On Hybrid Heavy Quark Pseudo-Potentials at Finite Temperature and Gauge/String Duality

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- Motivation & Background
  - hybrid heavy mesons
  - lattice gauge theory/effective string description
- Think Different

  a new approach using strings in 5d

  - overview of the approach
  - some examples of heavy quark pseudo-potentials at finite temperature
- Final Remarks

WARNING

The physical system of interest is not weakly coupled.

pQCD as well as instanton methods seem inappropriate.

✦ Hybrid mesons

Non-Quark model mesons: quark-antiquark pair + gluonic degrees of freedom/excited states of the flux tube

Isgur-Paton

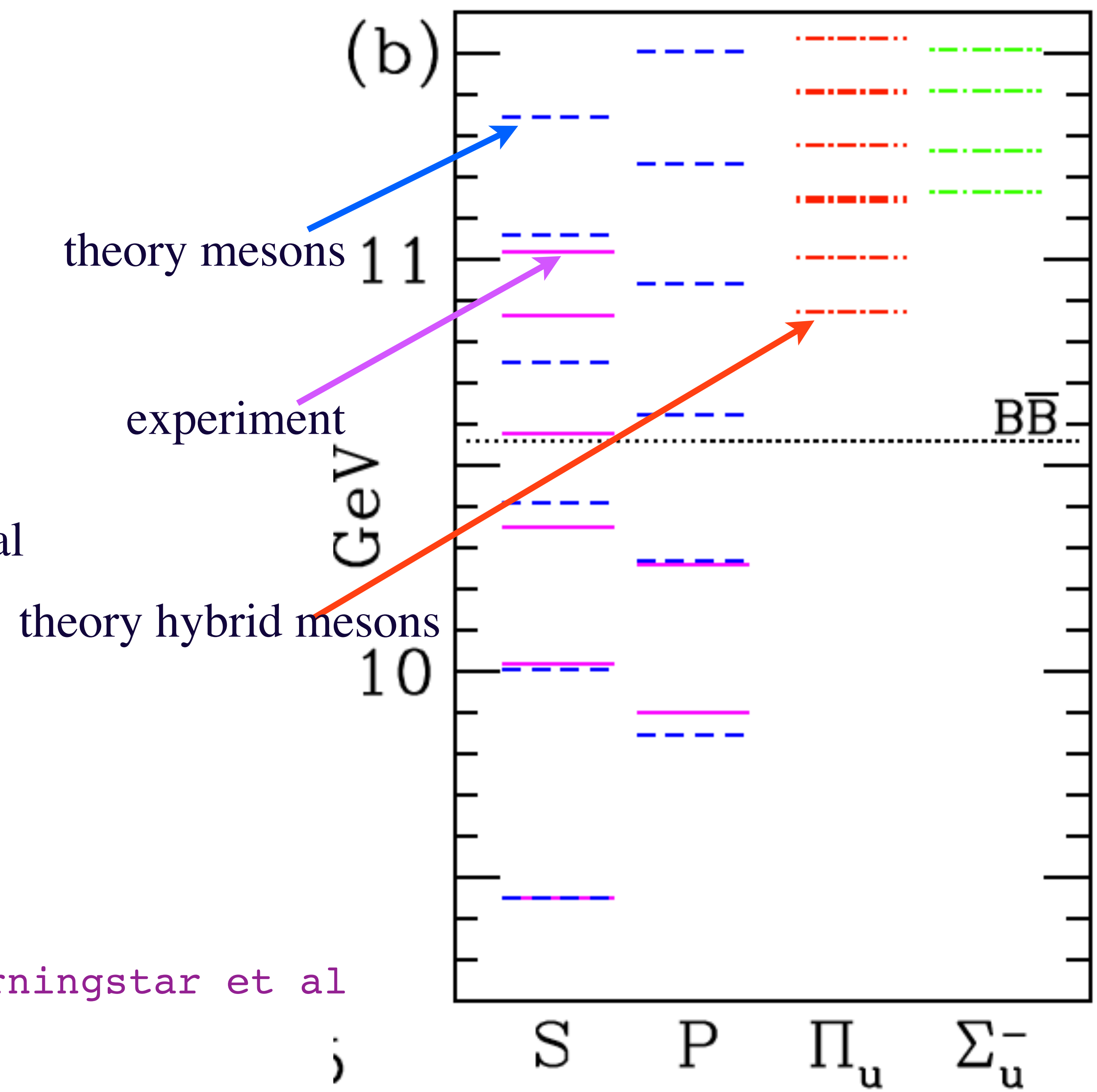
to get hybrid meson spectrum

$$V_0 \to V_n$$

heavy quark potential

hybrid potential

in the Schroedinger equation



The GlueX Experiment

✦ Excited states of the gluon flux tube as seen from the lattice

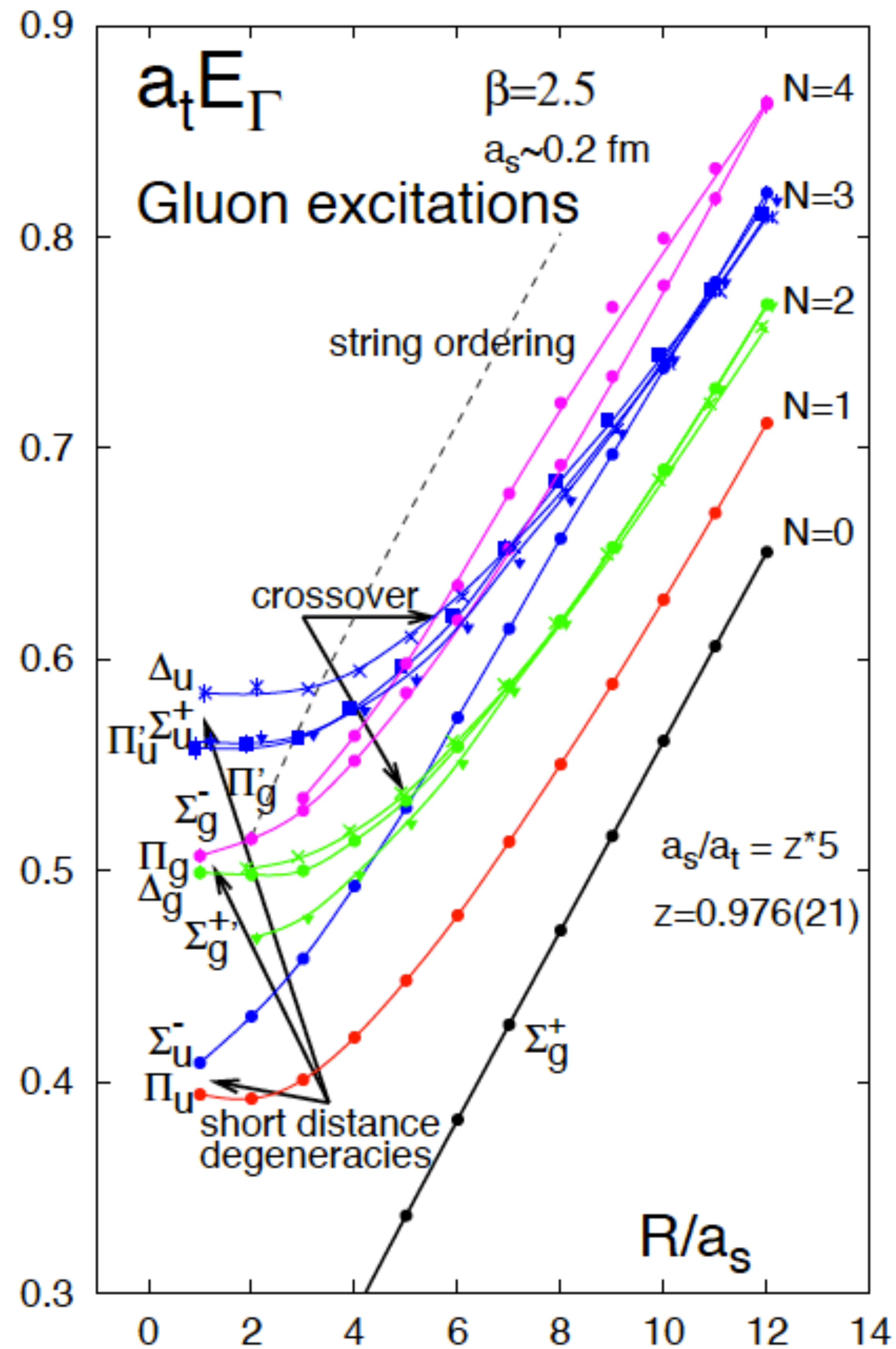
$N_c = 3$, pure glue

classification via reps. of D_{4h}

here $\Sigma_g^+ \equiv V$

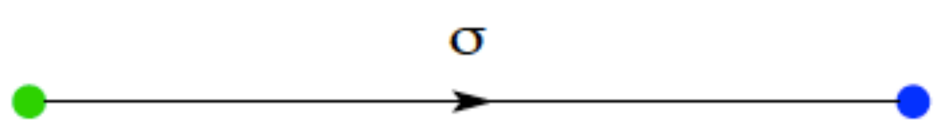
if Λ is a projection of angular momentum onto the quark-antiquark axis, then $\Sigma's$ have $\Lambda = 0$, etc

Morningstar et al

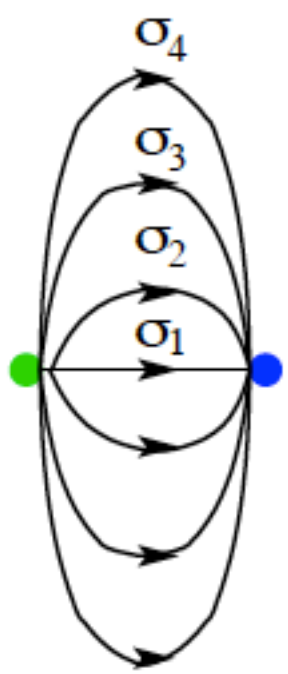


Think Different

✦ Stringy reason for the 5th "dimension"



Faraday picture of fluxes



$$\sigma_n l_n = const$$

Left: a string-like flux tube of tension σ. Right: a "fat string" as a collection of thin strings of different tensions $\{\sigma_n\}$.

- Continuos spectrum. σ can be promoted to a new spacetime coordinate.

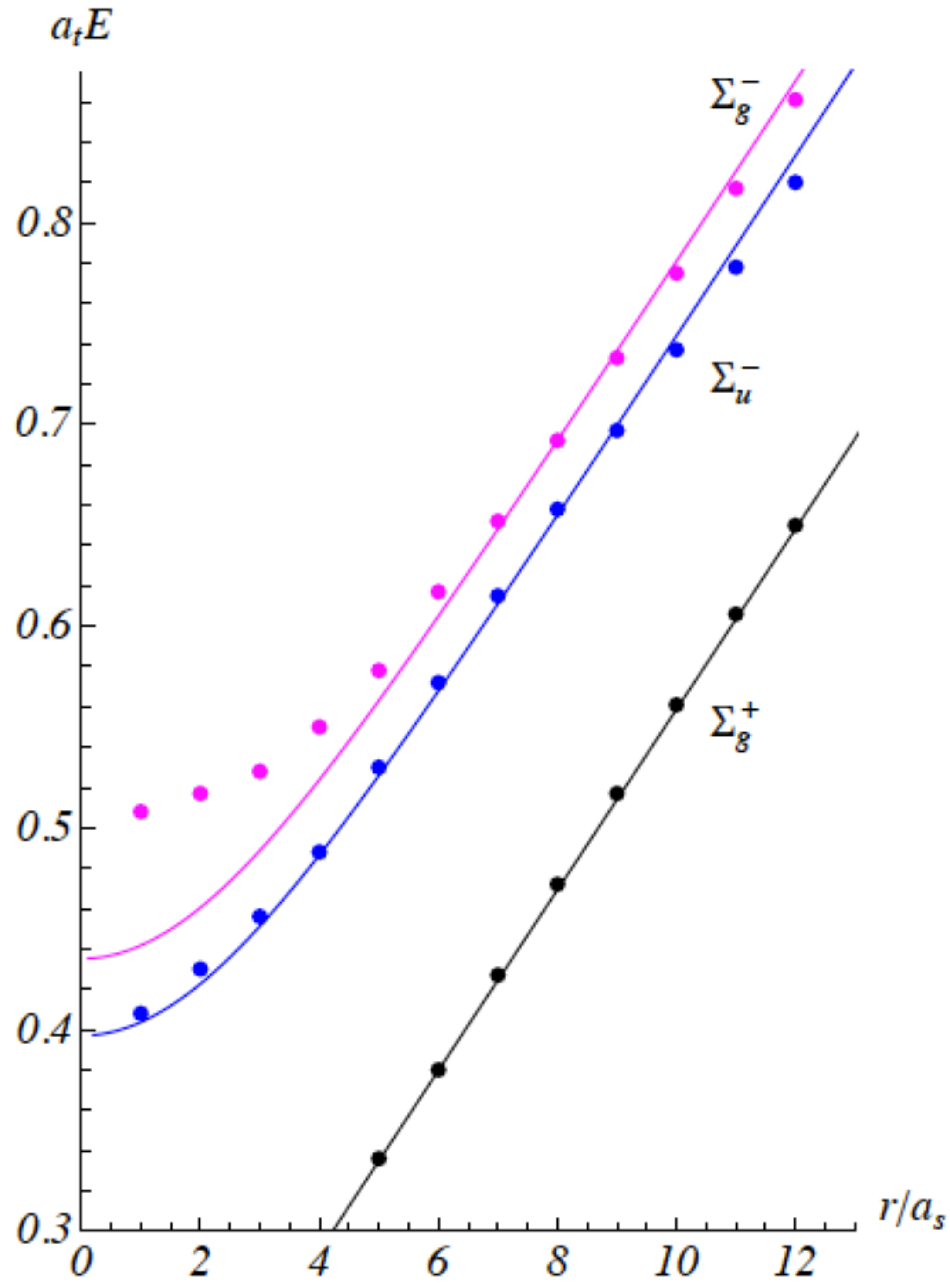
Polyakov: Liouville field as the 5th dimension.

- Discrete spectrum $\longrightarrow$ generalized Veneziano models. Andreev-Siegel

✦ A **big** question to ask:

quantum fluctuations in 4d $\approx$ geometry modification or $\{\sigma_n\}$ in 5d

✦ How it works for the potentials at T=0

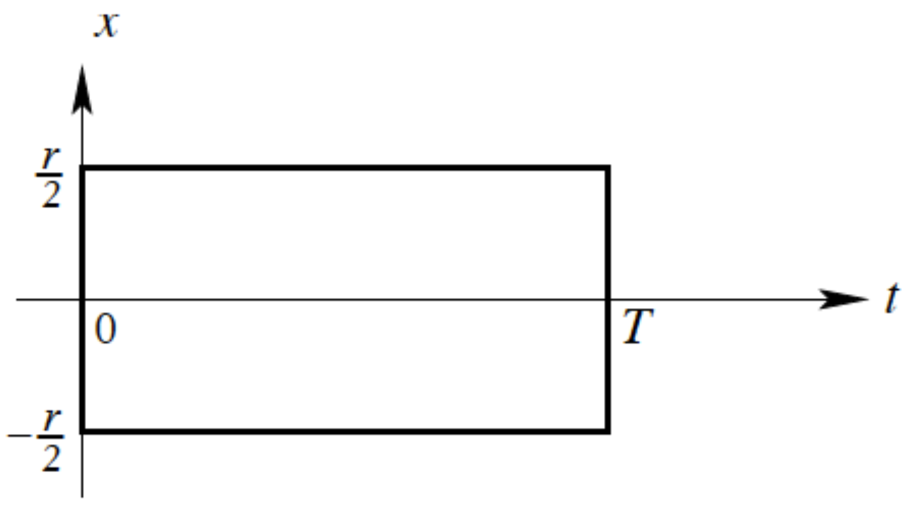


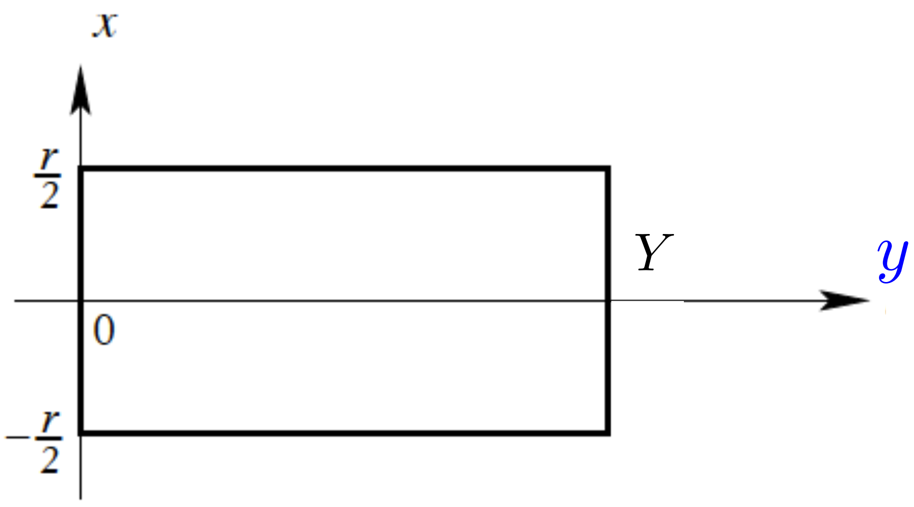
The problem is to compute the potentials at finite temperature

The first step is to compute the pseudo-potentials at finite temperature

- Technical reasonings.
- At the present time, this is of "academic" interest only.

Spatial Wilson Loop





At finite T , one identifies $t \equiv t + \dfrac{1}{T}$

The expectation value of the loop

$$W(C) = \left\langle \frac{1}{3} \mathrm{tr}\ \mathrm{Pexp}\left[ig \oint dx^{\mu}\, A_{\mu} \right] \right\rangle = \sum_{n=0}^{\infty} c_n(R)\, \mathrm{e}^{-\tilde{V}_n(R) Y}$$

with $\tilde{V}_n$ the hybrid pseudo-potentials.

✦ Our primary interest is in understanding $\tilde{V}_0$ and $\tilde{V}_3$

Spatial Wilson Loop II

For $\tilde{V}_0$, we take a rectangular Wilson loop, then adopt the proposal

$$e^{-\tilde{V}_0 Y} \sim e^{-S_{\rm NG}}$$

Rey-Yee-Maldacena

The pseudo-potential is written in parametric form

$$r(\lambda) = 2\sqrt{\frac{\lambda}{s}} \int_0^1 dv\, v^2 e^{\lambda(1-v^2)} \left(1 - \left(\frac{\lambda}{\tau}\right)^2 v^4\right)^{-1/2} \left(1 - v^4 e^{2\lambda(1-v^2)}\right)^{-1/2}$$

$$\tilde{V}_0(\lambda) = 2g\sqrt{\frac{s}{\lambda}} \int_0^1 \frac{dv}{v^2} \left[e^{\lambda v^2} \left(1 - \left(\frac{\lambda}{\tau}\right)^2 v^4\right)^{-1/2} \left(1 - v^4 e^{2\lambda(1-v^2)}\right)^{-1/2} - 1 - v^2 \right] + C$$

with λ a parameter, $\tau = s/\pi^2 T^2$.

The physical parameters: s (Λ_{QCD})

g (coupling constant)

C (normalization constant)

Andreev-Zakharov

Spatial Wilson Loop III

For $\tilde{V}_3$, we take a rectangular Wilson loop, then adopt the proposal

$$\mathrm{e}^{-\tilde{V}_3 Y} \sim \mathrm{e}^{-S_{\mathrm{NG}}-S'_{\mathrm{NG}}-S_{\mathrm{def}}}$$

Andreev

The hybrid pseudo-potential is written in parametric form

$$r(\lambda) = 2\sqrt{\frac{\lambda}{s}\bar{\rho}}\int_0^1 dv\, v^2 \mathrm{e}^{\lambda(1-v^2)}\left(1-\left(\frac{\lambda}{\tau}\right)^2 v^4\right)^{-1/2}\left(1-\bar{\rho}\, v^4 \mathrm{e}^{2\lambda(1-v^2)}\right)^{-1/2}$$

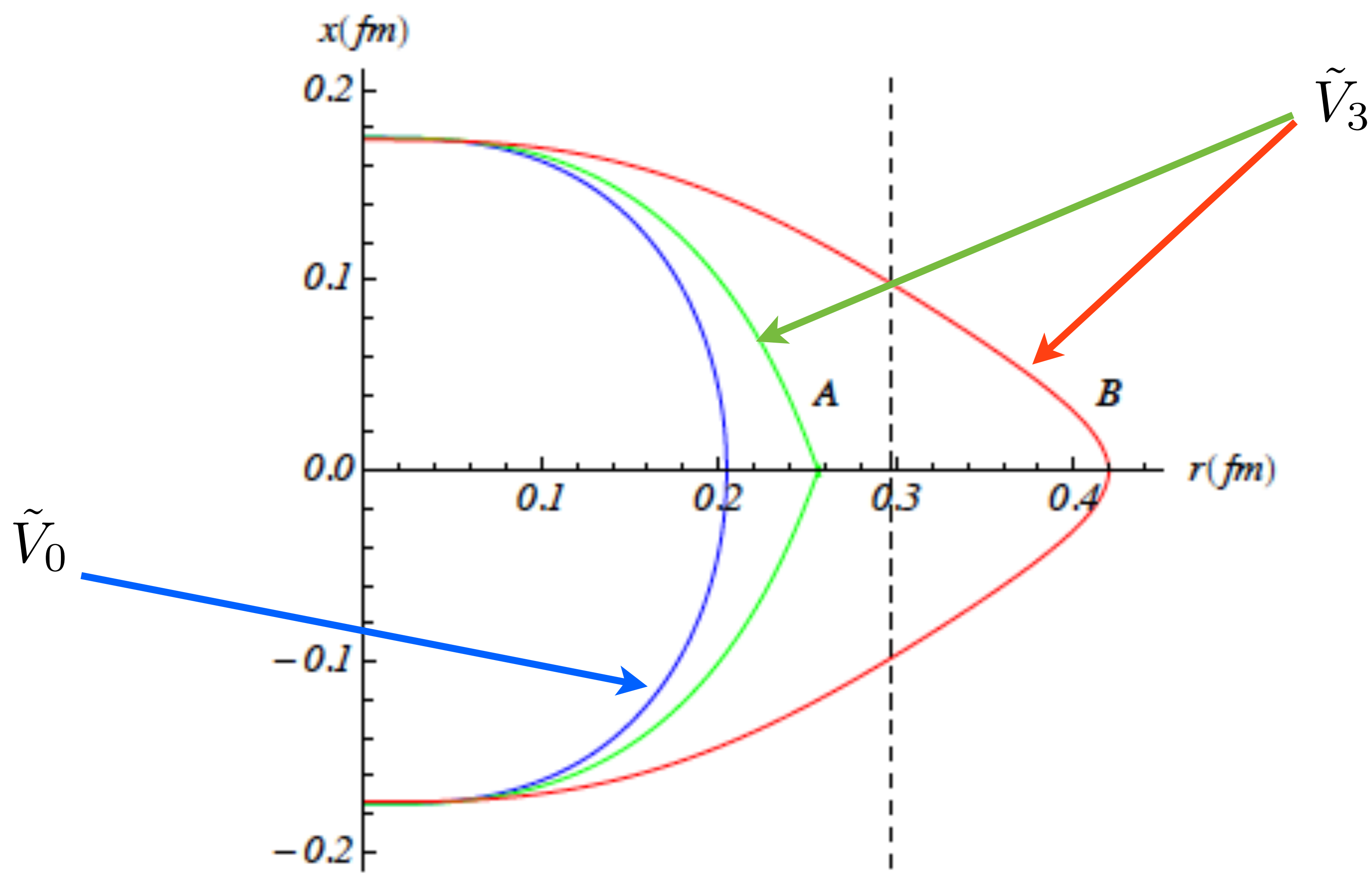
$$\tilde{V}_3(\lambda) = 2g\sqrt{\frac{s}{\lambda}}\left(\kappa\,\mathrm{e}^{-2\lambda} - 1 + \int_0^1 \frac{dv}{v^2}\left[\mathrm{e}^{\lambda v^2}\left(1-\left(\frac{\lambda}{\tau}\right)^2 v^4\right)^{-1/2}\left(1-\bar{\rho}\, v^4 \mathrm{e}^{2\lambda(1-v^2)}\right)^{-1/2} - 1\right]\right) + C$$

with $\bar{\rho}(\lambda) = 1 - \kappa^2(1-(\lambda/\tau)^2)\,(1+4\lambda)^2\,\mathrm{e}^{-6\lambda}$ and κ a physical parameter.

✦ Our construction of the pseudo-potentials has no free parameters.

The values of s, g, C, and κ are fixed from the corresponding potentials.

Cusps Formation



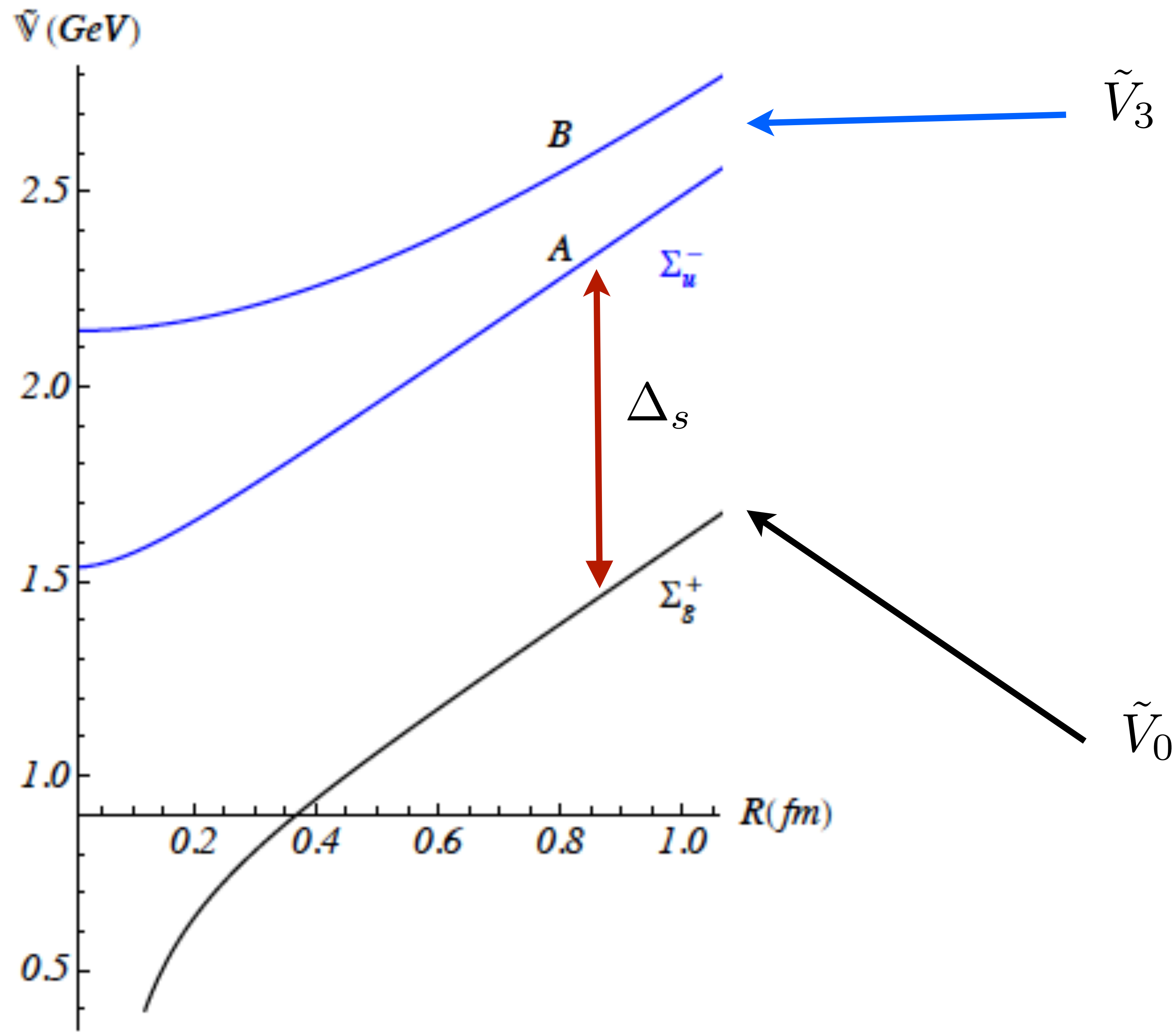
Here $T = 150\,\mathrm{MeV}$, $s = 0.44\,\mathrm{GeV}^2$, $C = 0.71\,\mathrm{GeV}$, $g = 0.176$, and

$\kappa(A) = 2.3$ $\kappa(B) = 2000$

Predictions

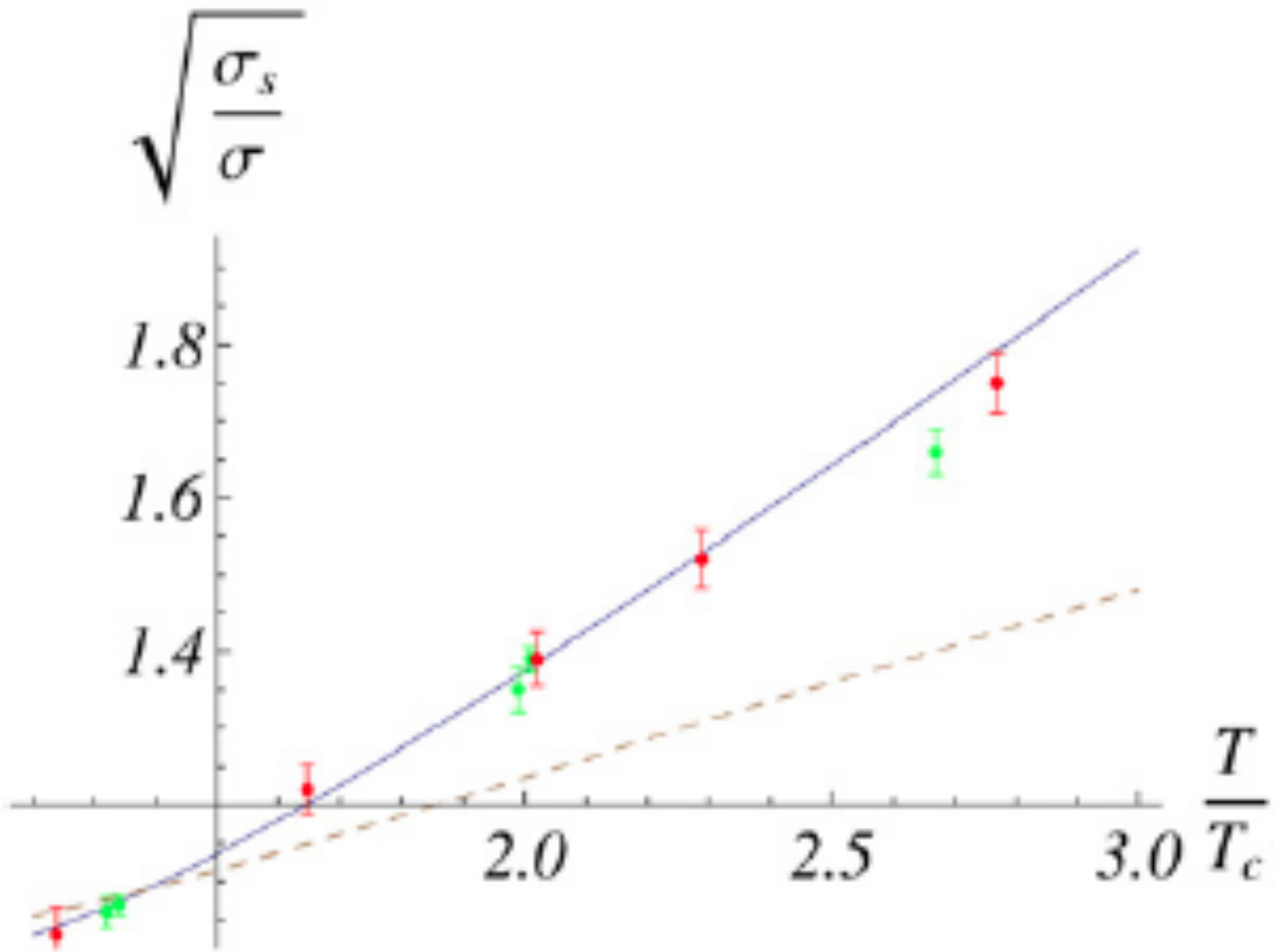
✦ For the hybrid pseudo-potentials, no results from the lattice yet

Here $T = 105\,\mathrm{MeV}$



- At large r, $\tilde{V}_n = \sigma_s r + \ldots$, σ_s is the spatial string tension. It is universal.

Spatial String Tension



- Very good agreement with the lattice data up to $3\,T_c$

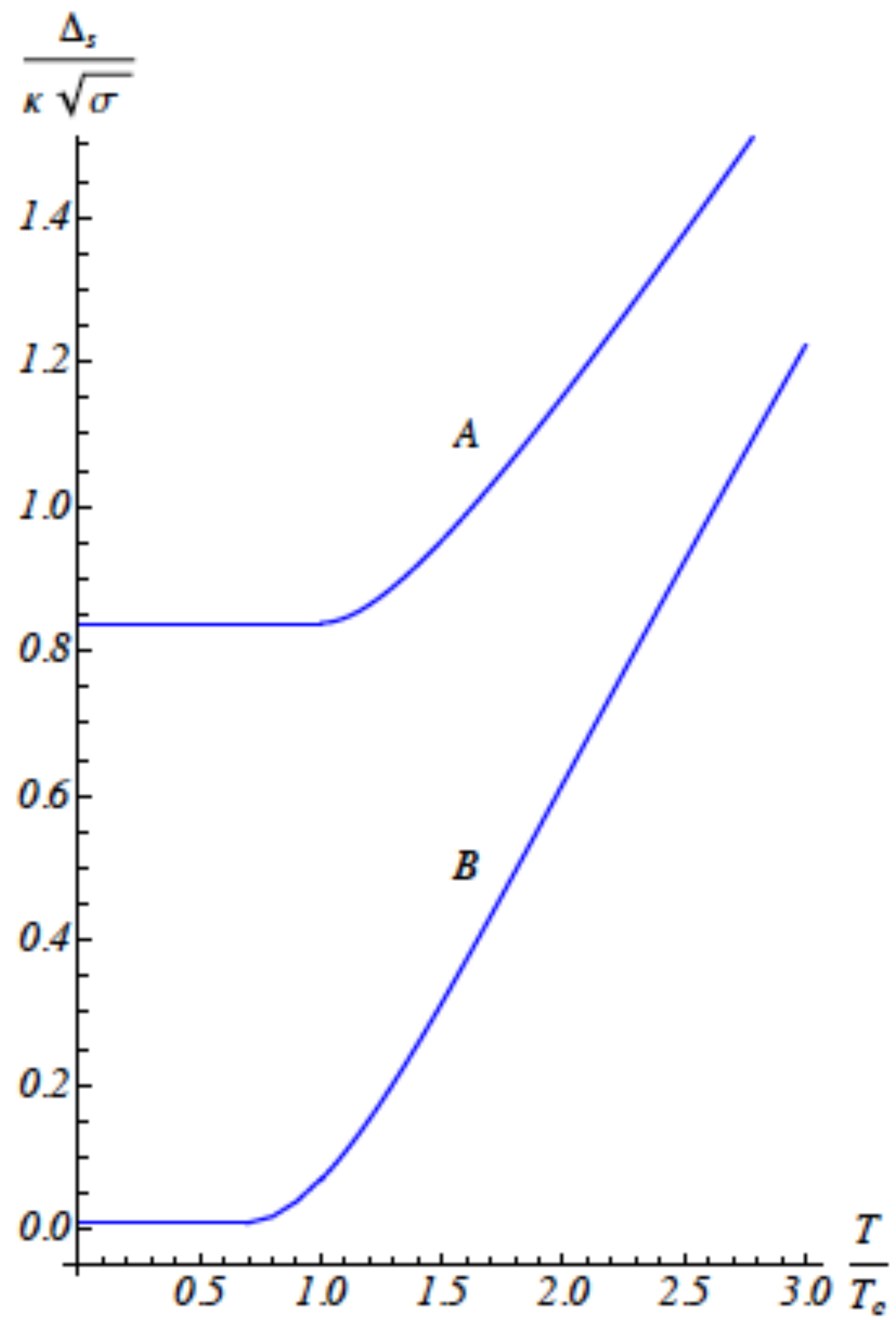
$$\sigma_s = \sigma \qquad T < T_c$$

$$\sigma_s = \sigma \frac{T^2}{T_c^2} \exp\left\{ \frac{T_c^2}{T^2} - 1 \right\} \qquad T > T_c$$

The Gap Δ_s

- The gap doesn't show any essential temperature dependence up to T_c , but then it rises.

  That is quite similar to the behavior of σ_s .

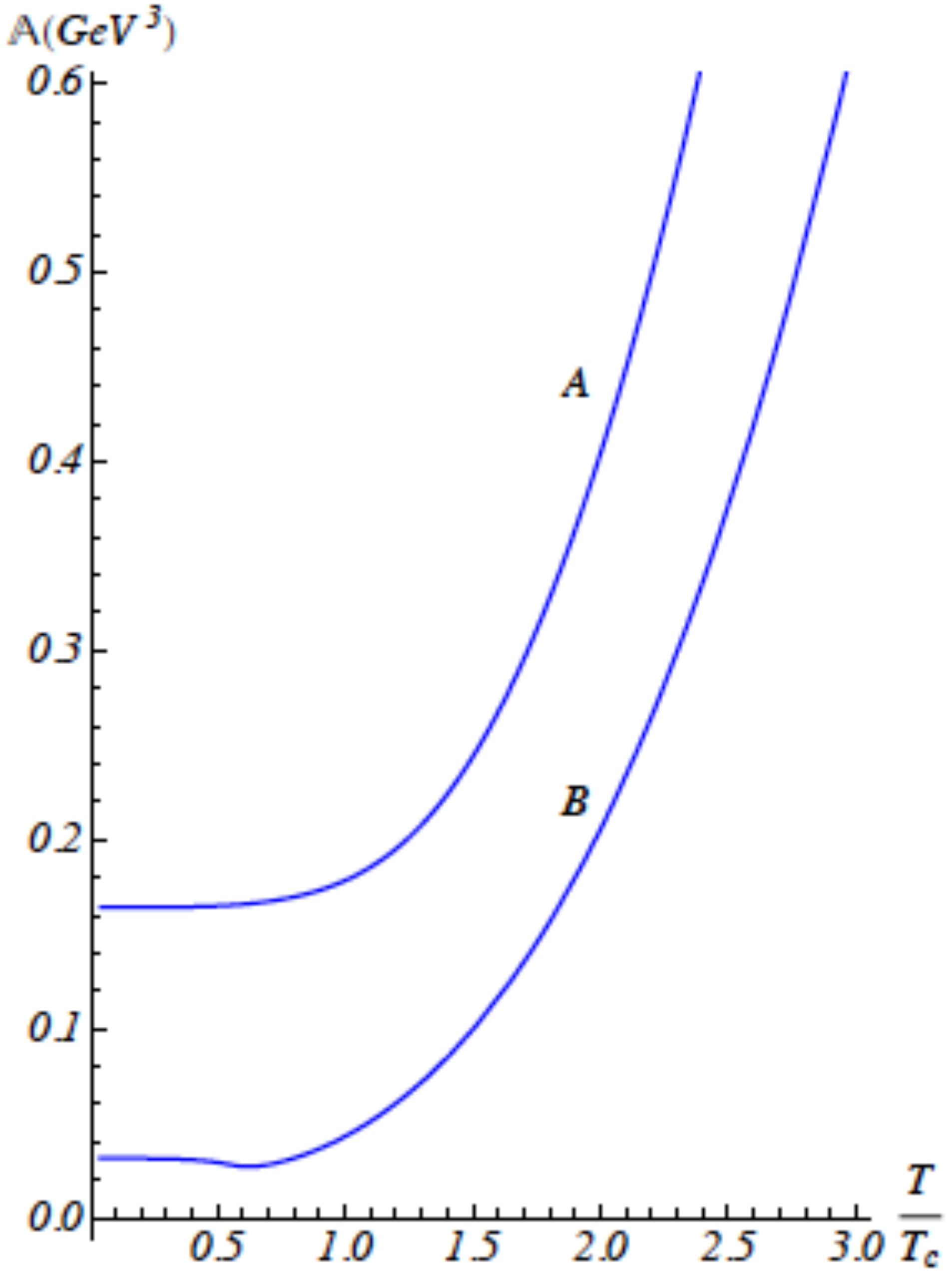


$$\Delta_s^B = 2\sqrt{\mathrm{e}g\sigma}\begin{cases}\kappa\lambda_c^{-\frac{1}{2}}\mathrm{e}^{-2\lambda_c-1} + \int_1^{\sqrt{\lambda_c}} dv\left(v^{-4}\mathrm{e}^{2(v^2-1)}-1\right)^{\frac{1}{2}}\left(1-\left(\frac{T}{T_c}\right)^4 v^4\right)^{-\frac{1}{2}} & \text{if} \quad T < T_c\,, \\ \kappa\frac{T}{T_c}\exp\left\{-2\left(\frac{T_c}{T}\right)^2-1\right\} & \text{if} \quad T \geq T_c\,.\end{cases}$$

Small r behavior

At small r, $\tilde{V}_n(r) = a + Ar^2 + \ldots$

- A also doesn't show any essential temperature dependence up to T_c , but then it rises.



Final Remarks

- phenomenological string model
- it allows to compute almost all, analytically
- Very often, surprisingly good agreement with the lattice data and phenomenology

A BIG QUESTION

is

can string theory provides a key to the solution of strongly coupled physical systems?