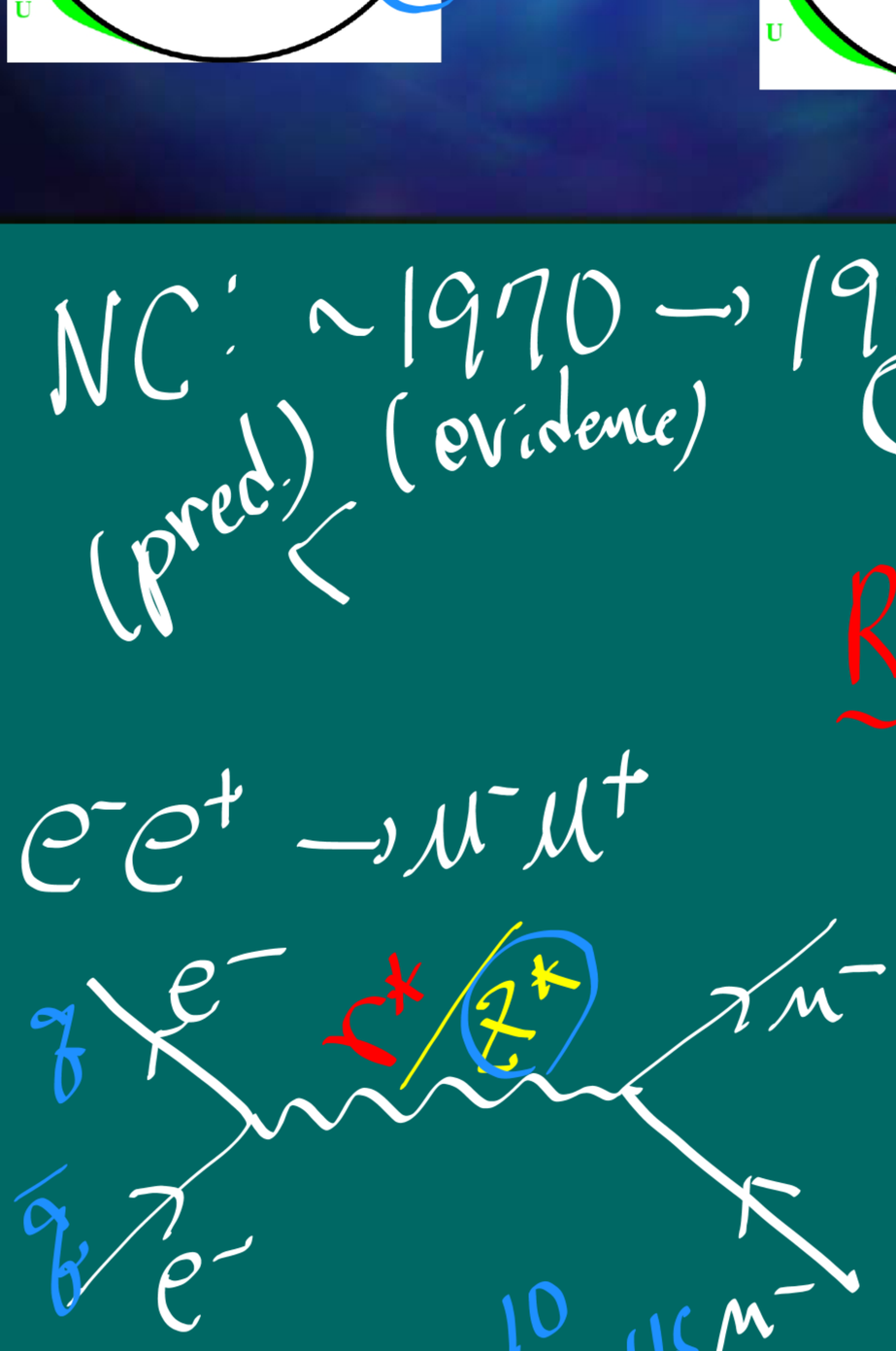




NC: ~1970 → 1981 (discovery)
(pred.) (evidence)

ν

Resonance



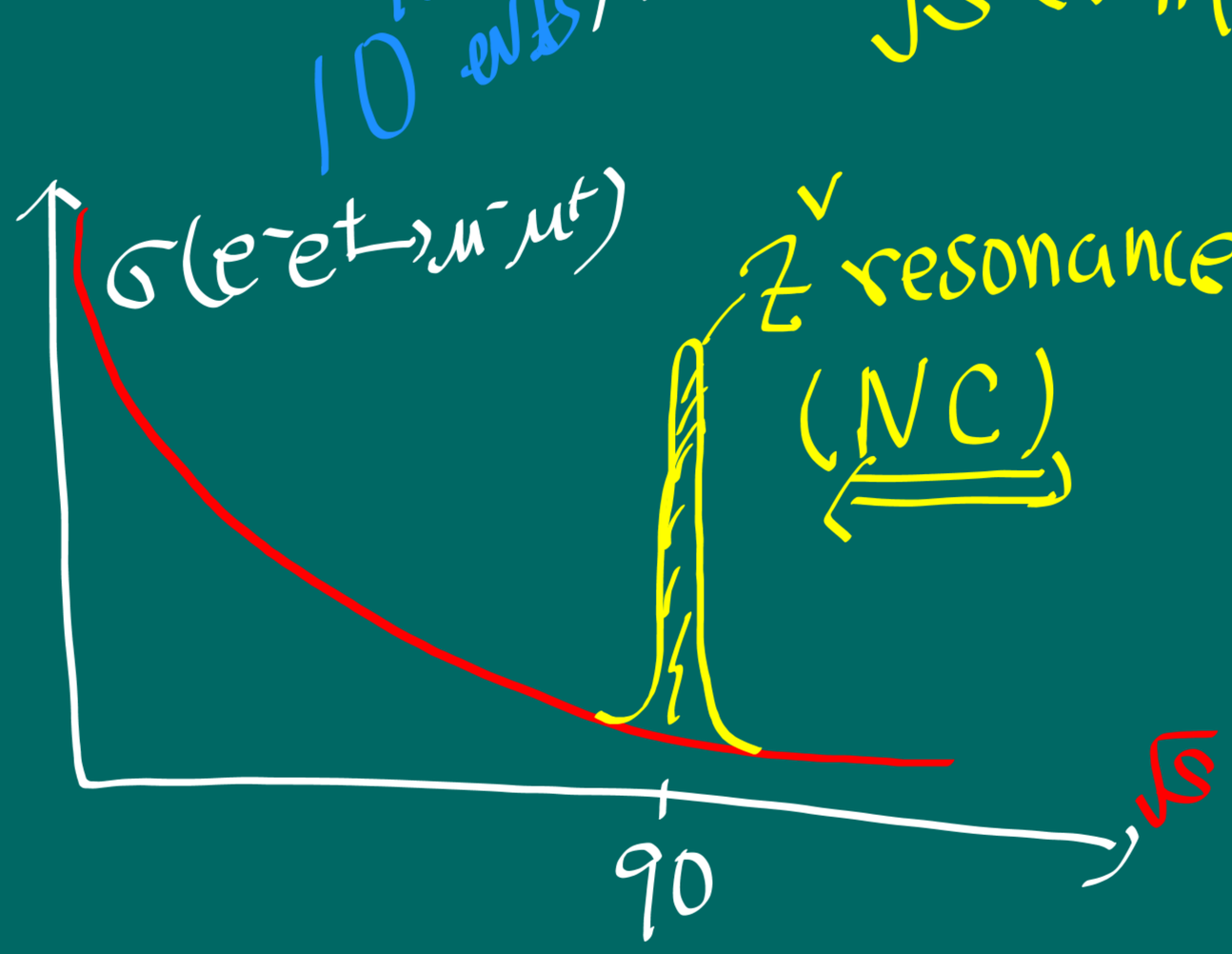
$\sigma \sim \frac{\alpha_{em}^2}{s}$ ⇒ $\sqrt{s} \ll m_Z$

↓ em.

$G_{Fi}^2 \sim 10^{-10}\,\alpha_{em}^2$ (Not possible)

Weak.

$\frac{G_{Fi}^2}{(m_W^2 + \Gamma^2 + \gamma)} \to \infty$



$$\frac{g_W^2}{(M_W^2 + Q^2)} \xleftarrow{} em$$

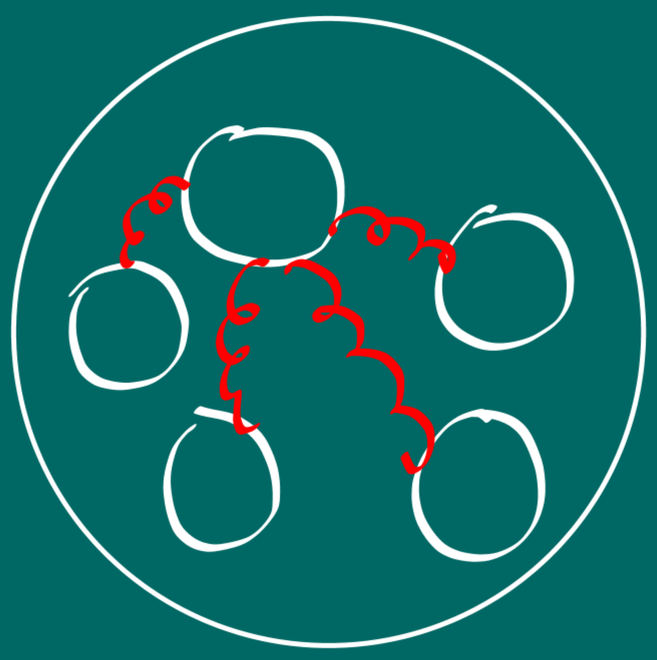
$$\Big\Downarrow$$

unified

$$Q^2 \sim 10^4\ GeV^2$$

$$\alpha_{em} \sim \alpha_{weak}$$

p



Strong Int: mediated by gluon.

em. → electric charge.

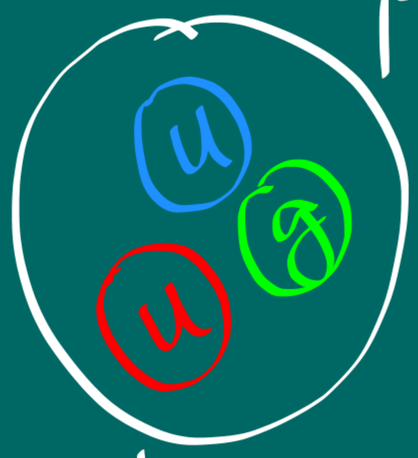
Weak → ..

Strong → "color" r̄ ḡ b̄

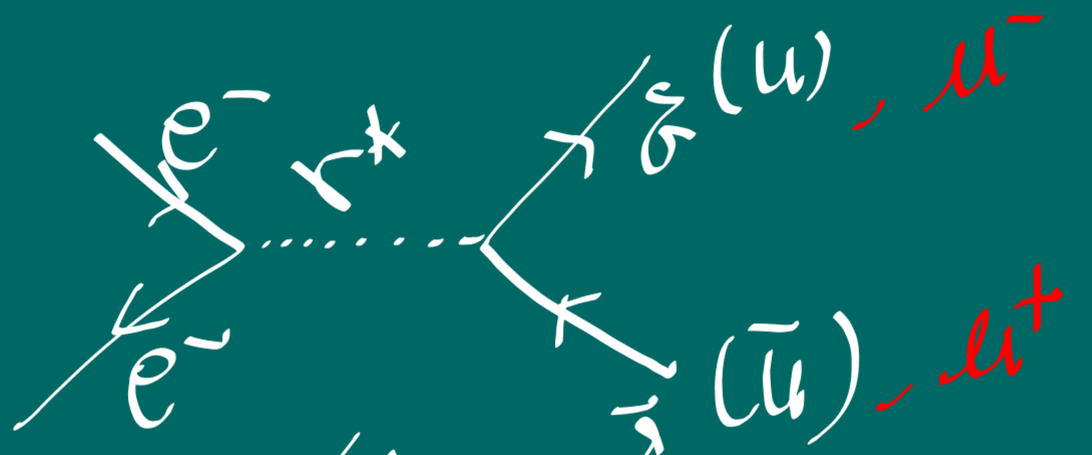
$e^-e^+ \to$ 3 jets.

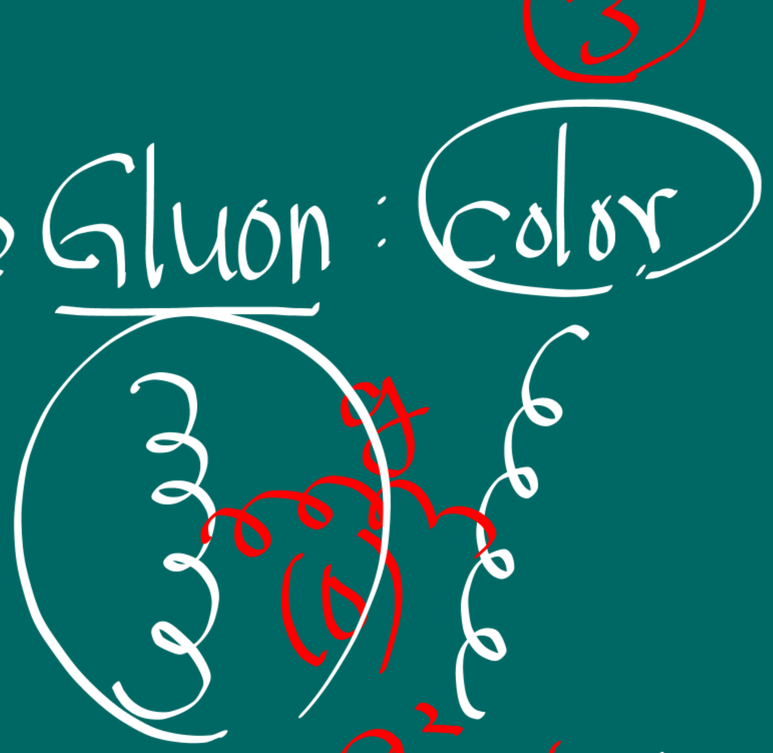
P(colorless) quarks: 3개 (r, g, b)

gluon : 8개



→ How many colors?



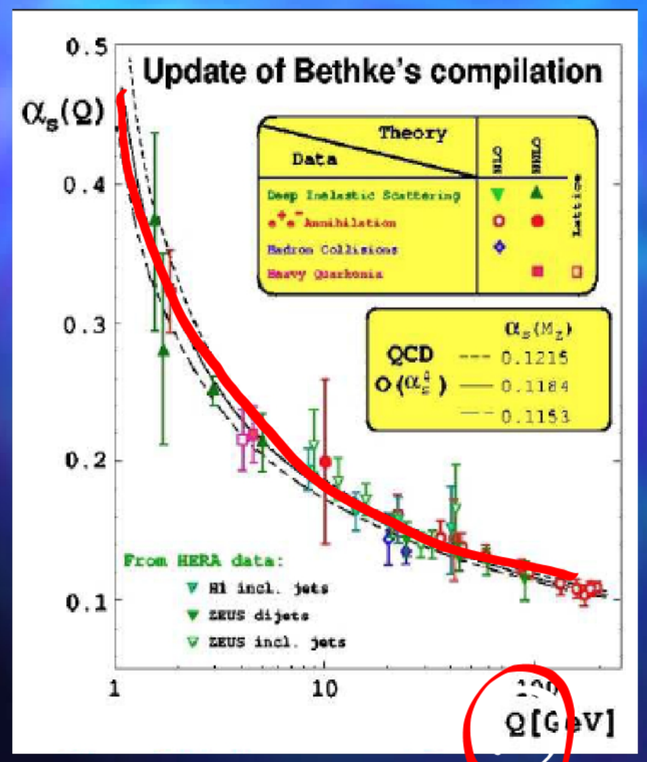


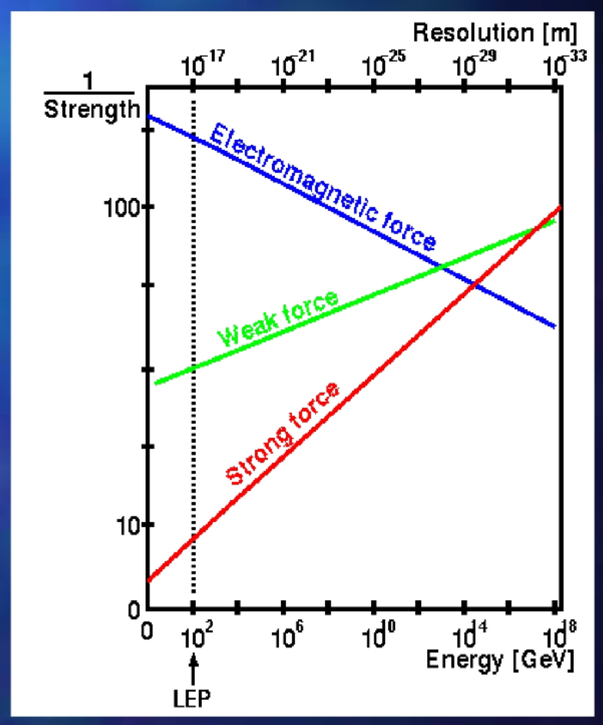
• Gluon : color

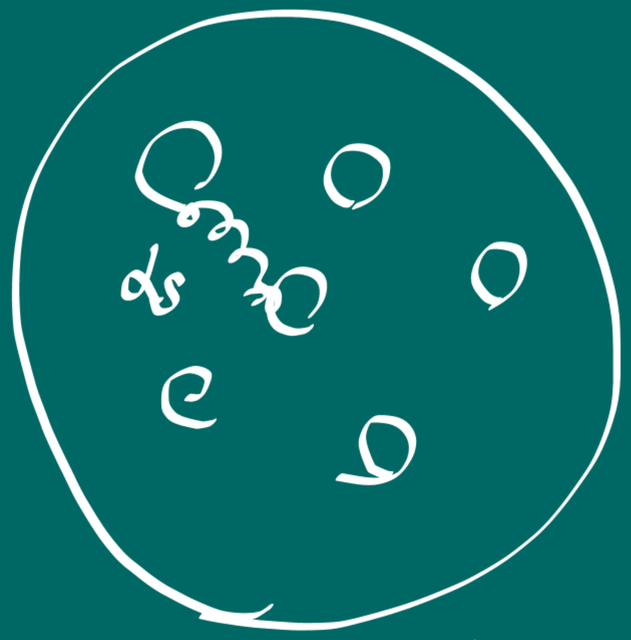
$\Rightarrow \alpha_s \sim \frac{g_s^2}{4\pi}$ (↓ _ QP)

anti-screening. ⇒ Non-abelian Gauge theory

Strong Coupling





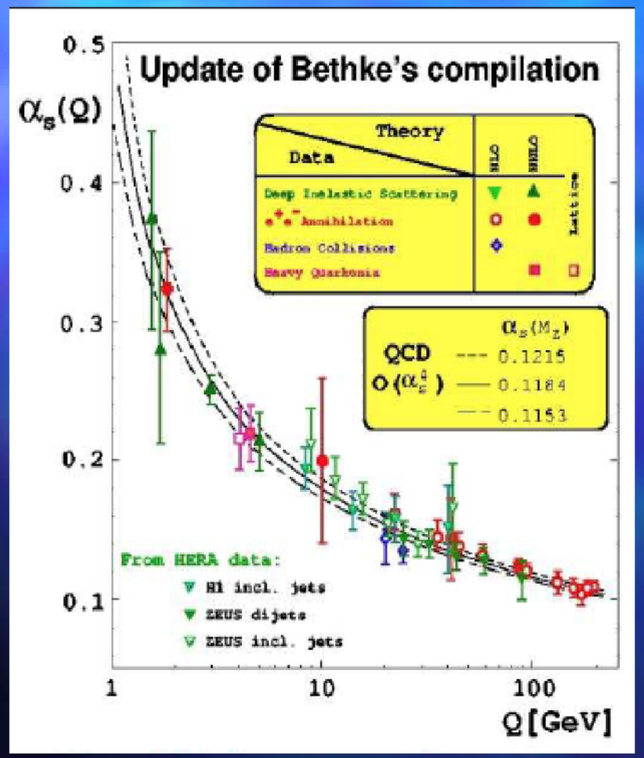


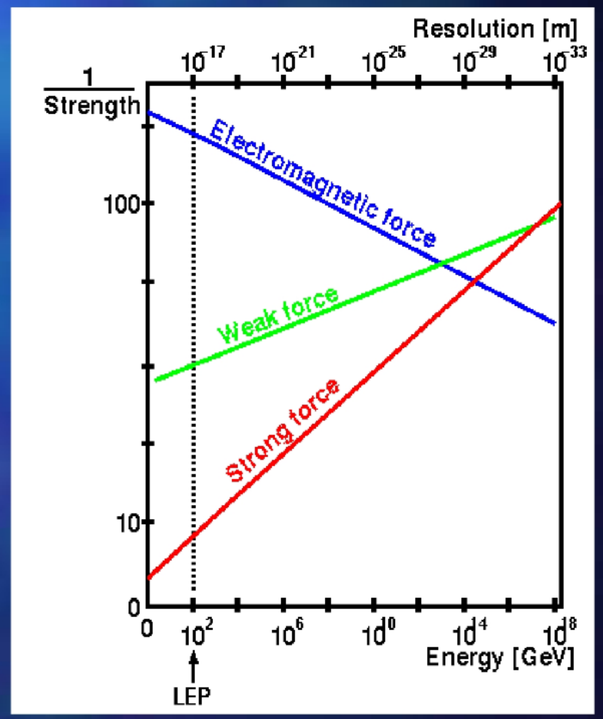
At very high Q^2
$\alpha_s \sim 0$
"Free gluons"

=> r

disk
free gluons

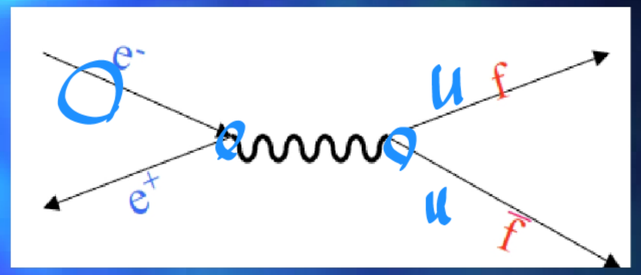
Strong Coupling

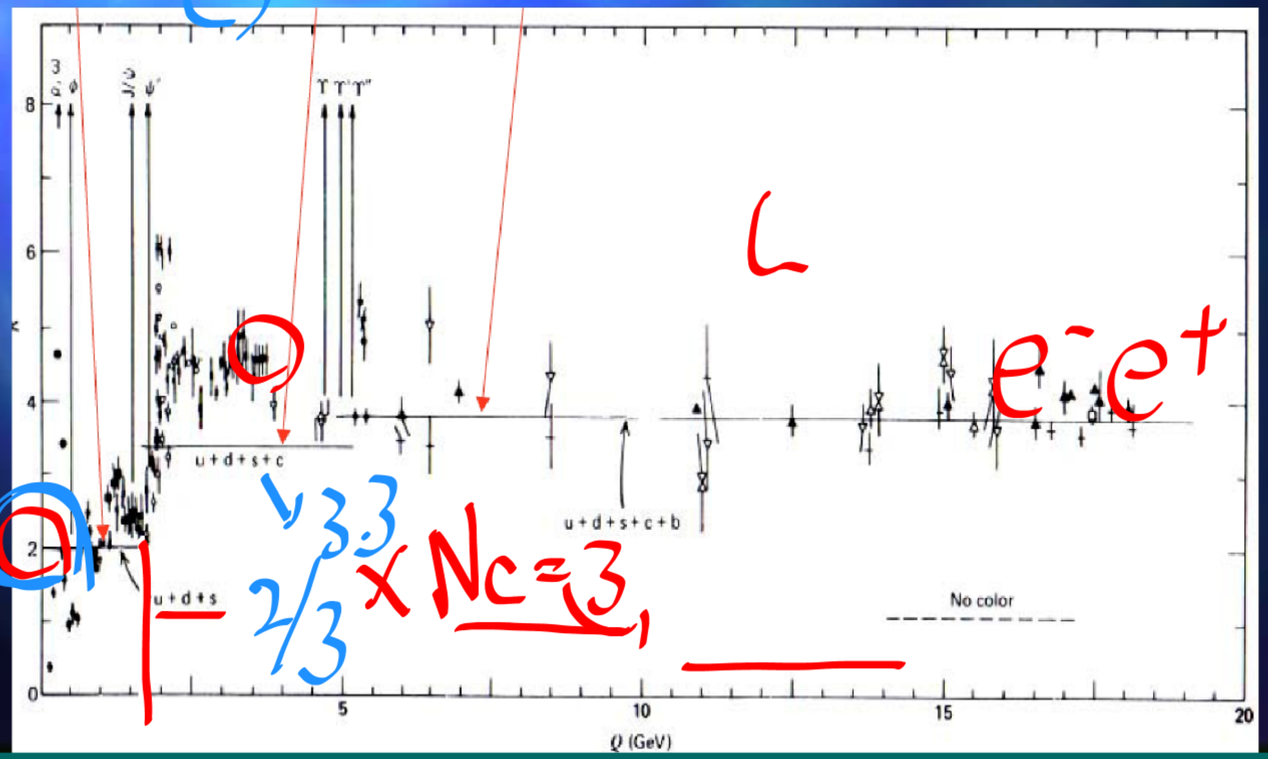




QCD Color

$$R = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$





$e^-e^+ \to q\bar{q}\,(u\bar{u},\ d\bar{d},\ s\bar{s})$

$u\ \left(\frac{2}{3}\right)^2 \cdot \alpha_{em}^2$

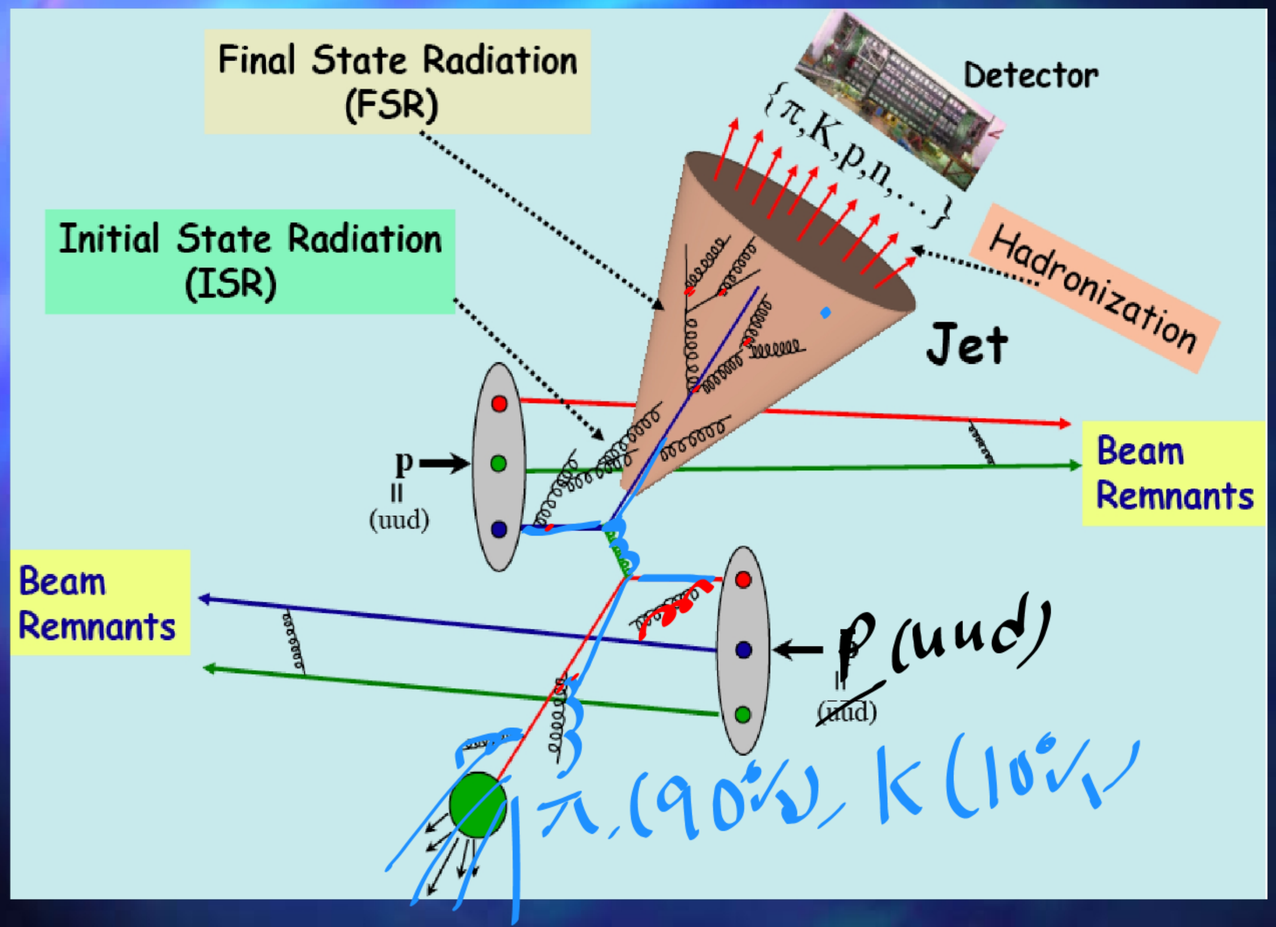
$d\bar{d}\ \left(\frac{1}{3}\right)^2 \cdots$

$s\bar{s}\ \left(\frac{1}{3}\right)^2 \cdots$

$= \frac{6}{9}\alpha_{em}^2 \cdot 1_{\text{loop}}^3$

$= \frac{2}{3}\alpha_{em}^2 \cdot N_c = 2$

pp collisions



$p + p \rightarrow g \rightarrow q\bar{q} \rightarrow 2\ \underline{\text{jets}}$

$\sigma(2\ \text{jets}) = ?$

= a Impossible

Jet

PS-Frag

측정

α_s α_s

q $\bar{q}$

g

$Q^2 > M_{\pi}^2$

$\hat{\sigma}(g\bar{g} \to g\bar{g})$

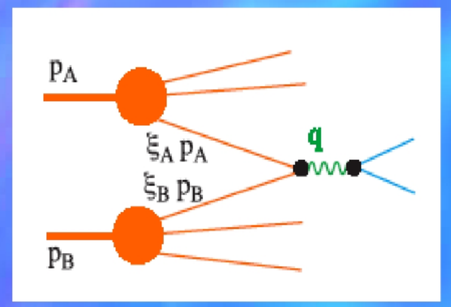
$\alpha_s^2 \cdot N_c^2$

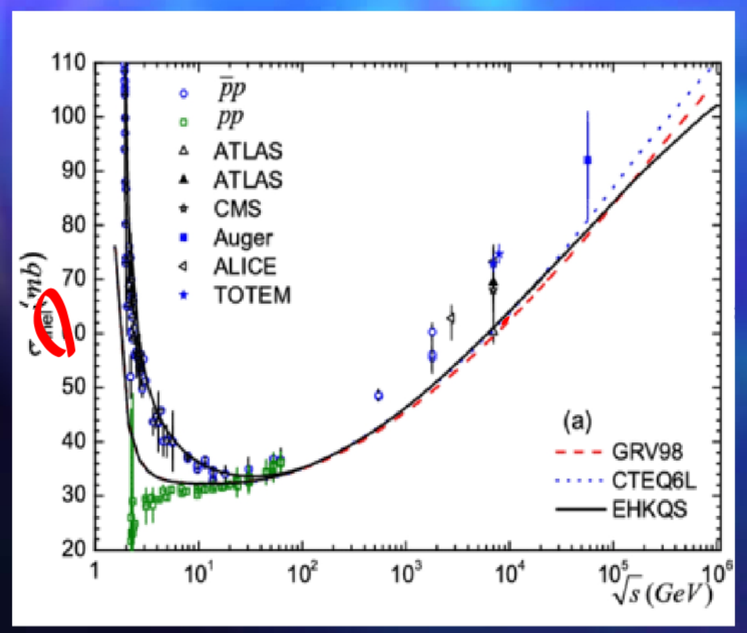
$Q^2 < M^2$

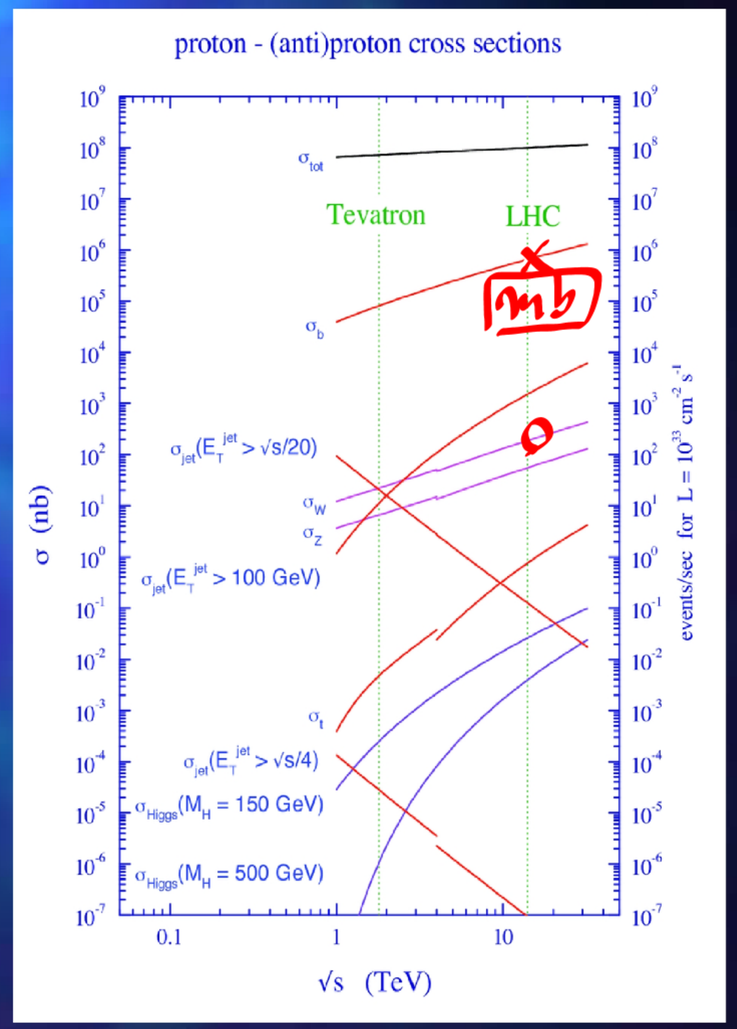
pdf 계산

$\bar{U}_{eff}$

Productions at the LHC

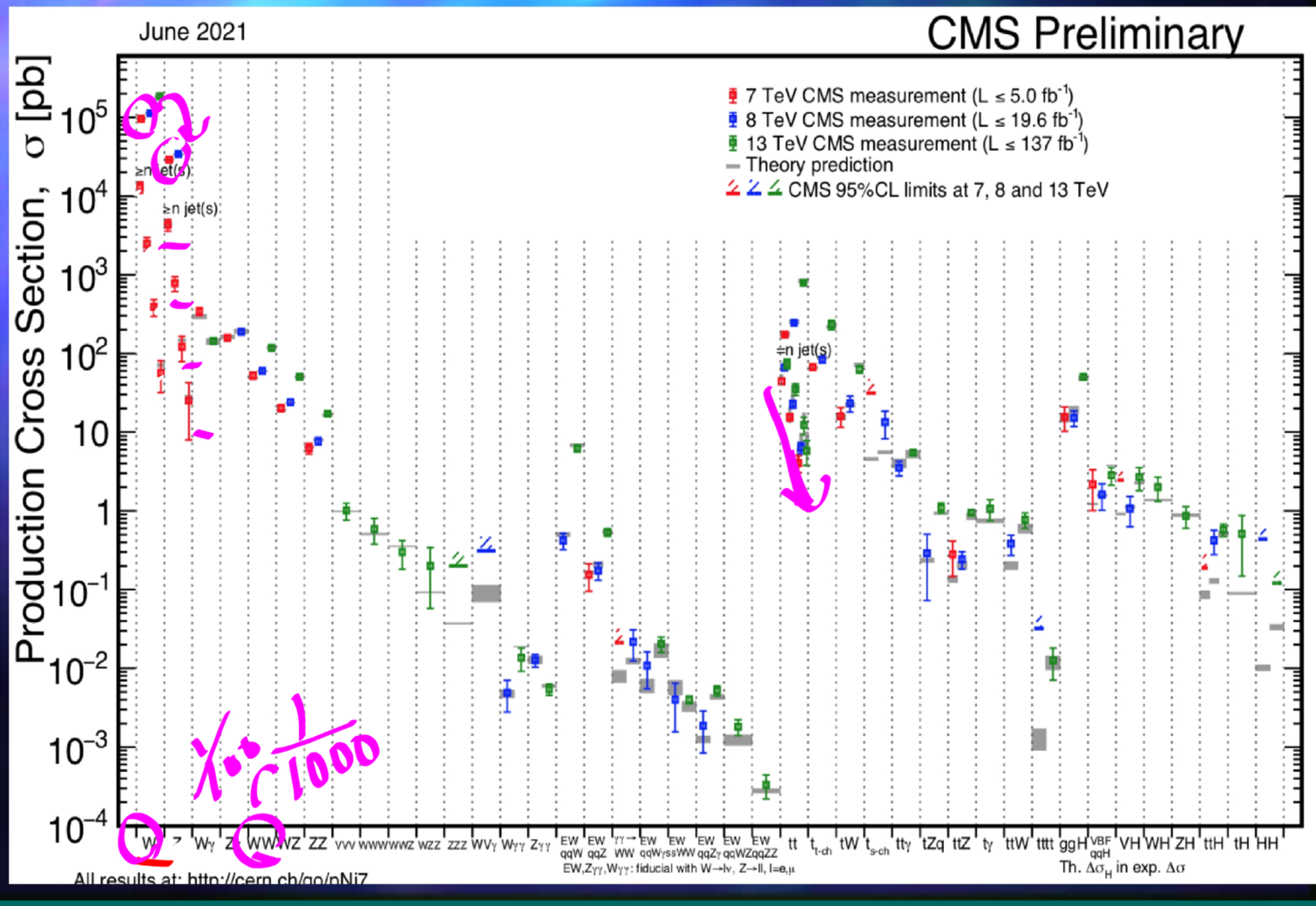






$pp \to$ (total)
~ 100 mb
Tnel: $\sigma \sim 60$ mb
$\alpha_s \sim 0.1$
$\alpha_{em} \sim 0.01$
$\alpha_{weak} \sim 10^{-5} \alpha_{em}$
verb

Productions at the LHC



$\sigma[b\bar{b}] \sim 1\,mb$

$\sigma(W) \sim 10^5\,pb$

$\sigma(W)/\sigma(Z) \sim 5$

$\alpha_{em} \sim 0.1 \sim 0.2$

$\sigma(W) + jet \sim \frac{1}{5}$

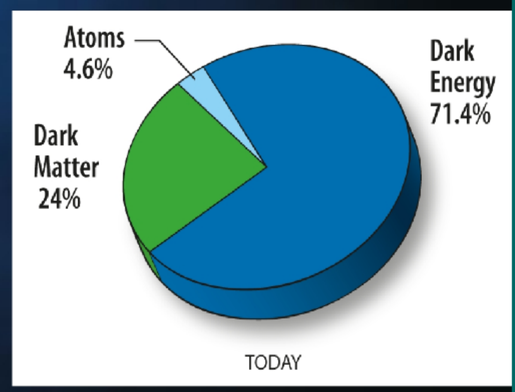
New Symmetry at the LHC?

"new force"

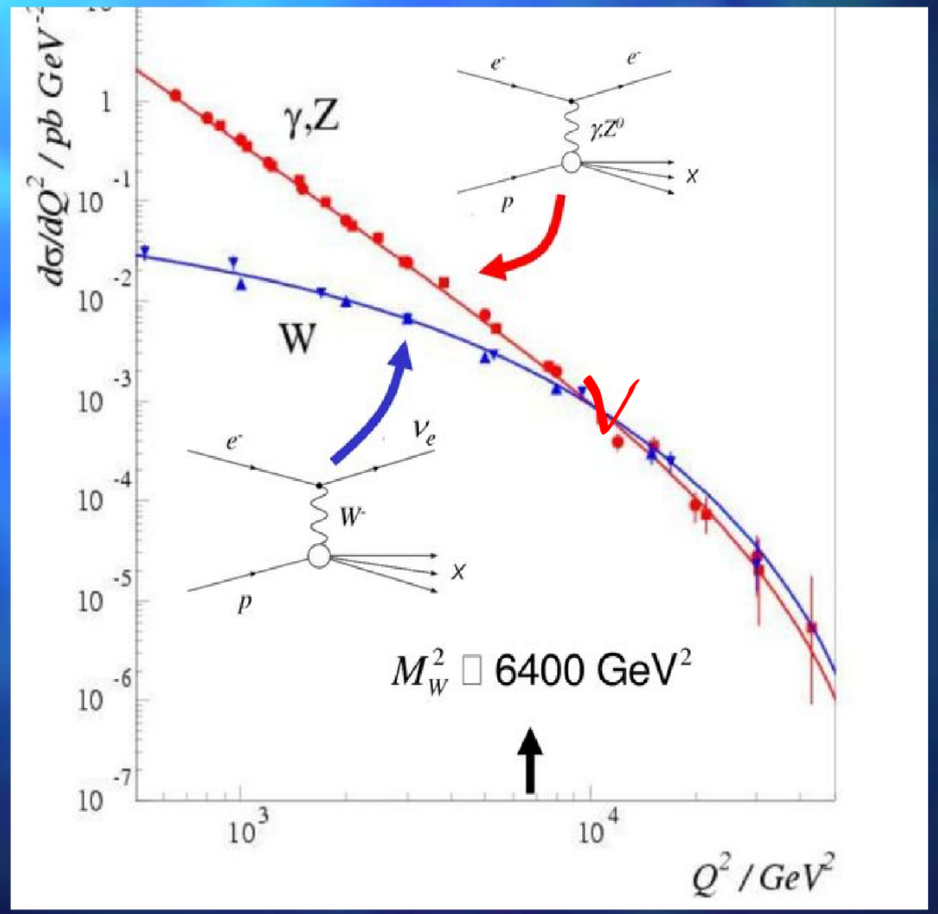
ν_{M+N}

"ν osc."

- Dark matter?
- Matter and Anti-matter asymmetry?
  Where is anti-matter?
- Neutrino oscillation
  Where is my right-handed partner?



EM+Weak: Unified

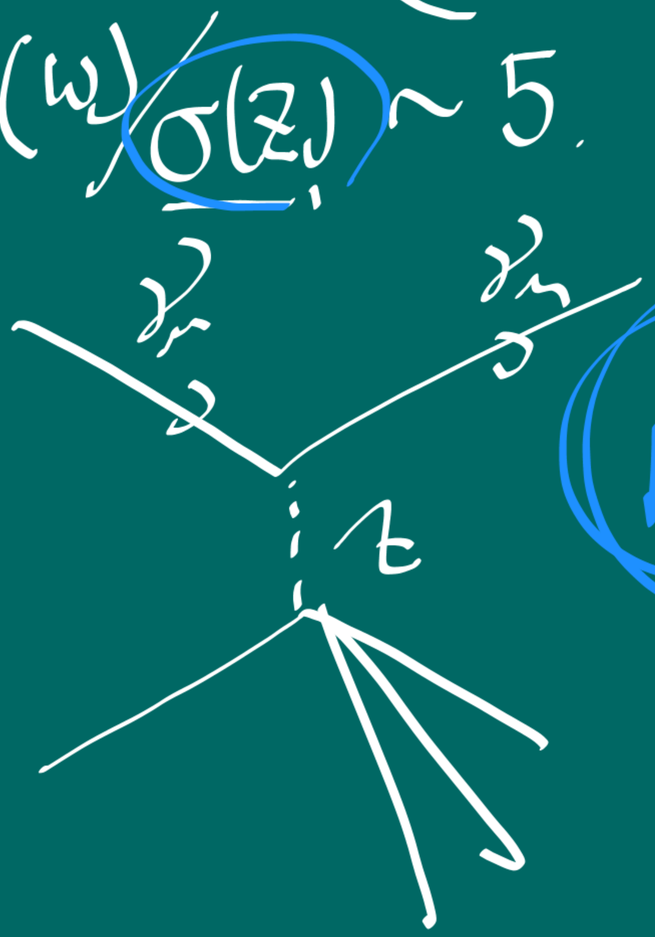


π ↓ $\nu_\mu + N \to e^- + X$ (x)

$\mu^- + X$ (CC: neo type of ν)

~1960

$\sigma(\nu)/\sigma(\bar{\nu}) \sim 5$.



NC ?

How come even Leon Lederman miss the NC Z events?