

Some selected results of lattice QCD

Heidelberg, October 12, 2007

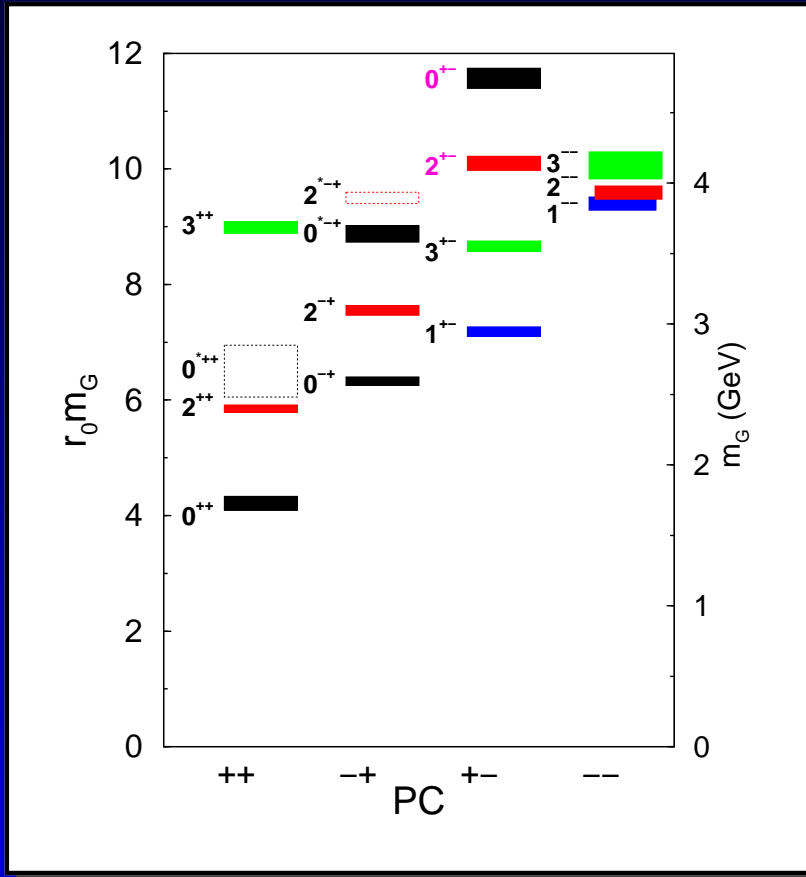
Kurt Langfeld

*School of Mathematics and Statistics
University of Plymouth*



Glueball spectrum:

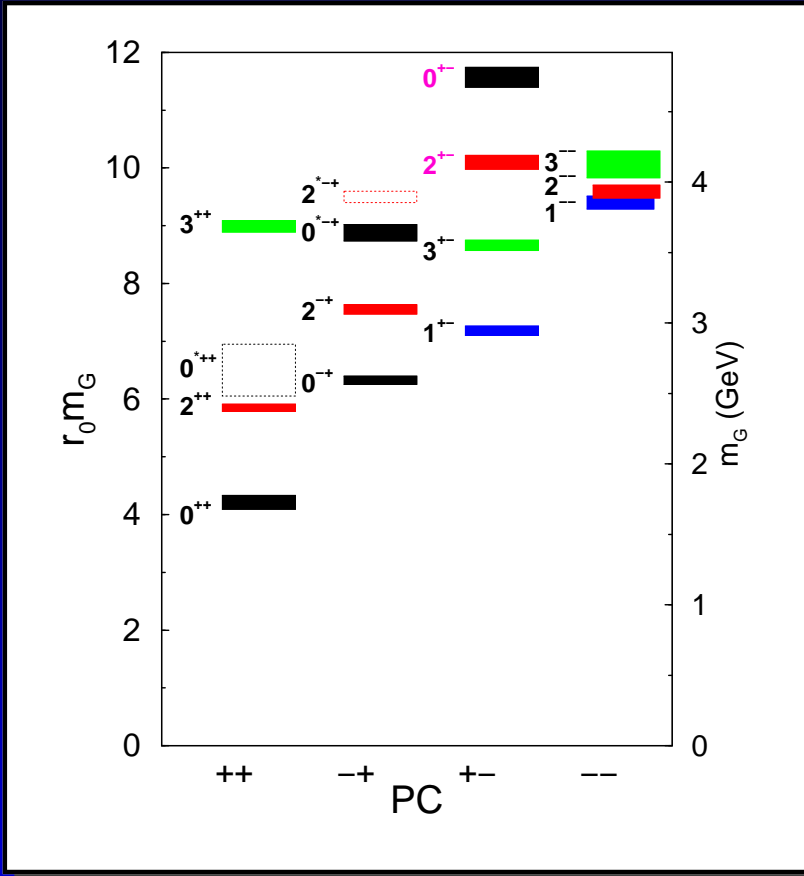
no quarks (quenched approximation)



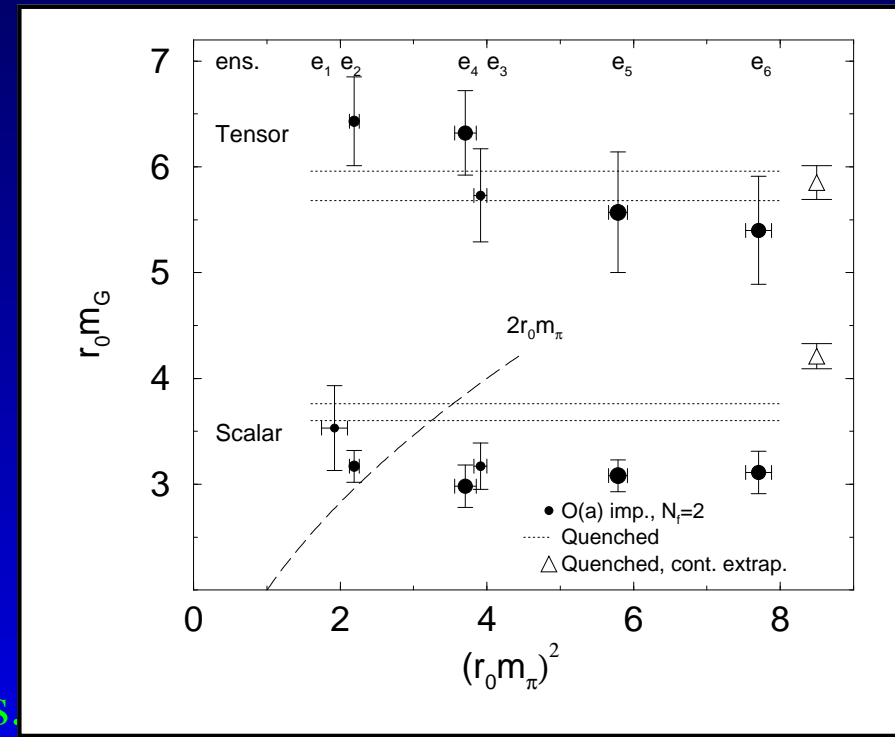
C. J. Morningstar and M. J. Peardon, Phys. Rev. D **60**, 034509 (1999)

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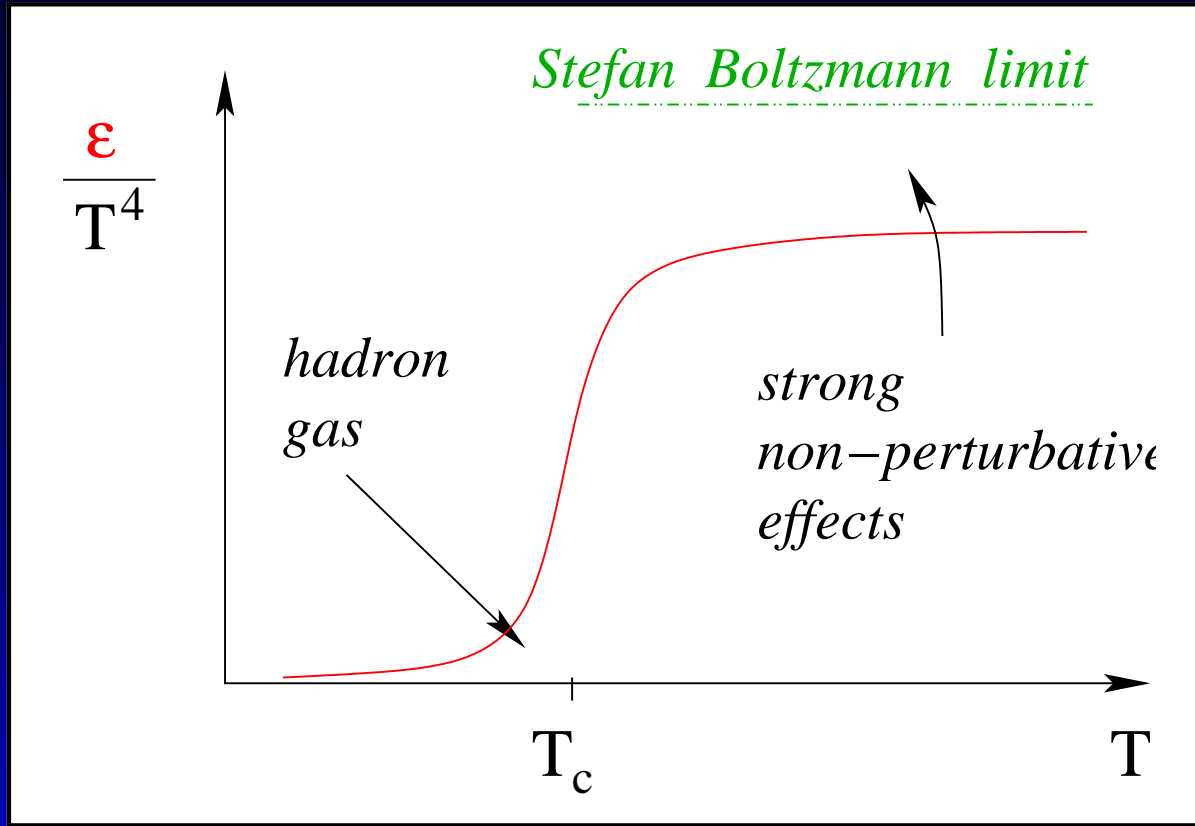
...and beyond:



C. J. Morningstar and M. J. Peardon, Phys. Rev. D **60**, 034502 (1999)

A. Hart and M. Teper [UKQCD Collaboration], Phys. Rev. D **65**, 034502 (2002)

The quark gluon plasma:



offset?

gluon deconfinement - strongly interaction QGP

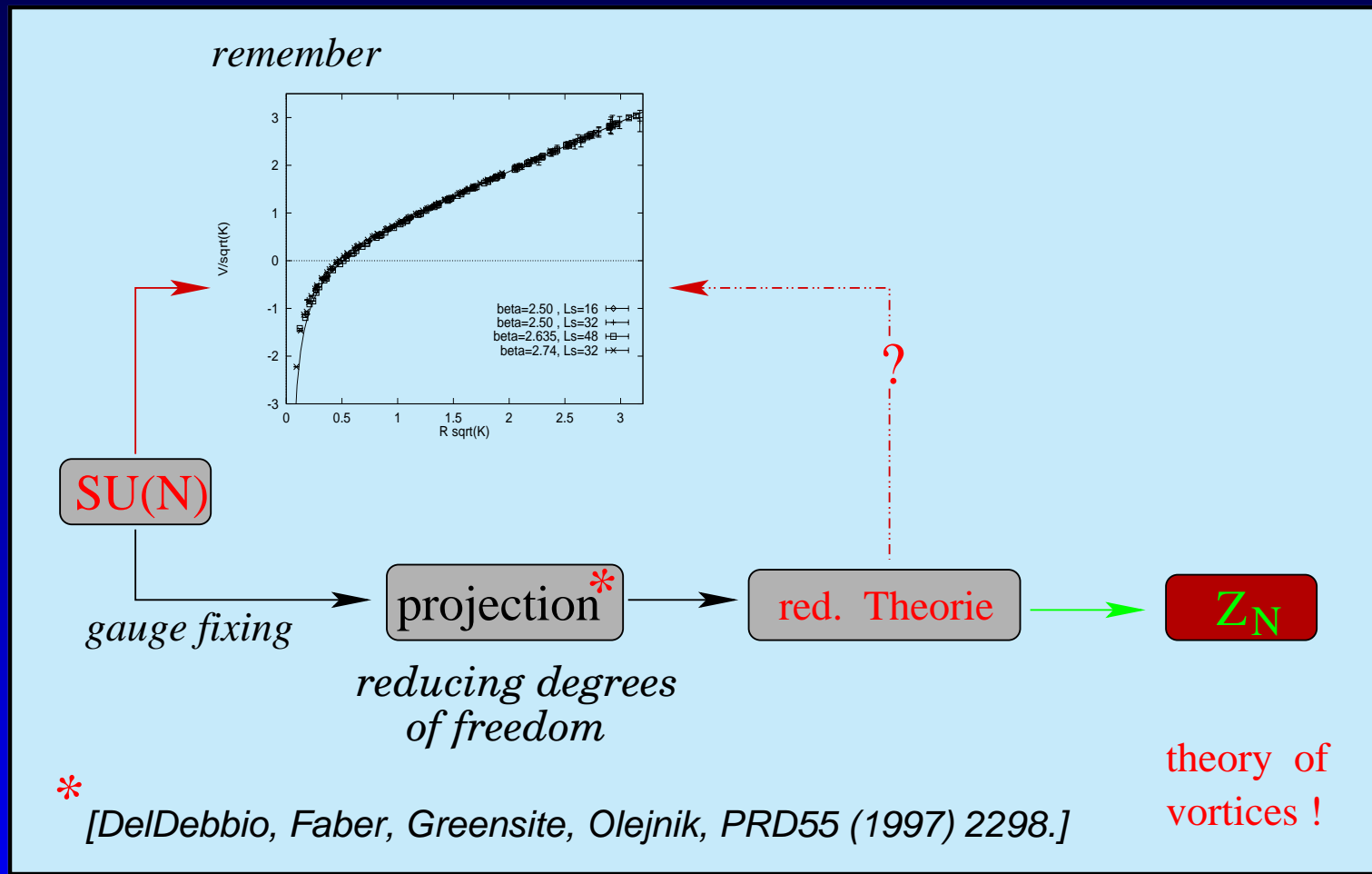
J. Engels, F. Karsch and K. Redlich, Nucl. Phys. B **435**, 295 (1995)

Vortex picture of confinement

- Too much information in full SU(3) lattice configurations

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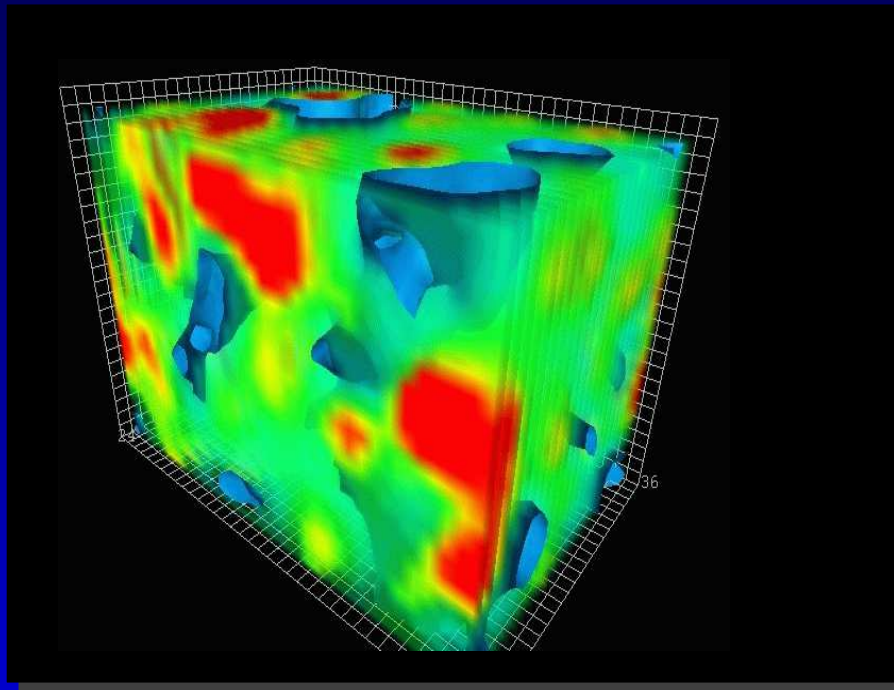
- Too much information in full SU(3) lattice configurations



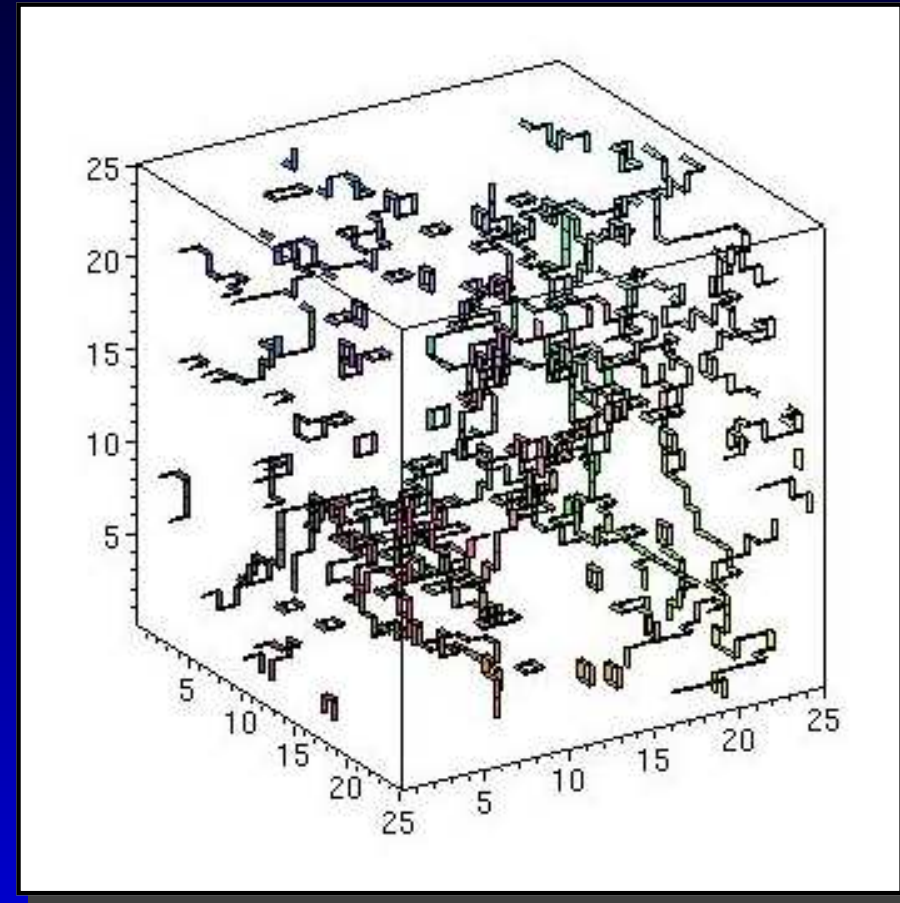
Understanding confinement:

SU(2) action density

[CSSM, Adelaide]



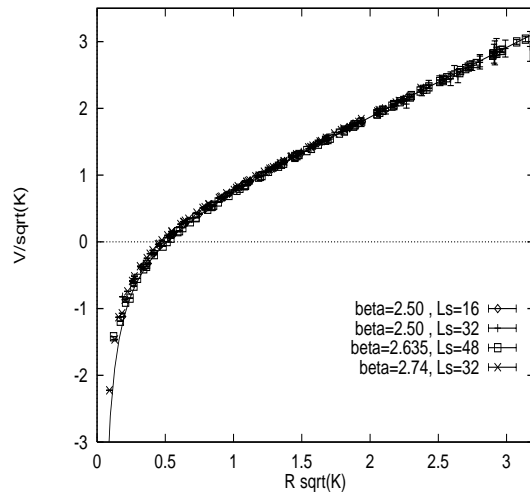
vortex content



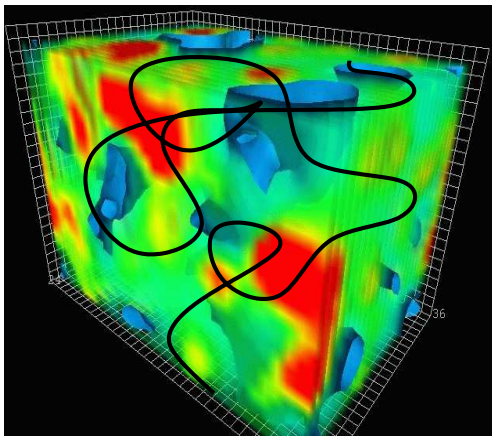
[MCG, LCG,...]

(pure) $SU(2)$ gauge theory

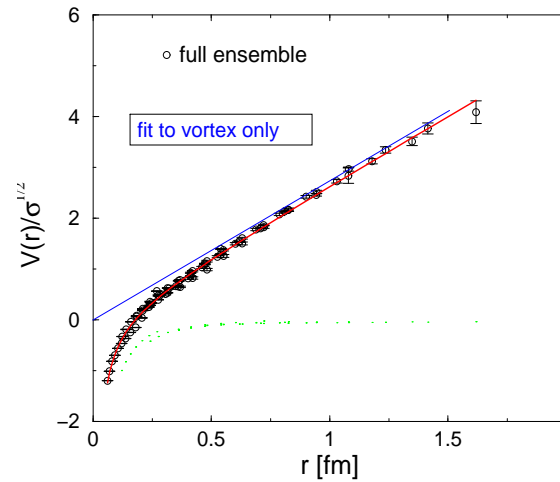
Vortex impact on confinement [SU(2)]:



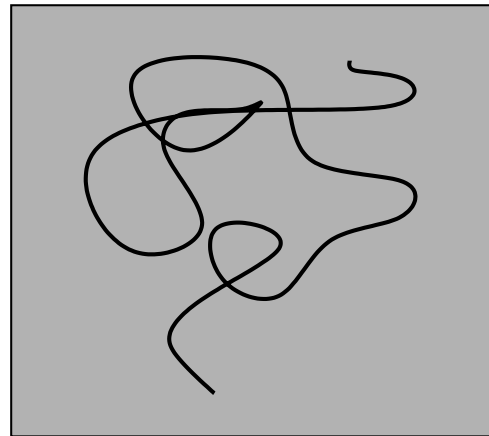
full SU(2)



SU(2), 12^4

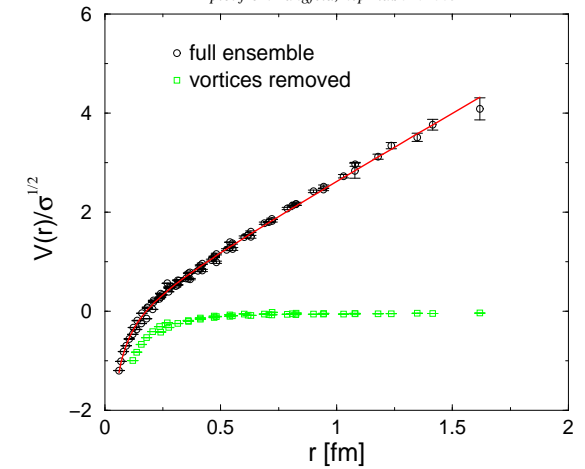


vortices only

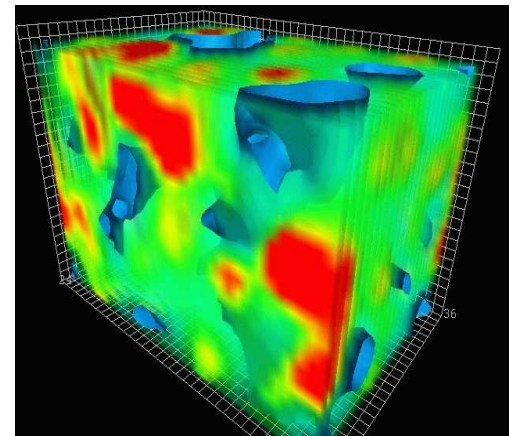


SU(2), 12^4

plot from Langfeld, hep-lat/0104003

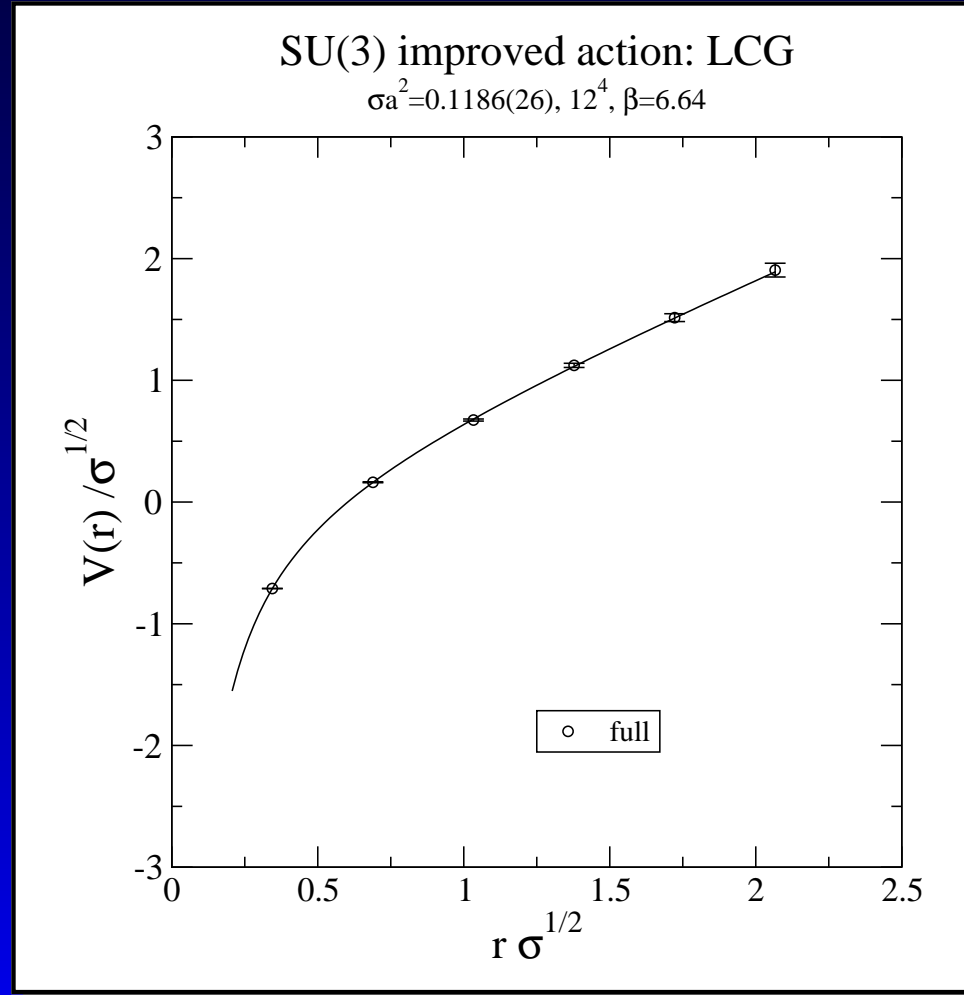


vortices removed



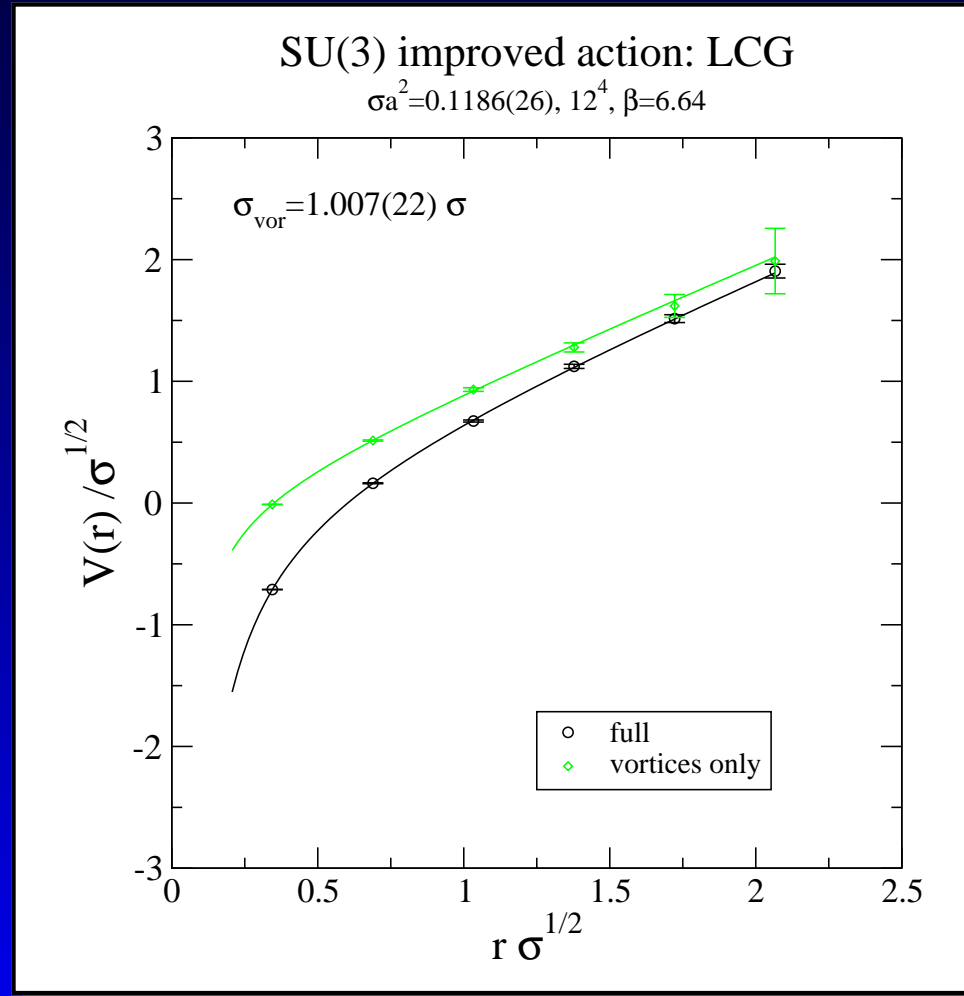
(pure) $SU(3)$ gauge theory

Vortex impact on confinement [SU(3)]: quark antiquark potential:



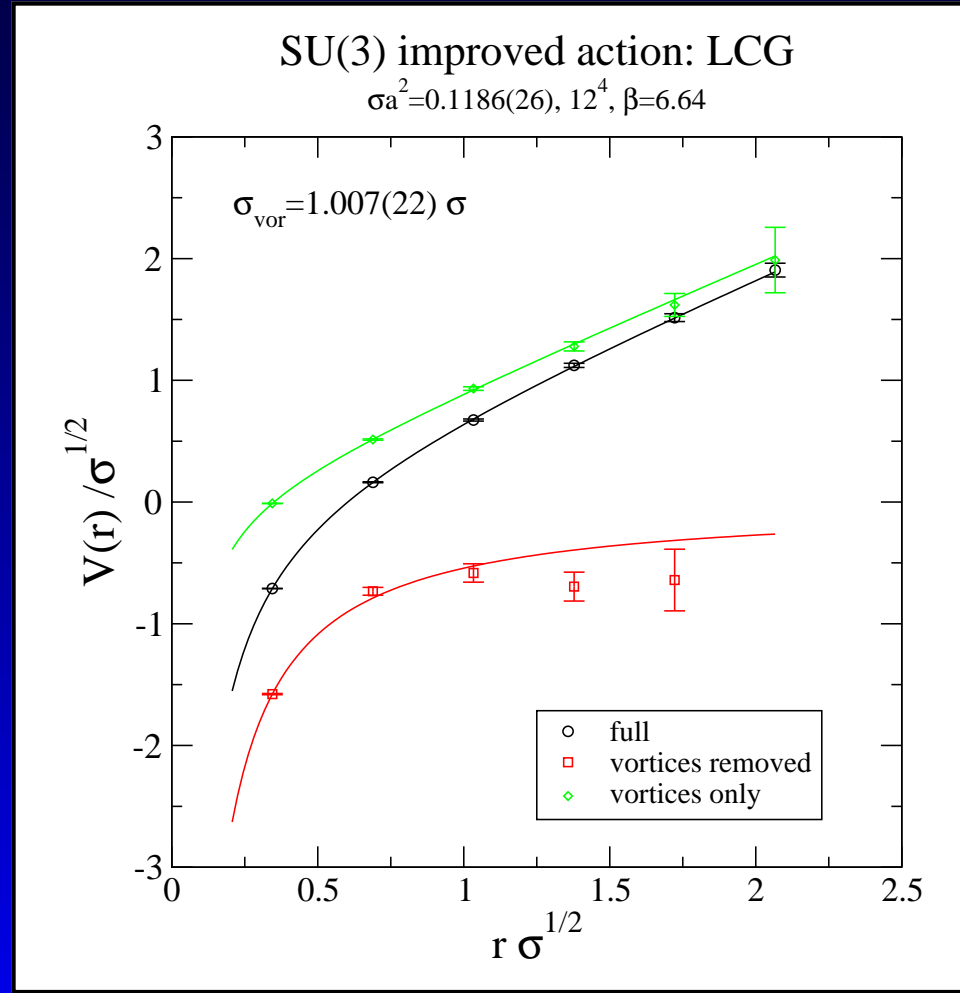
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Vortex impact on confinement [SU(3)]:

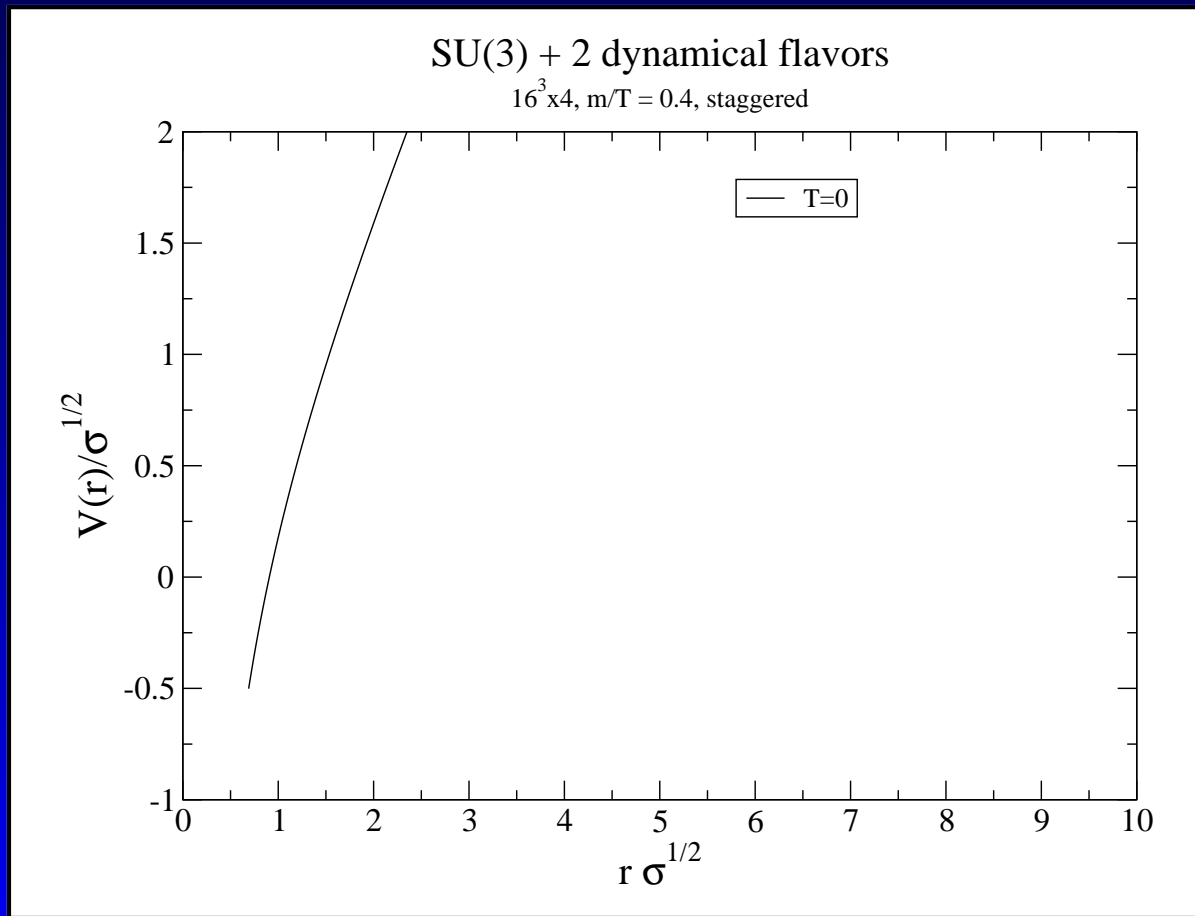
quark antiquark potential:



$SU(3) + 2$ dynamical flavors

Vortex impact on confinement [SU(3) + 2dyn]:

String breaking:



O. Kaczmarek

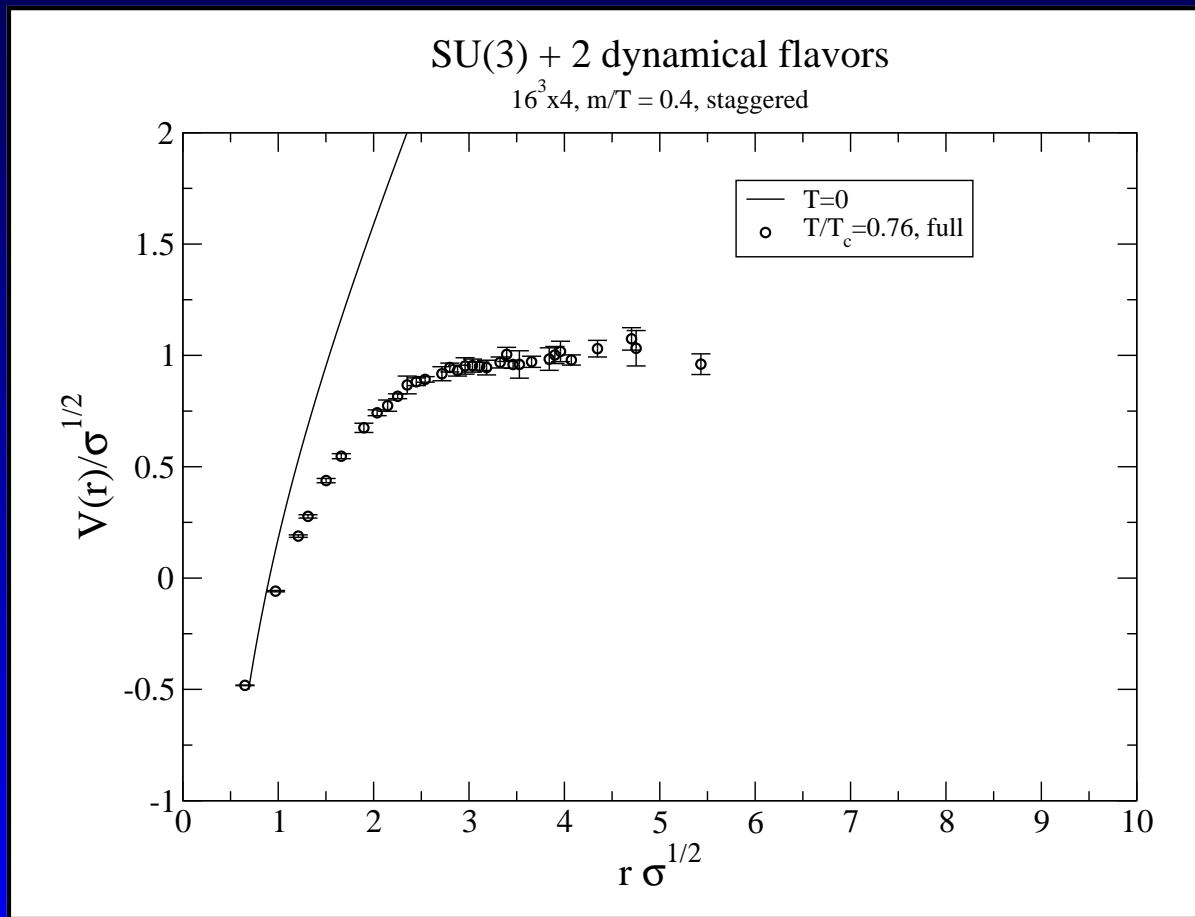
F. Karsch

K. Langfeld

(GSI Virtual Institute)

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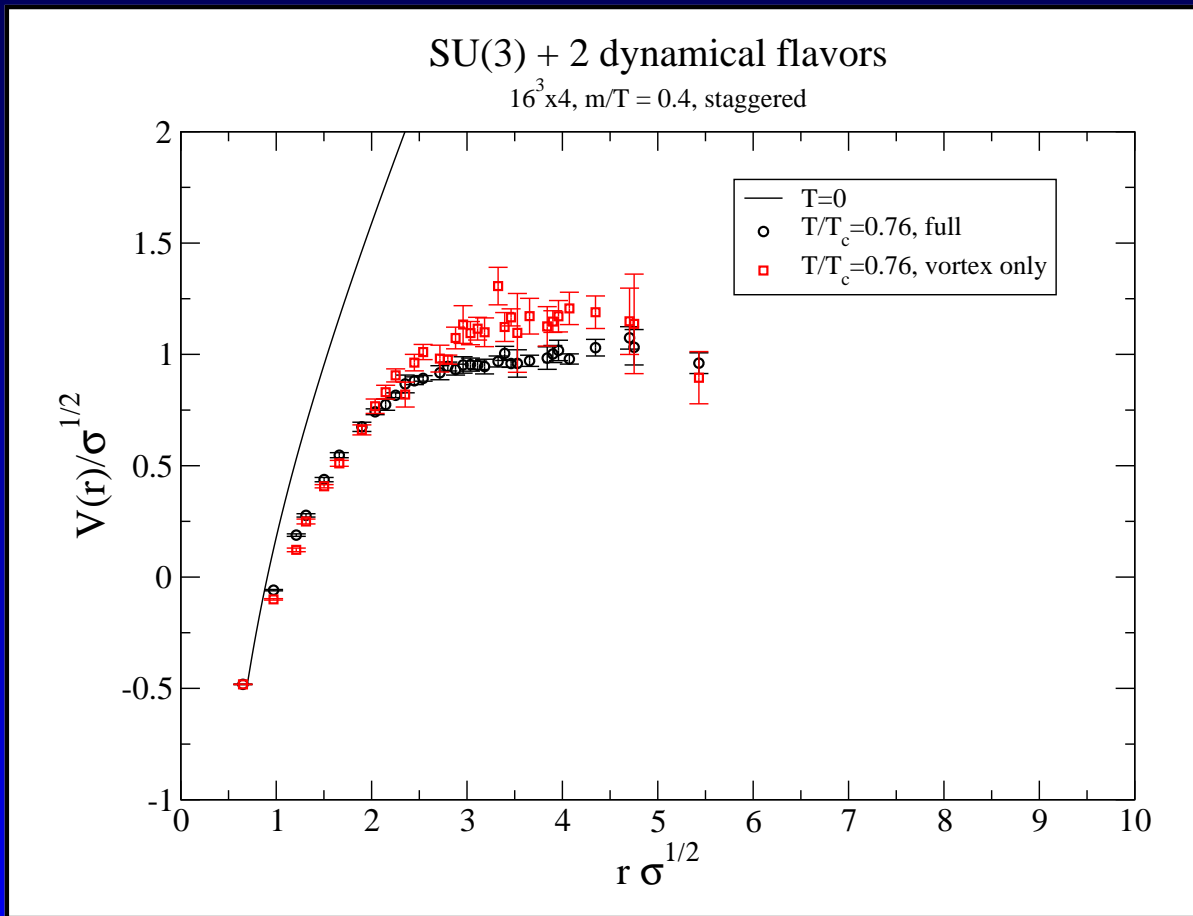
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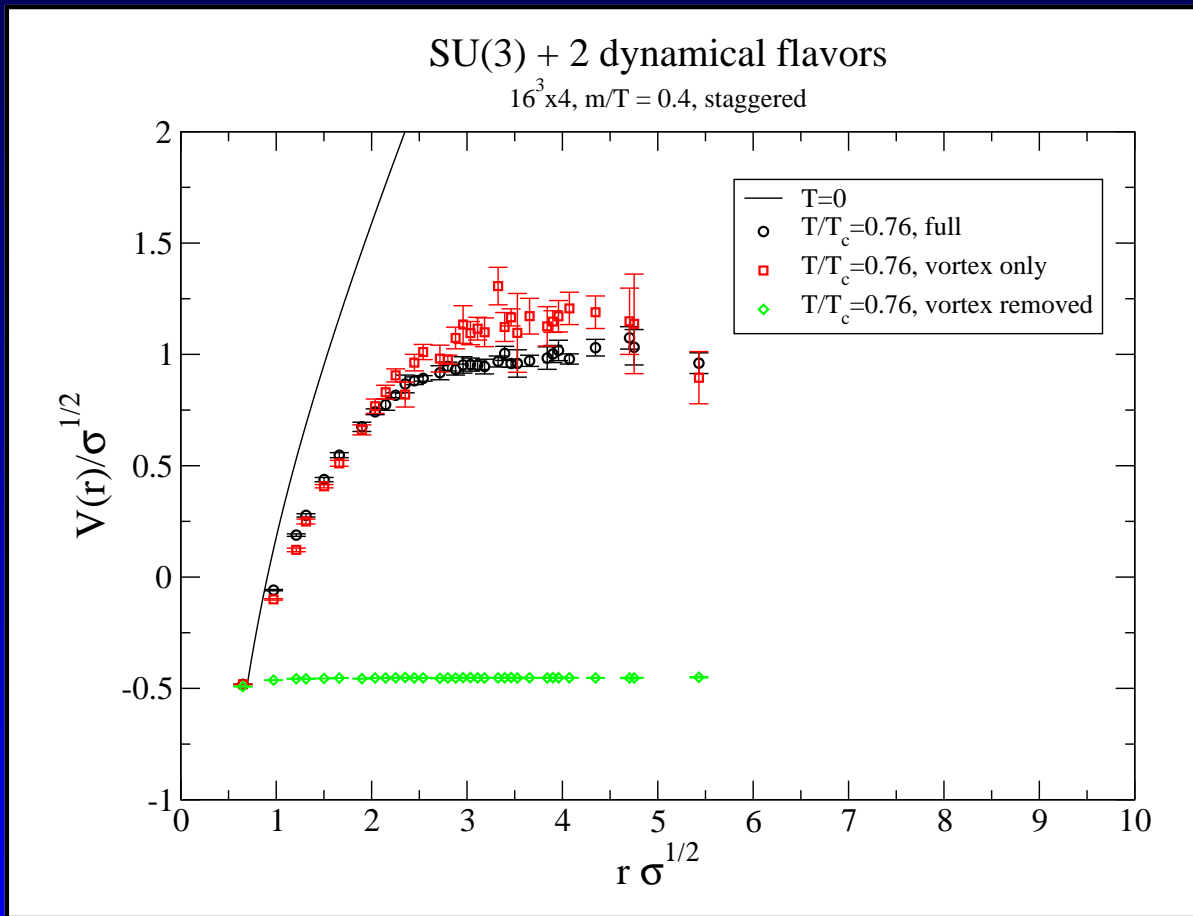
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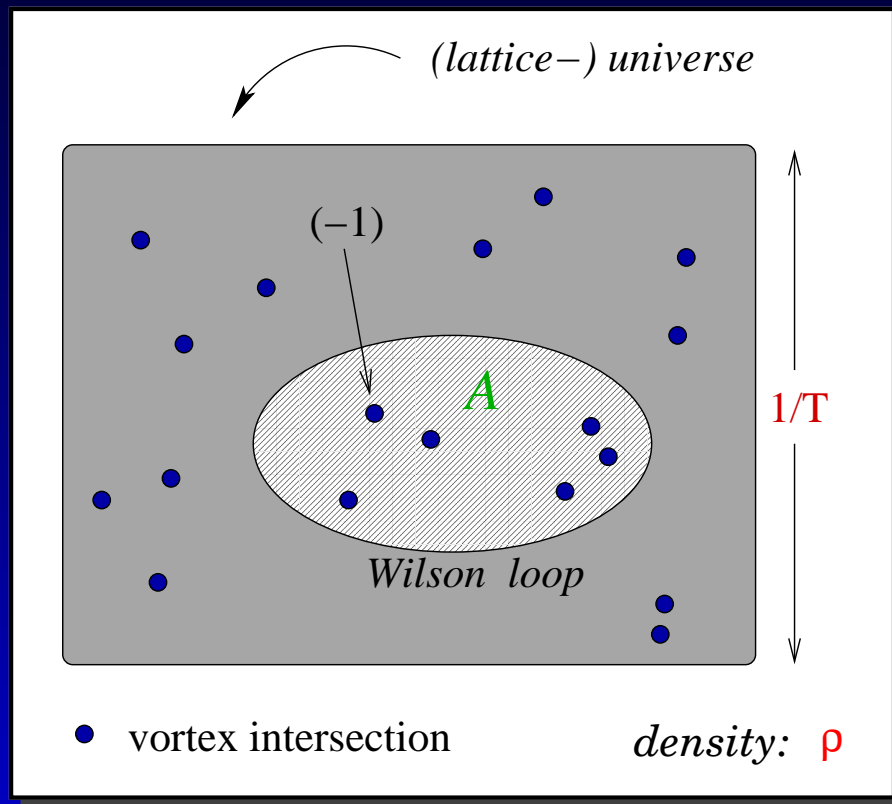
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Random vortex model

Why do vortex ensembles confine quarks?



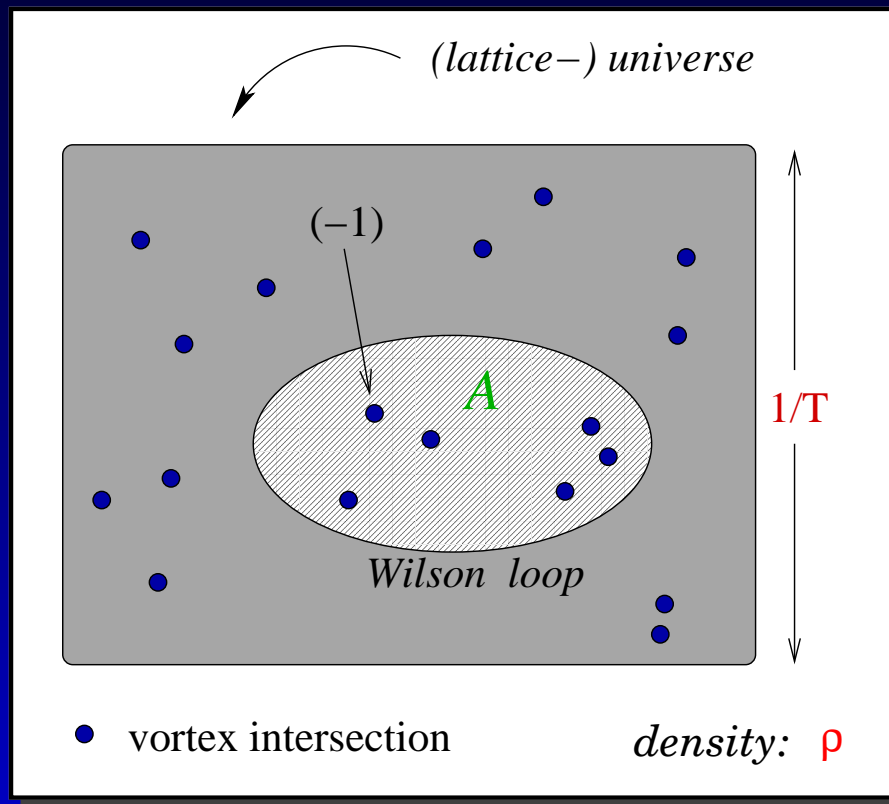
$$\langle \text{Wilson loop} \rangle \propto \exp\left\{-V(r)/T\right\}$$

$V(r)$ static quark potential

$$\text{here: } V(r) = 2\rho r$$

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here: $V(r) = 2\rho r$

Vortex density ρ



string tension: $\sigma = 2\rho$

Are vortices “physical”?

Vortex density ρ \longrightarrow string tension



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- The quest for physical vortices: gauge + projection \rightarrow vortex matter

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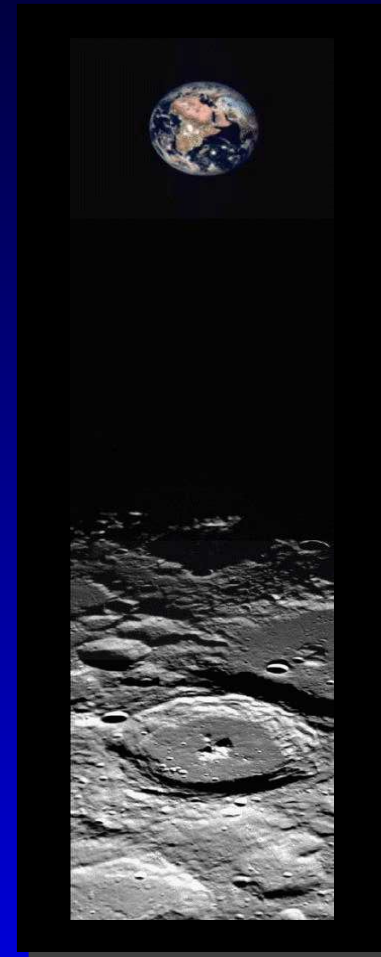
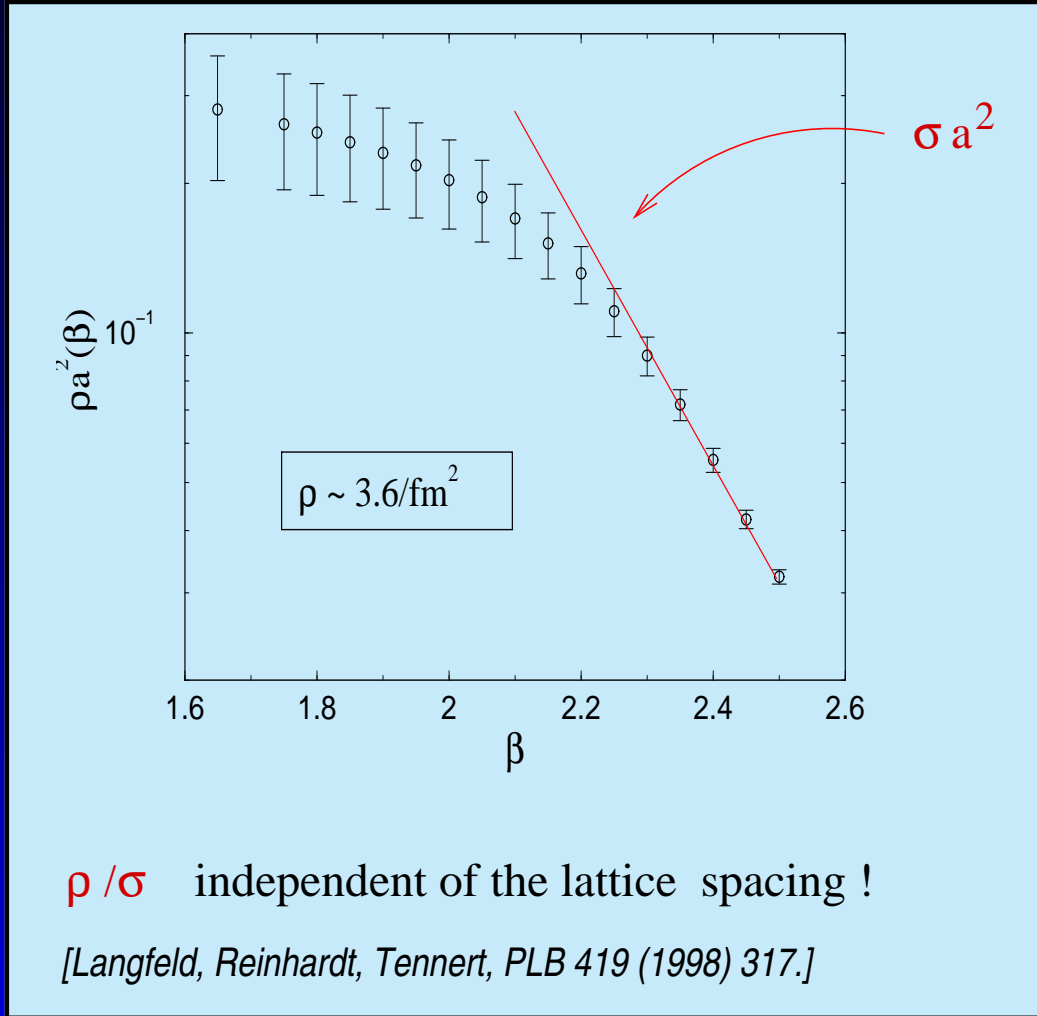
Vortex density ρ \longrightarrow string tension



- Vortex properties must be independent of the lattice spacing a
- The quest for physical vortices: gauge + projection \rightarrow vortex matter

Mandelstam	1975	continuum limit ?
t'Hooft	1978	
Mack	1980	
Tomboulis	1981	
...	...	
Debbio, Faber, Greensite, Ojelnik	1997	MCG
Langfeld, Reinhardt, Tennert	1998	continuum dofs !
[Alexandru, Engelhardt, Forcrand, Haymaker, Kovacs, Stack, ...]		

Vortex density: SU(2)



Brief summary [T=0]:

[remember SU(2): MCG]

- ▣ Vortices extrapolate to the continuum limit
- ▣ Vortex configurations recover ~100% string tension
- ▣ Vortex removed configurations do not confine quarks

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[here SU(3): LCG]

- ▣ Vortices extrapolate to the continuum limit: **liquid**
- ▣ Vortex configurations recover the string tension
- ▣ There is no string tension without vortices
- ▣ Vortices realize string breaking

What do we learn from the vortex picture about
deconfinement at high temperatures ?

A puzzle at high temperatures

- Spatial Wilson loop:

$$\langle W_s(R, L) \rangle \propto \exp\{-\sigma_s R L\}$$

Expectations:

Dimensional reduction:

3D Yang-Mills theory

$$\sigma_s \approx \sigma_3 \neq 0$$

[Appelquist,

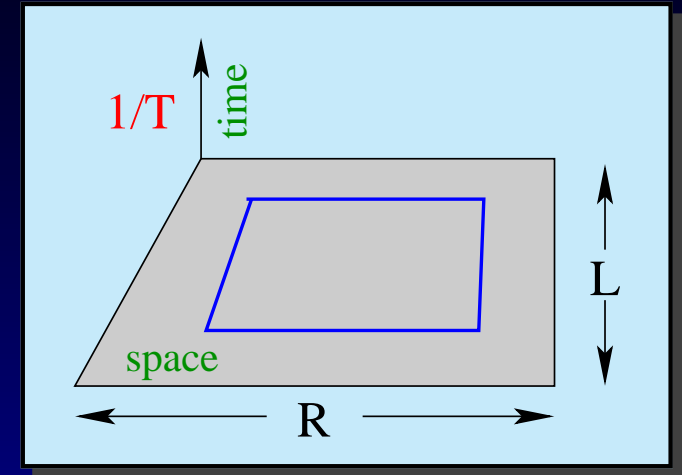
Pisarski, 1981]

Perturbation theory:

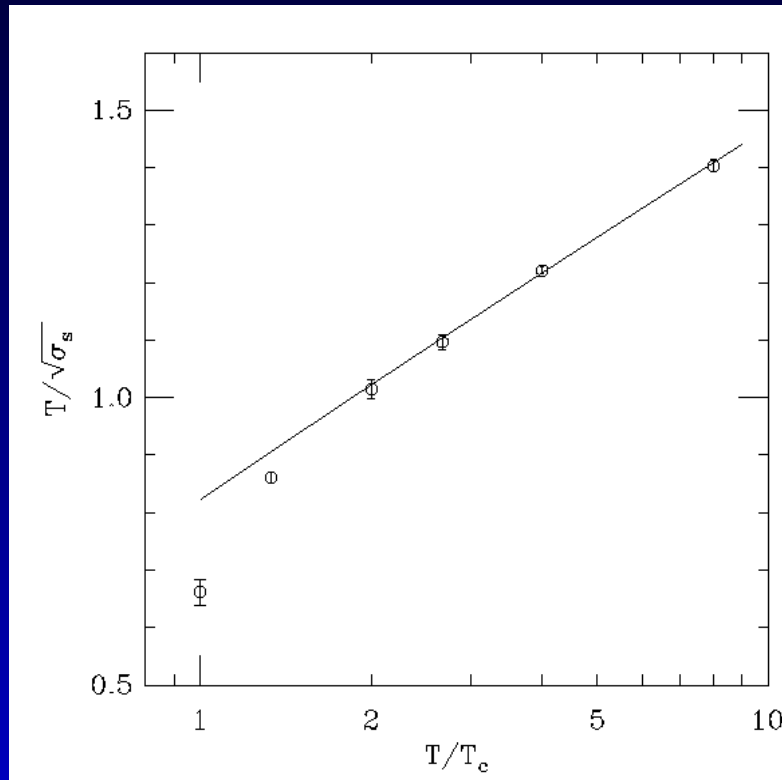
$$T \gg \Lambda_{QCD}$$

asymptotic freedom

$$\sigma_s = 0$$



Lattice calculation:

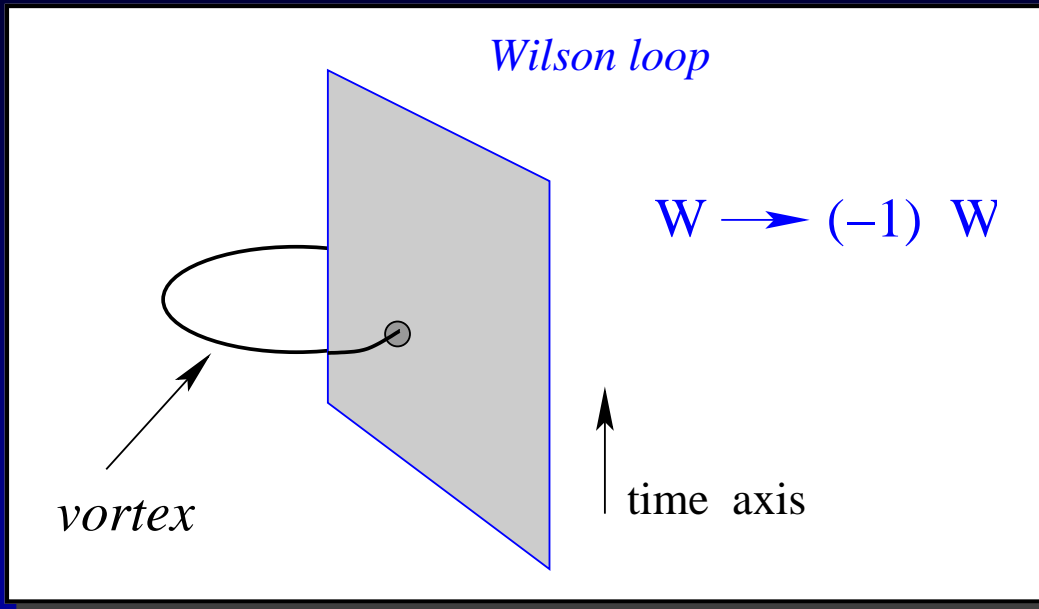


$$\sigma_s = 0.136 g^4(T) T^2$$

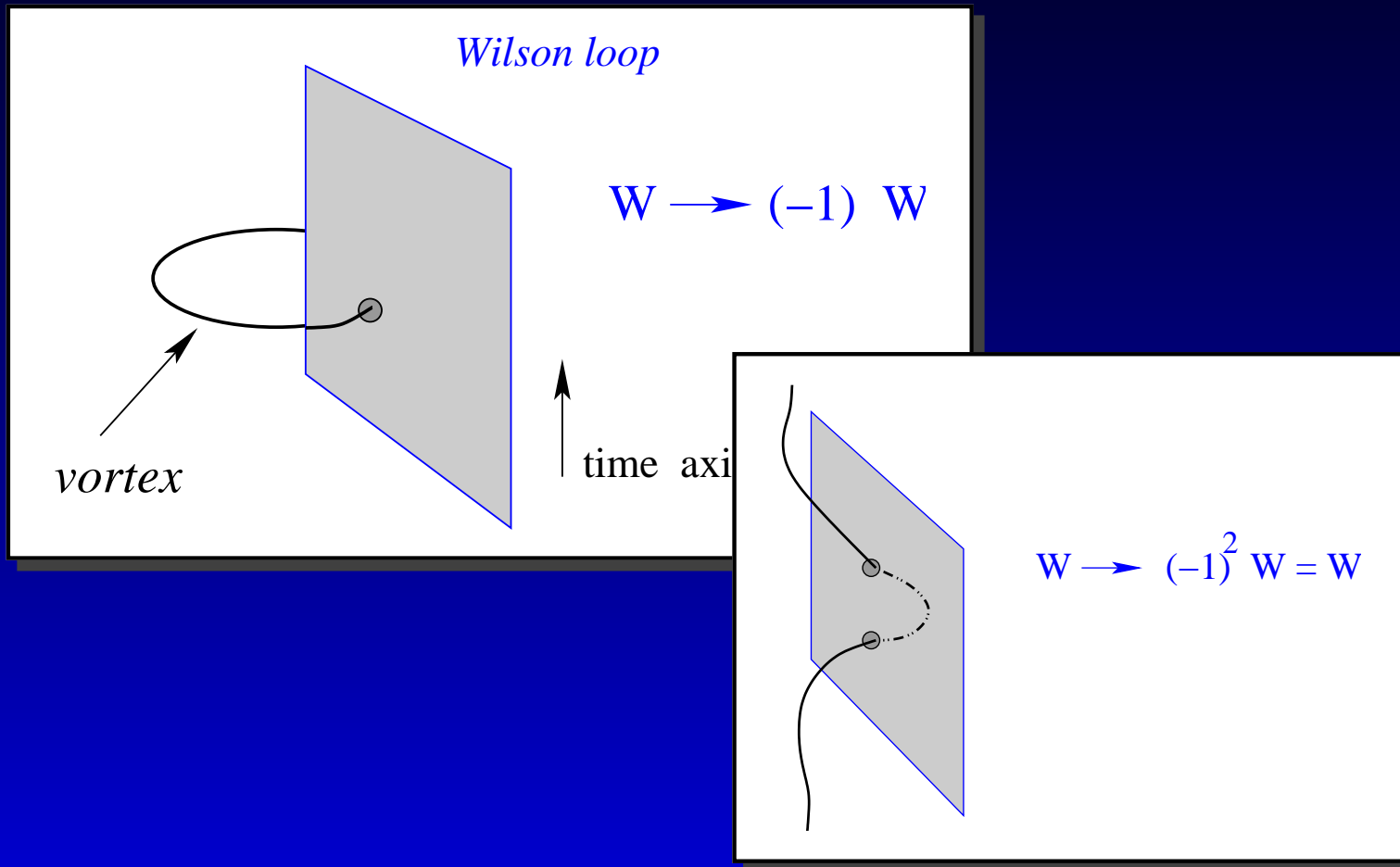
$$\frac{T}{\sqrt{\sigma_s}} \propto \frac{1}{g^2(T)}$$

[Bali, Fingberg, Heller, Karsch, Schilling,
PRL 71 (1993) 3059.]

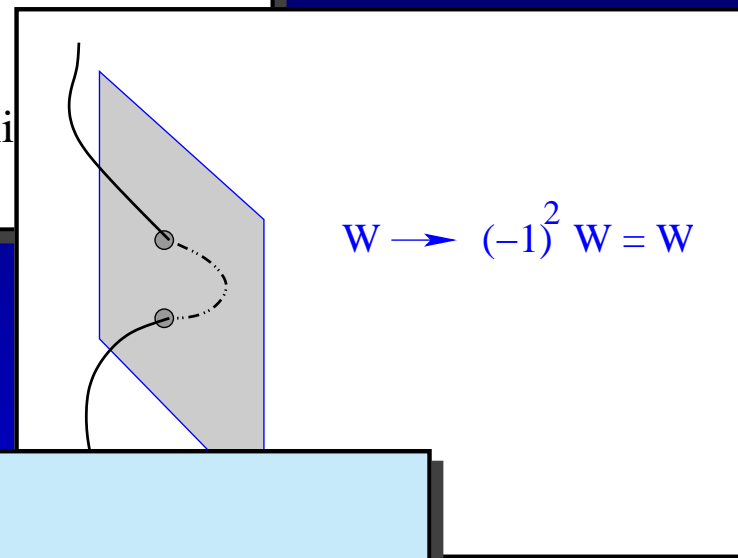
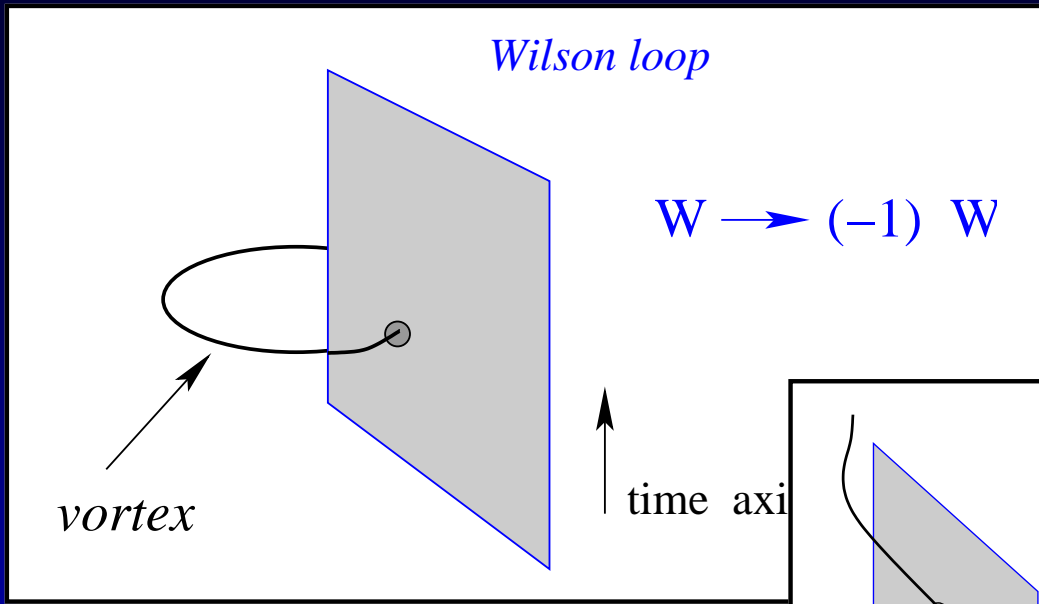
Deconfinement at high T [SU(2) so far]



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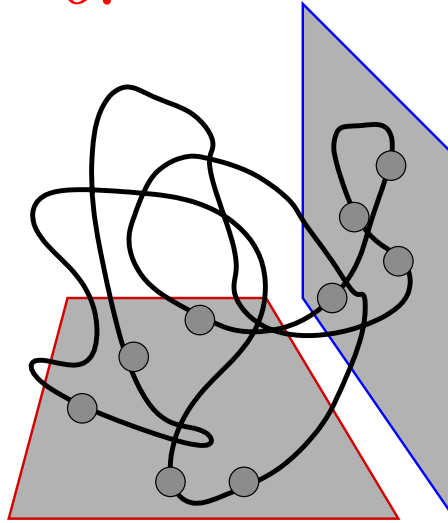
remember

$$\langle \square \rangle = \exp\{-V(r)/T\}$$

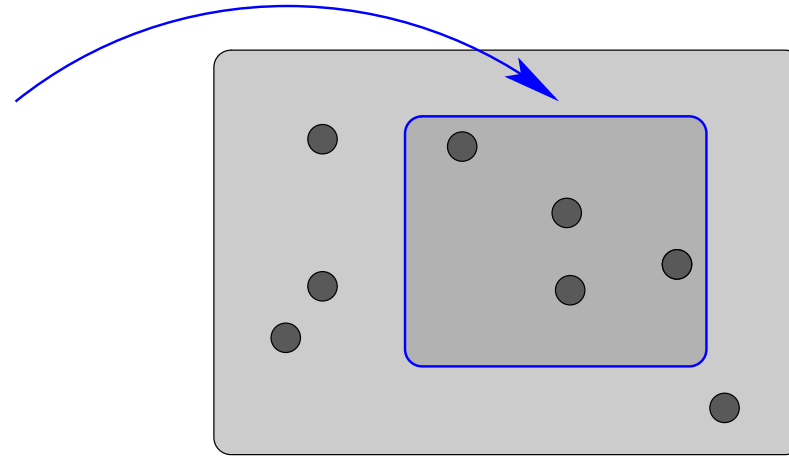
static quark potential

Vortex picture of deconfinement

$T=0$:

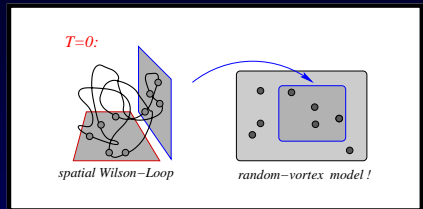


spatial Wilson-Loop

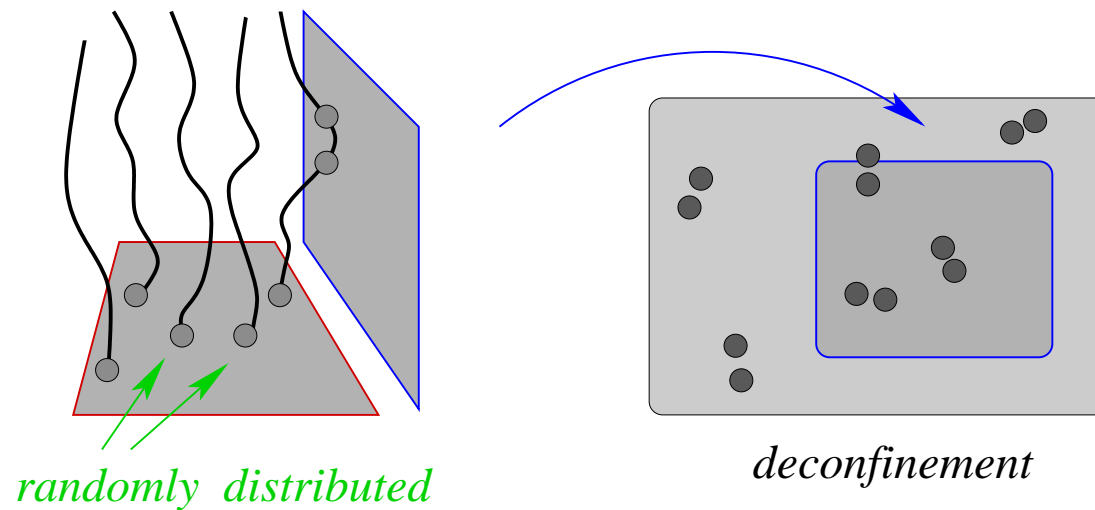


random-vortex model !

Vortex picture of deconfinement



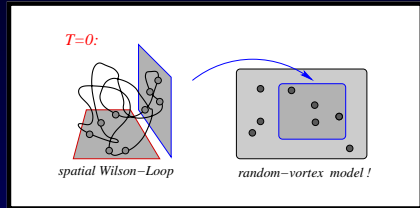
$T > T_c$: *vortex depercolation*



$$\sigma_s \propto T^2$$

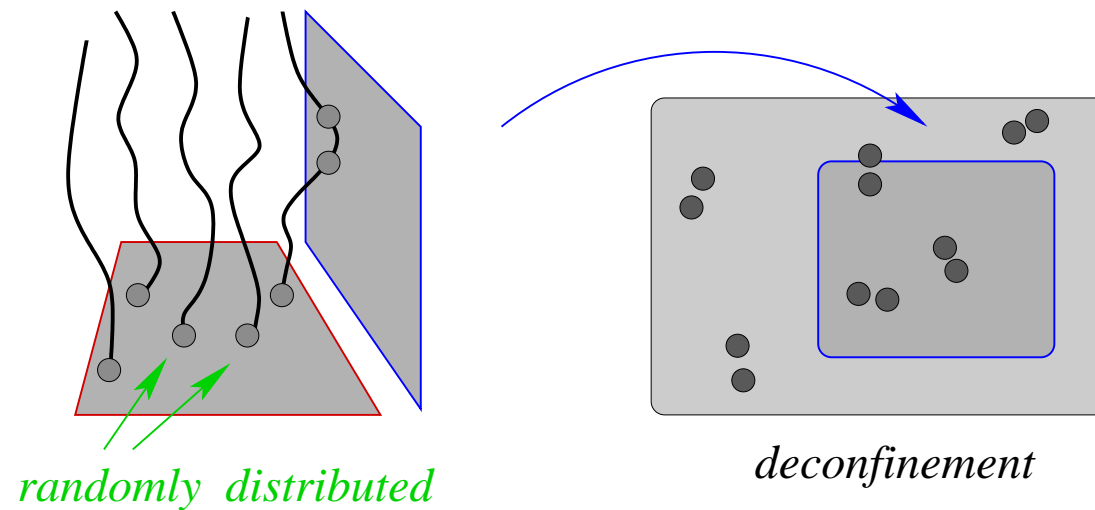
[Gattnar, KL, Schäfke, Reinhardt, PLB 489 (2000) 251.]

Vortex picture of deconfinement



Langfeld, Tennert, Engelhardt, Reinhardt, PLB 452 (1999) 301.
Engelhardt, Langfeld, Reinhardt, Tennert, PRD 61 (2000) 054504.
Langfeld, PRD 67 (2003) 111501 (rapid comm.)

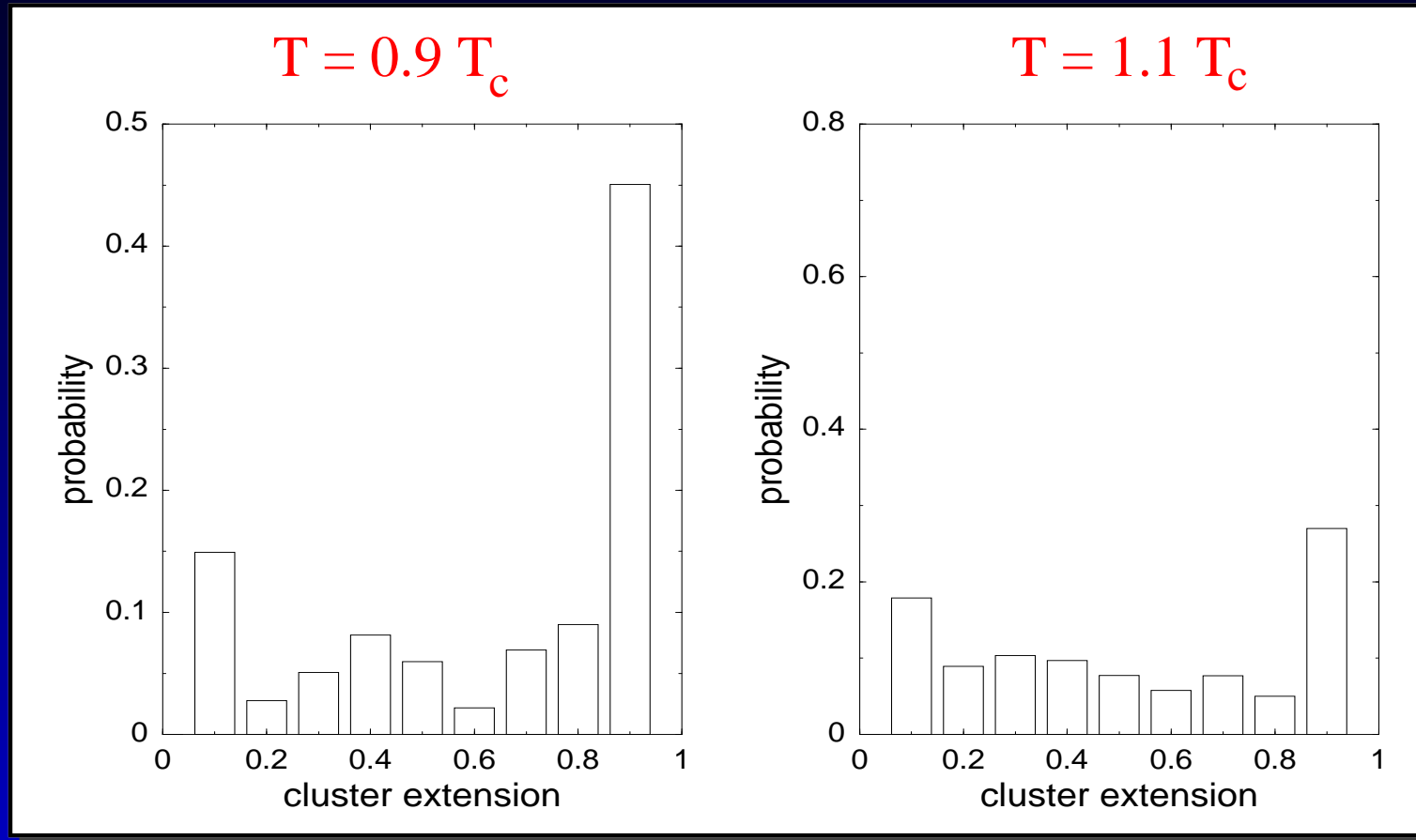
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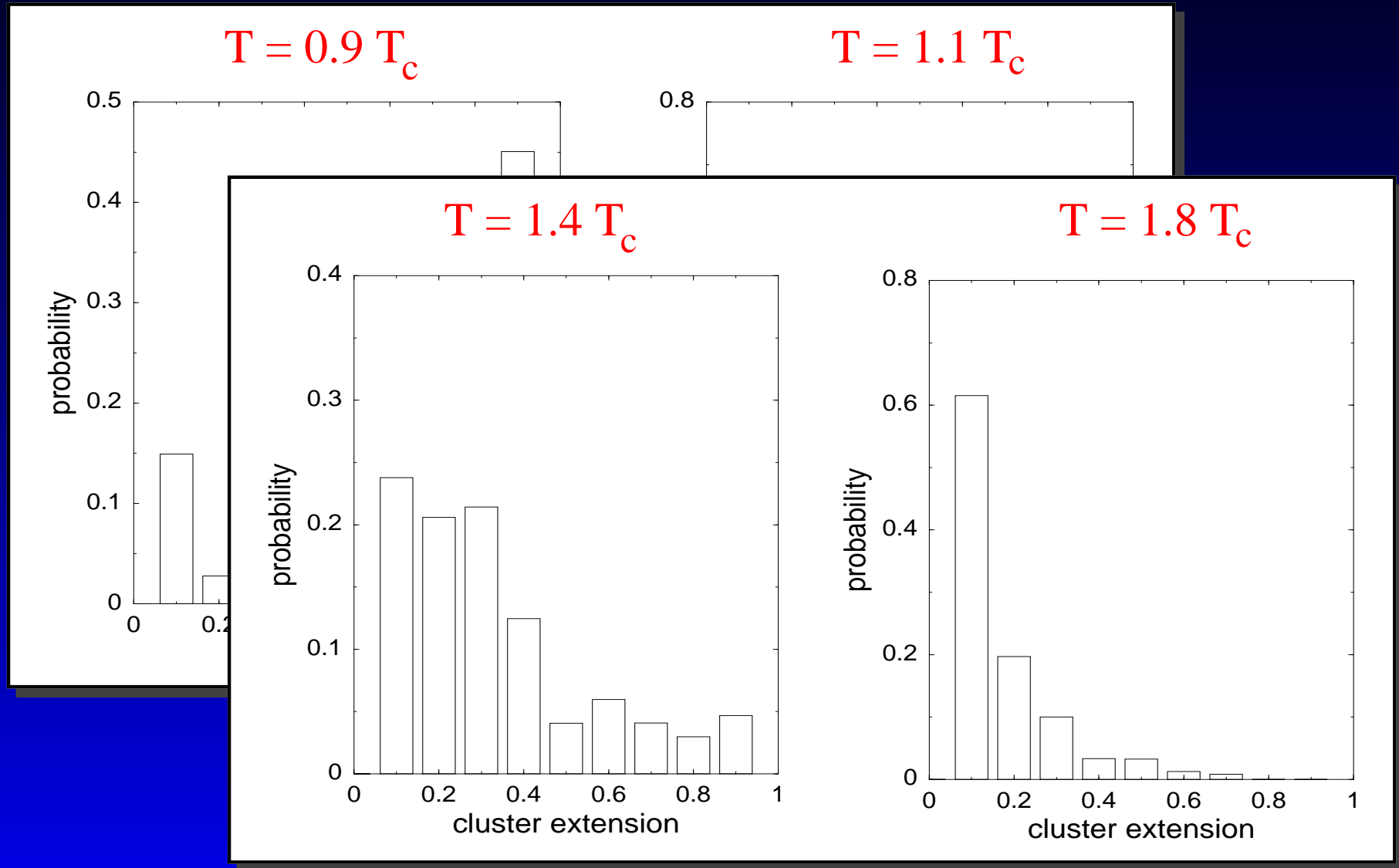
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Depercolation of vortices:



from Engelhardt, Langfeld, Reinhardt, Tennert, PRD 61 (2000) 054504.

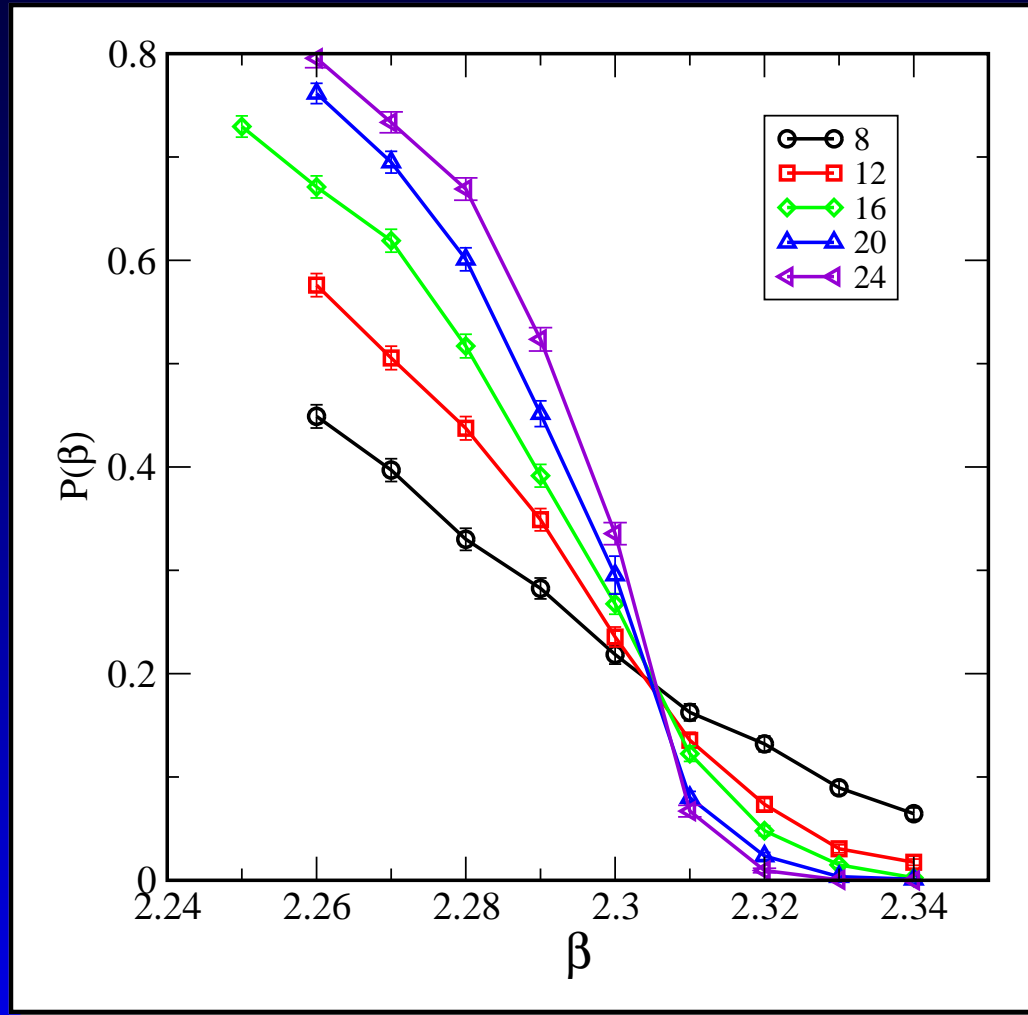
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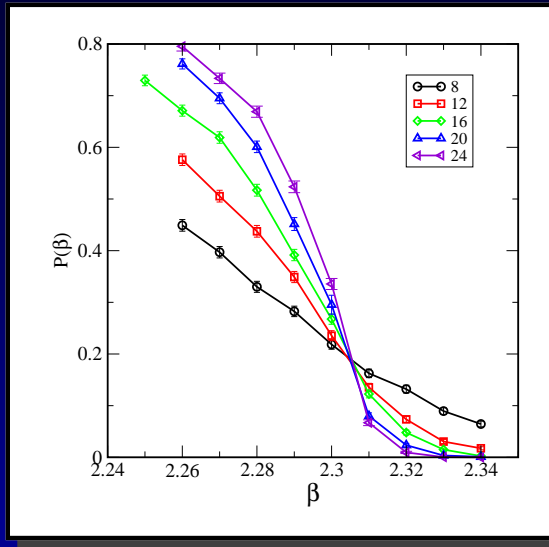
Finite size scaling analysis:

Can we realize the order of the phase transition in the vortex picture?



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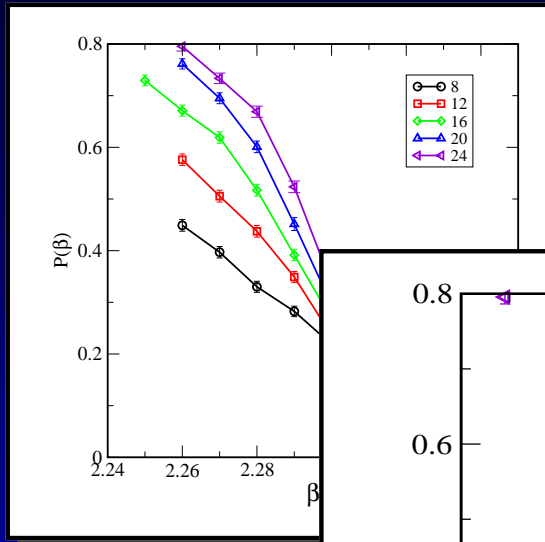
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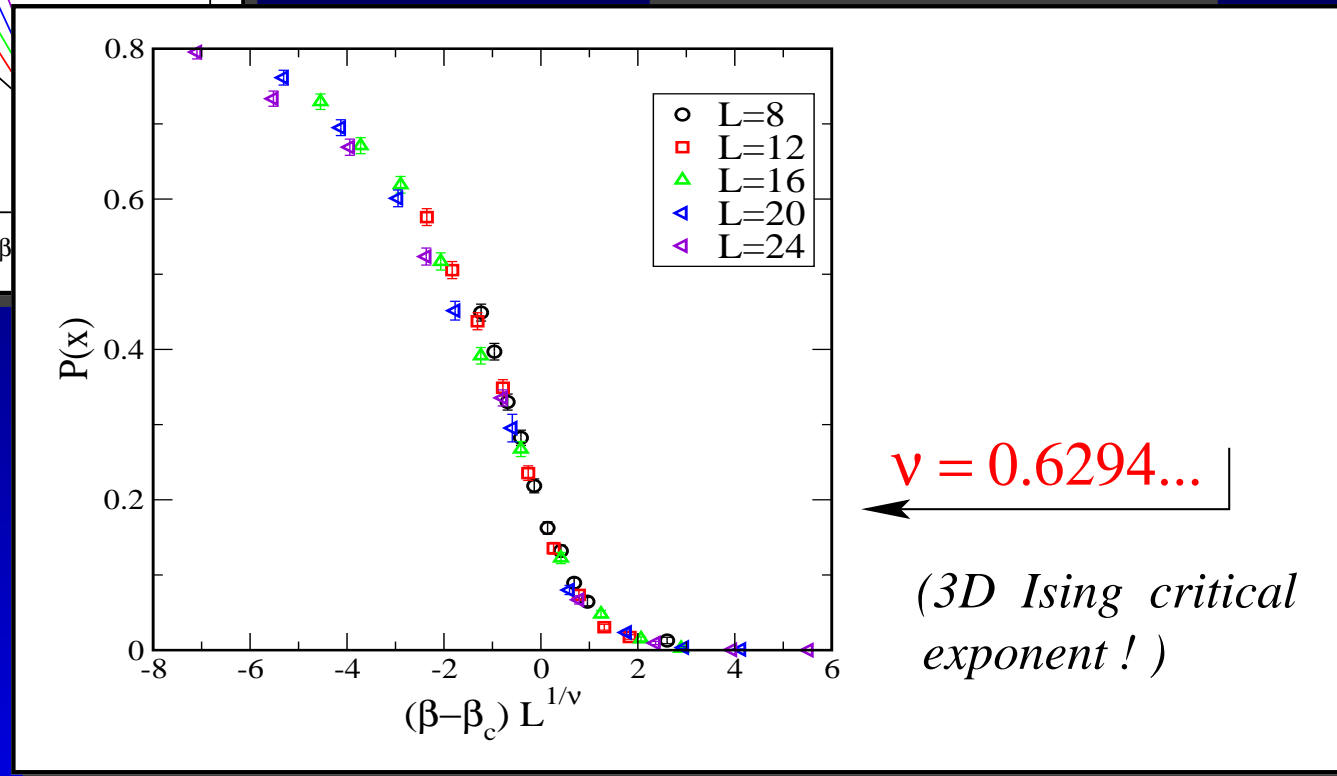
$$x = (\beta - \beta_c) L^{1/\nu}$$

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$$x = (\beta - \beta_c) L^{1/\nu}$$



$$\nu = 0.6294\dots$$

(3D Ising critical exponent !)

from Langfeld, PRD 67 (2003) 111501 (rapid comm.)

Brief summary [$T \neq 0$]:

[SU(2): lattice]

- ▣ deconfinement \leftrightarrow vortex depercolation transition
- ▣ explains the spatial string tension: $\sigma_s(T)$
- ▣ universality class correctly anticipated by the vortex structure

[SU(3): vortex model]

- ▣ correctly reproduces the **1st** order transition

[Engelhardt, Quandt, Reinhardt, NPB 685 (2004) 227.]