Surface operator study in SU(2) gauge field theory

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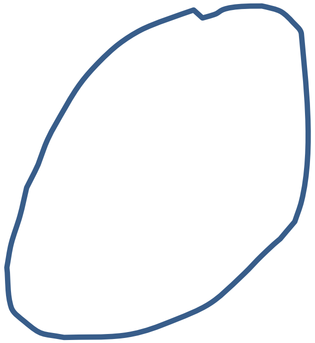
Line operator

- Wilson loop operator:

$$W_C = Tr\left(Pe^{ig\oint_C Adc}\right)$$

C



Confinement phase: area law

$$W_C \propto e^{-\sigma S(C)}$$

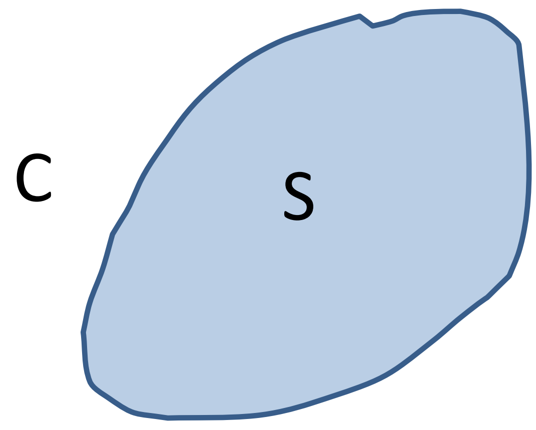
Deconfinement phase: perimeter law

$$W_C \propto e^{-kp(C)}$$

Surface operators

- For a general gauge group

$$W_S = Tr\left(Pe^{ig\int\limits_S F d\sigma}\right)$$



- E. Witten, S. Gukov:

4D SYM Theory, spatial surface operator

Area law at low T: $W_S \propto e^{-\sigma S}$

Volume law high T: $W_S \propto e^{-\gamma V}$

From surface to lines

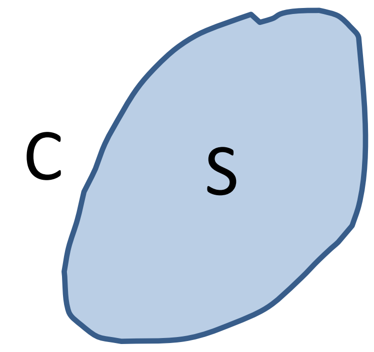
- In the limit β **-> 0** the 4D SYM theory reduces to a pure (non- supersymmetric) three-dimensional Yang-Mills theory on **S.**
- In this limit, a temporal surface operator turns into a line operator (supported on γ) in the 3D theory.
- Therefore, surface operators in the four-dimensional gauge theory exhibit volume (resp. area) law whenever the corresponding line operators in the 3D theory exhibit area (resp. circumference) law.

S. Gukov, E. Witten

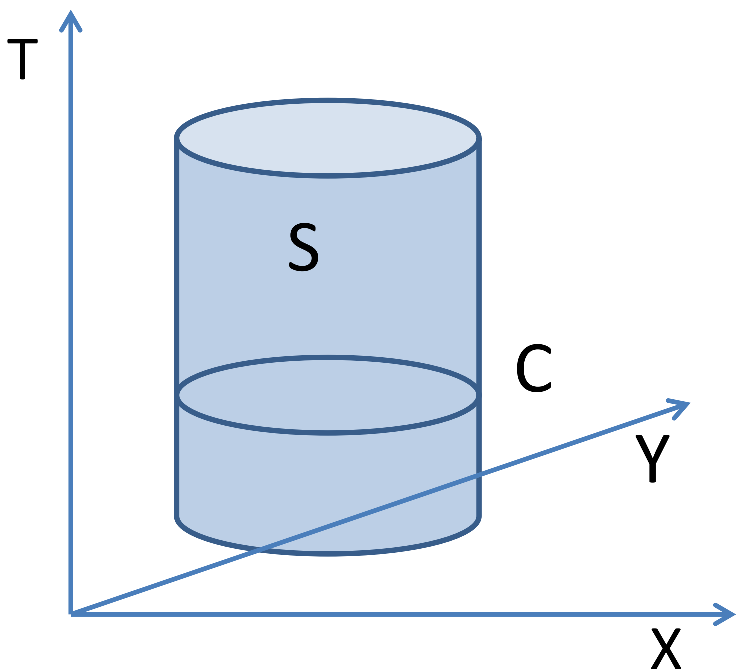
Line – Surface operators correspondence

- In abelian gauge field theory

$$Tr\left(Pe^{ig\oint\limits_C Adc}\right) = Tr\left(Pe^{ig\int\limits_S Fd\sigma}\right)$$



- In general case:



Deconfinement phase

Spatial Wilson loop: perimeter law

$\Downarrow$

Temporal surface operator: area law

Calculation within SU(2) LQCD

- Surface operator on lattice:

$$W_S = Re\, S \prod e^{\imath \theta_p} \qquad\qquad \theta_p = g \int\limits_S F d\sigma$$

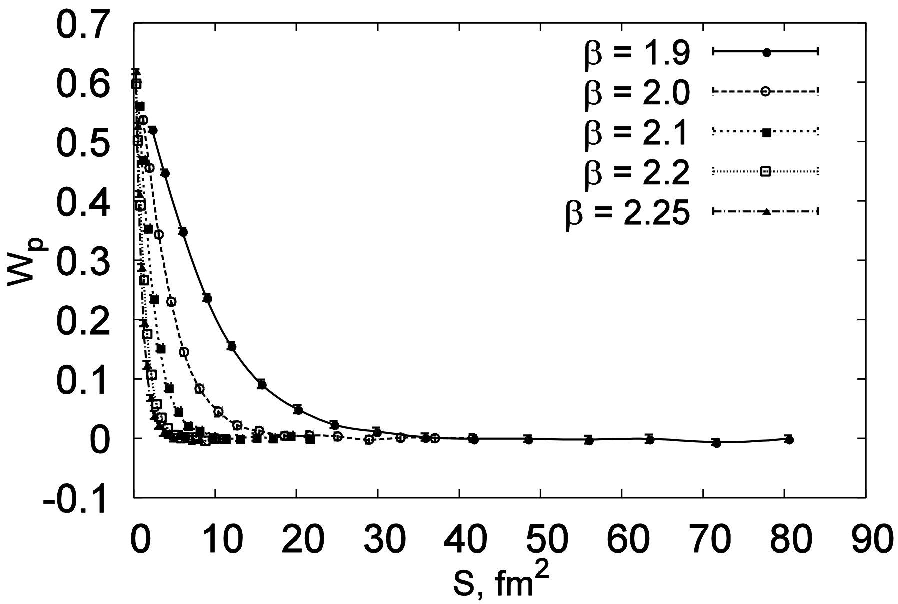
- SU(2) pure gauge:

$$F_p = \widehat{1} \cos\theta_p + \imath\, n_i \sigma_i \sin\theta_p$$

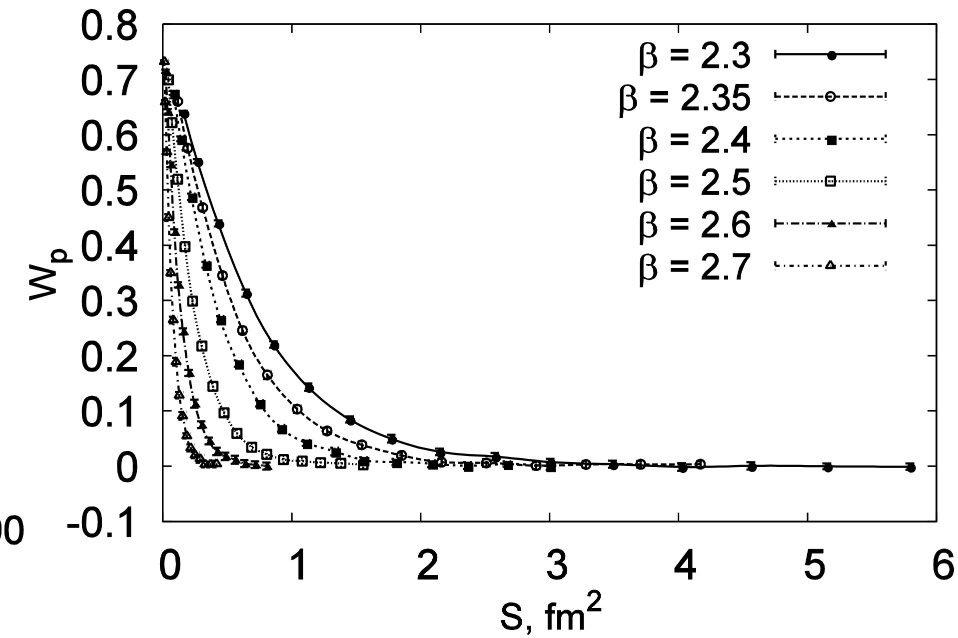
$$\theta_p = \arccos\left(\frac{1}{2} Tr\, F_p\right)$$

Surface operator calculation

Confinement phase



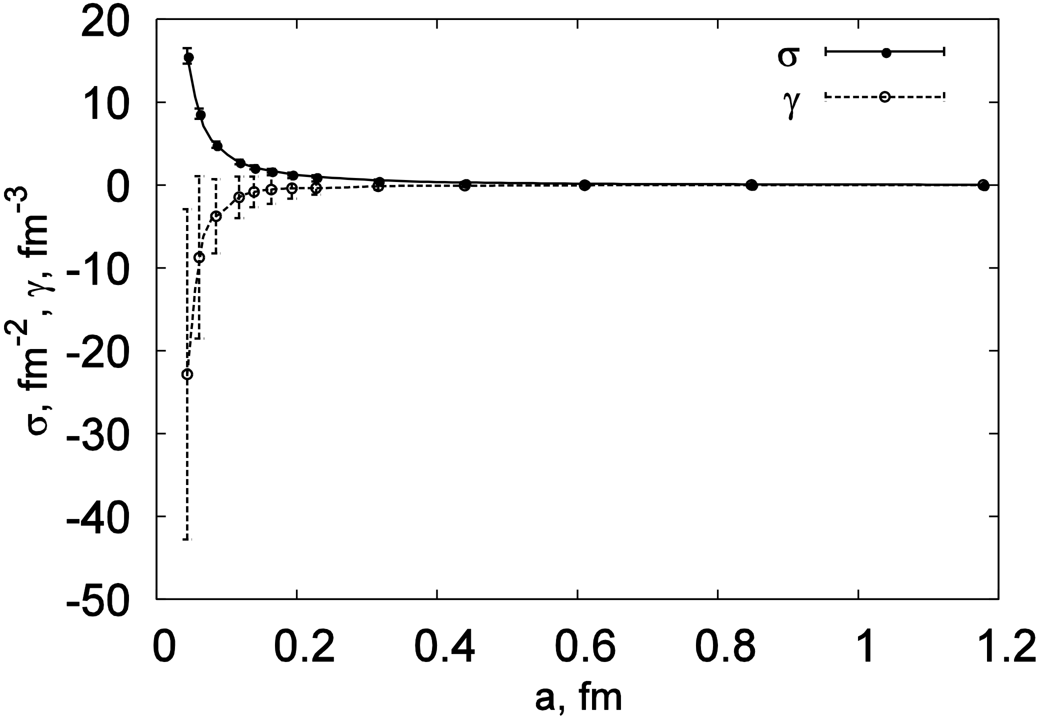
Deconfinement phase



Surface operator parameterization:

$$W_S = Ce^{-\sigma S - \gamma V}$$

Lattice spacing dependence



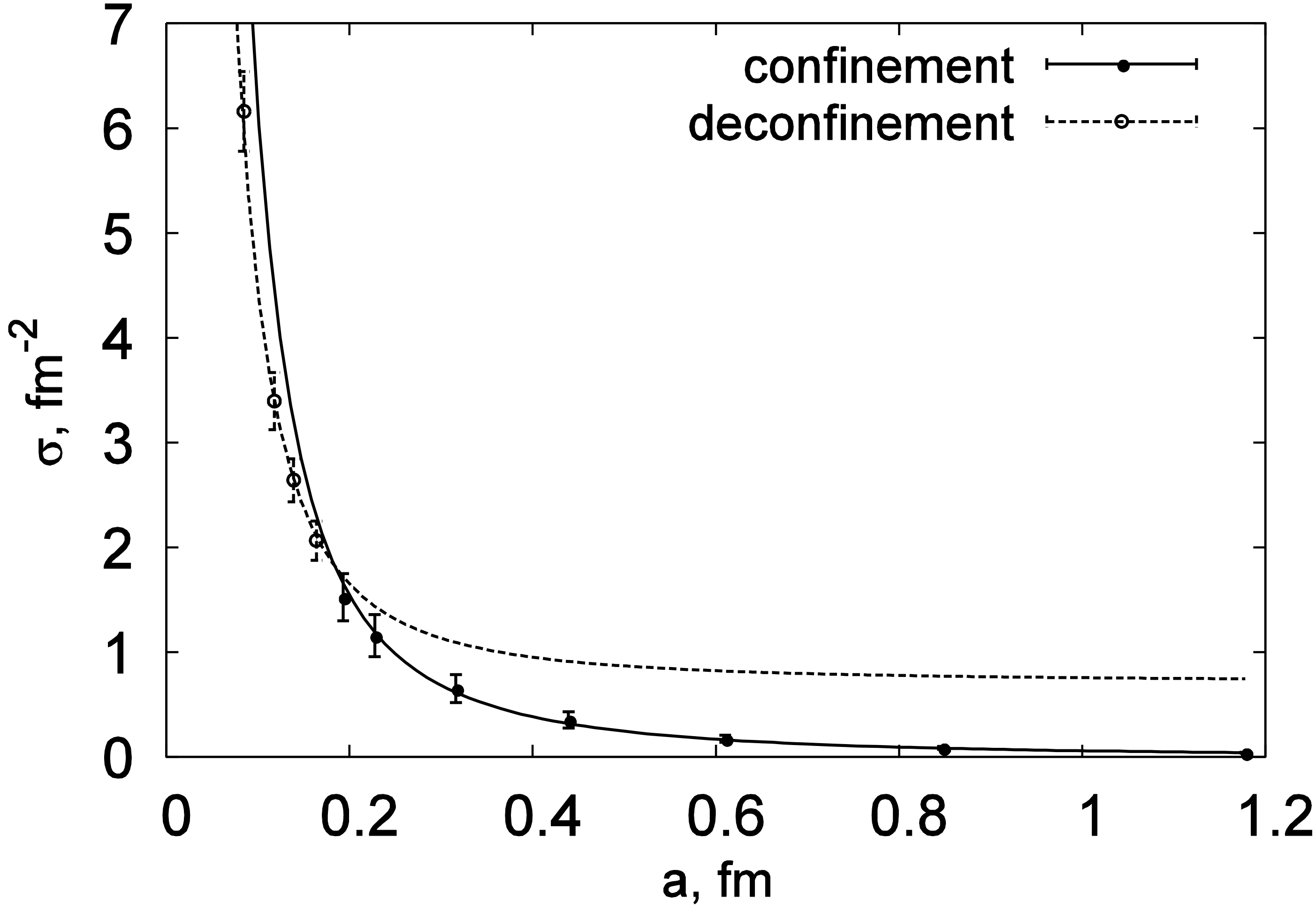
- Dipole self-energy -> area coefficient divergence:

$$\sigma(a) = \sigma_{ph} + \sigma_{div}/a^2$$

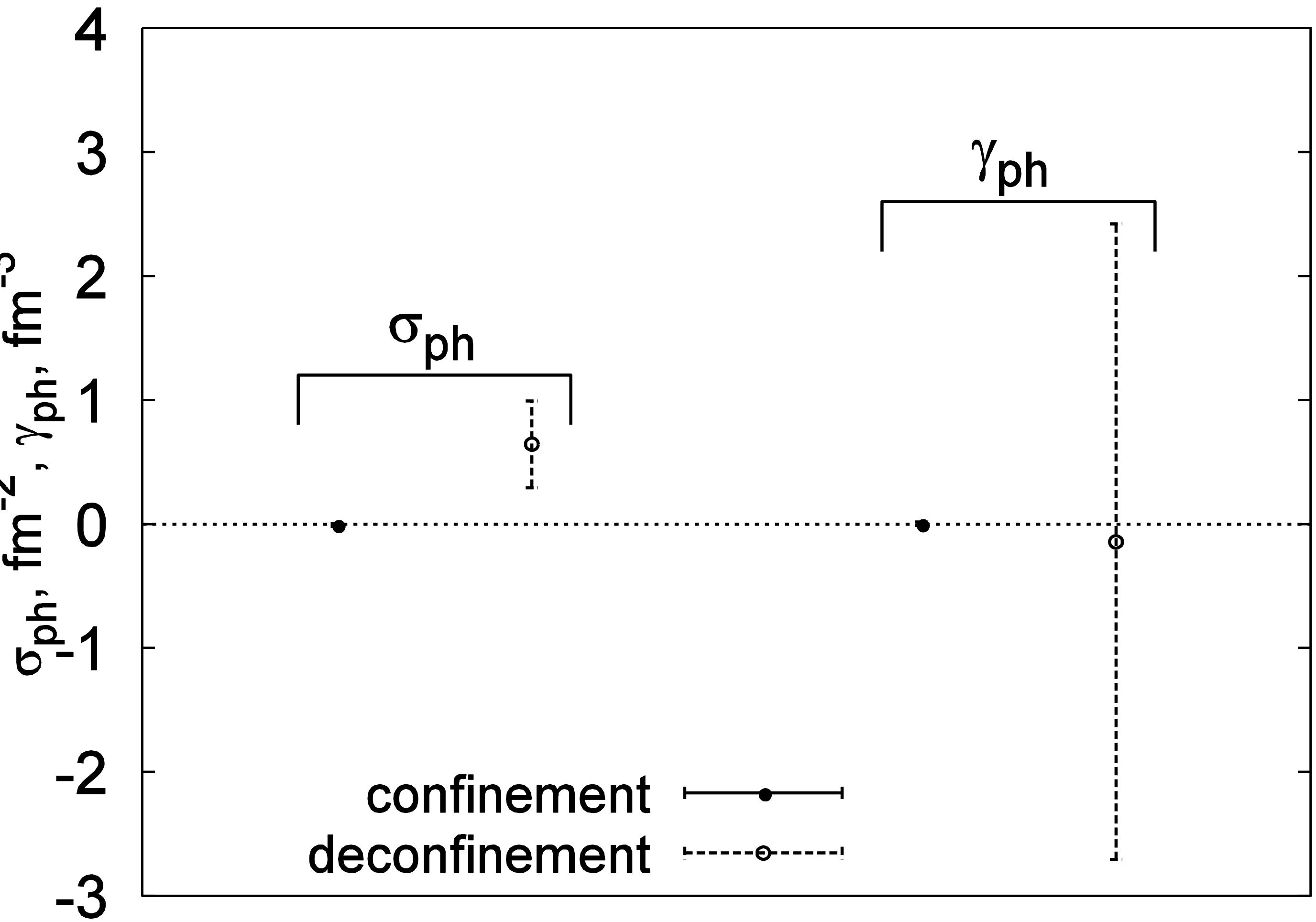
- Volume coefficient divergence:

$$\gamma(a) = \gamma_{ph} + \gamma_{div}/a^3$$

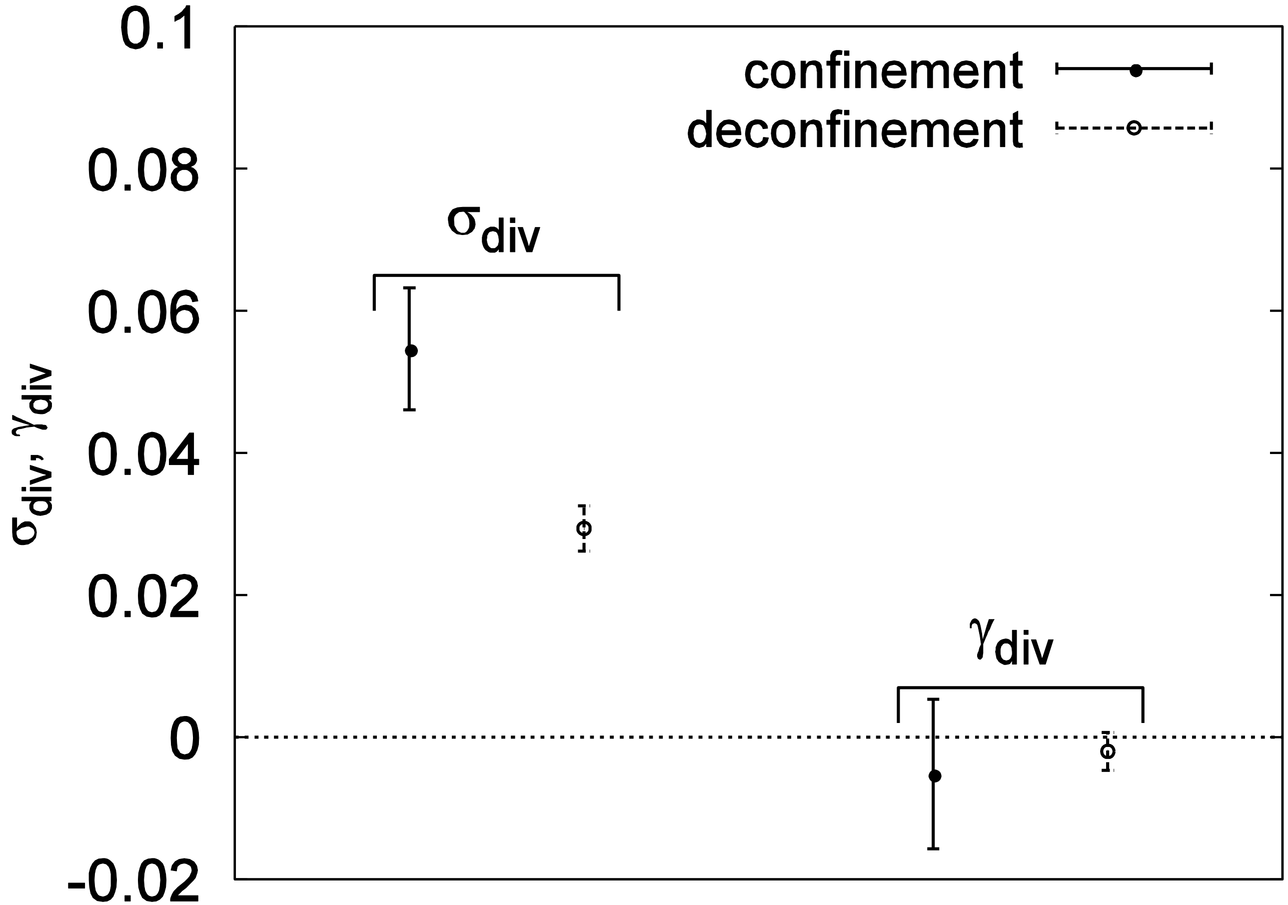
Extraction of the S dependence



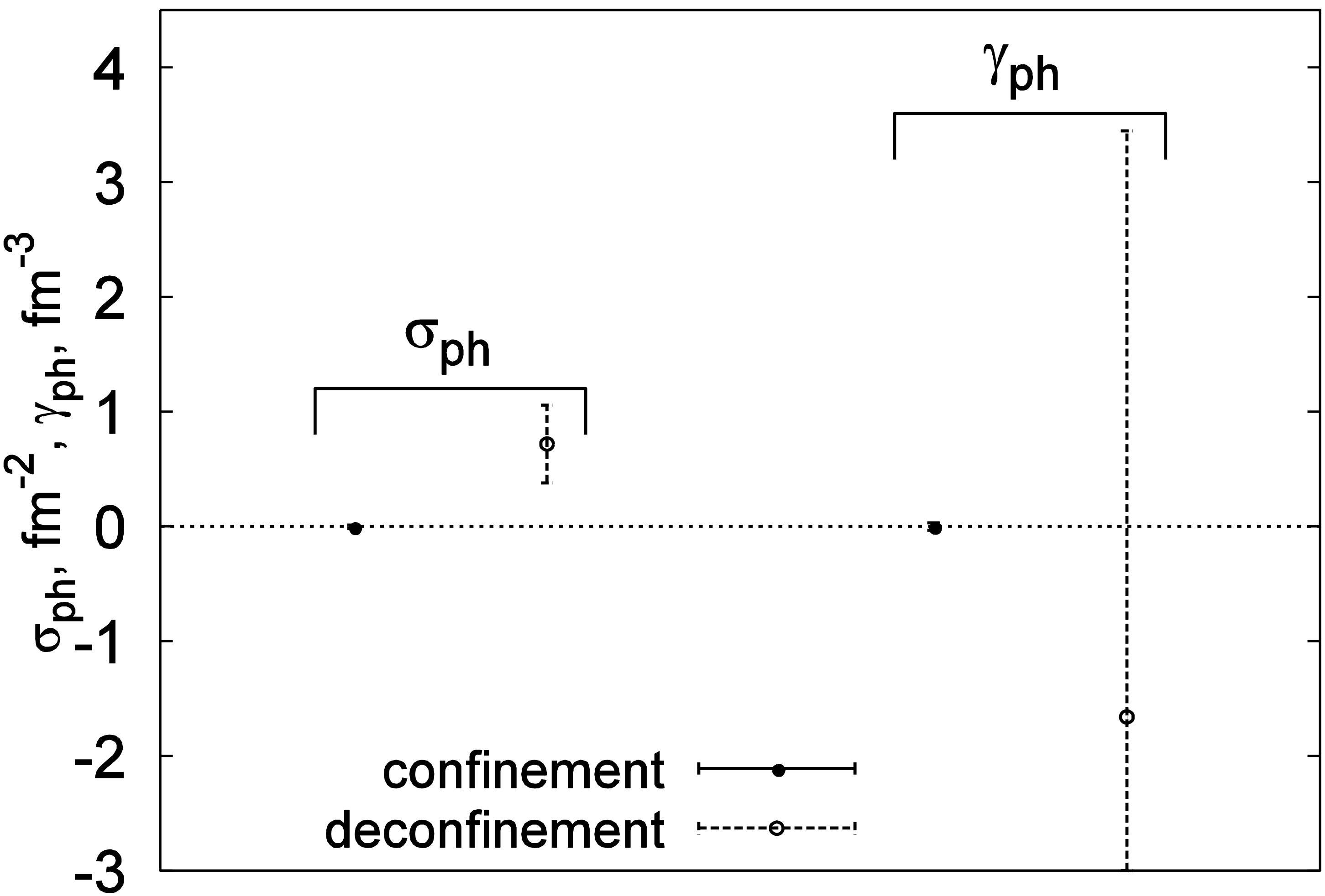
Temporal surface



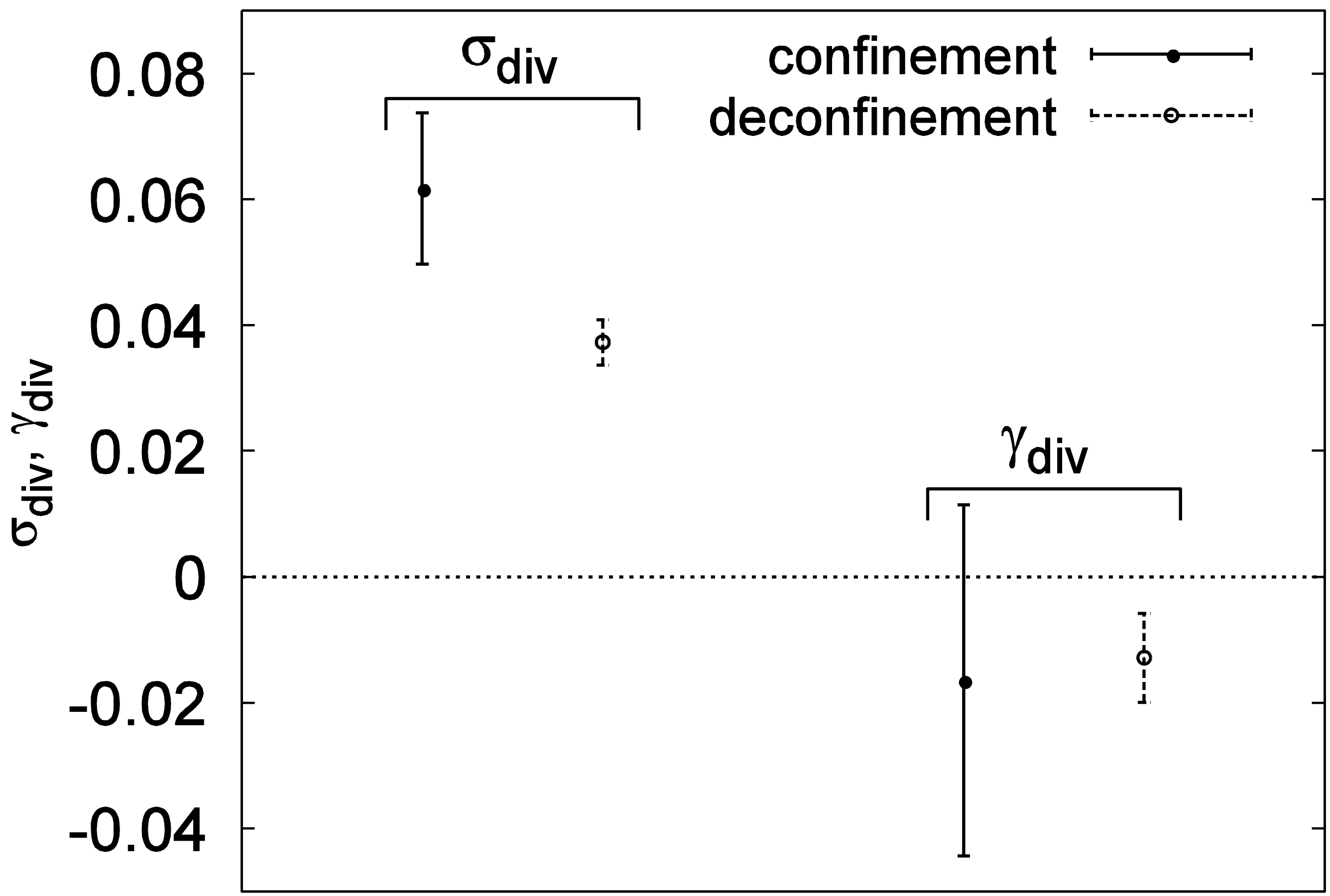
Temporal surface (divergent part)



Spatial surface



Spatial surface (divergent part)



Conclusion

- Area law of the temporal surface operator corresponds to the perimeter law of the Wilson loop
- Temporal surface operator has no volume dependence
- Volume dependence of the spatial surface needs more precise study