

# Scalar coupling evolution in a non-perturbative QCD resummation scheme

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ITM

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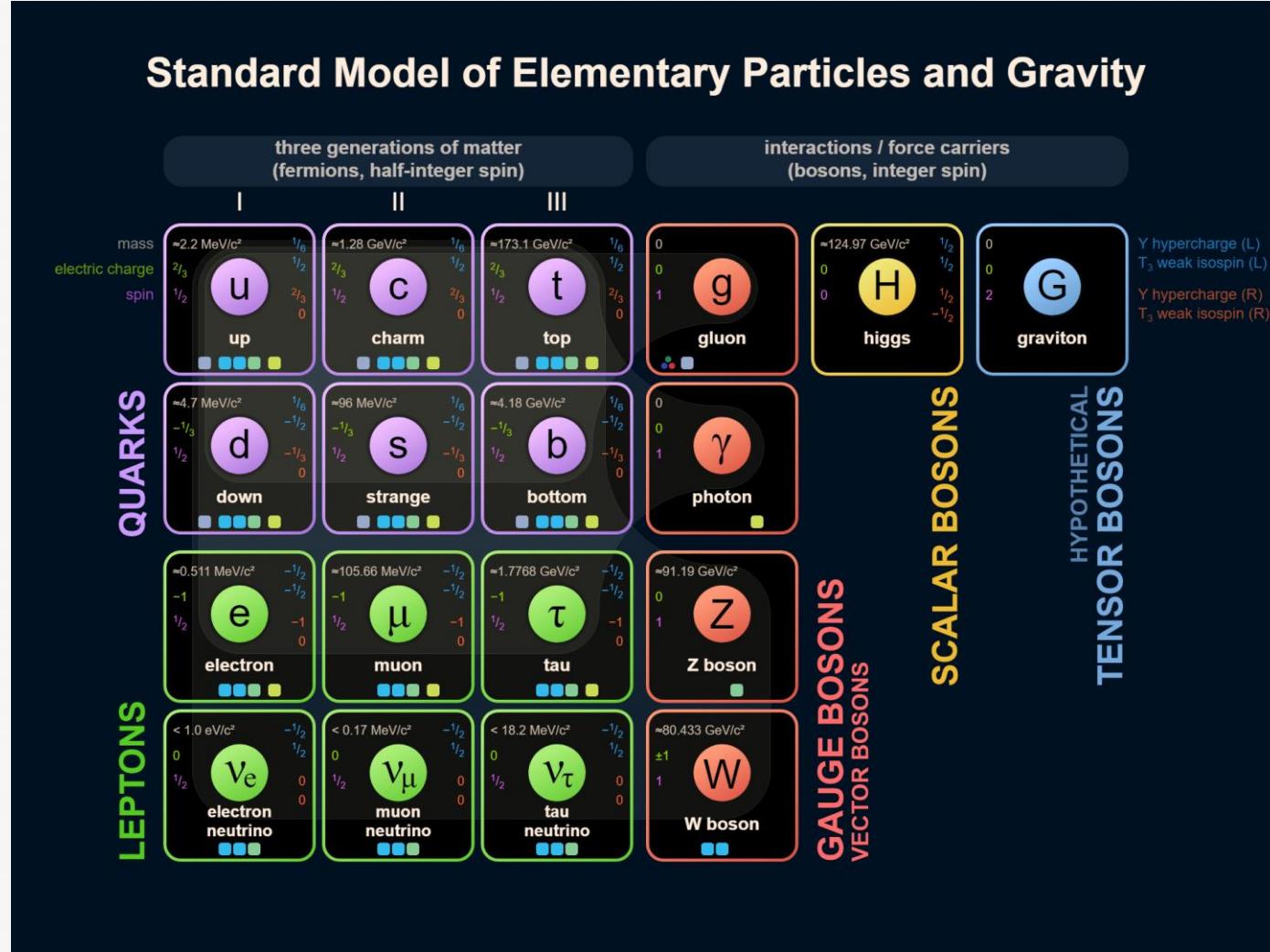
7th ComHEP: Colombian Meeting on  
High Energy Physics

# OUTLINE

- Introduction
- SM Stability
- Conclusion

# Introduction

## Standard Model of Elementary Particles and Gravity

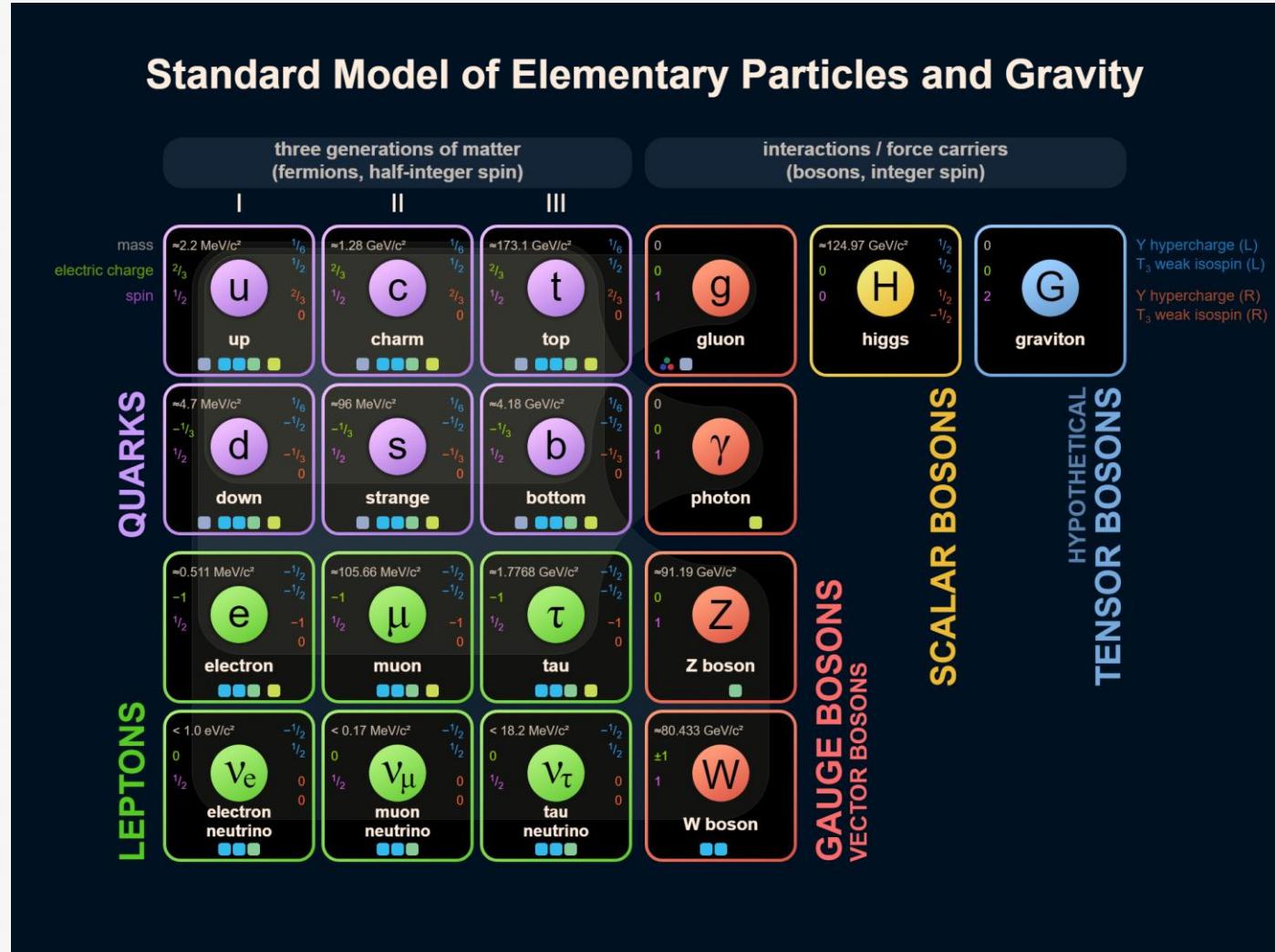


$$SU(3)_c \times SU(2)_L \times U(1)_Y$$

From Wikimedia Commons

# Introduction

## Standard Model of Elementary Particles and Gravity



From Wikimedia Commons

$$SU(3)_c \times SU(2)_L \times U(1)_Y$$

↓

QCD

↓

EW Theory

# Introduction

## Quantum Chromodynamics (QCD)

$$\mathcal{L} = \sum_q \bar{\psi}_{q,a} (i\gamma^\mu \partial_\mu \delta_{ab} - g_s \gamma^\mu t^C_{ab} \mathcal{A}_\mu^C - m_q \delta_{ab}) \psi_{q,b} - \frac{1}{4} F_{\mu\nu}^A F^{A\mu\nu} \quad F_{\mu\nu}^A = \partial_\mu \mathcal{A}_\nu^A - \partial_\nu \mathcal{A}_\mu^A - g_s f_{ABC} \mathcal{A}_\mu^B \mathcal{A}_\nu^C$$

The first hint of color was the  $\Delta^{++}$  baryon found in 1951

$$\Delta^{++} = u \uparrow u \uparrow u \uparrow$$

- Fermion (Spin-3/2)
- Symmetric in space, spin & flavour
- Antisymmetric in what?

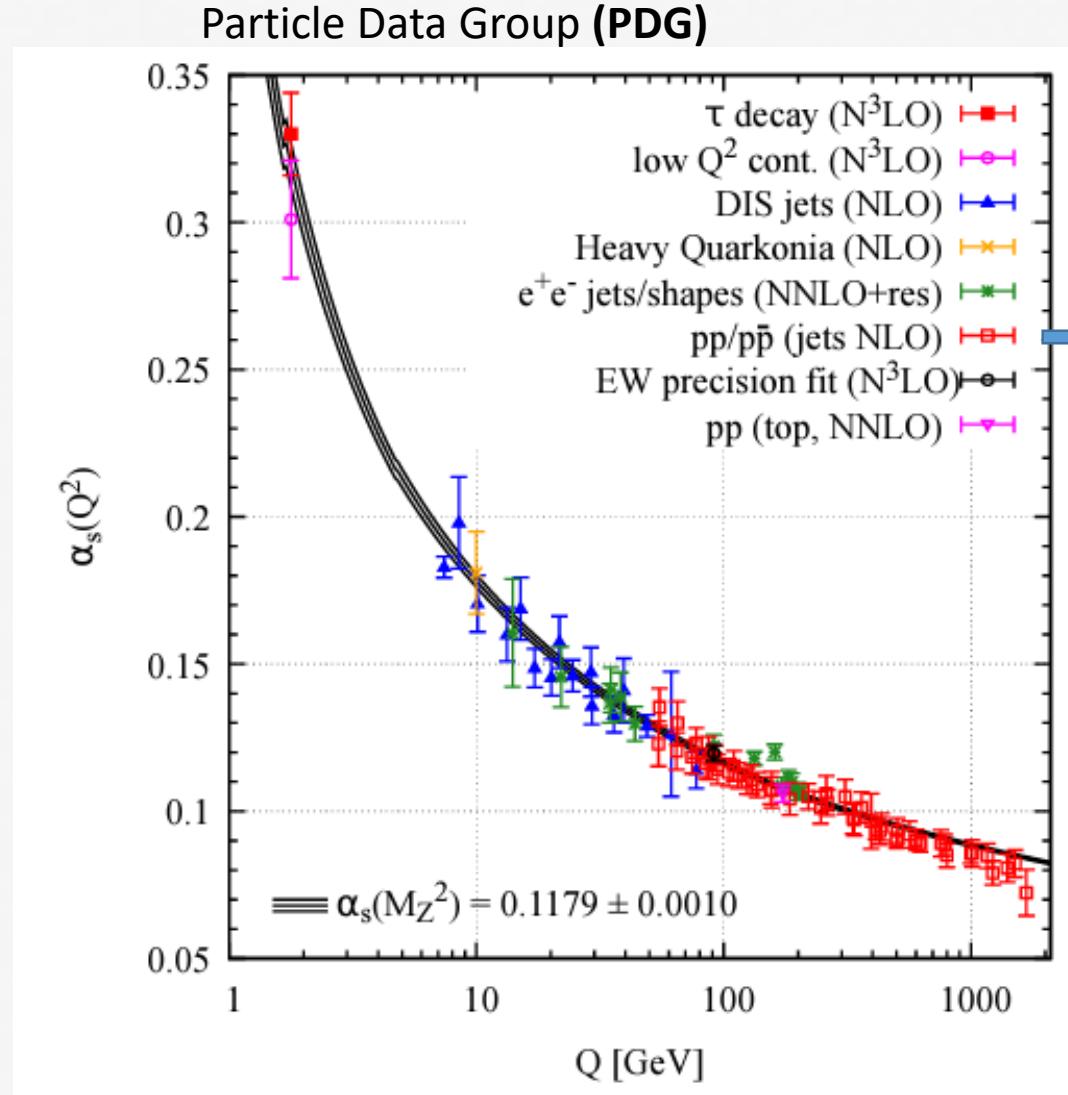
Is the Pauli Exclusion principle violated?

1965 – Introduction of color as a new quantum number

Direct experimental test

- Decay width of  $\pi^0 \rightarrow \gamma\gamma \sim N_c^2$
- R ratio in  $e^+e^- \sim N_c$

# Introduction



1-Loop

$$\alpha_s(Q^2) = \frac{1}{\beta_0 \ln(Q^2/\Lambda_{QCD}^2)}$$

Small coupling

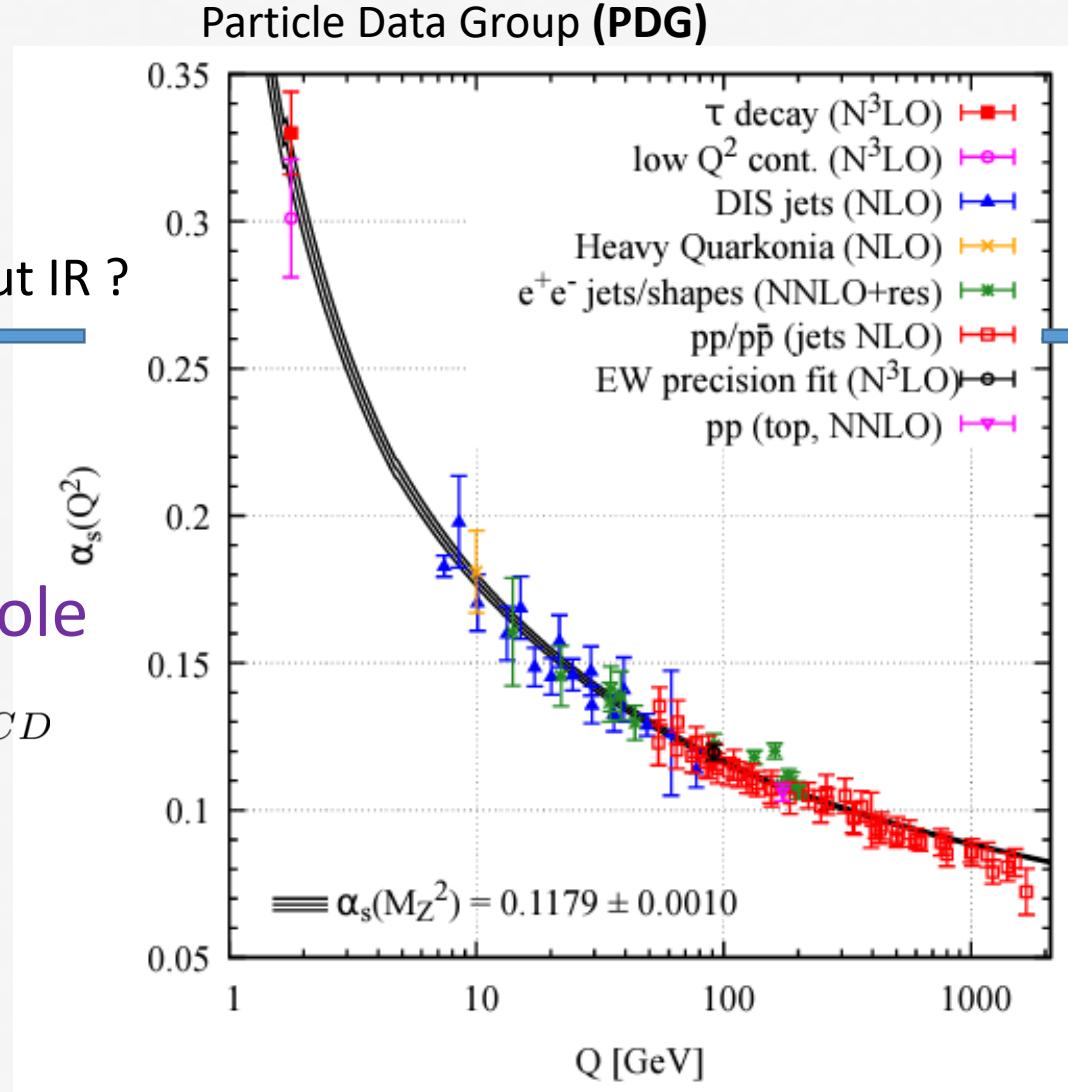
$$Q^2 \gg \Lambda_{QCD}^2$$

# Introduction

What about IR ?

Landau Pole

$$Q^2 \approx \Lambda_{QCD}^2$$



Asymptotic Freedom

1-Loop

$$\alpha_s(Q^2) = \frac{1}{\beta_0 \ln(Q^2/\Lambda_{QCD}^2)}$$

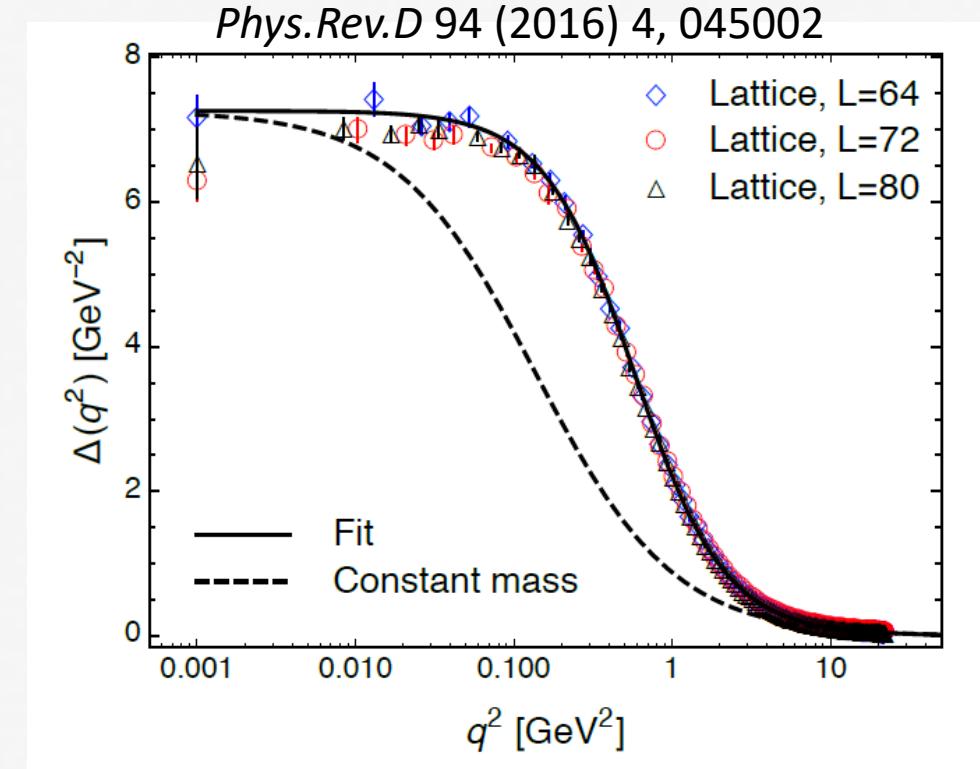
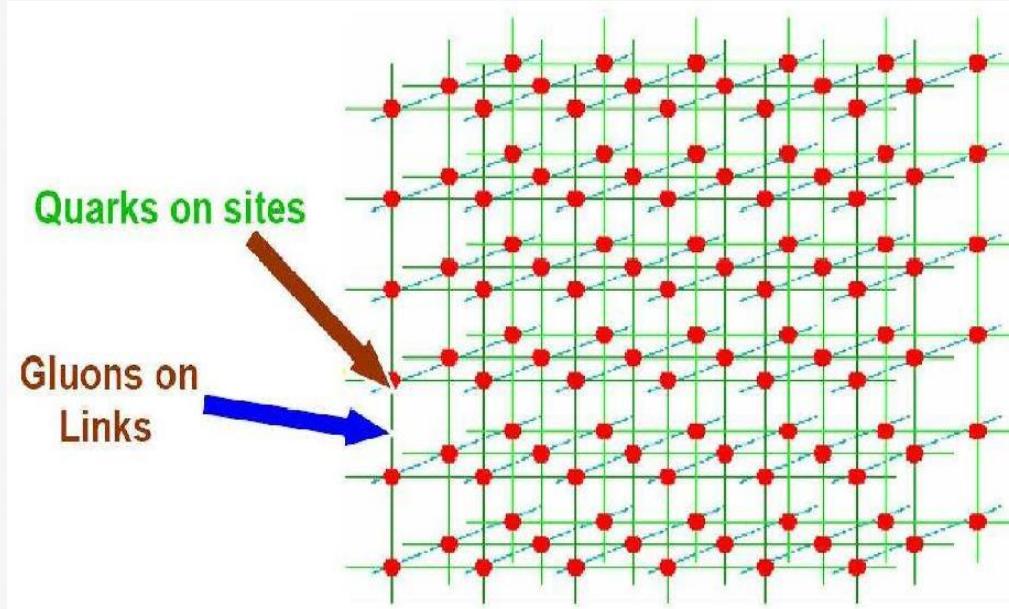
Small coupling

$$Q^2 \gg \Lambda_{QCD}^2$$

# Introduction

## Non perturbative Physics

### Lattice QCD



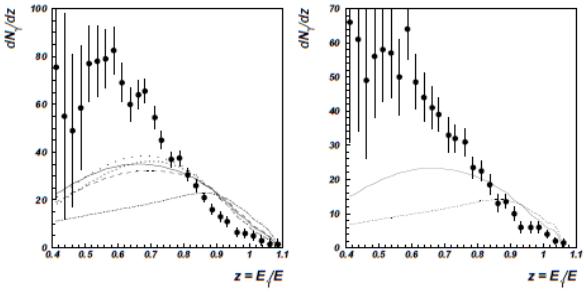
$$\Delta^{-1}(q^2) = m^2 + q^2 \left[ 1 + \frac{13C_A g_f^2}{96\pi^2} \ln \left( \frac{q^2 + \rho m^2}{\mu^2} \right) \right]$$

$$d(q^2) = g^2 \Delta(q^2)$$

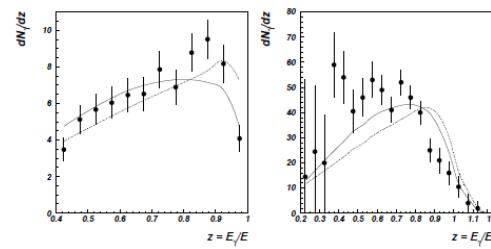
# Introduction

$$J/\psi \rightarrow \gamma X$$

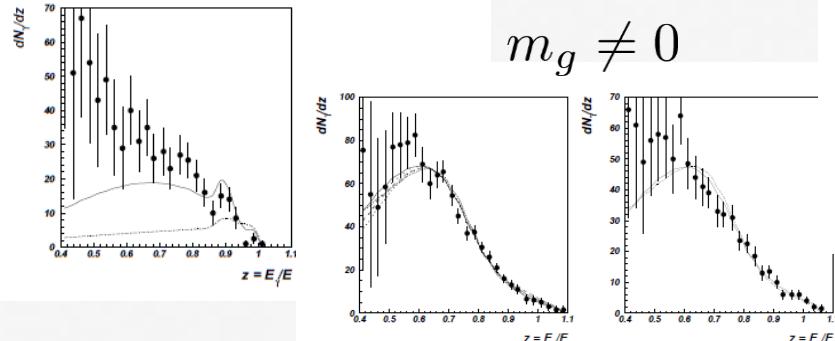
$$m_g = 0$$



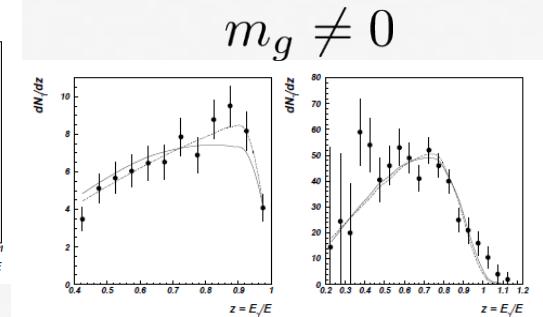
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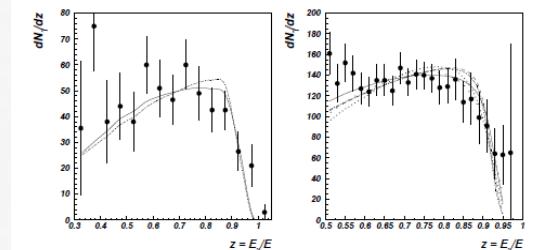
$$\Upsilon \rightarrow \gamma X$$



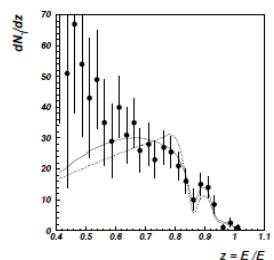
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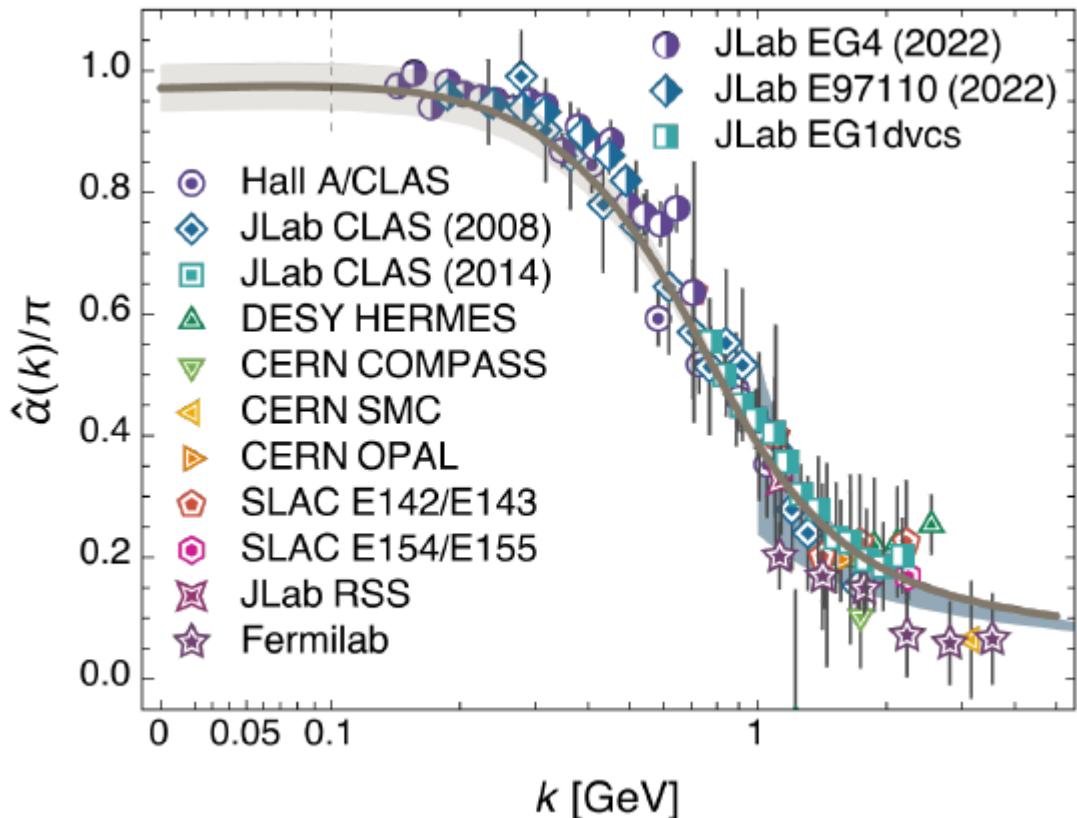


PRD 66, (2002) 013013



# Introduction

## Non perturbative Physics



Chin. Phys. C **2020**, 44, 083102.  
 Particles **2022**, 5, 171.

Evidences for a finite coupling:

- Jet shapes observables Dokshitzer, Weber,....  
 $PLB$  352 (352)451,  $Nucl.Phys.B$  469(1996)93
- Quarkonium potential models Godfrey, Isgur, PRD 32(1985)189; Einchen, et al.  $PRL$  34(1974)369;....
- Optimized perturbation theory Mattingly and Stevenson,  $PRL$  69(1992)1320,  $PRD$  49(1994)437
- Quarkonium fine structure Badalian, Simov, Baker,...  
 $PRD$  60(1990)116008,  $PRD$  62(2000)0944031
- Unpolarized proton structure function Courtois, Liuti,  $PLB$  726(2013)320

# Introduction

Swinger-Dyson-Equations  
(SDE)



Gauge invariant solutions for  
propagators and vertices

Pinch Technique

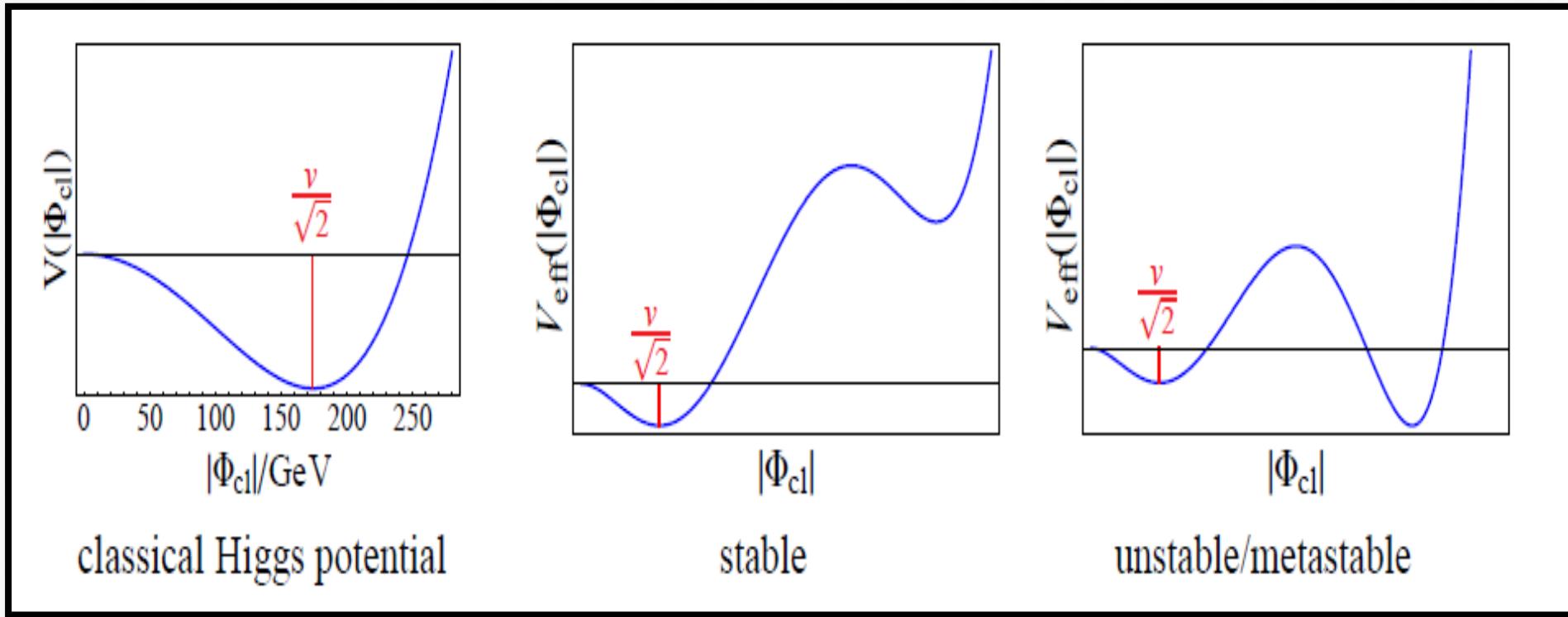
Cornwall, Aguilar, Binosi, Papavassiliou, et al .....

an effective infrared finite QCD charge

$$\alpha_s(Q^2) = \left[ 4\pi\beta_0 \ln \left( \frac{Q^2 + 4m_g^2(Q^2)}{\Lambda^2} \right) \right]^{-1}$$

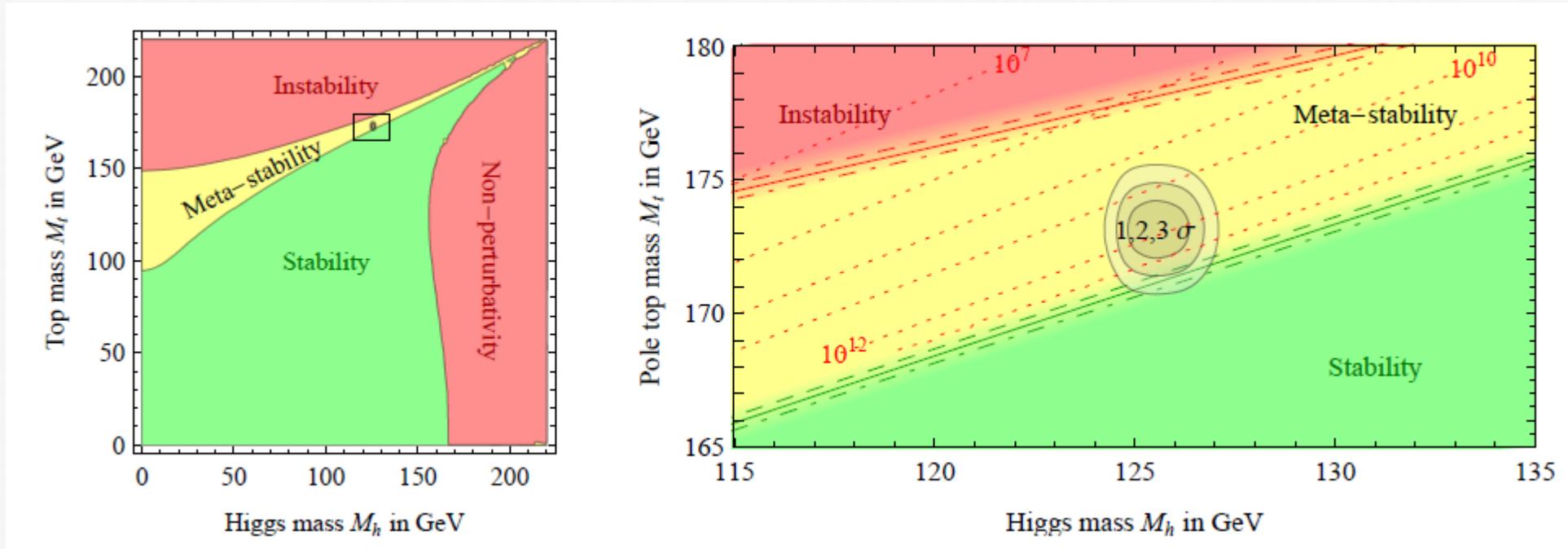
Cornwall, PRD 26(1982)1453

# SM Stability



*PoS(LL2014)014*

# SM Stability



JHEP 08 (2012) 09

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13

# SM Stability

$$\alpha_s(Q^2) = \frac{1}{4\pi\beta_0 \ln \left( \frac{Q^2 + 4m_g^2(Q^2)}{\Lambda_{QCD}} \right)}$$

$$0.4 \leq \alpha_s(0) \leq 0.8$$

$$m_g^2(Q^2) \approx \frac{m_g^4}{Q^2 + m_g^2}$$

$$1.2 \leq \frac{m_g}{\Lambda_{QCD}} \leq 2.86$$

$$\boxed{\beta_i(\alpha_i) = \mu^2 \frac{d}{d\mu^2} \alpha_i(\mu)}$$

$$\mu = M_t$$

Initial  
conditions

K.G. Chetyrkin, M.F. Zoller  
JHEP 1304(2013)091

$$M_t = 172.9 \pm 0.6 \pm 0.9$$

$$\alpha_s(M_Z) = 0.1185 \pm 0.0007$$

# SM Stability

one loop beta functions in the  $\overline{\text{MS}}$  scheme

$$\beta_\lambda = \frac{1}{(4\pi)^2} \left[ 24\lambda^2 - 6y_t^4 + \frac{3}{8}(2g_2^4 + (g_2^2 + g_1^2)^2) - (9g_2^2 + 3g_1^2 - 12y_t^2)\lambda \right] \rightarrow \text{Scalar coupling}$$

$$\beta_{y_t} = \frac{y_t}{(4\pi)^2} \left[ -\frac{9}{4}g_2^2 - \frac{17}{12}g_1^2 - 8g_3^2 + \frac{9}{2}y_t^2 \right], \rightarrow \text{Yukawa top quark}$$

$$\beta_{g_1} = \frac{1}{(4\pi)^2} \frac{41}{6} g_1^3 \rightarrow \text{U(1)}$$

$$\beta_{g_2} = \frac{1}{(4\pi)^2} \frac{-19}{6} g_2^3 \rightarrow \text{SU(2)}$$

$$\beta_{g_3} = -\beta_0 g^3 \rightarrow \text{SU(3)}$$

$$\beta_0 = \frac{11N - 2n_q}{48\pi^2}$$

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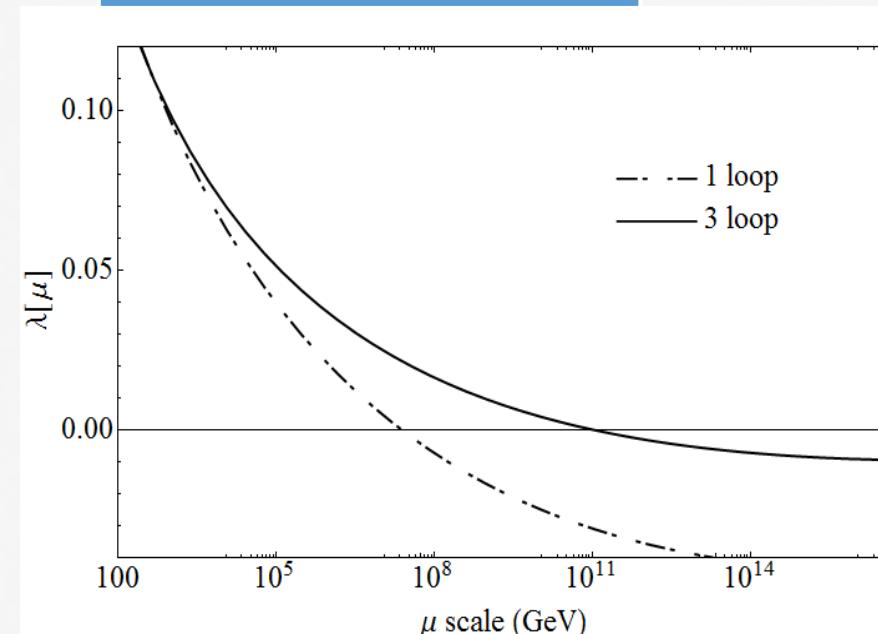
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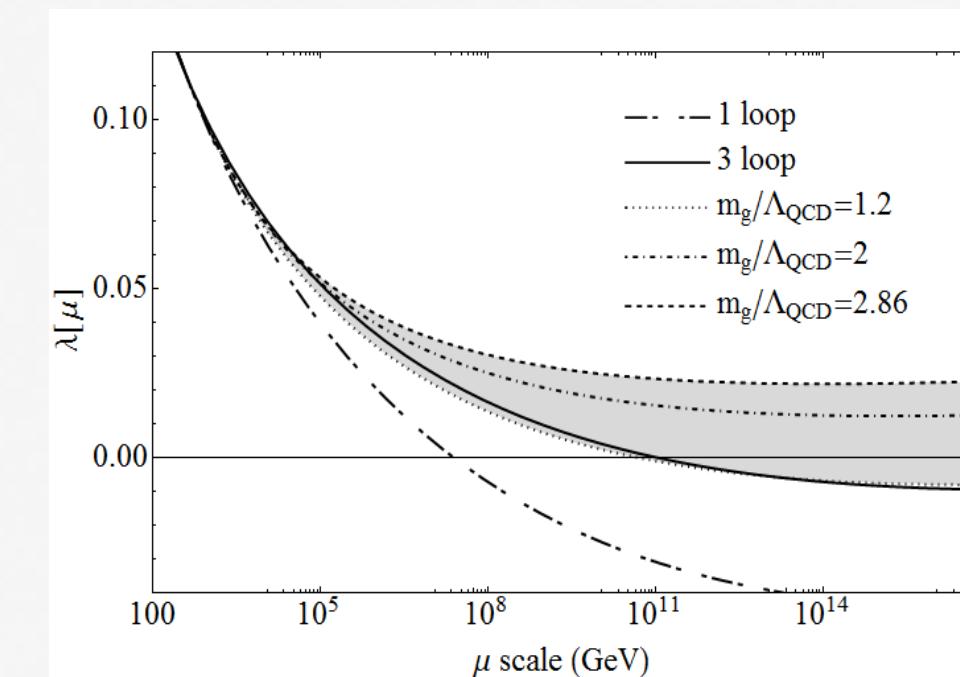
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$$\beta_{g_3} = -\beta_0 g^3 \frac{e^t}{e^t + 4\frac{m_g^2(t)}{\Lambda^2}} \left( 1 - \frac{4}{e^t + \frac{m_g^2}{\Lambda^2}} \frac{m_g^2(t)}{\Lambda^2} \right)$$

NP QCD coupling constant



# SM Stability

$$\hat{\alpha}(k^2) = \frac{\gamma_m \pi}{\ln \left[ \mathcal{K}^2(k^2) / \Lambda_{\text{QCD}}^2 \right]}, \quad \mathcal{K}^2(y = k^2) = \frac{a_0^2 + a_1 y + y^2}{b_0 + y}$$



$\beta$ -function ?

$$\lambda(\mu) \leq 0, ?$$



**Portals into Higgs Stability**

Arxiv:2207.07737

# Conclusion

- We found several values of  $m_g/\lambda$  that stabilized the Standard Model (SM) potential up to the Planck scale.

**THANKS!**