26/01/2018

STANDARD MODEL

- MATTER
  - LEPTONS
  - QUARKS ⇒ HADRONS
- INTERACTIONS
  - EM
  - STRONG
  - WEAK
- HIGGS BOSON

1) FLAVOUR/FAMILY PROBLEM

WHY 3 GENERATIONS?

WHY m_e, m_q, m_h

$N_{PAR} \simeq 20$ FREE PARAMETERS

$m_u/m_t \sim 10^{-6}$ $m_t \simeq m_h$

LEP

$e^+ + e^- \longrightarrow Z \Rightarrow \nu_e + \bar{\nu}_e$

$m_\nu < m_Z/2 \sim 45\, GeV/c^2$

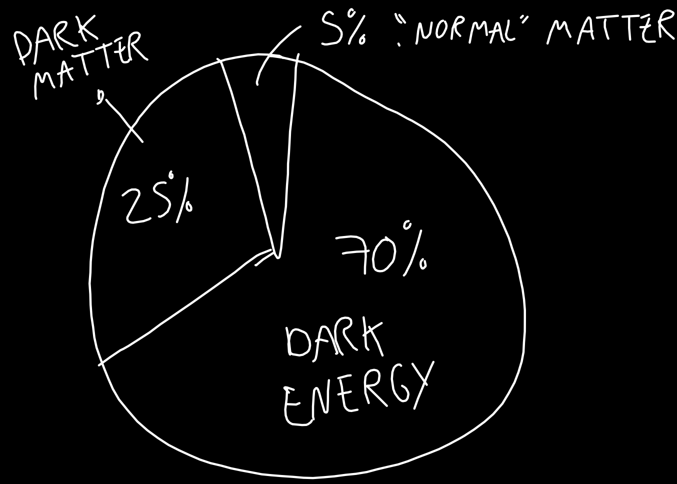
2) DARK MATTER

$$M_{DM} \simeq 5 \times M_{\text{VISIBLE MATTER}}$$

3) DARK ENERGY

UNIVERSE IS ACCELARATING

ENERGY BUDGET OF UNIVERSE



4) MATTER-ANTIMATTER ASYMMETRY

5) $m_\nu = 0$ (SM)

EXP $m_\nu \neq 0$

LONG DISTANCES L_e, L_μ, L_τ NOT CONSERVED

UNIFTICATION

MAGNETISM
ELECTRICITY
} ELECTROMAGNETISM

WEAK FORCE
RELATIVITY
QUANTUM THEORY
} QUANTUM THEORY WEAK INTERACTION

} ELECTROWEAK FORCE

EM, STRONG

$$g(Q^2) = \frac{1}{b_0 \ln Q^2/\Lambda^2} \quad [\simeq e^2]$$

$\downarrow$

SCALE OF PROCESS

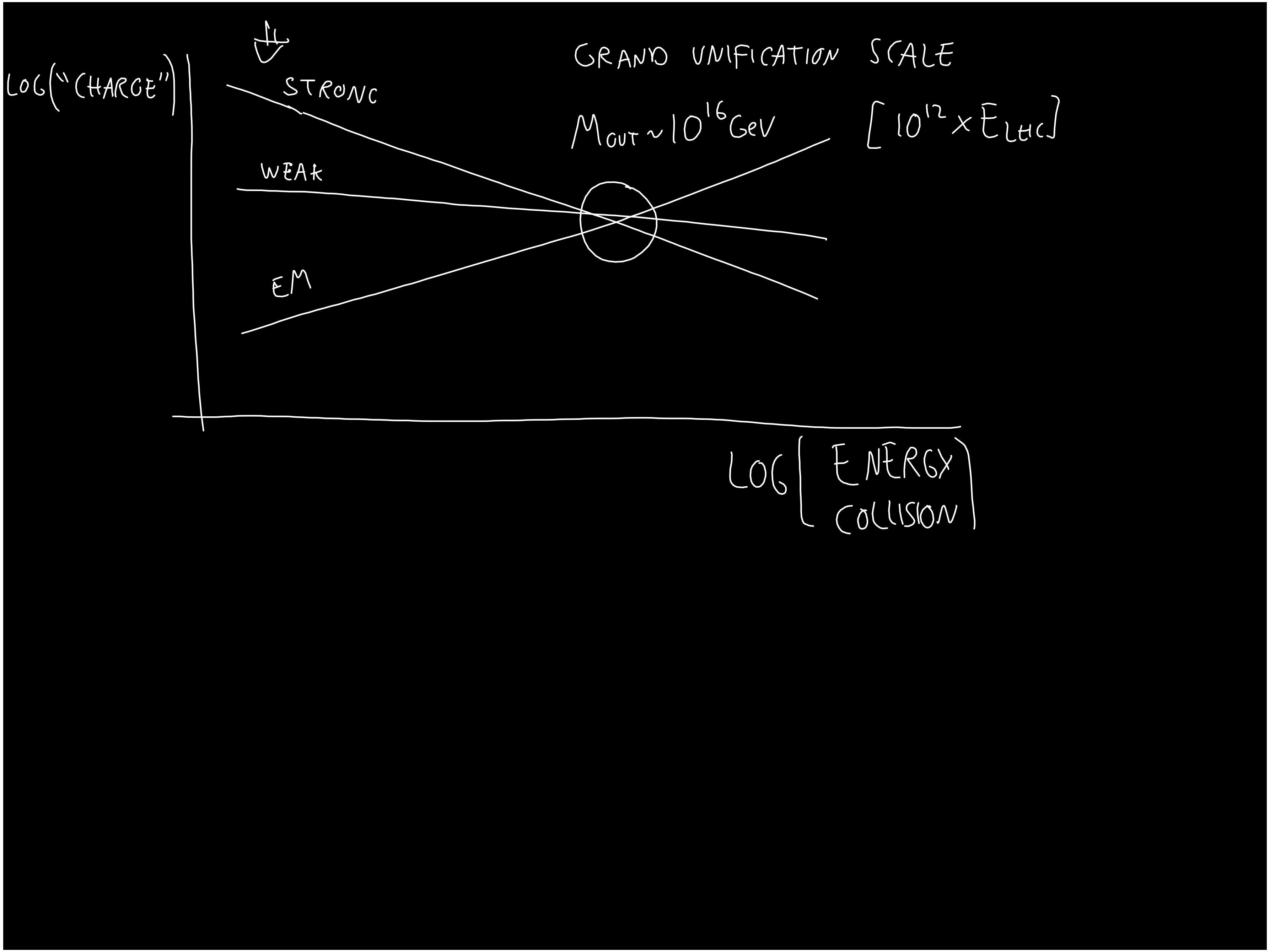
$Q \to \Lambda \quad g(Q^2) \to \infty$

EM $\quad b_0 = -\frac{4 N_q}{12\pi}$

$\Lambda \simeq 10^{90}$ GeV

STRONG $\quad b_0 = \frac{33 - 2N_q}{12\pi}$

$\Lambda = 300$ MeV



LOG("CHARGE")
STRONG
WEAK
EM
GRAND UNIFICATION SCALE
M_GUT ~ 10^16 GeV
[10^12 x E_LHC]
LOG(ENERGY COLLISION)

DARK MATTER

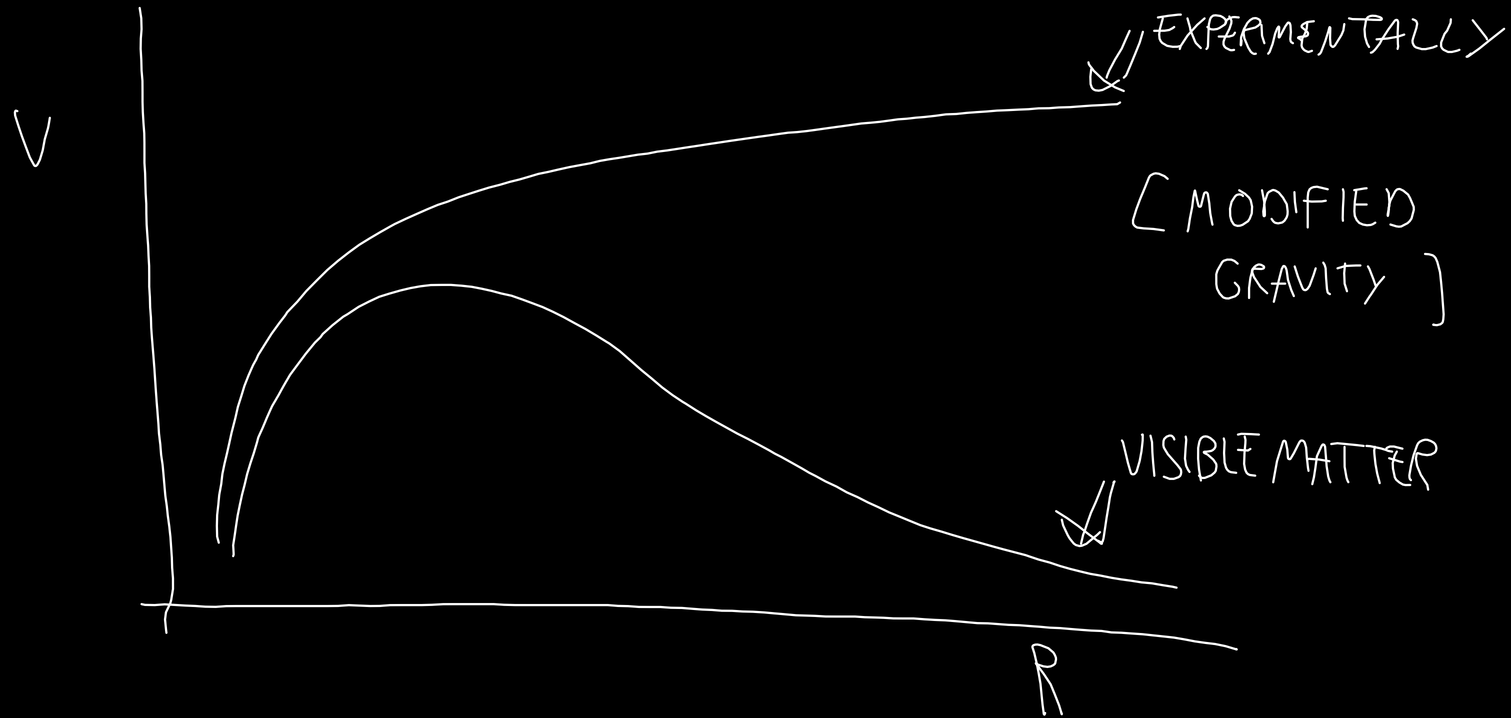
i) $Q_{DM} = 0$

$, \cancel{Z^0}, \cancel{\gamma},$

ii) $m_{DM} \neq 0$

iii) DM STABLE

GALACTIC ROTATION CURVES



$$\rho(r) \sim \frac{1}{r^n}$$

$$\Rightarrow v(R) \sim R^{(-n+1)/2}$$

QUANTUM GRAVITY

PLANCK'S ENERGY $E_P \simeq \sqrt{\frac{hc^3}{G}} \simeq 10^{19}\,GeV$

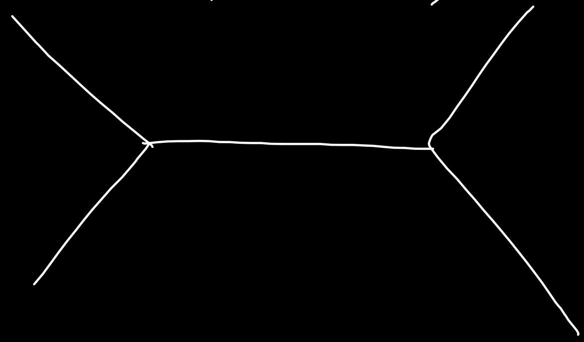
$E_{lhc} \sim 10^4\,GeV$

$$E_{MAX} \sim 0.3 \times B[T] \times R[m]$$

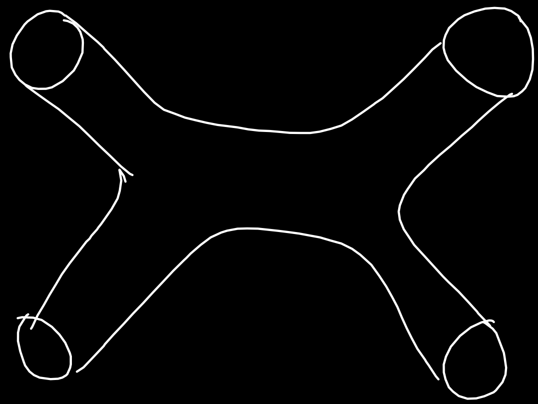
$$E_{MAX} \simeq E_p \qquad L = 10^{14}\,km$$

STRING THEORY

PARTICLES



STRING



PROBLEMS

$$E = \gamma m c^2$$

$$|\vec{p}| = \sqrt{p_x^2 + p_y^2 + p_z^2}$$

2.2) $p^\mu = (E/c, p_x, p_y, p_z)$

$$(p^\mu)^2 = (E/c)^2 - |\vec{p}|^2$$

LORENTZ INVARIANT

a) $p^\mu = (E/c, p_x, p_y, p_z)$

$= (m_p c, 0, 0, 0)$

$E_{rest} = m_p c^2$

$(p^\mu)^2 = (E/c)^2 = m_p^2 c^2$

b) $E_n = 1500$ MeV, z direction

$p^\mu = (E_n/c, 0, 0, p_z)$

$(p^\mu)^2 = (E_n/c)^2 - p_z^2 = m_n^2 c^2$

$p_z = \sqrt{(E_n/c)^2 - m_n^2 c^2}$

$$\left\{\begin{aligned} m^2c^2 &= \left(E/c\right)^2 - (\vec{p})^2 \\ \left(E/c\right)^2 &= m^2c^2 + (\vec{p})^2 \\ (\vec{p}) &= \left(E/c\right)^2 - m^2c^2 \end{aligned}\right.$$

c) $E_{KIN} = 500\,\text{keV}$, z direction

$$p^{\mu} = \left(\frac{E}{c}, 0, 0, p_z\right)$$

$$\boxed{p_z = \tilde{\gamma}\beta m c}$$

$$E = \tilde{\gamma} m c^2 \qquad \beta = v/c$$

$$\tilde{\gamma} = (1-\beta^2)^{-1/2}$$

$$\boxed{\begin{aligned} E &= E_{REST} + E_{KIN} \\ &= mc^2 + \underbrace{(\tilde{\gamma}-1)mc^2}_{=\,500\,\text{keV}} \end{aligned}}$$

$E_\nu >> 1\ \text{GeV}\ (\simeq m_p)$

$\nu_\mu + X \longrightarrow \mu^- + Y$

i) $X = p$

$\nu_\mu + (uud) \longrightarrow \mu^- + \underbrace{(uuu)}_{\Delta^{++}}$

$Q_I = +1$

$Q_F = +1$

$\underline{Q_X = +2}$

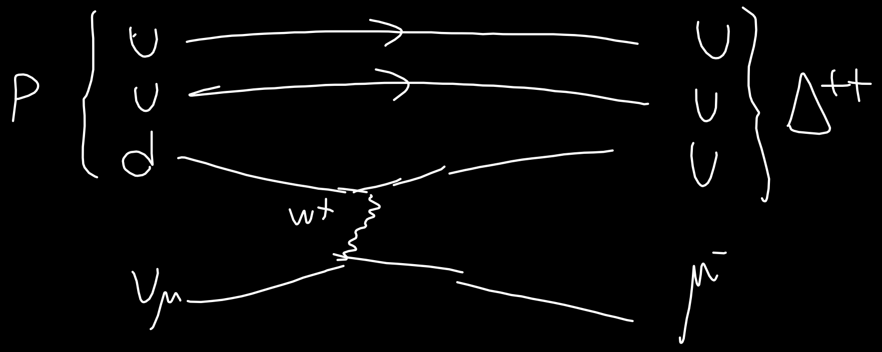
(uuu) $+2/3$

$Q = 3 \times Q_u = +2$

$$\nu_\mu + (uud) \longrightarrow \mu^- + (uuu)$$

$$\nu_\mu \rightarrow W^+ + \mu^-$$

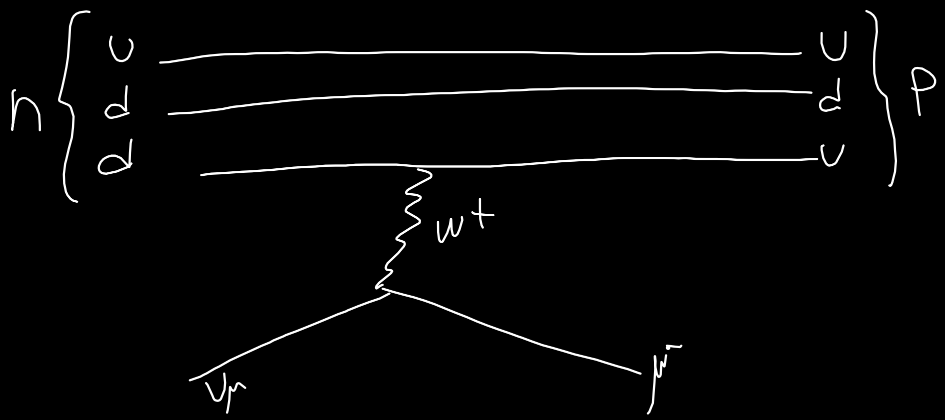
$$d + W^+ \rightarrow u$$



$$\nu_\mu + p \longrightarrow \mu^- + \Delta^{++}$$

$X = n$

$\nu_\mu + (udd) \longrightarrow \mu^- + p$



$A \rightarrow B + C$

$m_A > m_B + m_C$

$$m_\nu = 0$$

$$p_p^\mu = (m_p c, 0, 0, 0)$$

$$p_\nu^\mu = (E_\nu/c, 0, 0, E_\nu/c)$$

$$p_{TOT}^\mu = p_p^\mu + p_\nu^\mu = \left(m_p c + E_\nu/c, 0, 0, E_\nu/c\right)$$

$$(p_{TOT}^\mu)^2$$

$$= \left(m_p c + \frac{E_\nu}{c}\right)^2 - \left(\frac{E_\nu}{c}\right)^2$$

$$= m_p^2 c^2 + 2 m_p E_\nu \simeq 2 m_p E_\nu$$

$$(p^\mu)^2 = \text{"}M_{TOT}\text{"}^2 c^2$$

1.5) $X \longrightarrow A + B$

$\underline{m_A}$ $\underline{\beta_A}$ $\underline{m_B}$

m_X? $\underline{\beta_B}$?

$$p_{z,A} = (1-\beta_A^2)^{-1/2} m_A c$$

$$= (1-\beta_B^2)^{-1/2} m_B c$$

$\beta_B = 0.87$

$$p^\mu_X = (m_X c, \vec{0})$$

$$p^\mu_A = (E_A/c, 0, 0, p_z)$$

$$p^\mu_B = (E_B/c, 0, 0, -p_z)$$

$$m_X c = E_A/c + \frac{E_B}{c}$$

$$\boxed{m_X = 6557 \text{ MeV}/c^2}$$

$$E_A = (1-\beta_A^2)^{-1/2} m_A c^2$$

$$m^2c^2 = \left(E/c\right)^2 - \left(\vec{p}\right)^2$$