Heavy quark diffusion: pQCD perspective

On work w/ G. Moore

PRL100:052301 (2008)
JHEP0802:081 (2008)

Why do NLO computations?

- Leading-order pQCD is notoriously difficult to match with RHIC data
  (low viscosity, heavy vs. light E loss, small g^2 needed in jet quenching...)

  -> How much of this is due to pQCD systematics?

- Learn what physical effects might take over

$$\frac{\alpha_s}{\pi}$$

Quantum mechanics

$$g_s \approx \frac{m_D}{T}, \frac{g_s^2 T}{m_D}$$

Plasma physics

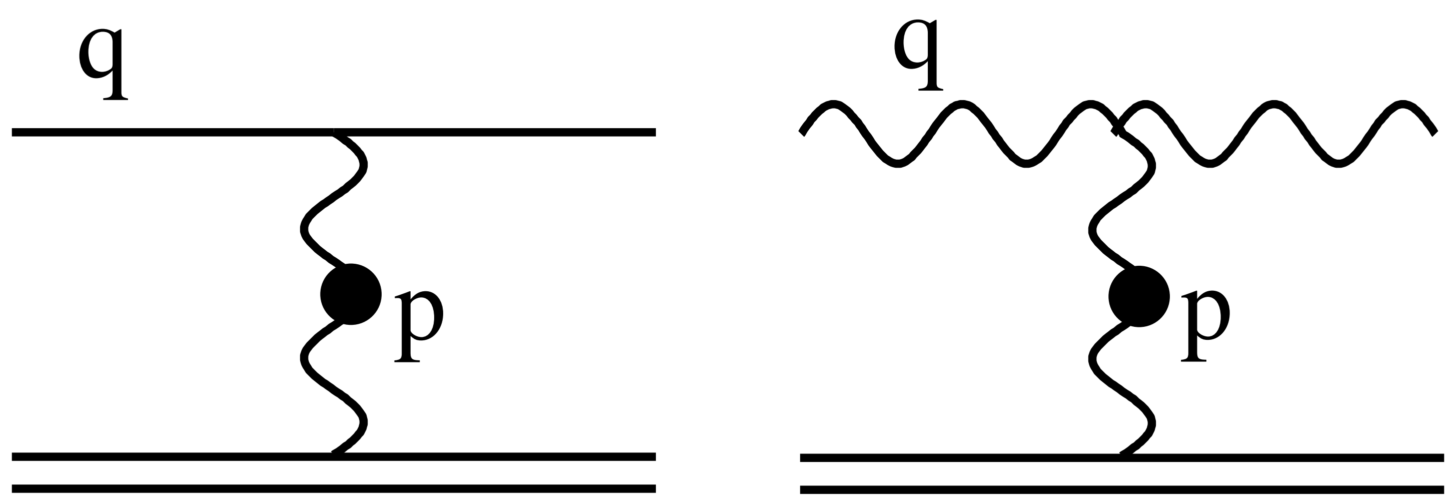
Setup

- Imagine a very weakly coupled QGP
- Imagine a very heavy quark (think bottom)
- Has radiative & collisional E loss. Focus on collisional.
- This can be done cleanly by sending M to infinity: reduce to Langavin dynamics

$$\frac{dp_i}{dt} = -\eta_D \, p_i + \xi_i(t) \, , \quad \langle \xi_i(t) \xi_j(t') \rangle = \kappa \, \delta_{ij} \delta(t - t') \, .$$

What's new at NLO?

- Reminder: LO is

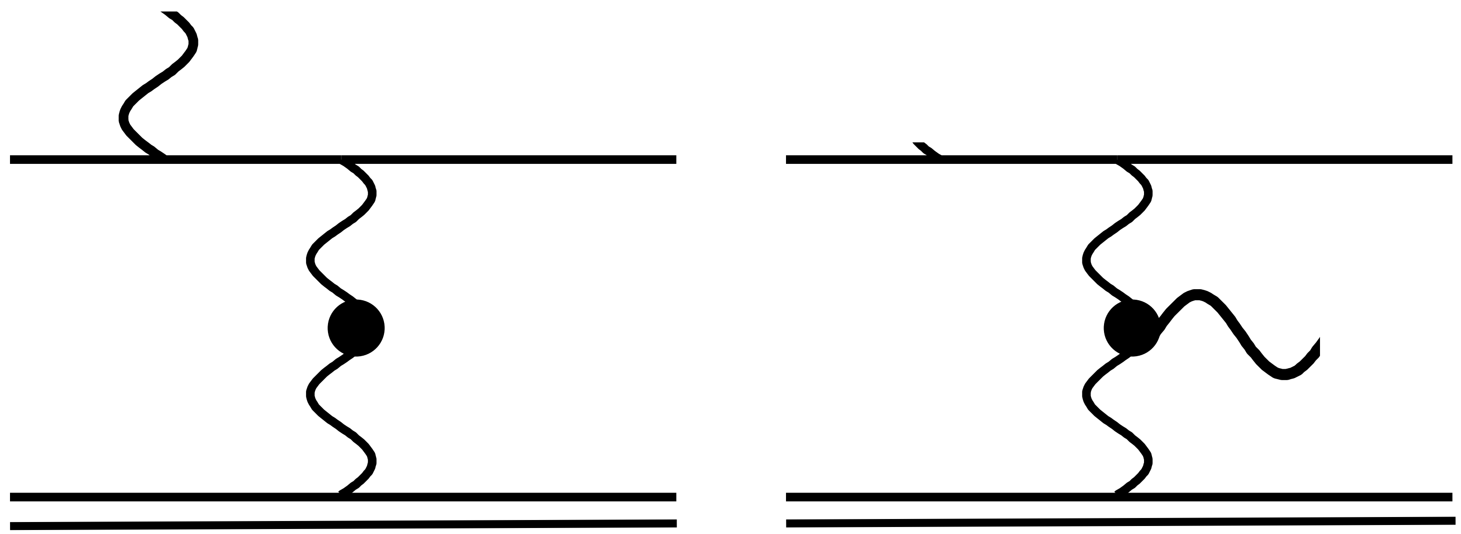


- 2->2 scattering
- Need (electric) screening at soft p
- IR log divergent at soft p

$$\kappa \propto g^4 T^3 (\log \frac{T}{m_D} + C)$$

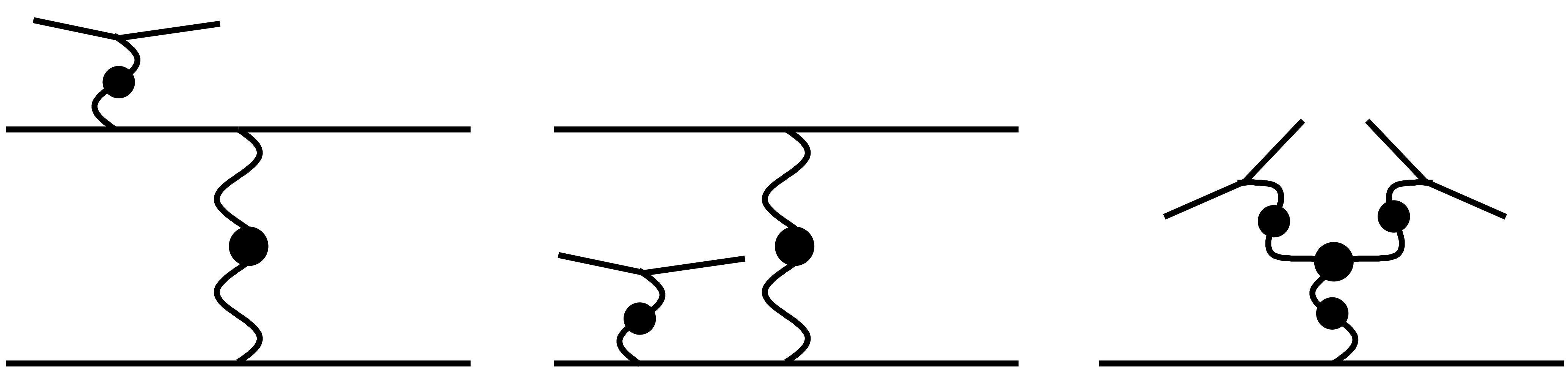
What's new at NLO (II)

- Multiple scattering (2->3, 3->2)



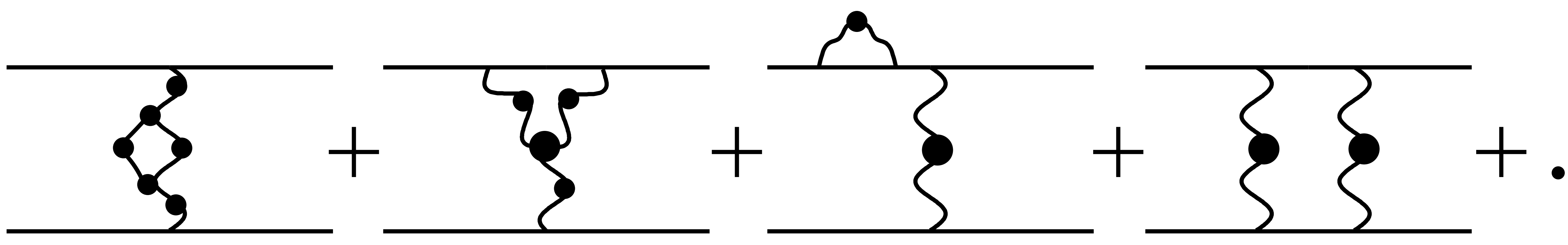
...

- Multiple scattering (3->3)



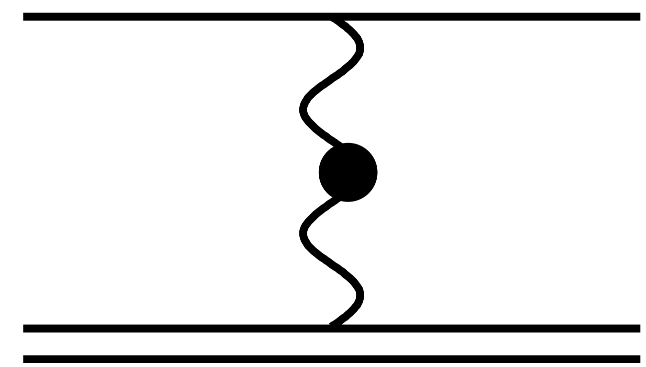
What’s new at NLO (III)

- Virtual corrections (HTL)

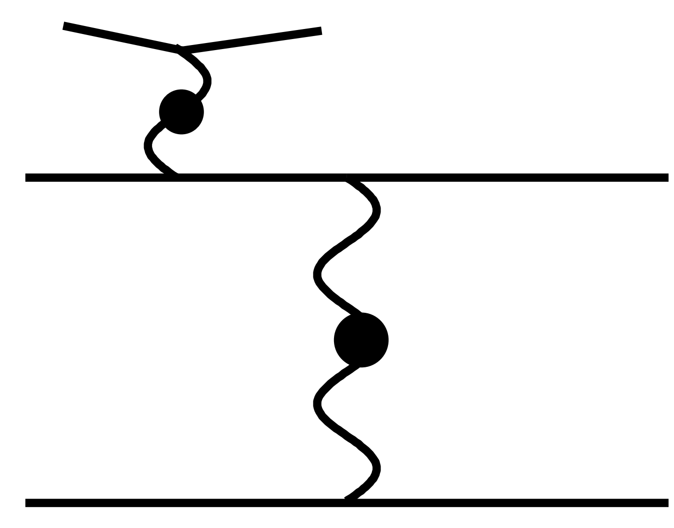


Why 3->3 is O(g) ?

Take a LO scattering with $q \sim m_D$



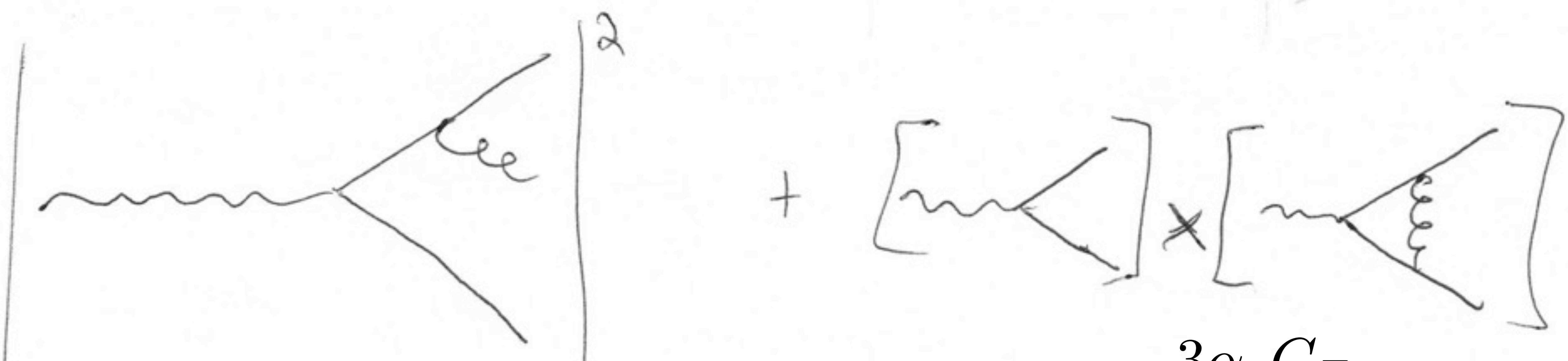
Will be disturbed if a collision with $q' > m_D$ occurs at same time



Cross-section $\sim g^4/m_D^2$, duration $\sim 1/m_D$, probability $\sim g^4 T^3/m_D^3 \sim g$

General comment on real+virtual

- Consider a simple example
- e+e- -> hadron, at NLO in QCD (T=0)



Total: $+\sigma^{(0)}\frac{3\alpha_s C_F}{4\pi}$

Same will be true here:
real and virtual corrections equally important.

Technical slides

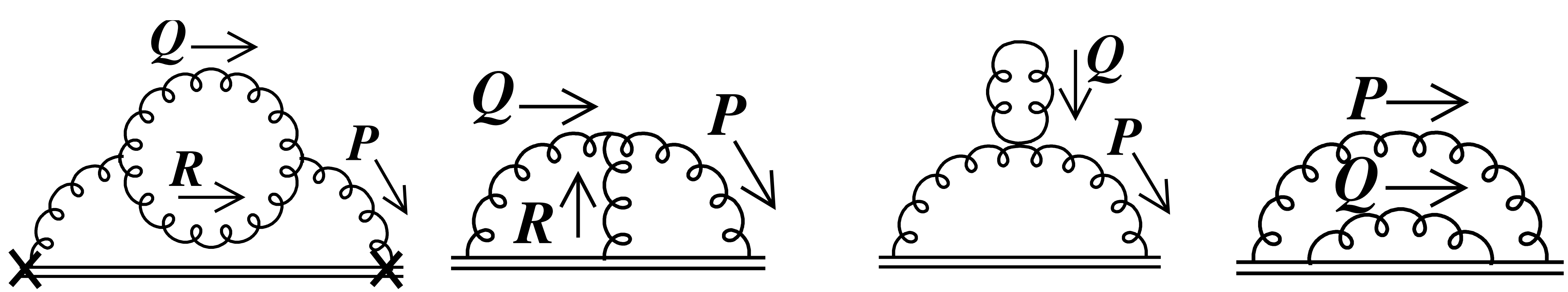
- We need a systematic power counting: HTL

Braaten, Pisarski

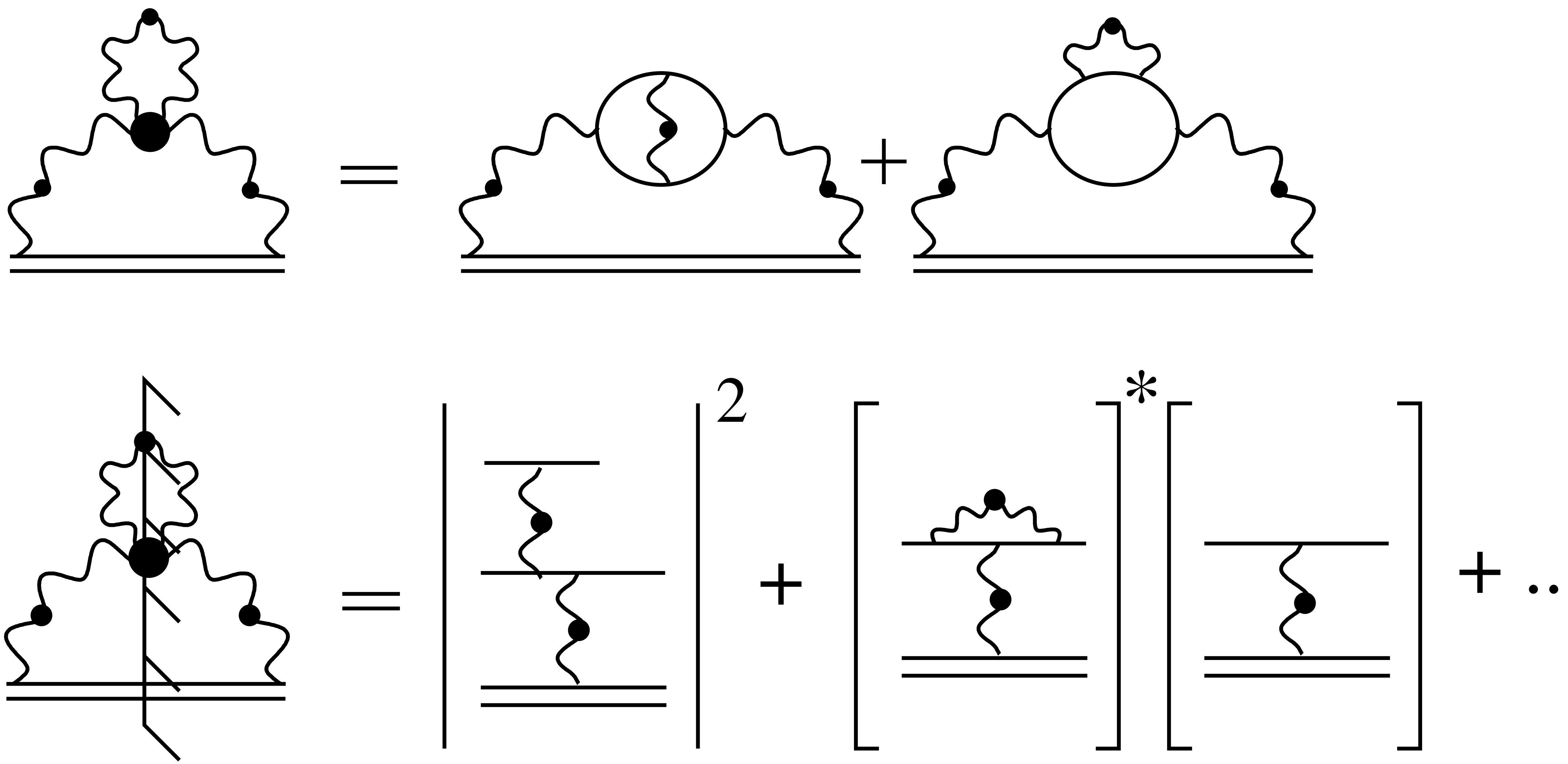
- Kappa becomes E-E correlator

Casalderry-Solana& Teaney,...

- Only four diagrams at NLO (=2loops):



``Blowing up'' HTL diagrams



There are four diagrams like this, both of us authors computed them numerically.

Result

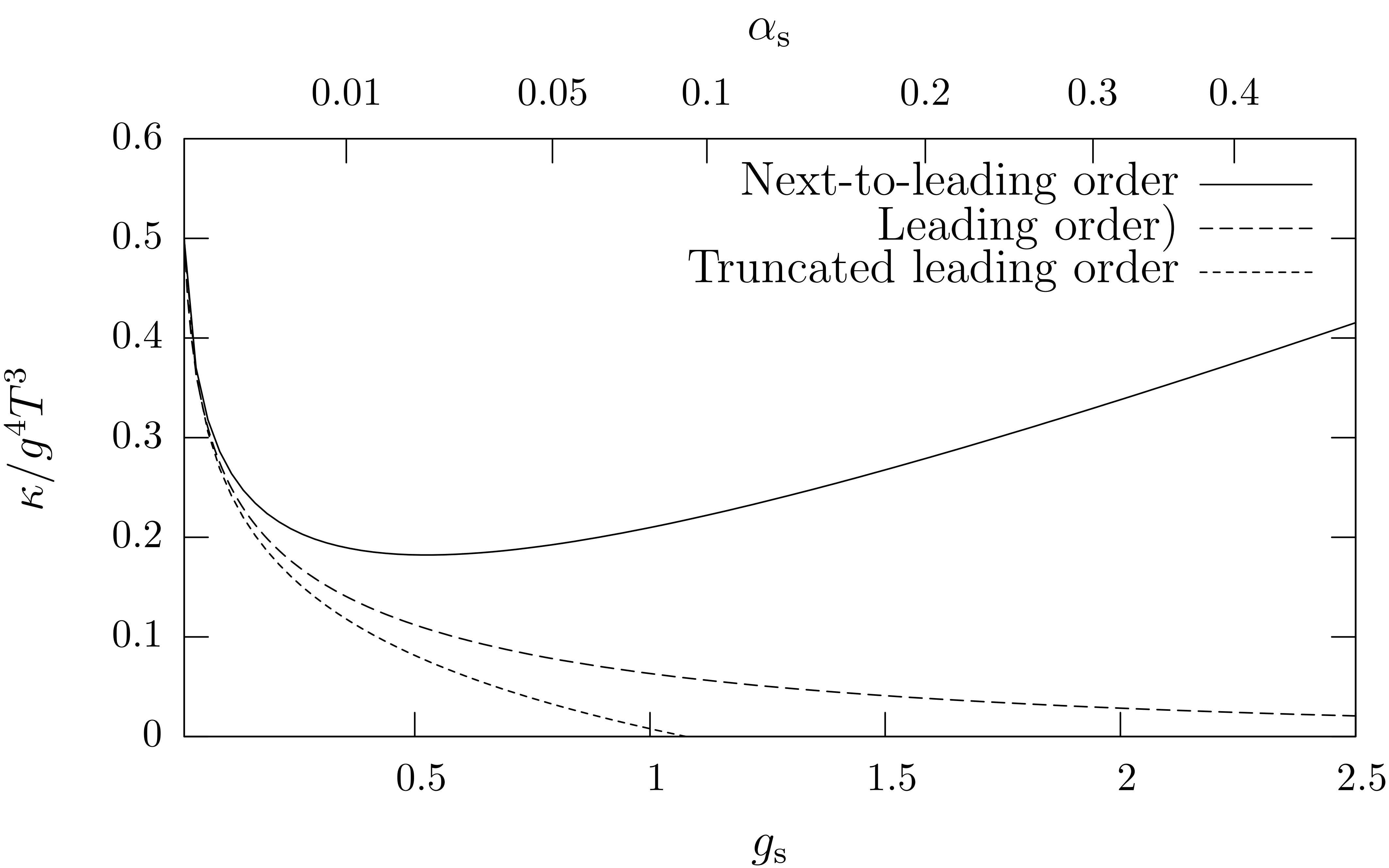
$$\kappa = \frac{C_H g^4 T^3}{18\pi}\left\{\left(N_c + \frac{N_f}{2}\right)\left(\ln\frac{2T}{m_D} + \xi\right) + \frac{N_f \ln 2}{2} \right.$$
$$+ \frac{N_c m_D}{T} C$$
$$\left. + \mathcal{O}(g^2)\right\}$$

Braaten& Thoma
Svetitsky
Moore& Teaney

Our computation

$C \approx 2.3302$

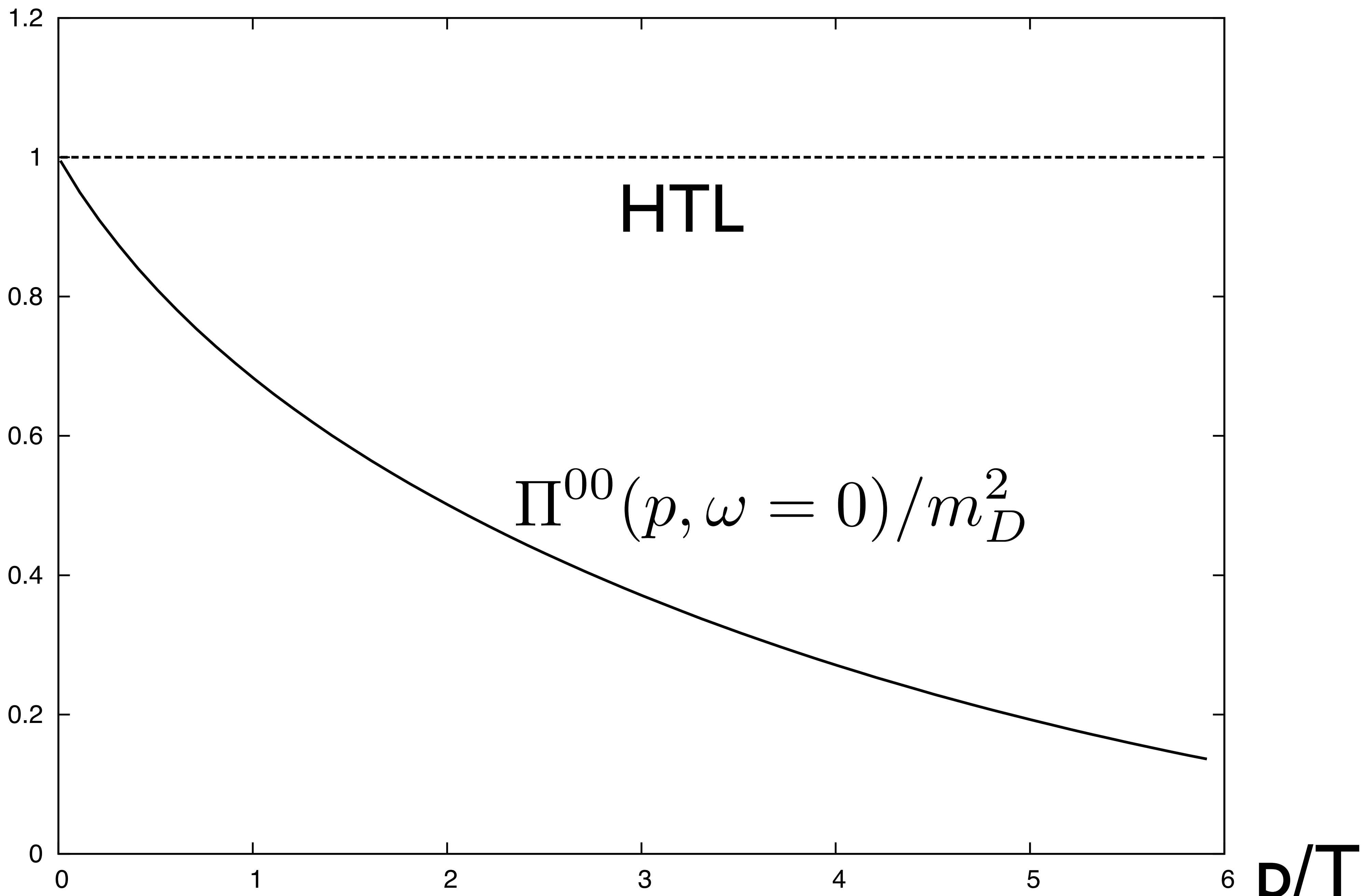
Result



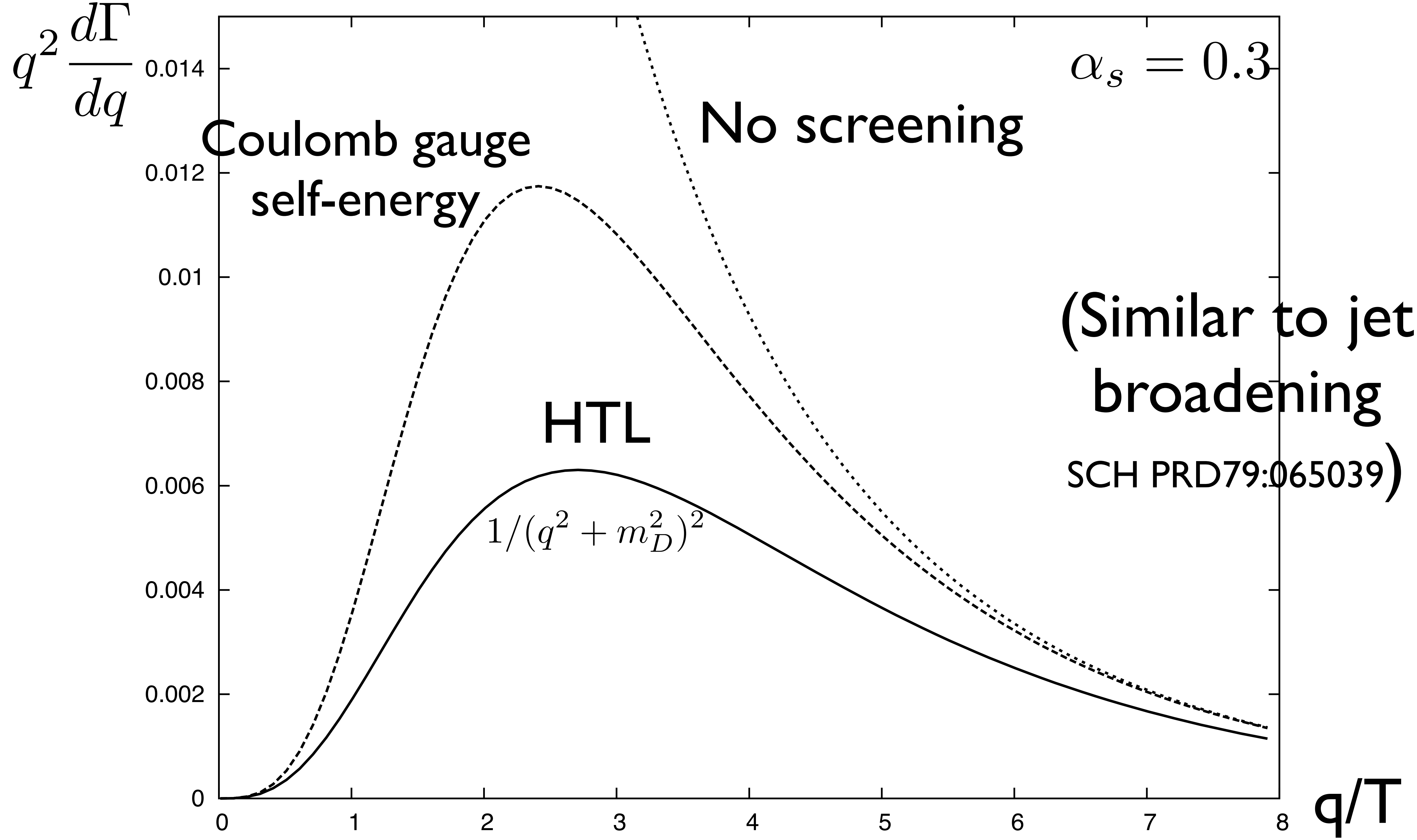
α_s
0.01
0.05
0.1
0.2
0.3
0.4
Next-to-leading order
Leading order)
Truncated leading order
κ/g^4T^3
0.6
0.5
0.4
0.3
0.2
0.1
0
0.5
1
1.5
2
2.5
g_s

Why is the correction large?

- Don't use soft limit (HTL) of Π^{00} self-energy



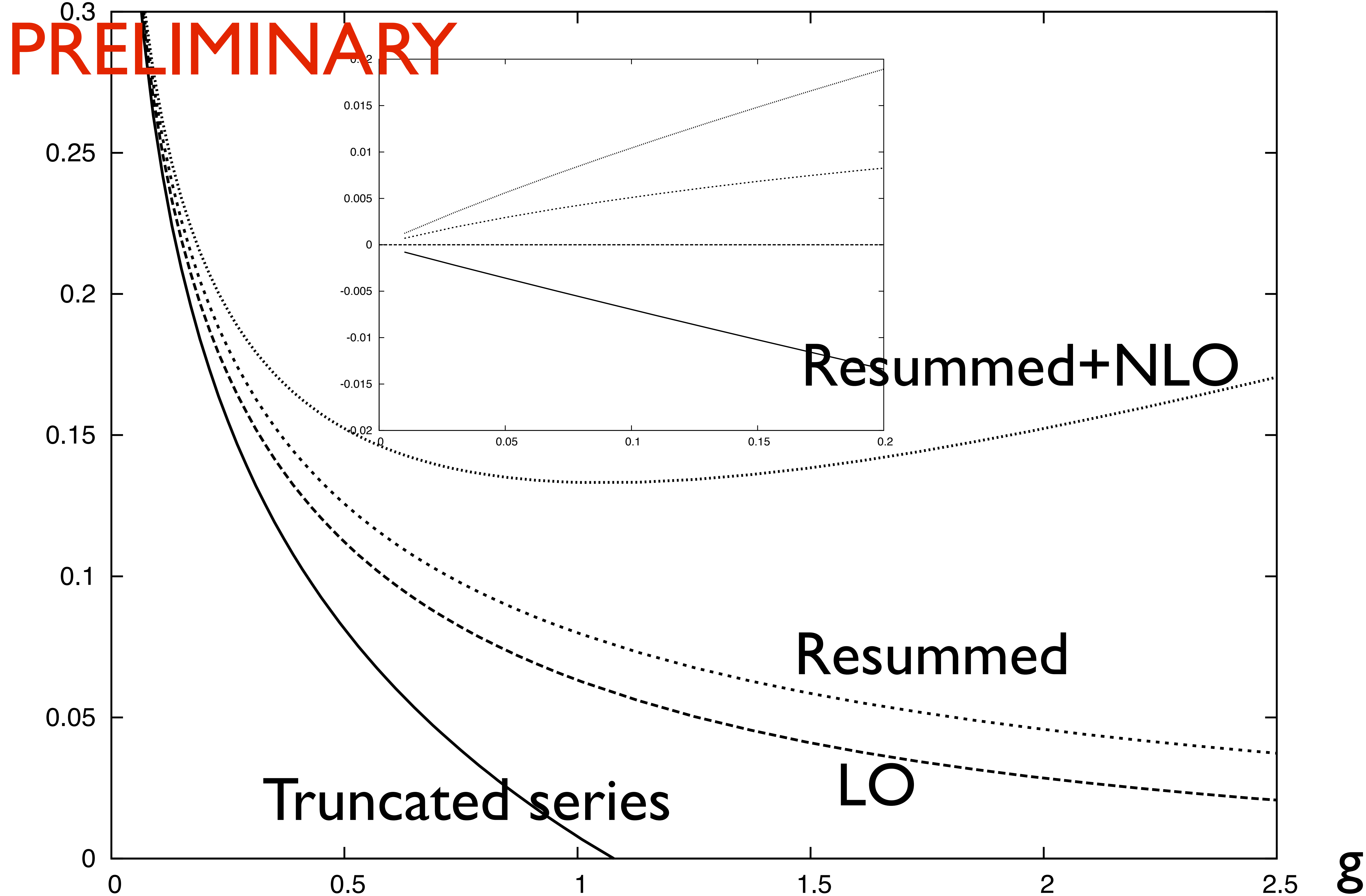
The importance of screening



Lesson: Use full leading-order self-energies

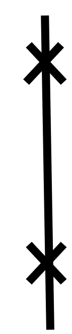
Partial resummation

$$\kappa \approx 0.1 g_s^3 T^3$$
$$(\alpha_s(2\pi T) \sim 0.2 \div 0.4)$$

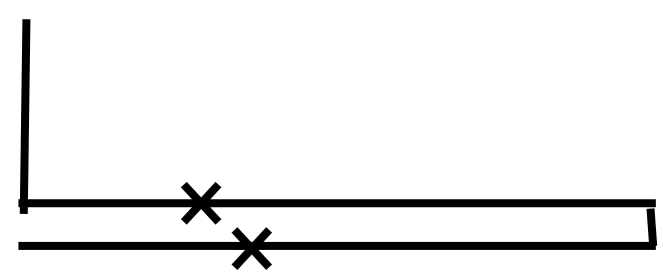


More on <EE>

- One can define a Euclidean <EE>(t_E) along the Polyakov loop



- One can define a real-time <EE>(t) spectral function



- The two are related by the usual analytic continuation

Laine,Moore,SCH

- Spectral function has no sharp peak

Laine,Moore,Philipsen & Tassler

- Some measurements have been done

(H. Meyer 1012.0234)

Conclusion

Prospects for predicting, using PT, transport coefficients in the QGP:

- PT has a tiny convergence radius
- That NLO is to be increased is a robust prediction.
  Expected to be generic for soft physics in general eta/s, q-hat,...
- Some effects can be resummed & reasonable extrapolation to T ~ few Tc can be attempted (w/help from lattice)