12) Outlook; some stories ...

((we now have the tools . many directions to go ...))

compute higher orders

4) tech. problem : technology for part. calc's in thermal FT

probl #1) gauge invariance

sol'n 1990 [Braaten/Pisarski, NPB 337 ('90) 569]

application 1) g^6 [BP, PRD 42 ('90) 2156]

2) ω to NLO [H. Schulz, NPB 413 ('94) 353]

probl #2) massless (sum-) integrals

g^4 terms in free E

ϕ^4 [Frenkel/Saa/Taylor] 1992

QED [Corianò/Parwani] 1994

QCD [Arnold/Zhai] 1994

g^5 terms in free E

ϕ^4 [Parwani/Singh], [Braaten/Nieto] 1995

QED [Parwani/Corianò] 1995

[Andersen] 1996

QCD [Kastening/Zhai] 1995

[Braaten/Nieto] 1996

((g^6, QCD, KK et.al. 200?X ??))

⇝ new problem: convergence (of weak coupling expansion) ⇝ B)

probl #3) massive (sum-) integrals

state of art: ϕ^4, g^4 [Andersen/Braaten/Strickland] 2000

hep-ph/0002048 (for refs ↑)

3-loop $0 + \infty + \infty\infty + \infty$

B) conceptual problem : convergence of weak coupling expansion

- Screened part. theory [Karsch et.al] 1997

  massless → massive theory : $+-m^2$; ϕ^4 only

  ↑ optimal ? gap ? min. sens. ?

  done to $O(g^2)$

  $g^6 \to$?000 , [Andersen/Braaten/Strickland] ???

- HTL part. th. (screened p.t. ✓ for gauge theories (QCD), since local mass term not g.i.)

  nonlocal mass term (qv? local ct's ? unclear...)

  → eff. propg's are complicated fct's of momenta

  done to LO (⬡) [Andersen/Braaten/Strickland]

  PRD 61 ('00) 014017 : ⬡

  PRD 61 ('00) 074016 : $\bigcirc_g$

dimensional reduction

note : high T QCD generates a hierarchy of length scales

$(T)^{-1}$ → inverse of typical momenta of plasma particles

$(gT)^{-1}$ → electric screening length ; first scale of collective excitations

$(g^2T\ln\frac{1}{g})^{-1}$ → damping length of color exc. } we have not seen yet

$(g^2T)^{-1}$ → non-pert. magnetic fluctuations }

scales T, gT

idea : $\sum_{n=-\infty}^{\infty} \frac{1}{\omega_n^2+\vec{k}^2}$ $\xrightarrow{\text{bosons}}$ { 1 massless field (n=0) ; ∞ many massive fields ; one per Fourier mode ↑ $n \sim T$

traded sum → more fields ; these $\neq T$ → $\int_0^\beta d\tau \cdot \text{const} \to 3D$!!!

integrated out scale T ((heavy modes in loops only, light external → give effective couplings))

before: $\mathcal{L}$: g^2, T ; SU(N) 3+1D , fields A_μ^a

after: $\mathcal{L}$: g_3^2, m_3^2, λ_3 ; SU(N) + adj. Higgs , 3D , fields A_i^a, A_0^a

$\mathrm{fct}(g^2,T)$ as result of integration out

or

QCD	SM	MSSM
↓	↓	↓
same	SU(N) + adj + fund	✗
	same	

→ universality of 3D theories

two big advantages: • 3D is super-renormalizable !
(finite # of div. diagrams)
→ ct's known exactly @ 2-loop

• 3D much easier on lattice !

[Kajantie et.al]

things done: Debye mass, free en. ... [Braaten/Nieto]

• integrate out more scales of hierarchy:

recently gT , gT_{hg} [Bödeker] 1998

goal $g^{T_{hg}}$, g^2T unsolved

e.g. [Guerin, hep-ph/0004046]

Leads; IR problem

we have seen: Π_t (in our LO approx.) can vanish → unscreened propag's

consider l+1-loop graph for $\ln Z$

leading IR behaviour?

propg: $\frac{1}{\omega_n^2+\vec{k}^2+m^2}$ ← (some screening mass), $\omega_n = 2\pi n T$

leading IR: $n=0$

$\rightsquigarrow \underbrace{(T\sum_n \int d^3k)^{l+1}}_{\text{loop int's}}\ \underbrace{g^{2l}}_{\text{vertices}}\ \underbrace{\left(\frac{1}{k^2+m^2}\right)^{3l}}_{\text{propg's @ } n=0}$

$k=mx = T^{l+1} m^{3(l+1)} g^{2l} m^{2l} \left(\frac{1}{x^2+1}\right)^{3l} m^{-6l} \left(\int d^3x\right)^{l+1}$

$= g^6 T^4 \left(\frac{2\pi T}{m}\right)^{l-3} \left(\int d^3x\right)^{l+1} \left(\frac{1}{x^2+1}\right)^{3l}$

→ ok for $l<3$; log div for $l=3$ ($g^6T^4 l \frac{T}{m}$);
div for $l>3$ ($g^6T^4(\frac{2\pi T}{m})^{l-3}$)

long. gluons, screening $m \sim gT$ ⇒ ord. part. fct: g^{2l}; here: g^{l+3}

transv. gluons, earliest $m \sim g^2T$ ⇒ all $\sim g^6T^4$;
complete failure of part. fct!

2+1 D Yang-Mills: progress! hot ooo

[Karabali/Kim/Nair] series of papers 1998 (hard; hep-th; extract g.i. d.o.f's)
→ solvable? (well, so far only Gaussian fun — interaction?)
→ derive mass-gap
via dim. red. ⇝ this is 'magn. mass' !!??

lots to do in FTFT → Invitation! (not many open problems in other physics...)

(rel.) young field (1990) → (big) discoveries + breakthroughs possible!

field's games (ϕ^4..) are done → real stuff to be attacked.