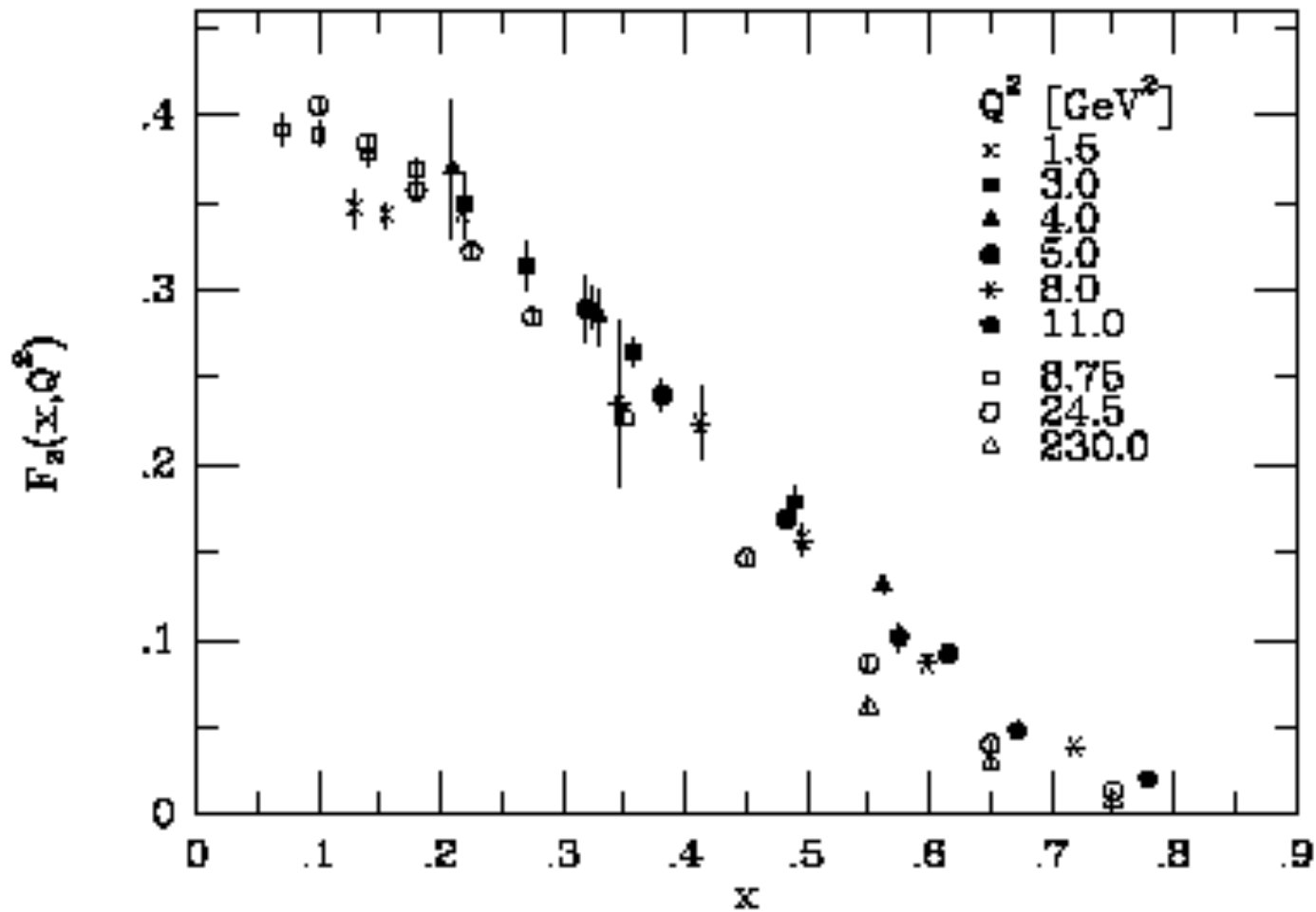
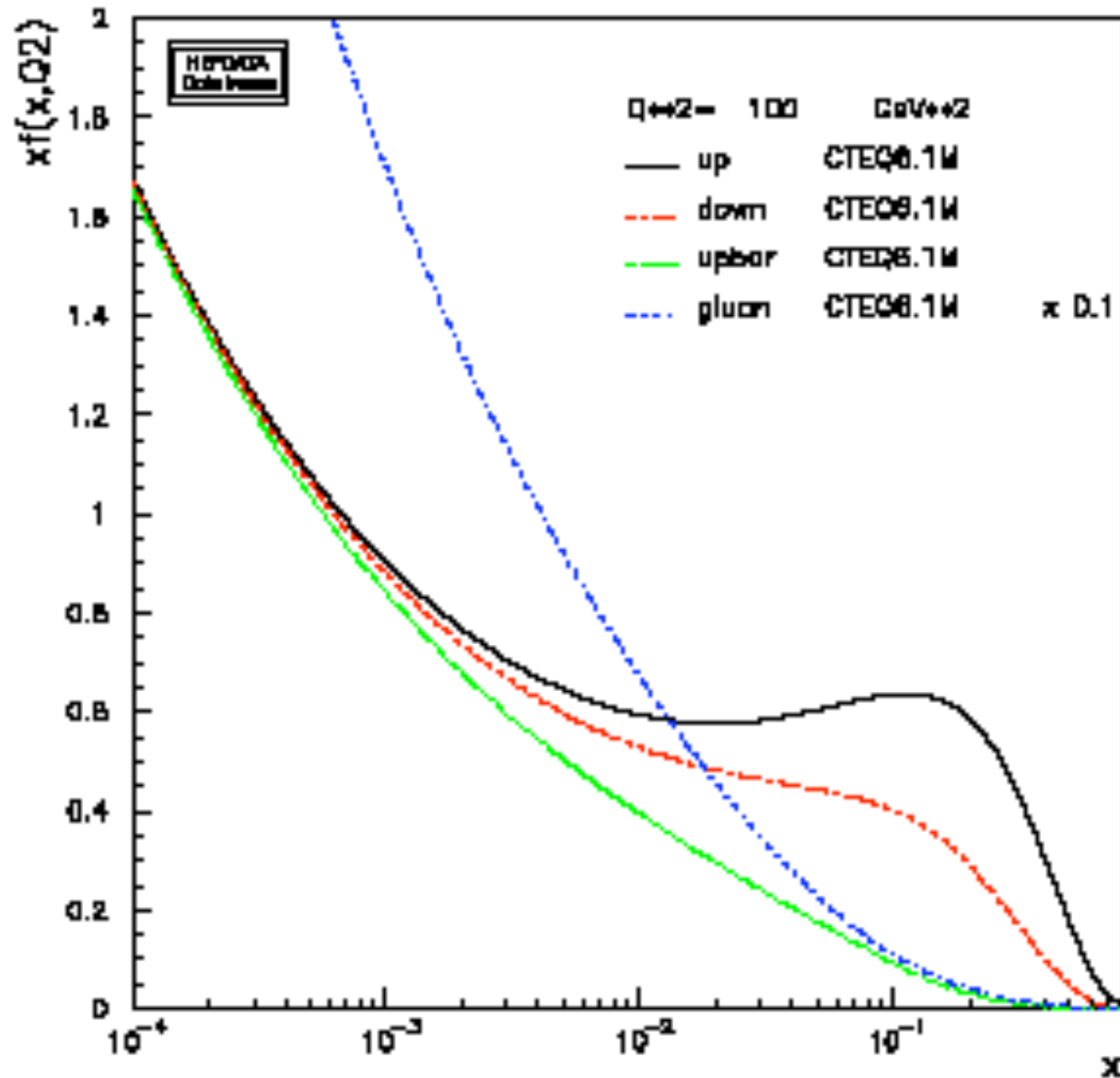


Scaling in F_2



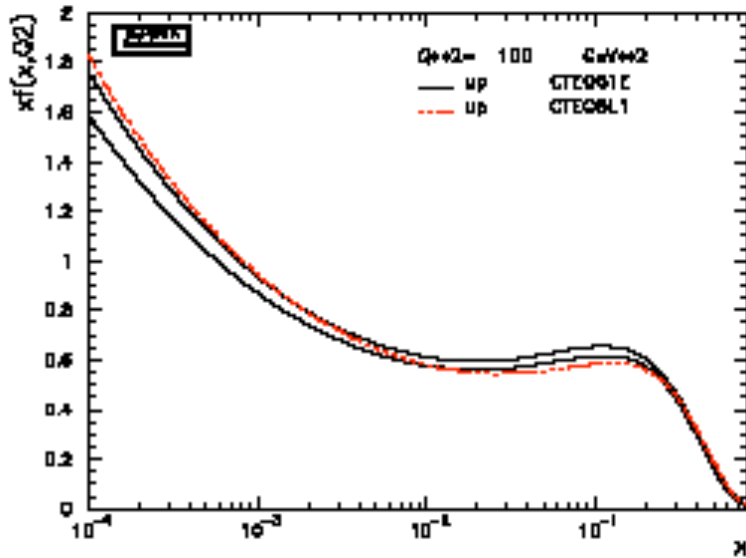
Q^2 varies over 2 orders of magnitude!

Parton Distribution Functions

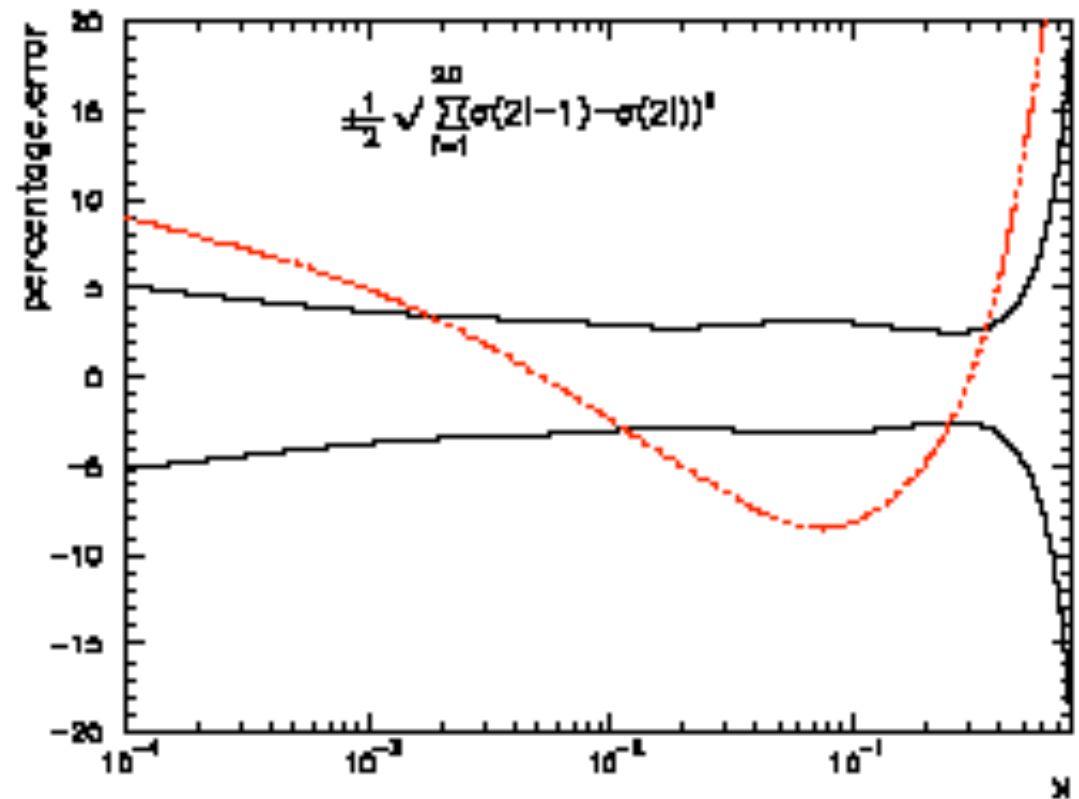


CTEQ 6.1
 $Q^2 = 100 \text{ GeV}^2$

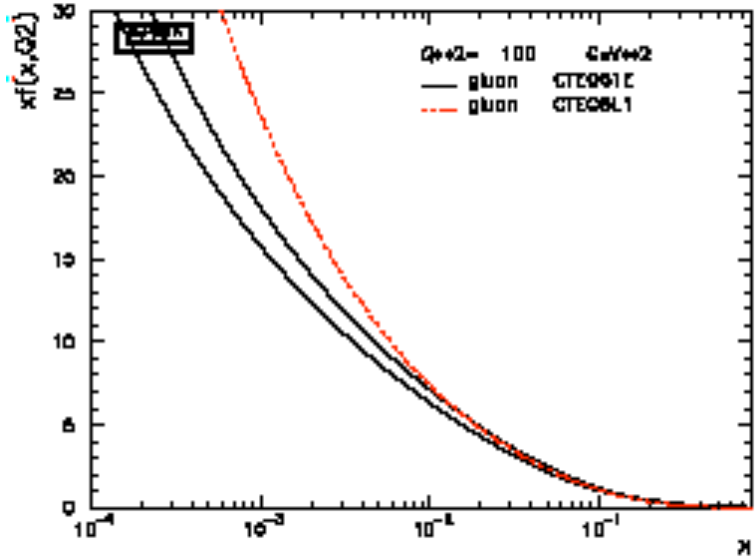
PDF Uncertainties, up quark



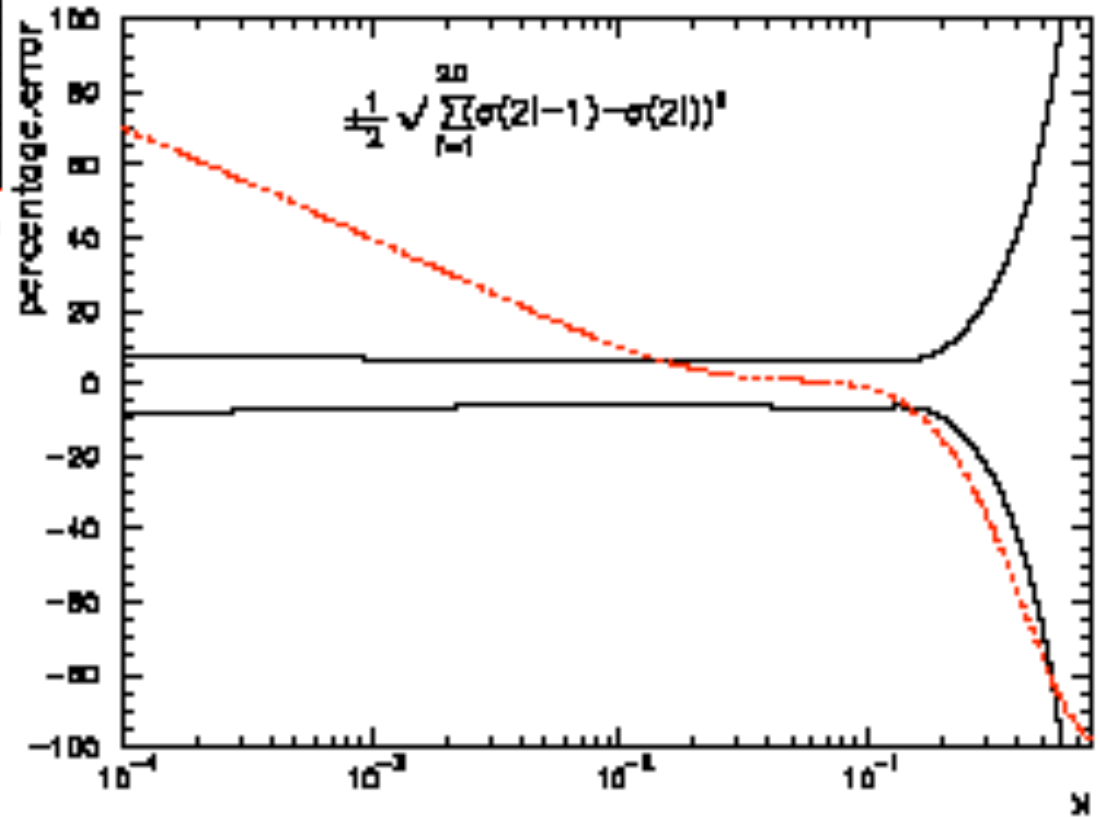
CTEQ 6.1
 $Q^2 = 100 \text{ GeV}^2$



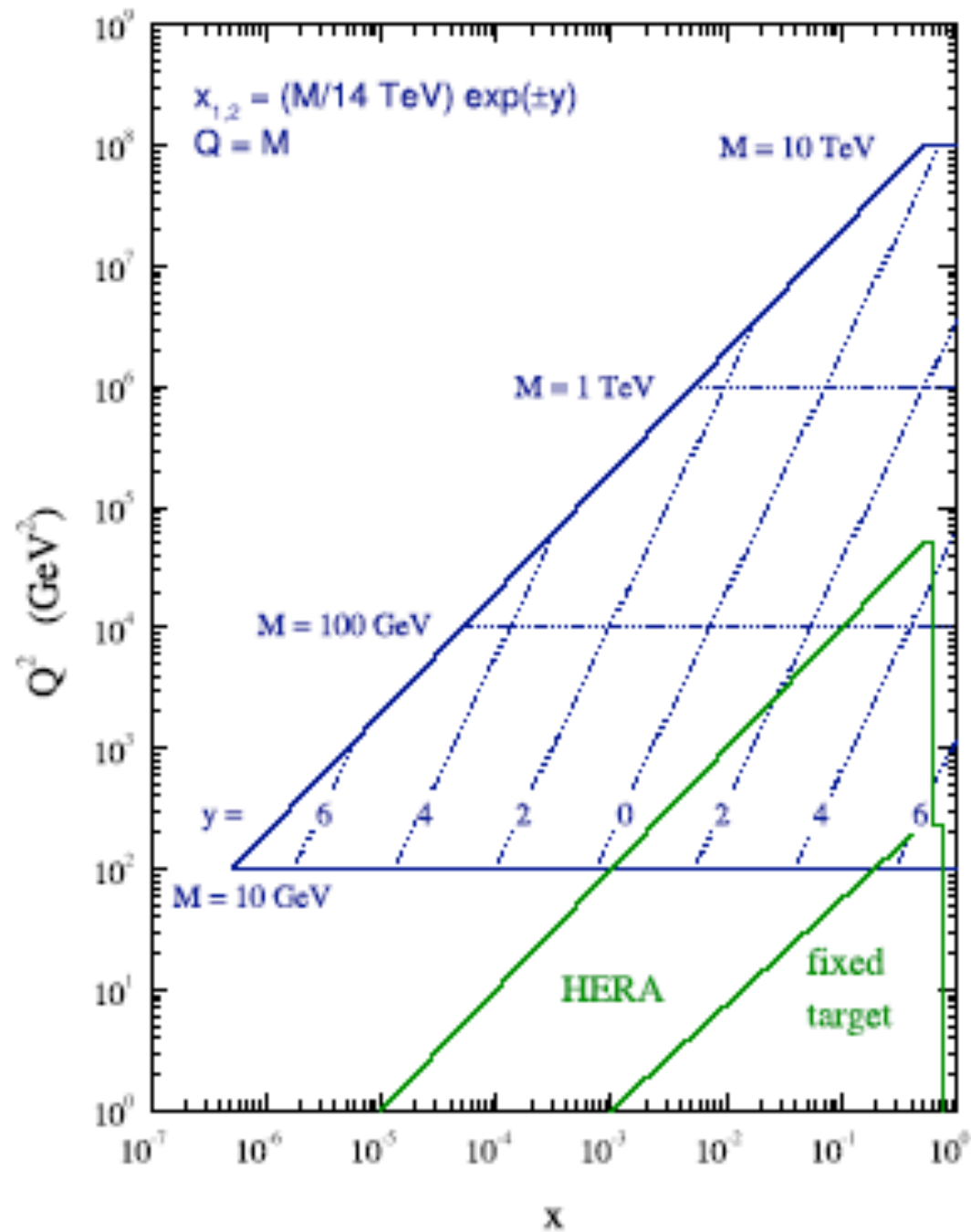
PDF Uncertainties, gluon



CTEQ 6.1
 $Q^2 = 100 \text{ GeV}^2$

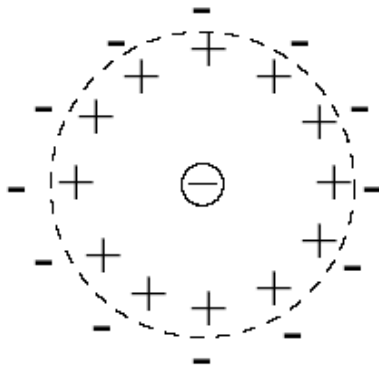


Parton Kinematics for LHC



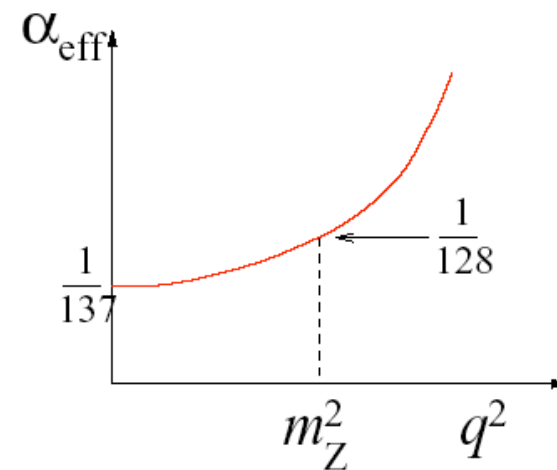
Running coupling constant and charge screening: how it works in QED

- **Vacuum polarization:** particle/antiparticle pairs pop in and out of the vacuum, and get polarized: **charge screening**



- **Measured charge depends on distance, or equivalently, energy, at which it's probed. It increases with increasing energy.**

- **Running of the coupling** $\alpha=e^2/4\pi$ is calculable from diagrams like



Today:

$$q^2 \frac{\partial a_s}{\partial q^2} = -\beta_0 a_s^2 - \beta_1 a_s^3 - \beta_2 a_s^4 - \beta_3 a_s^5 + O(a_s^6)$$

$$\beta_1 = \frac{34}{3} C_A^2 - 4 C_F T_F n_f - \frac{20}{3} C_A T_F n_f$$

$$\beta_2 = \frac{2857}{54} C_A^3 + 2 C_F^2 T_F n_f - \frac{205}{9} C_F C_A T_F n_f - \frac{1415}{27} C_A^2 T_F n_f + \frac{44}{9} C_F T_F^2 n_f^2 + \frac{158}{27} C_A T_F^2 n_f^2$$

$$\begin{aligned} \beta_3 = & C_A^4 \left(\frac{150653}{486} - \frac{44}{9} \zeta_3 \right) + C_A^3 T_F n_f \left(-\frac{39143}{81} + \frac{136}{3} \zeta_3 \right) \\ & + C_A^2 C_F T_F n_f \left(\frac{7073}{243} - \frac{656}{9} \zeta_3 \right) + C_A C_F^2 T_F n_f \left(-\frac{4204}{27} + \frac{352}{9} \zeta_3 \right) \\ & + 46 C_F^3 T_F n_f + C_A^2 T_F^2 n_f^2 \left(\frac{7930}{81} + \frac{224}{9} \zeta_3 \right) + C_F^2 T_F^2 n_f^2 \left(\frac{1352}{27} - \frac{704}{9} \right) \\ & + C_A C_F T_F^2 n_f^2 \left(\frac{17152}{243} + \frac{448}{9} \zeta_3 \right) + \frac{424}{243} C_A T_F^3 n_f^3 + \frac{1232}{243} C_F T_F^3 n_f^3 \\ & + \frac{d_A^{abcd} d_A^{abcd}}{N_A} \left(-\frac{80}{9} + \frac{704}{3} \zeta_3 \right) + n_f \frac{d_F^{abcd} d_A^{abcd}}{N_A} \left(\frac{512}{9} - \frac{1664}{3} \zeta_3 \right) \\ & + n_f^2 \frac{d_F^{abcd} d_F^{abcd}}{N_A} \left(-\frac{704}{9} + \frac{512}{3} \zeta_3 \right) \end{aligned}$$

4 loops!

QCD running coupling today:

