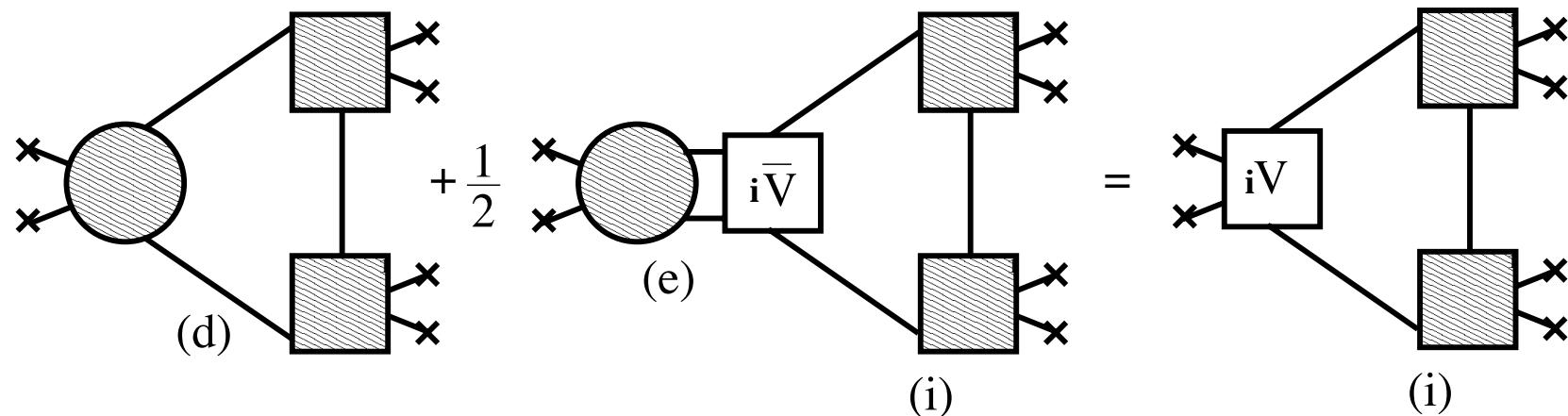
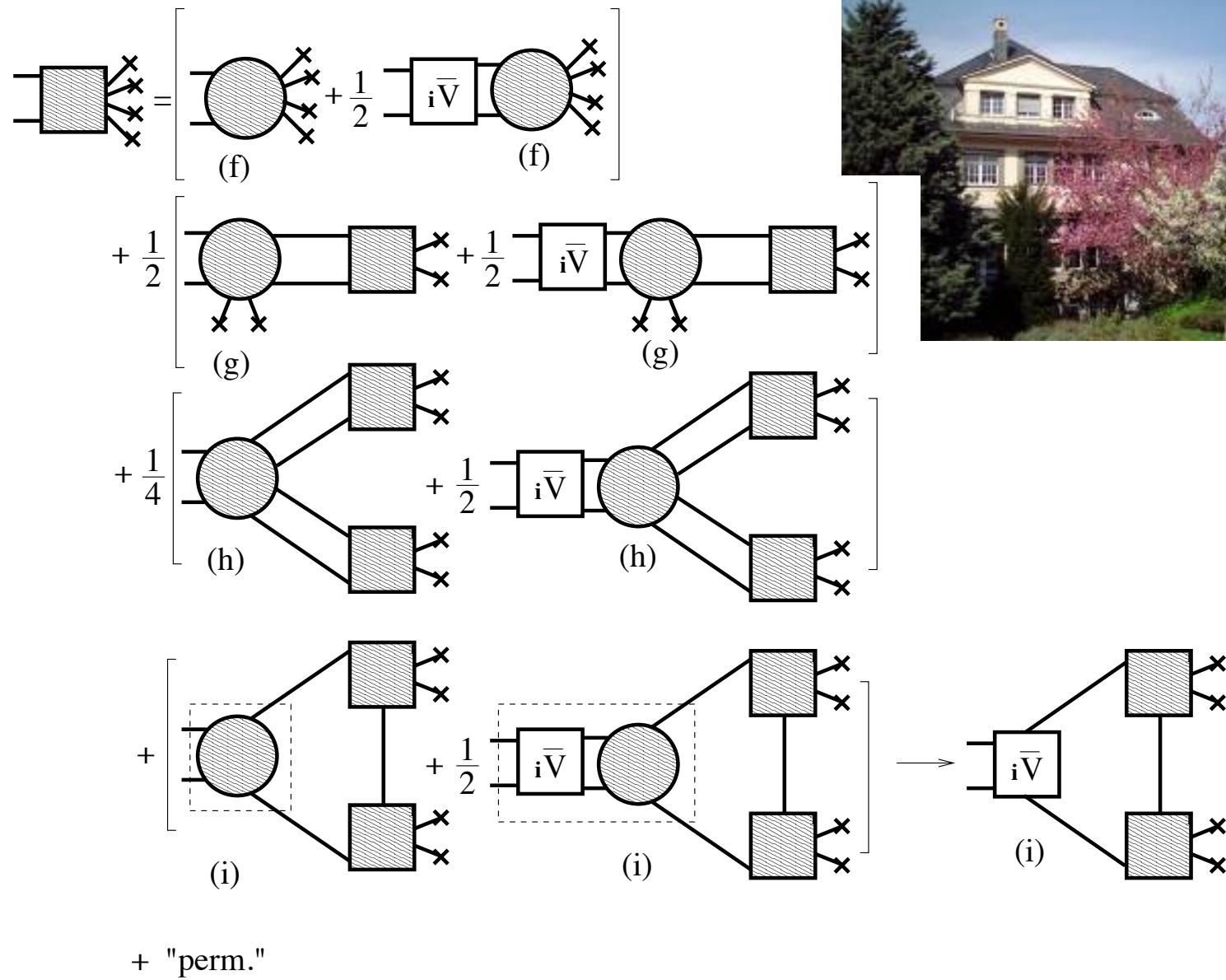
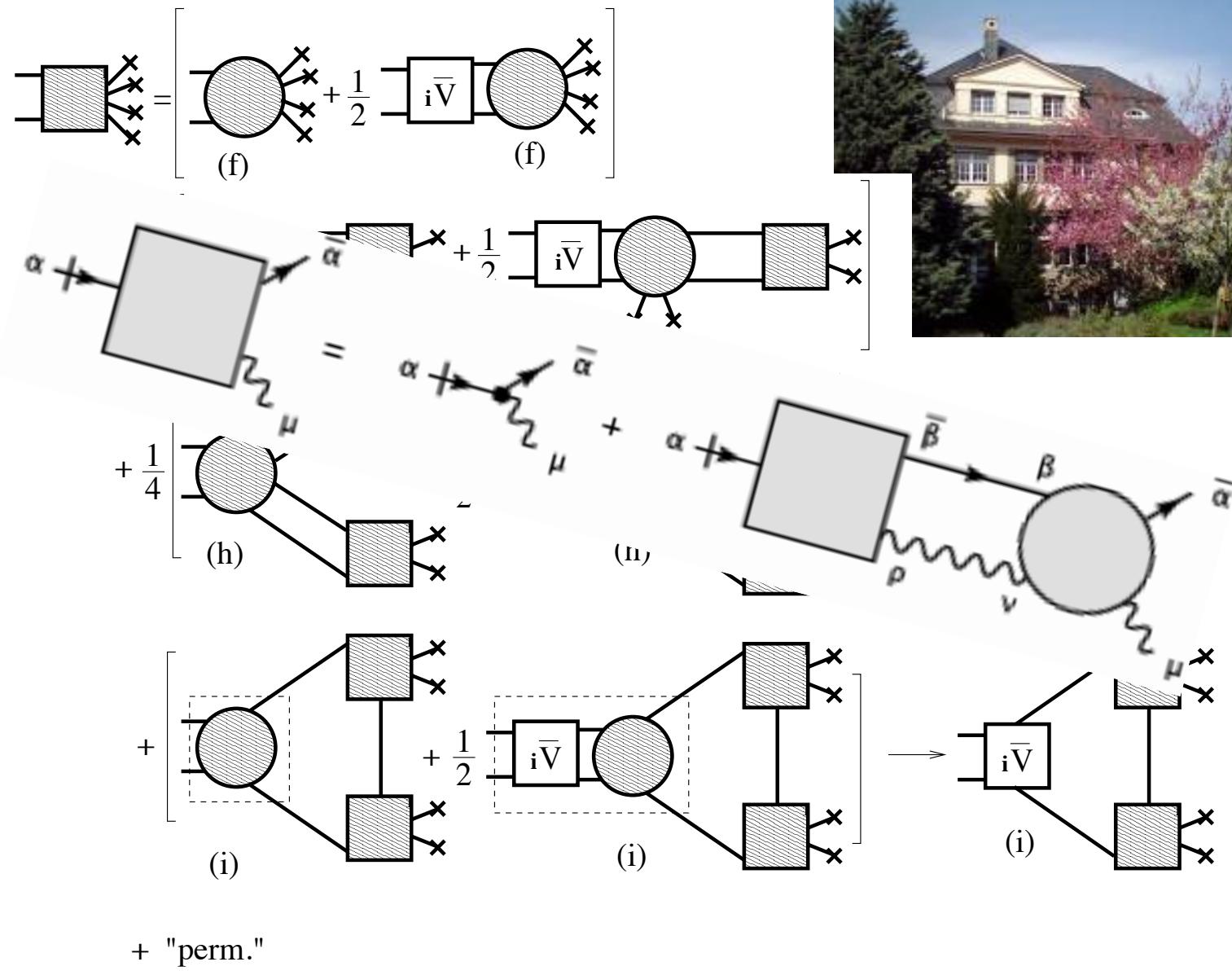


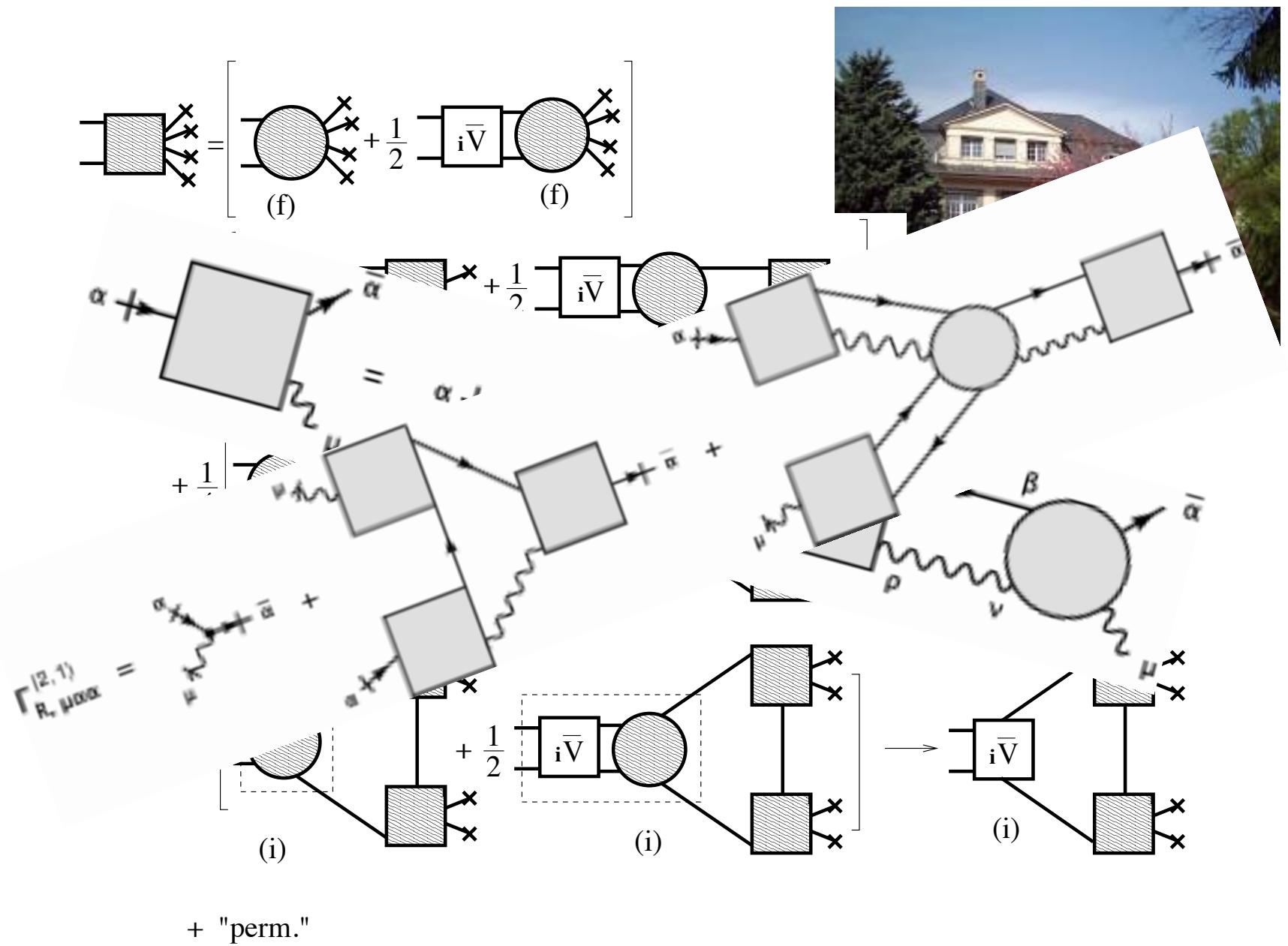
THE M~~A~~<sup>X</sup>SS OF THE GLUE

Back in the days  
(Heidelberg, 2002...)

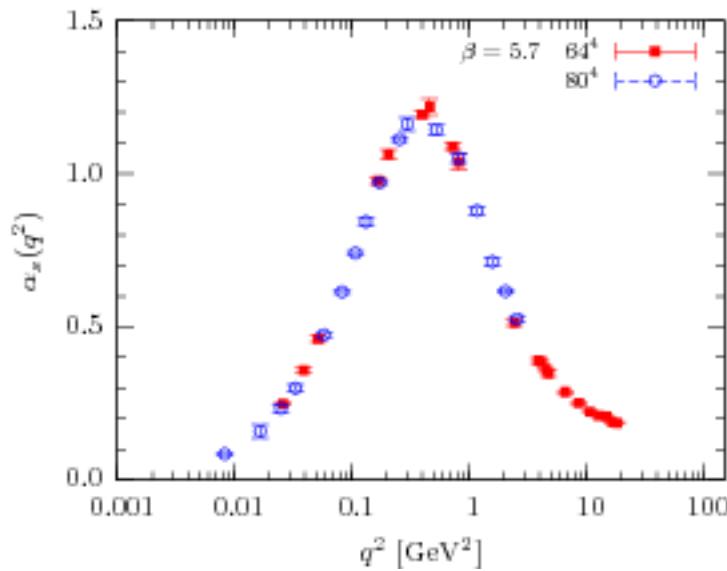
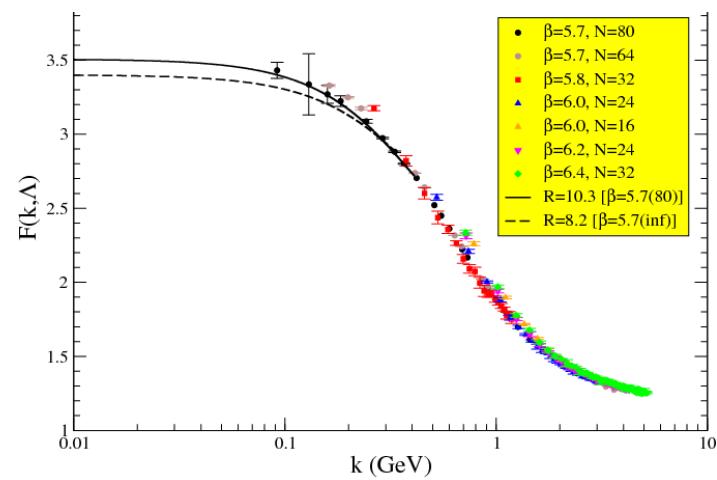
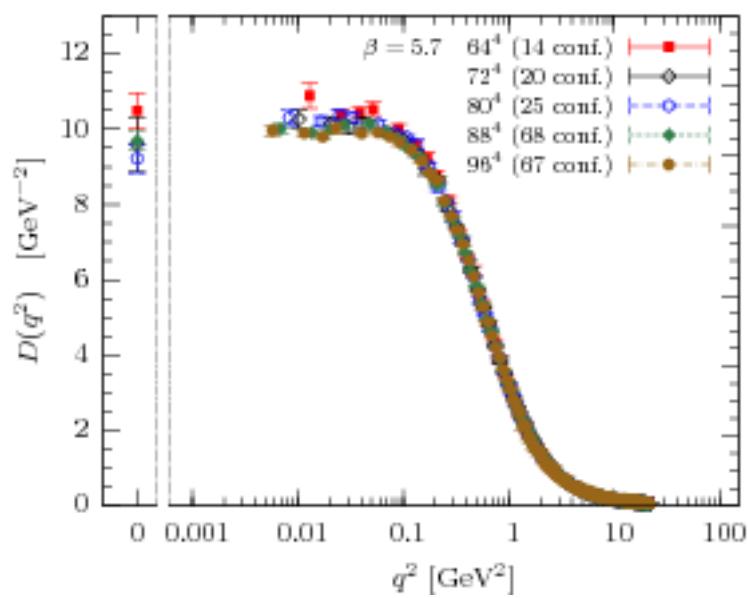




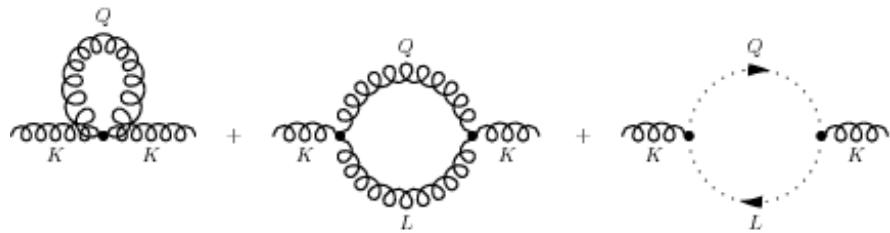




Meanwhile,  
on the lattice ...

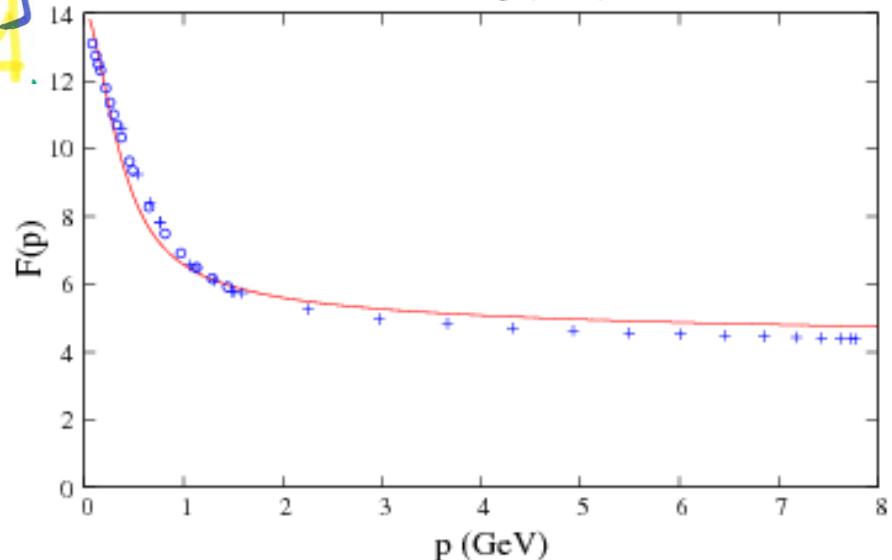
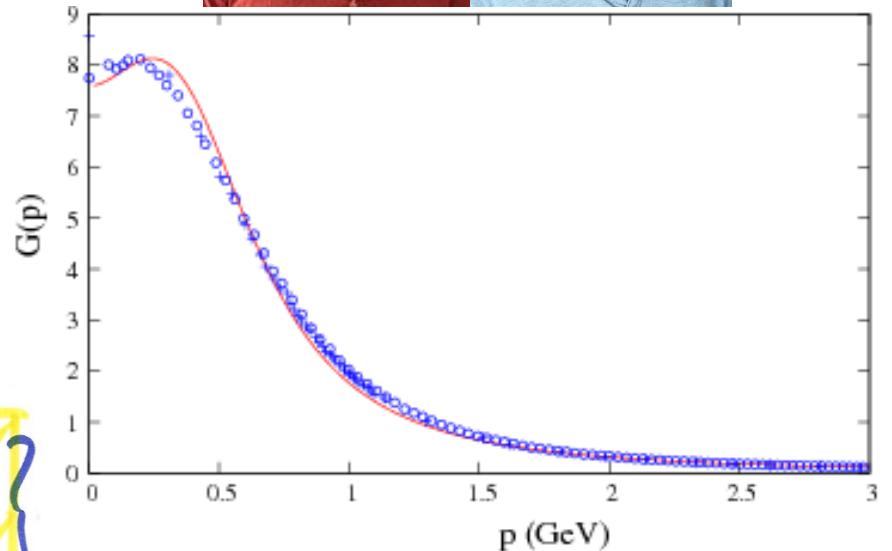
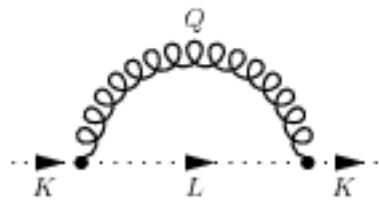


# A BREAKTHROUGH (2010)



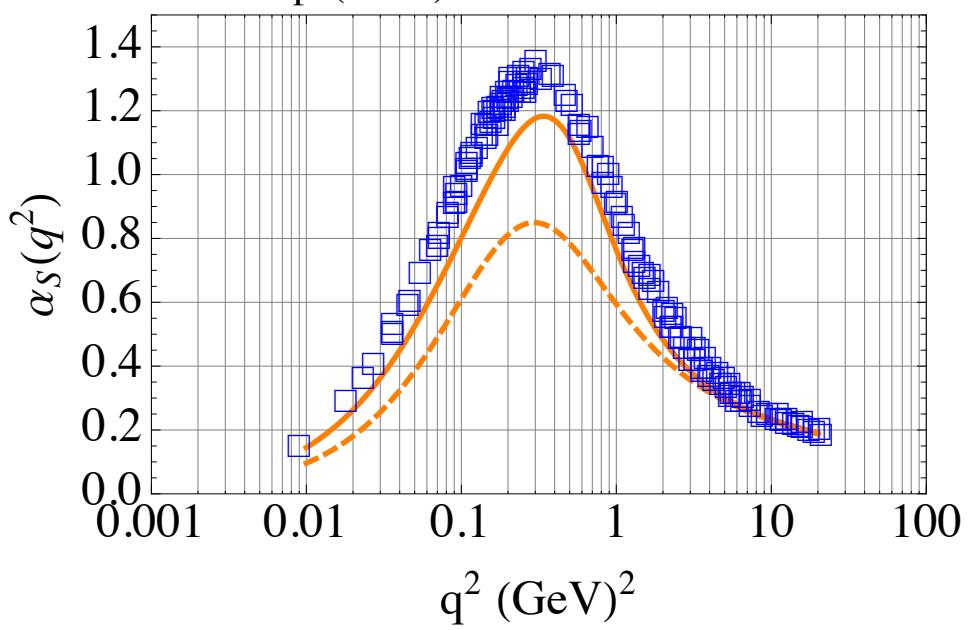
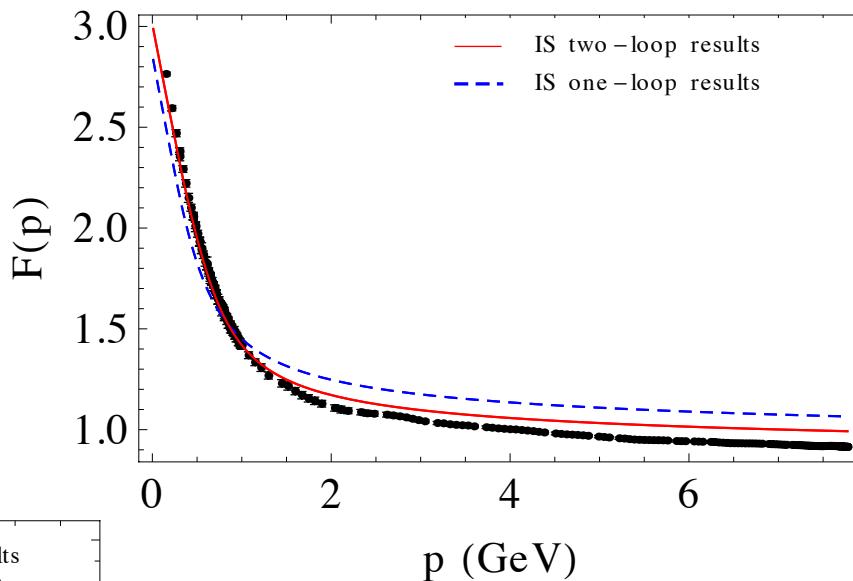
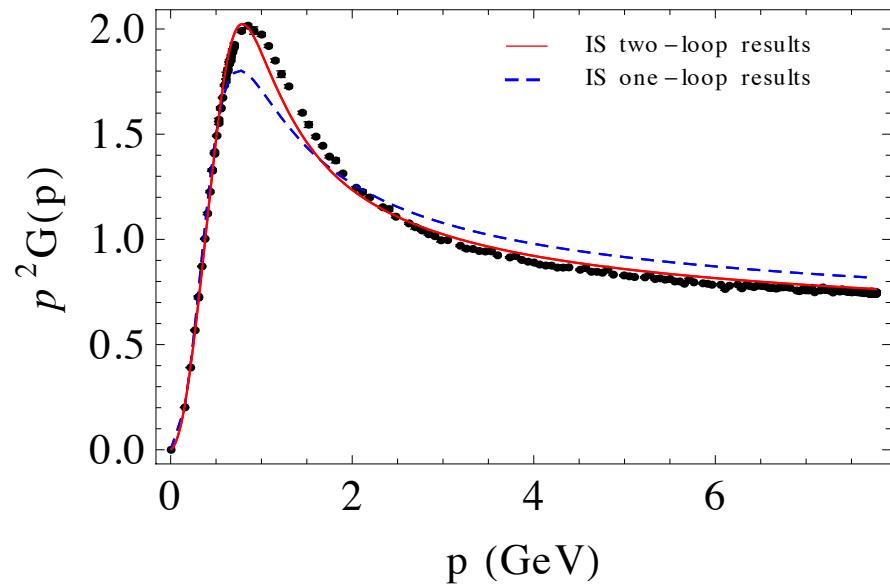
$$S = \int_x \left\{ \frac{E^2}{4} + i \hbar \partial A + \bar{D} \bar{C} D C + \frac{m^2}{2} A^2 \right\}$$

*Faddeev-Popov*

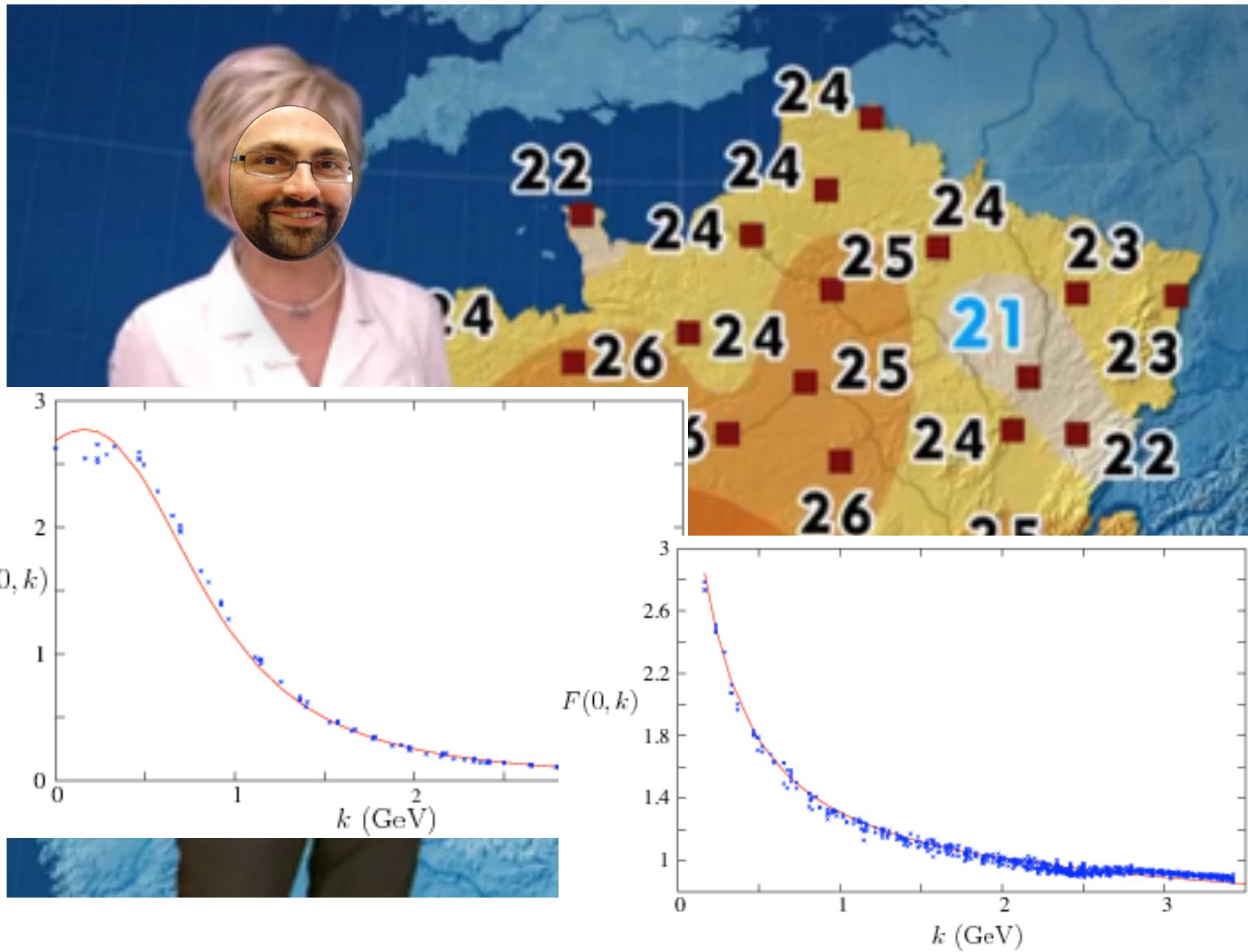


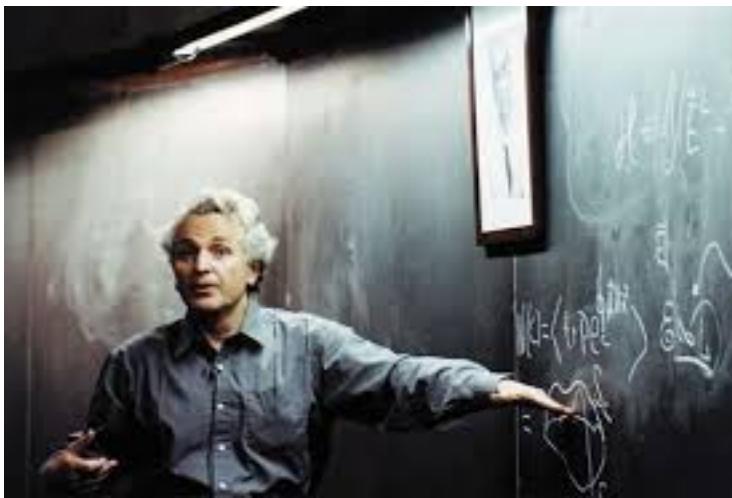


Two Loop



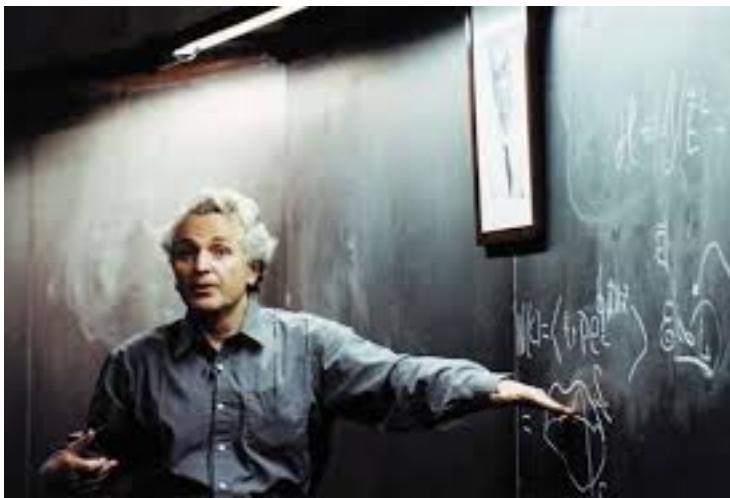






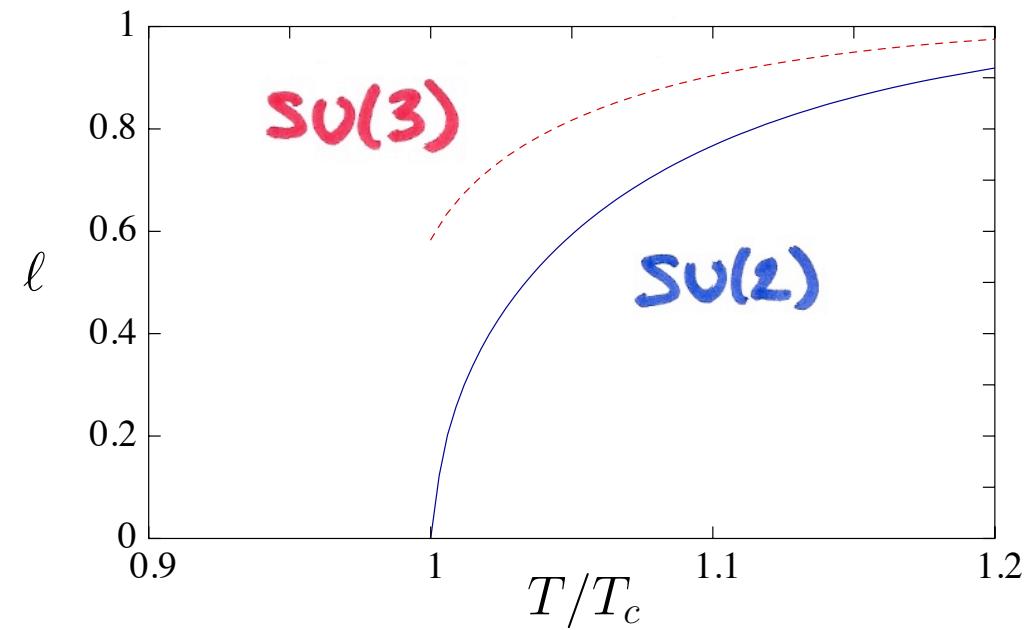
The Polyakov loop

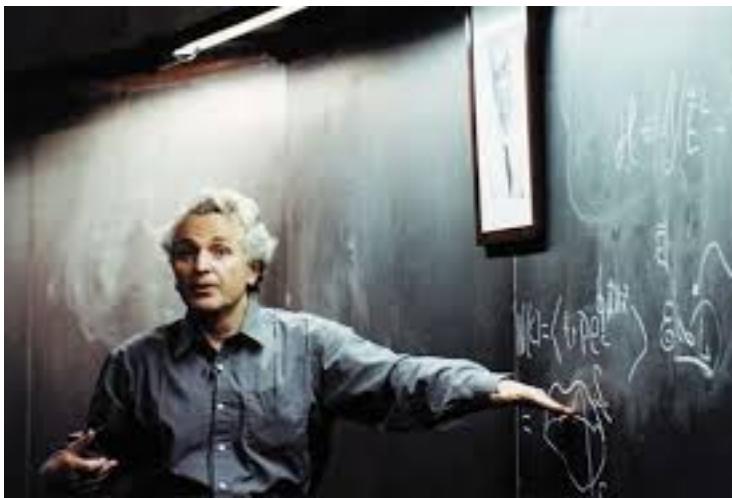
$$l \sim e^{-F_q/T}$$



## The Polyakov loop

$$\ell \sim e^{-F_q/T}$$



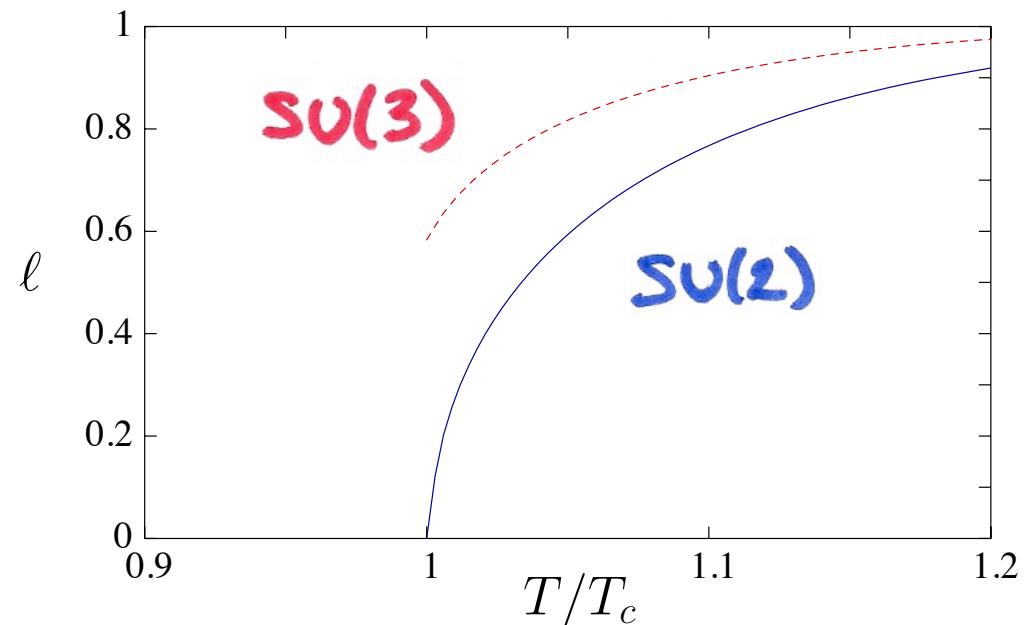


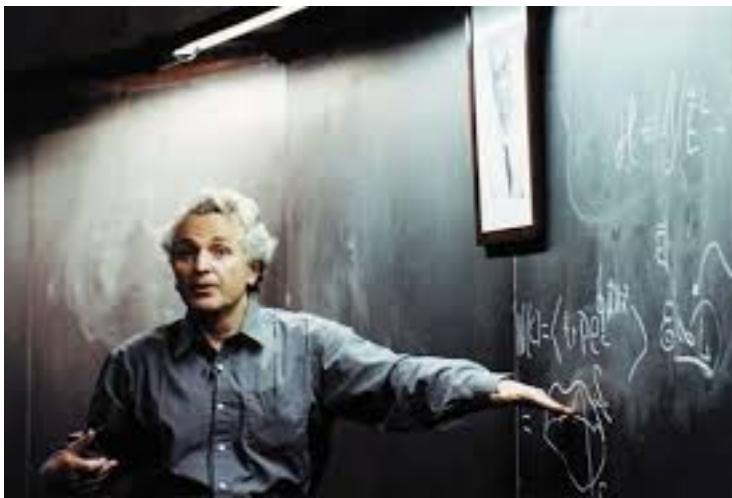
	$T_c/m$	$m$	$T_c$	$T_c^{\text{latt.}}$
SU(2)	0.33	710	238	295*
SU(3)	0.36	510	185	270

(All in MeV)

## The Polyakov loop

$$\ell \sim e^{-F_q/T}$$



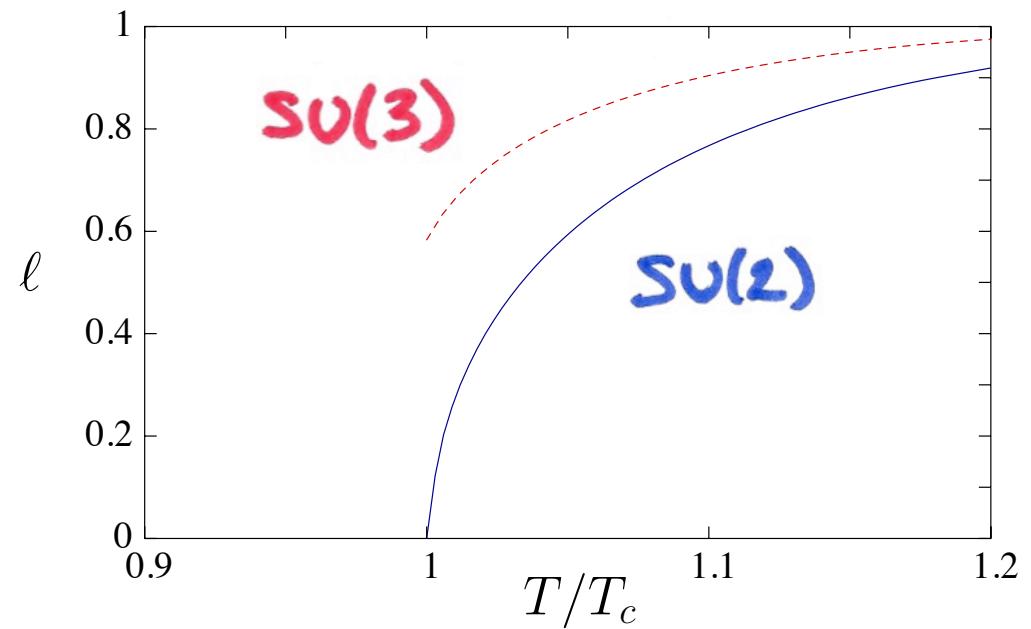


	$T_c/m$	$m$	$T_c$	$T_c^{\text{latt.}}$ *
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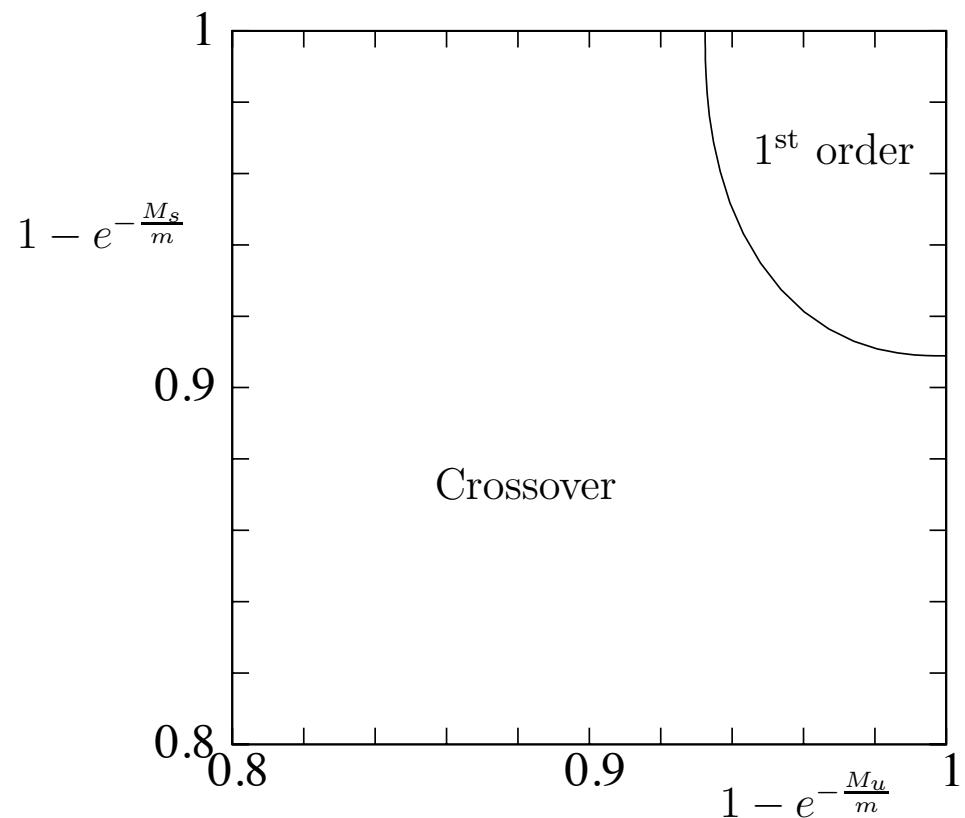
## The Polyakov loop

$$\ell \sim e^{-F_q/T}$$

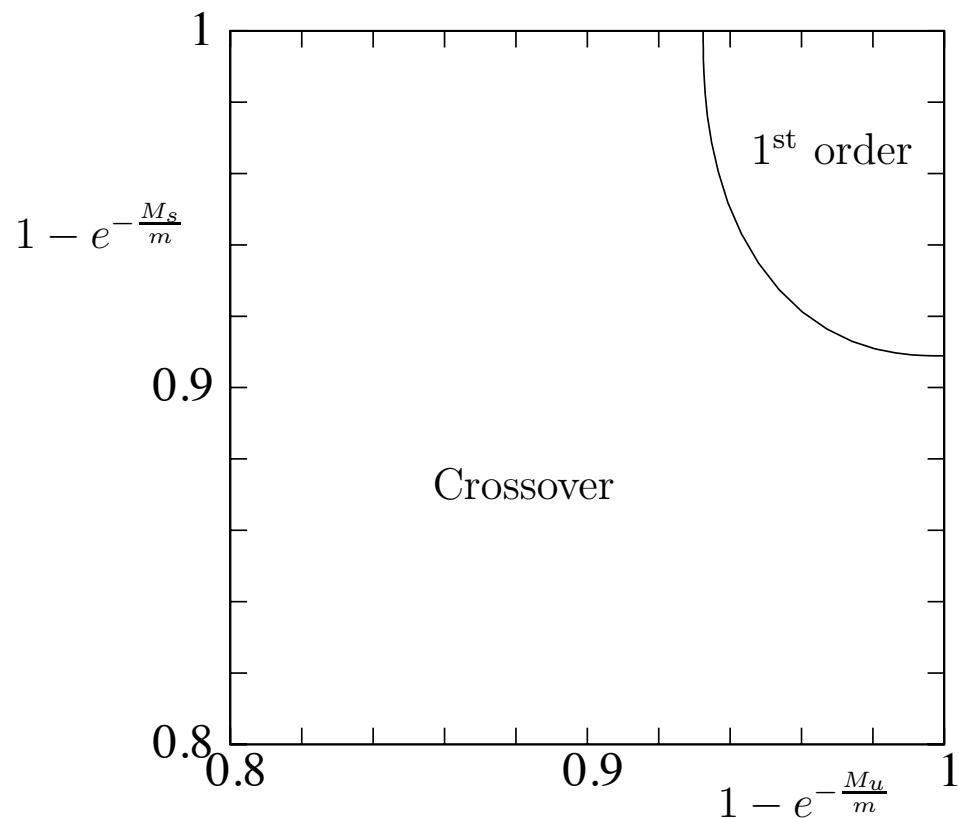


(de)confinement of static  
color charges from pert. theory!

Adding (heavy) quarks ...

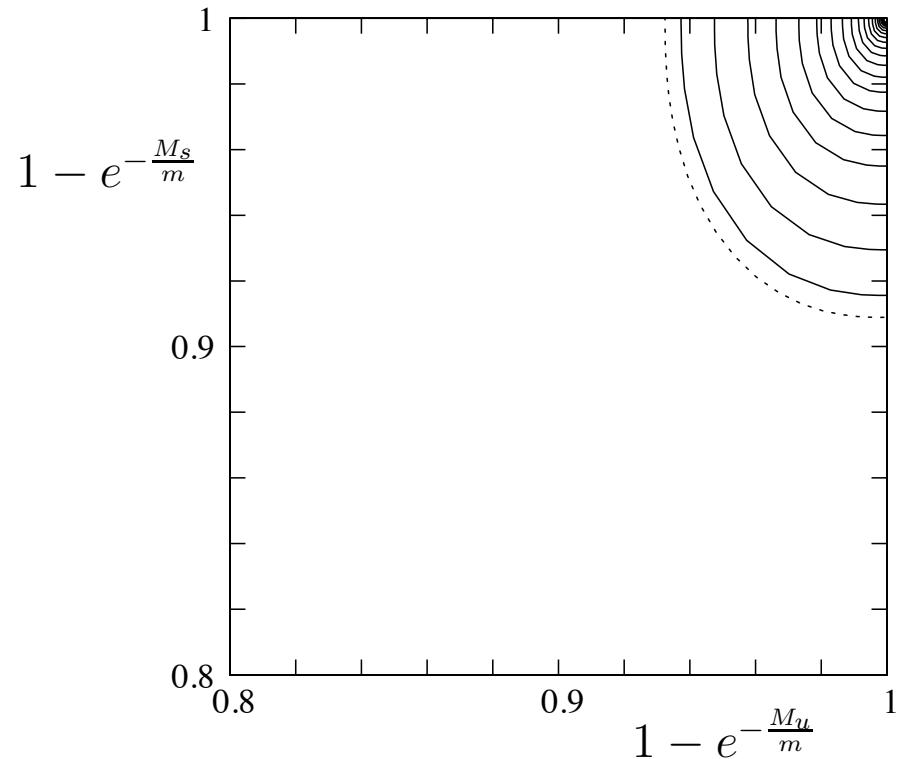


Adding (heavy) quarks ...

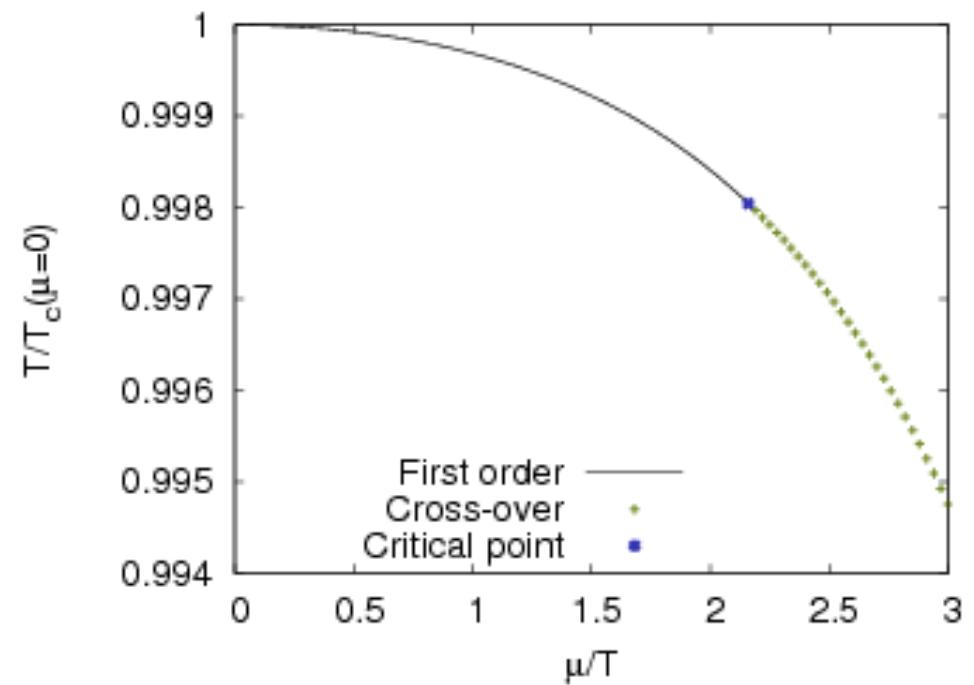
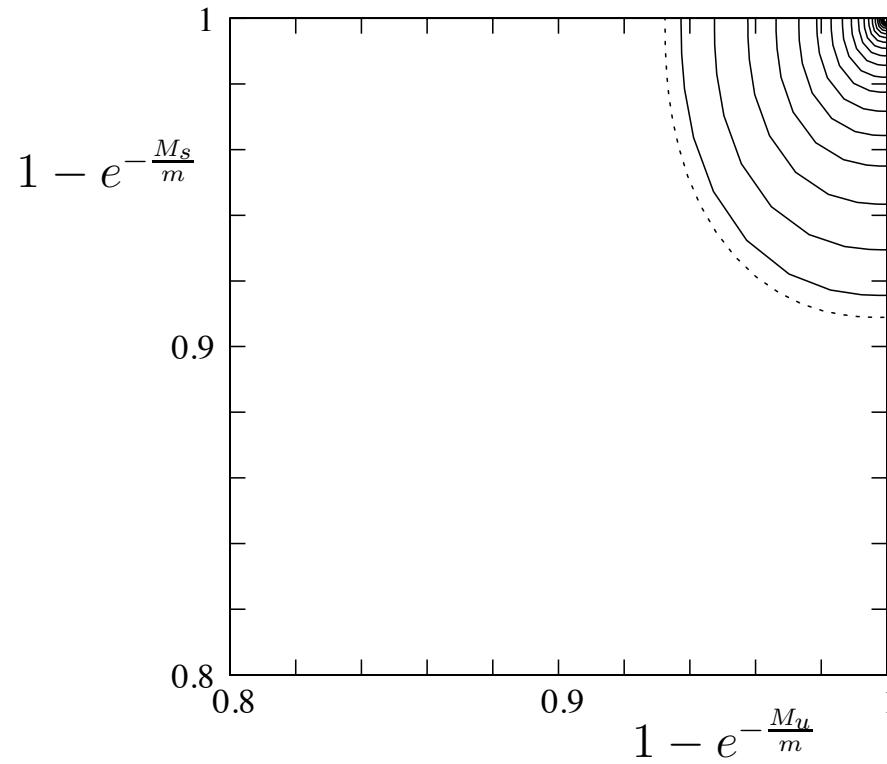


$N_f$	$M_c/T_c$	latt.*
1	<u>6.74</u>	7.22
2	<u>7.59</u>	7.91
3	<u>8.07</u>	8.32

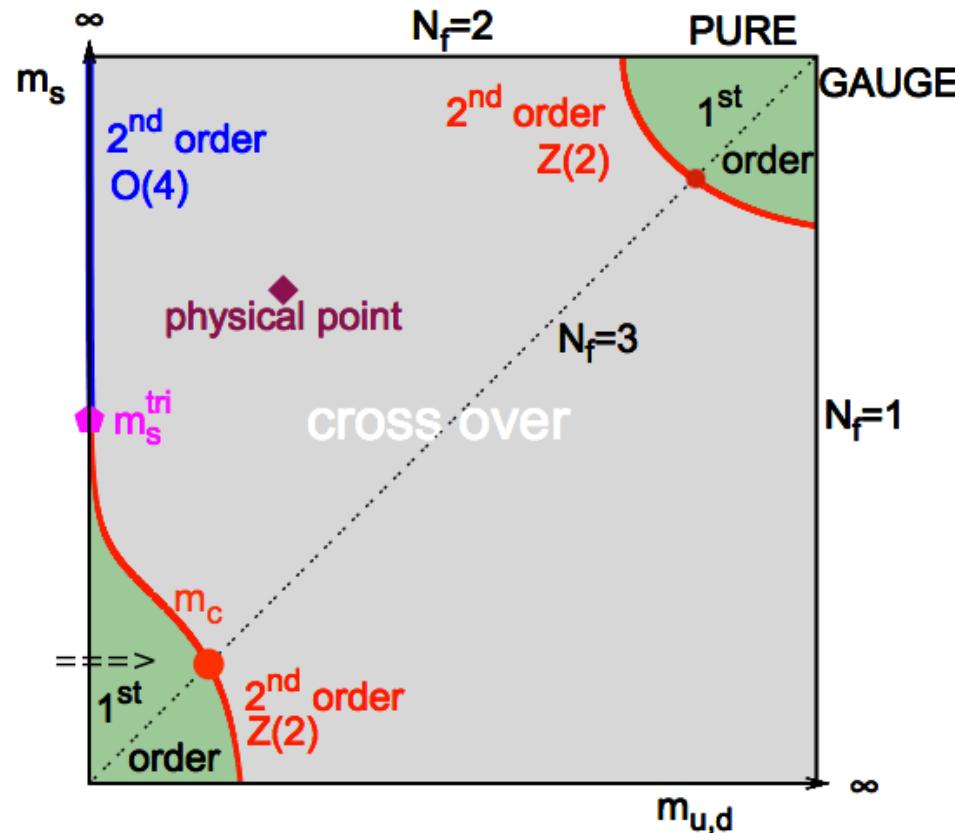
With a chemical potential



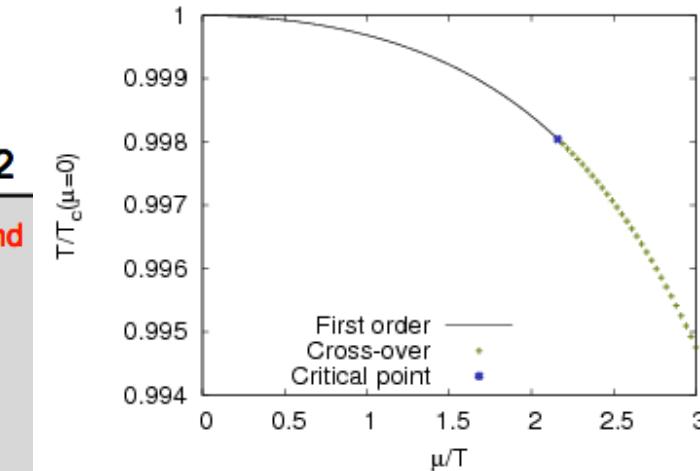
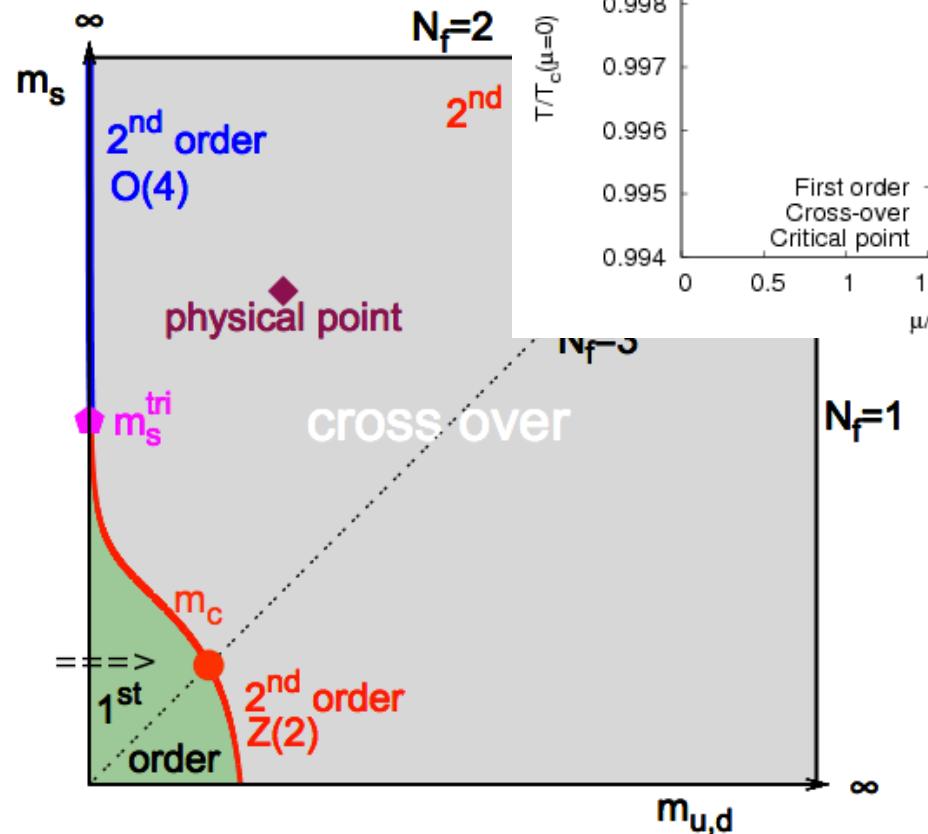
# With a chemical potential



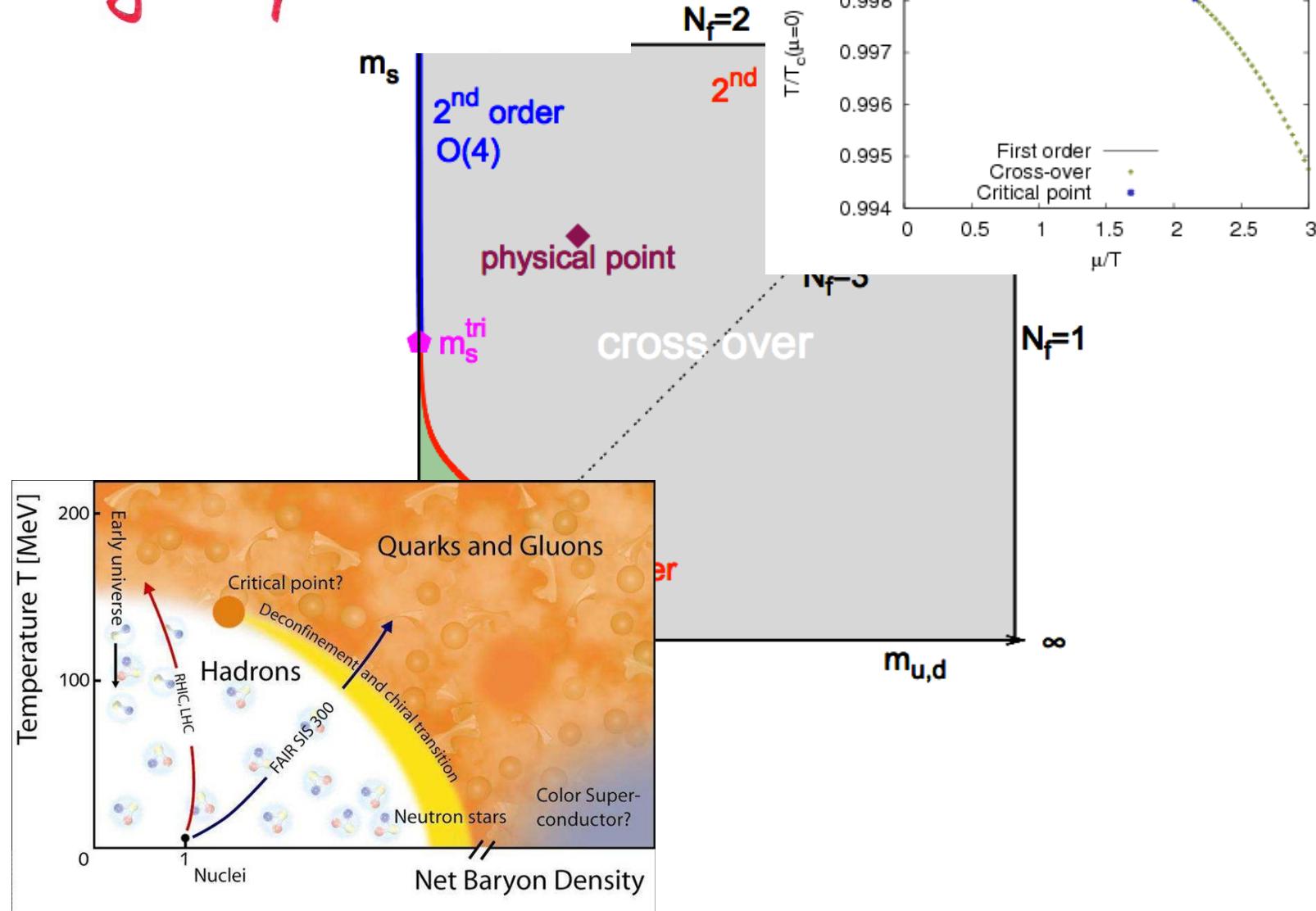
# Light quarks ?



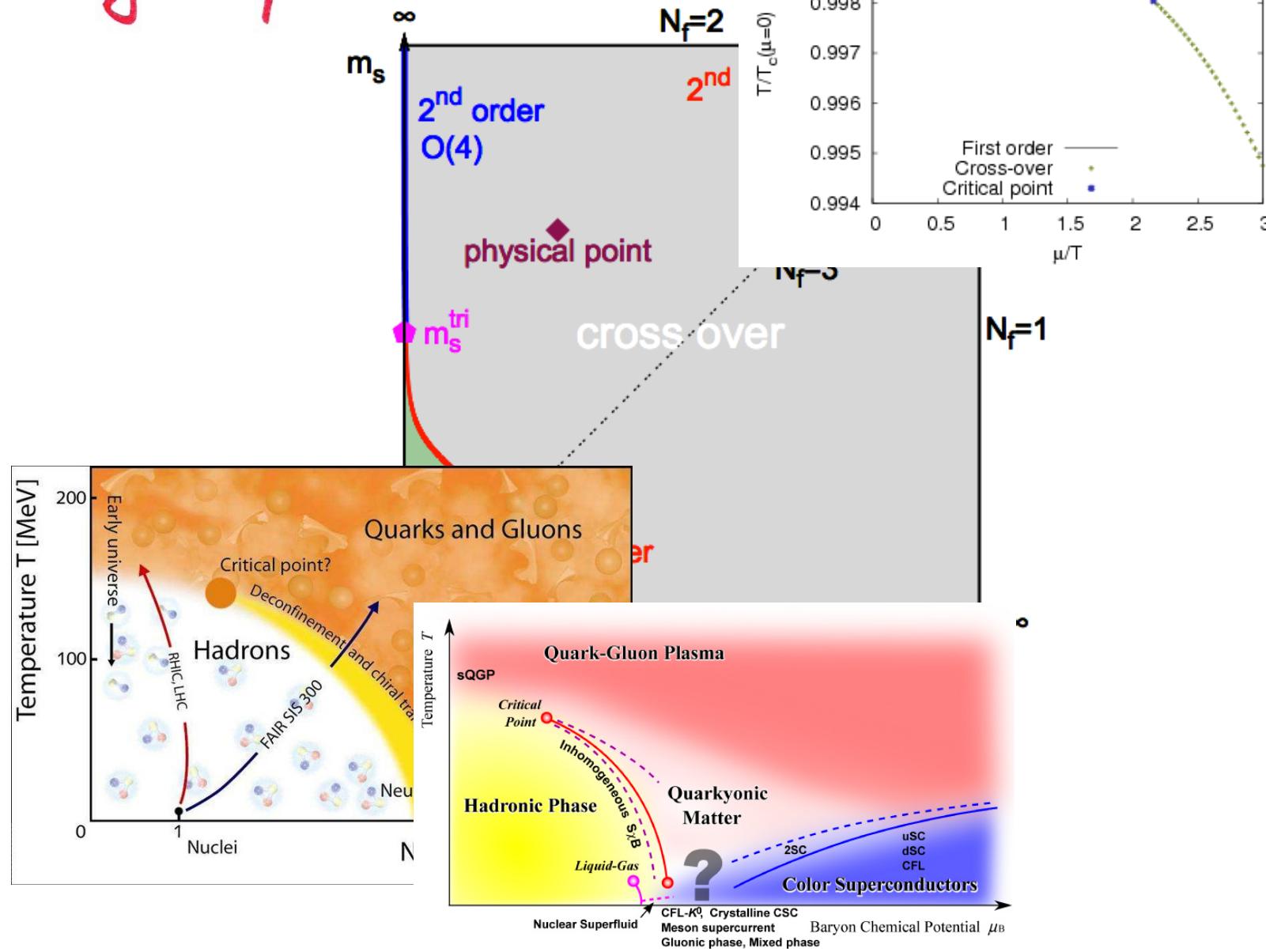
# Light quarks ?



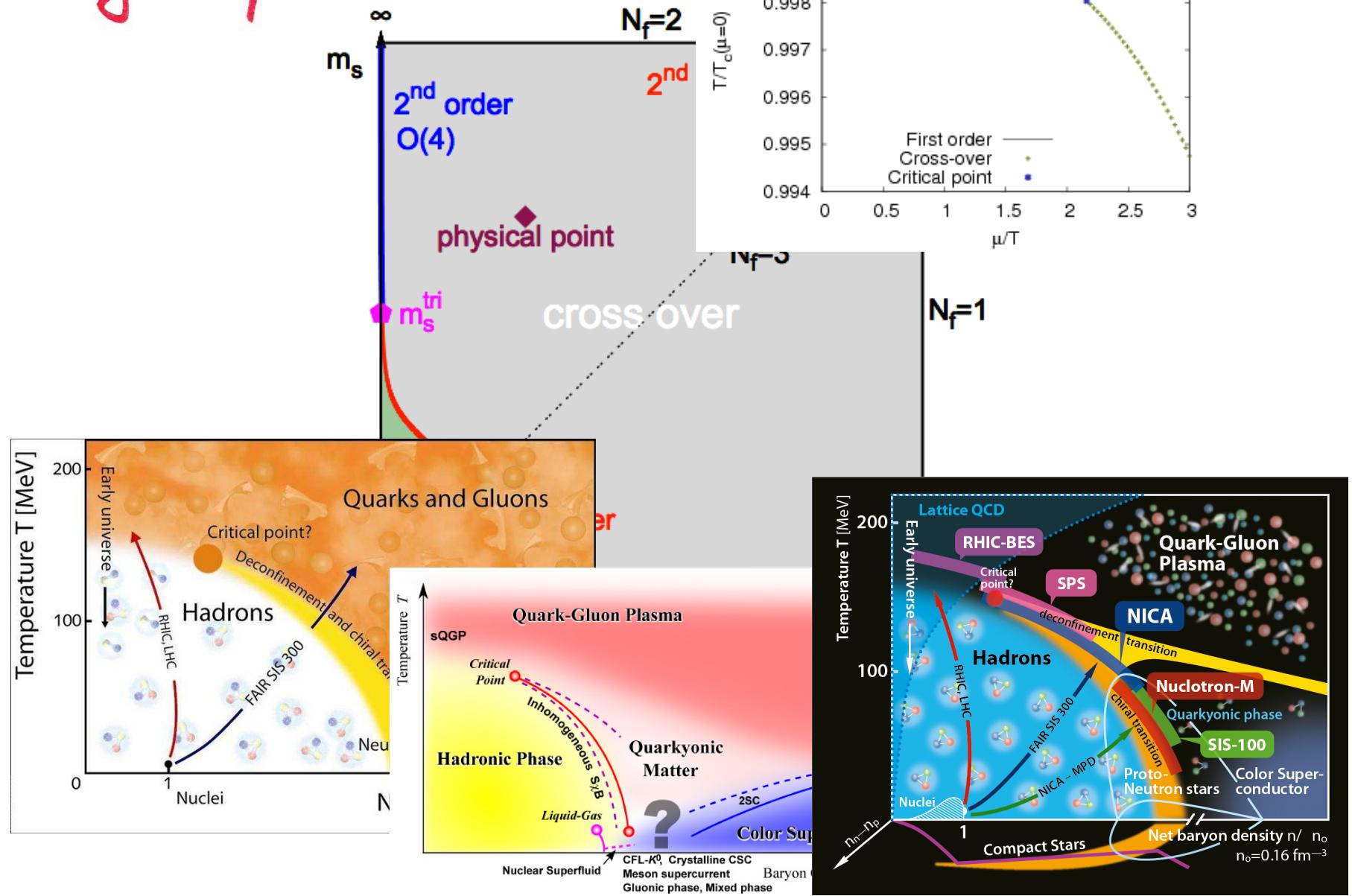
# Light quarks ?



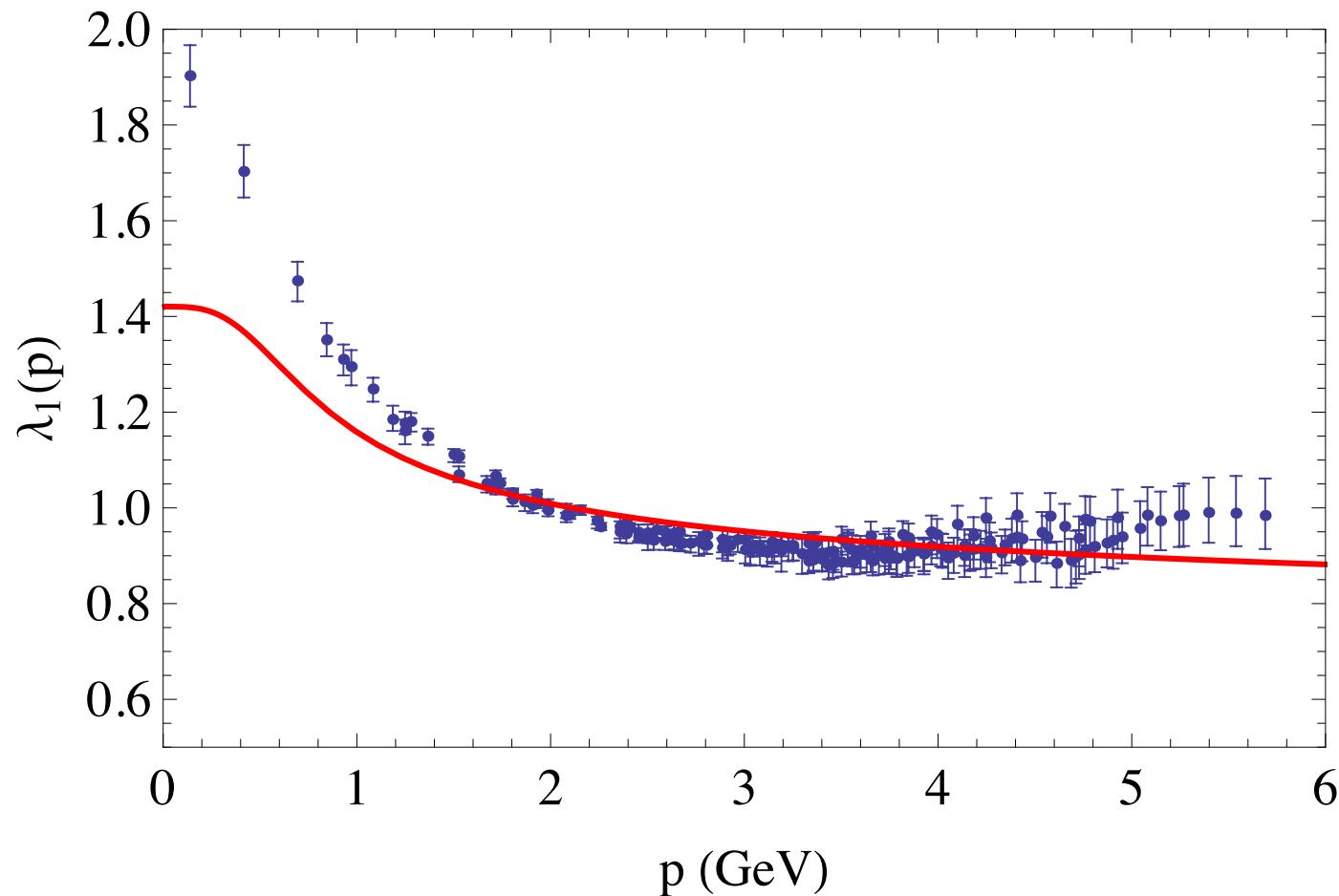
# Light quarks ?



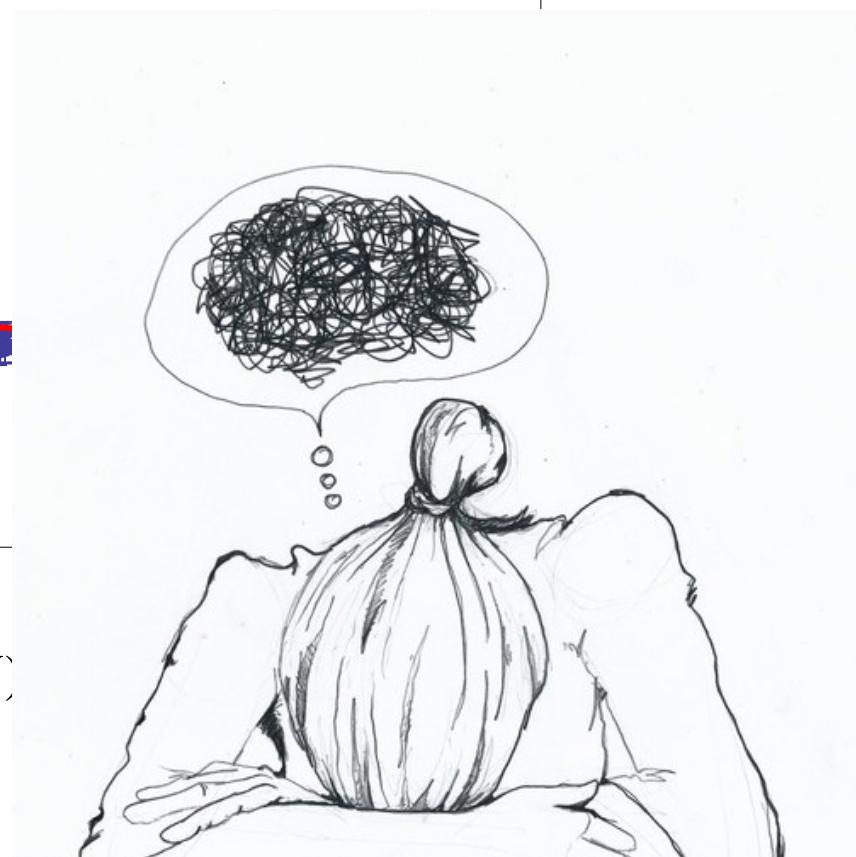
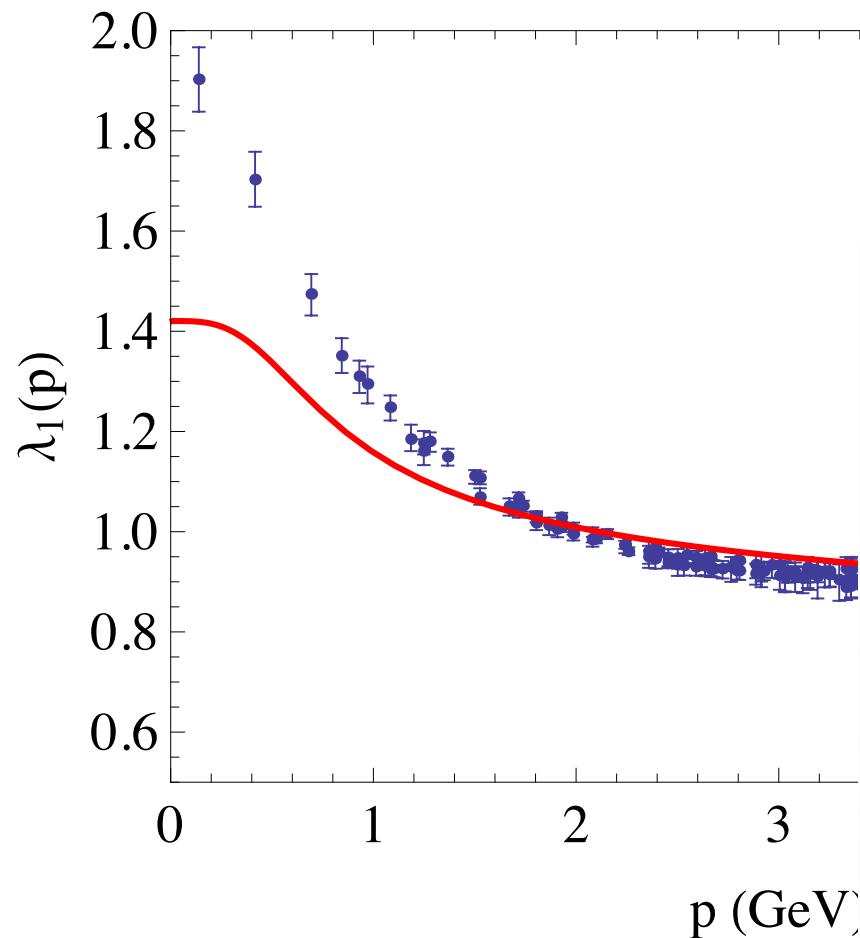
# Light quarks ?



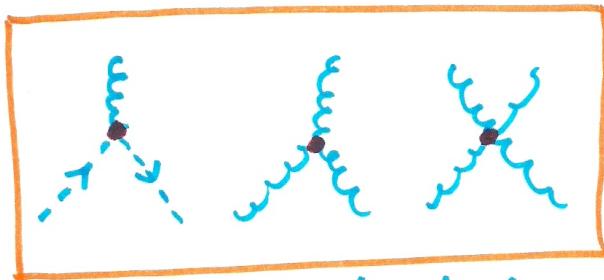
# The quark-gluon coupling in the infrared



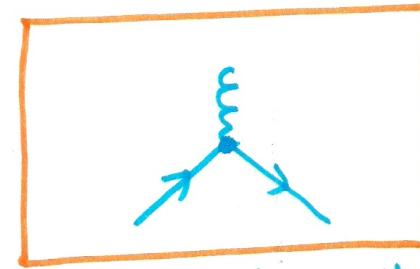
# The quark-gluon coupling in the infrared



# Small parameters in infrared QCD

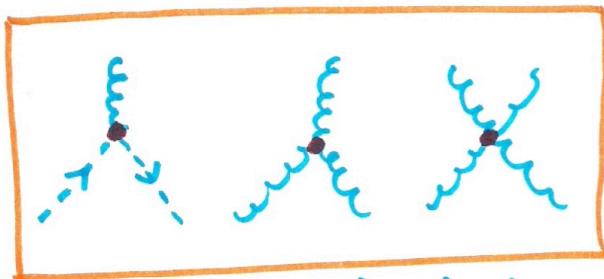


$g_g$  : can be treated  
perturbatively

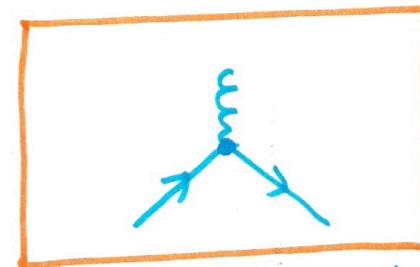


$g_q$  : not small !!

# Small parameters in infrared QCD



$g_g$  : can be treated perturbatively

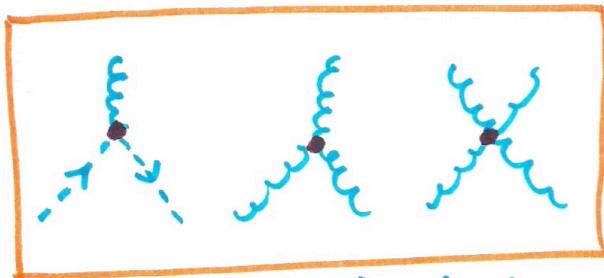


$g_q$  : not small !!

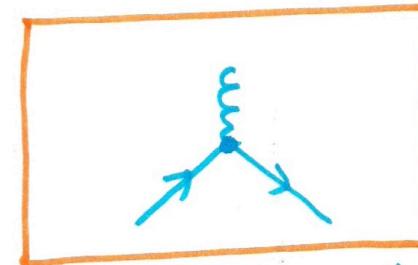
① Expand in  $g_g$ , not in  $g_q$ .

e.g. : only QED-like diagrams survive at L.O.  
in the quark sector

# Small parameters in infrared QCD



$g_g$  : can be treated perturbatively



$g_q$  : not small !!

① Expand in  $g_g$ , not in  $g_q$

e.g. : only QED-like diagrams survive at L.O.  
in the quark sector

② Expand in  $1/N_c$  with  $g_q^2 N_c$  fixed  
[ 't Hooft ('74) ... ]

captures essential aspects of  
QCD dynamics

## "Rainbow-improved" loop expansion

$$\begin{array}{c} \text{Diagram 1: } \text{A shaded circle with two horizontal arrows pointing left. Above it is a minus sign.} \\ = \quad \begin{array}{c} \text{Diagram 2: } \text{A horizontal line with a minus sign above it.} \\ + \quad \begin{array}{c} \text{Diagram 3: } \text{A cloud-like loop with a horizontal line passing through it.} \\ + \quad \begin{array}{c} \text{Diagram 4: } \text{A cloud-like loop with a horizontal line passing through it, with two red dots on the cloud.} \\ + \quad \begin{array}{c} \text{Diagram 5: } \text{A cloud-like loop with a horizontal line passing through it, with two red dots on the cloud and dashed lines extending from them.} \\ + \quad \begin{array}{c} \text{Diagram 6: } \text{A cloud-like loop with a horizontal line passing through it, with two red dots on the cloud and wavy lines connecting them.} \\ + \quad \begin{array}{c} \text{Diagram 7: } \text{A cloud-like loop with a horizontal line passing through it, with two red dots on the cloud and a zigzag line connecting them.} \\ + \quad \dots \end{array} \end{array} \end{array} \end{array} \end{array}$$

## "Rainbow-improved" loop expansion

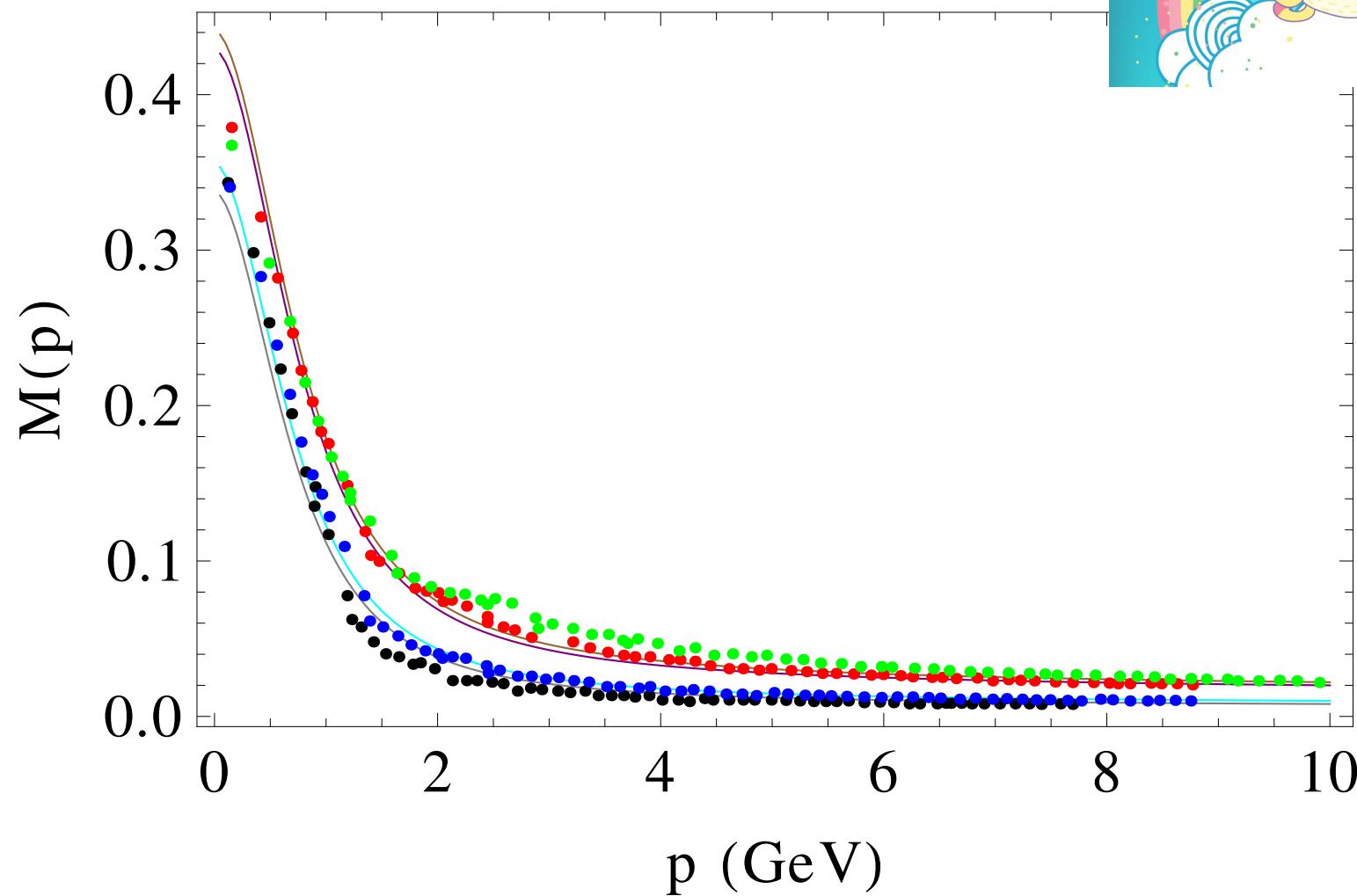


## "Rainbow-improved" loop expansion

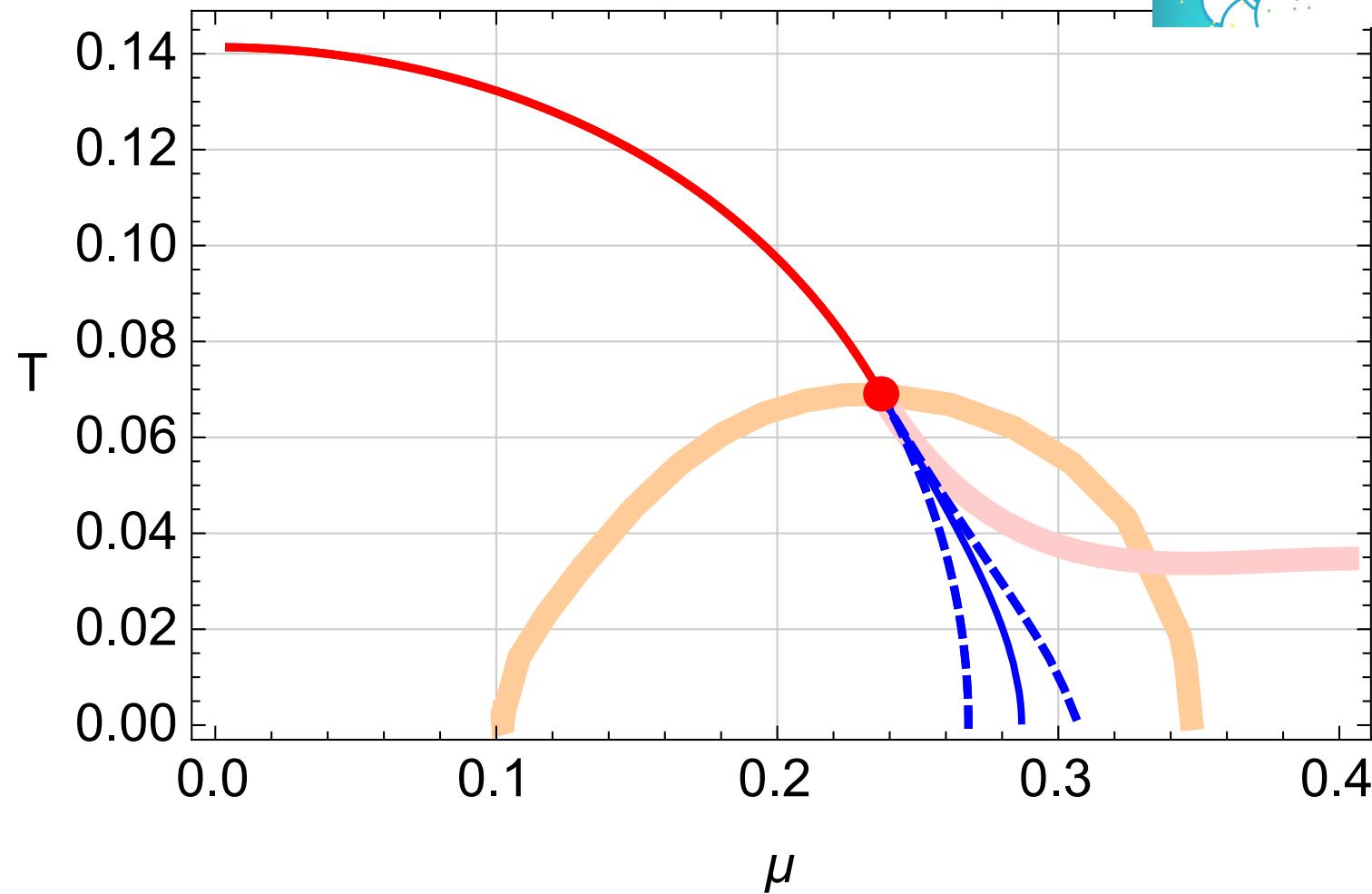
$$\text{Diagram with a shaded loop} = \text{Diagram with a shaded loop} + \text{Diagram with a cloud} + \dots$$

The equation illustrates the "Rainbow-improved" loop expansion. It shows a shaded loop diagram followed by an equals sign, then a plus sign, and a series of terms. Each term consists of a shaded loop diagram plus a cloud diagram. The cloud diagrams are composed of horizontal lines with arrows pointing left, and they contain red dashed arcs and red dots. The number of red dashed arcs in each cloud diagram increases sequentially from one to five. The final term in the expansion is followed by three dots.



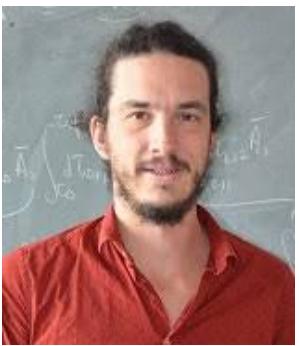




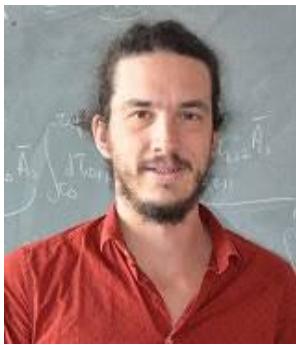
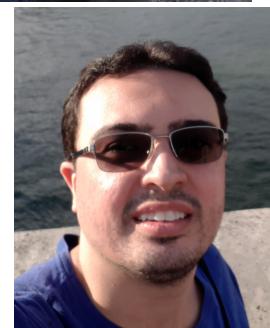
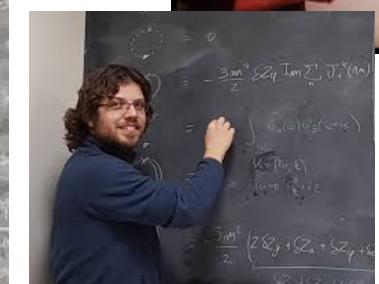


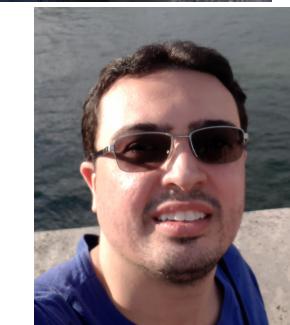
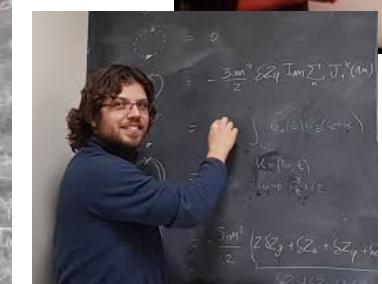
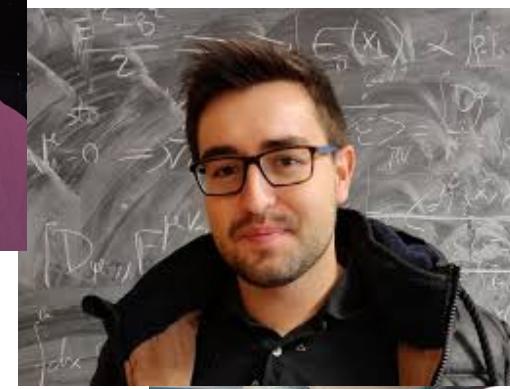
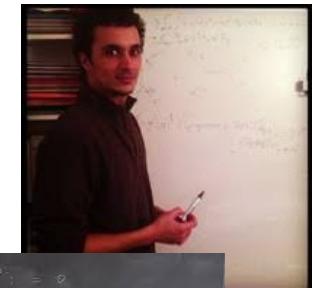
# THE TEAM















$$\begin{aligned} Z \stackrel{L^{\infty}}{\rightarrow} & \left( -\Omega + S \right) S_{\mu\nu} + \beta \bar{\beta} \right] C_2^{+}(\omega) \\ & - \left[ \frac{S \ln S_{\mu\nu}}{\beta \bar{\beta}} + \frac{3 M_+^4}{M_-^2 \Delta} \ln \frac{M_+^L}{\mu^2} - \frac{3 M_-^2 S}{M_-^2 \Delta} \ln \frac{S}{\mu^2} \right. \\ & \left. - \frac{3 M_-^4}{M_+^2 \Delta} \ln \frac{M_-^L}{\mu^2} + \frac{3 M_+^2 S}{M_+^2 \Delta} \ln \frac{S}{\mu^2} \right] \end{aligned}$$



$$\begin{aligned}
 & Z = \frac{1}{2} \left[ (-\Omega + S) S_{\mu\nu} + \beta \bar{\beta} \right] C_2^{(2)} \\
 & - \frac{S \ln S_{\mu\nu}}{\beta \bar{\beta}} + \frac{3 M_+^2}{M_-^2 \Delta} \ln \frac{M_+^2}{\mu_-^2} - \frac{3 M_+ S}{M_-^2 \Delta} \ln \frac{S}{\mu_-^2} \\
 & + \frac{3 M_-^2 S}{M_+^2 \Delta} \ln \frac{S}{\mu_+^2} \Bigg]
 \end{aligned}$$



$$Z \stackrel{L^*}{\rightarrow} (-\alpha + S) S_{\mu\nu} + \beta \delta \left[ C_2^{(x)} - \frac{S \ln S_{\mu\nu}}{\beta^3} + \frac{3 M_+^4}{M_-^2 \Delta} \ln \frac{M_+^4}{\mu_-^2} - \frac{3 M_+^2 S}{M_-^2 \Delta} \ln \frac{S}{\mu_-^2} + \frac{3 M_+^2 S}{M_-^2 \Delta} \ln \frac{S}{\mu_-^2} \right]$$

$$= + \frac{S}{2} - \frac{S}{4} - \frac{S}{4} - \frac{M_-^2}{M_-^2 - S} \left( T_S - T_{M_-^2} \right) - \frac{M_-^2}{M_-^2 - S} \left( T_S - T \right)$$

$$\frac{2}{g^{2/3}} = \underbrace{\frac{1}{16\pi^2} \left( 1 + \frac{3(\eta_+^2 - \eta_-^2)}{\Delta} \right)}_{4} + \frac{1}{16\pi^2} \left\{ \frac{S_-}{\beta^3} - \frac{2}{3\eta_-^2 - 3\eta_+^2} \right\}$$

$$\begin{aligned} & \left[ \left( T_S - T_{M_-^2} \right) \right] \\ & + \frac{1}{16\pi^2} \left\{ \frac{S_- \beta \delta}{\beta^3} \ln \frac{S_- \beta \delta}{\mu_-^2} - \frac{S \ln S_{\mu\nu}}{\beta^3} + \frac{3 M_+^4}{M_-^2 \Delta} \right. \\ & \left. - \frac{3 M_+^4}{M_-^2 \Delta} \right\} \end{aligned}$$



$$Z \stackrel{L^*}{\rightarrow} (-\Omega + S)S_{\mu\nu} + \beta \bar{\beta} \left[ C_2^{(L)} - \frac{S \ln S_{\mu\nu}}{\beta^3} + \frac{3M_+^4}{M_-^2 \Delta} \ln \frac{M_+^4}{\mu_-^2} - \frac{3M_+^2 S}{M_-^2 \Delta} \ln \frac{S}{\mu_-^2} + \frac{3M_+^2 S}{M_-^2 \Delta} \ln \frac{S}{\mu_-^2} \right]$$

$$\frac{2}{g^{2/3}} = \frac{1}{16\pi^2} \left( 1 + \dots \right)$$

$$\begin{aligned} & \left[ (T_S - T_{H_+^2}) \right] \\ & + \frac{1}{16\pi^2} \left\{ \frac{S - \beta \bar{\beta}}{\beta^3} \ln \frac{S - \beta \bar{\beta}}{\mu_-^2} - \frac{S \ln S_{\mu\nu}}{\beta^3} + \frac{3M_+^4}{M_-^2 \Delta} \right. \\ & \left. - \frac{3M_+^4}{M_-^2 \Delta} \right\} \end{aligned}$$





$$Z = \left[ (-\Omega + S) S_{\mu\nu} + \beta \delta \right] C_2^{(2)} - \frac{S \ln S_{\mu\nu}}{\beta^3} + \frac{3 M_F^4}{M_c^2 \Delta} \ln \frac{M_F^4}{\mu^2} - \frac{3 M_F^2 S}{M_c^2 \Delta} \ln \frac{S}{\mu^2} + \frac{3 M_F^2 S}{M_c^2 \Delta} \ln \frac{S}{\mu^2} \right]$$

$$\frac{2}{g^{2/3}} = \frac{1}{16\pi^2} \left( 1 + \dots \right)$$

$$\left[ (T_S - T_{H_c^2}) \right] + \frac{1}{4\pi^2} \left\{ \frac{S - \beta \delta}{\beta^3} \ln \frac{S - \beta \delta}{\mu^2} - \frac{S \ln S_{\mu\nu}}{\beta^3} + \frac{3 M_F^4}{M_c^2 \Delta} - \frac{3 M_F^2 S}{M_c^2 \Delta} \right\}$$



$$\frac{d}{dt} \left( \frac{\eta^2 - \eta_+^2}{\eta^2 - \eta_-^2} \right) = \frac{4\eta^2}{\eta^2 - \eta_-^2} \left( T_S - T_{H^2} \right)$$
  

$$\frac{2}{g_F^2} = \frac{1}{16\pi^2 c} \left( 1 + \frac{3}{4} \underbrace{\Delta}_{\frac{1}{4}} \right) + \frac{1}{16\pi^2} \left\{ \frac{S_-}{\beta} \right\} = \frac{2}{3g^2} - \frac{2}{3g_F^2}$$

$$\frac{d^3 k}{(2\pi)^3} \theta(k - \alpha H e) (a_k f_k(t) + a_{-k}^+ f_k^*(t)) / e^{i k \cdot \vec{r} - i \omega t}$$

$$+ m^2) \varphi = -e \alpha H^2 (1 - F(t, \vec{r}))$$

$$\begin{aligned}\dot{\Pi} &= -\frac{\alpha}{m} V^1 + \frac{3\pi}{\alpha d} \tilde{\zeta}_P \tilde{p} & \tilde{p} &= \frac{\Pi}{\alpha} \\ \dot{\phi} &= \tilde{p} + \frac{3}{4} \tilde{\zeta}_P \\ \dot{\tilde{p}} &= -V^1 + dH \tilde{p} + \frac{3}{4} \tilde{\zeta}_P \\ &\sim \frac{m^2}{H^2} \langle \tilde{\zeta}_P \tilde{\zeta}_Q \rangle\end{aligned}$$

$$\langle \vec{x} | F(t', \vec{x}') \rangle =$$

$$\frac{1}{2} m^2 A_\mu^a A_\mu^a$$

$$\begin{aligned}\langle \dots \rangle &= \langle a_k^+ a_k^- \rangle \\ \mu_k &= \langle a_k^- a_{-k}^+ \rangle\end{aligned}$$

$$\begin{aligned}f_K &= a_k^- u_k + a_{-k}^+ \bar{u} \\ &\quad \uparrow \qquad \uparrow\end{aligned}$$

$$= b_K^- f_K + b_{-K}^+ f_{-K}$$

$$\text{avec } f_K = \alpha_k u_k + (1 + R b_K^+) u_K + \dots$$

$$\begin{aligned}N_k &= \mu_k = 0 \\ N_k &= 0 \quad \alpha_k = \alpha \\ \alpha_k &= \\ 1 + M_s S(t) &= \\ M_s^2 \left( 1 - \ln k_0 \right) &= \left( \frac{-C_1 \beta}{k_0} N \right)^{-1} \ll 1\end{aligned}$$

$$\frac{d^3k}{(2\pi)^3} \theta(k - aHc) (a_k f_k(t) + a_{-k}^+ f_k^*(t)) / e^{i k \vec{r} - i \omega t}$$

$$+ m) \varphi = -e a H^2 (1 - F(t, \vec{r}))$$

$$\begin{aligned}\dot{\Pi} &= -\frac{a}{a_0} V' + \frac{3\pi}{a_0} \zeta p \quad \dot{p} = \frac{\dot{\Pi}}{a} \\ \dot{\phi} &= \dot{p} + \frac{3}{4} \zeta p \\ \dot{p} &= -V' + dH p + \frac{3}{4} \zeta p \\ &\sim \frac{m^2}{H^2} \zeta \rho \zeta p\end{aligned}$$

$$\langle \vec{x}) F(t', \vec{x}') \rangle =$$

$$\frac{1}{2} m^2 A_\mu^a A_\mu^a$$

$$\begin{aligned}\langle a_k^+ a_k \rangle &= \\ \langle \mu_k \rangle &= \langle a_k^+ a_{-k} \rangle\end{aligned}$$

$$n_k = \mu_k = 0$$

$$N_k = 0 \quad \alpha_k = \alpha$$

$$\alpha \alpha^*$$

$$1 + M_S(t)$$

A mass out of the mess?



A collage of various birthday-related words and phrases in different colors and fonts, including:

- Holiday
- Candy
- Wish
- Friends
- Day
- Cake
- Happy
- Birth
- Anniversary
- Present
- Age
- Greetings
- Invitations
- Gifts
- Surprise
- Anniversary
- Happy Birthday
- Friends



**I AM NOT  
61  
I AM 18  
WITH  
43 YEARS  
OF  
EXPERIENCE**

