A fresh look at the confinement mechanism

QCD-TNT conference
ECT Trento, Italy, September 7-11, 2009

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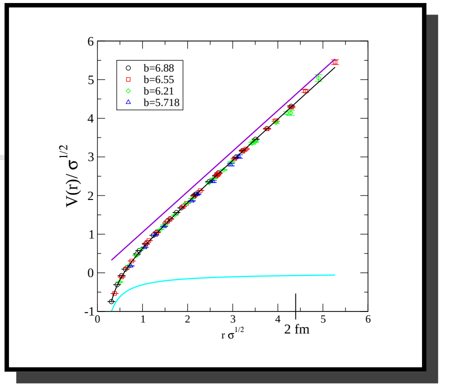
University of Plymouth

Introduction:



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  ... via YM Green functions (ghost dominance..)
  ... via confining dofs:
  instantons (?), calerons(?), monopoles (!), vortices (!)

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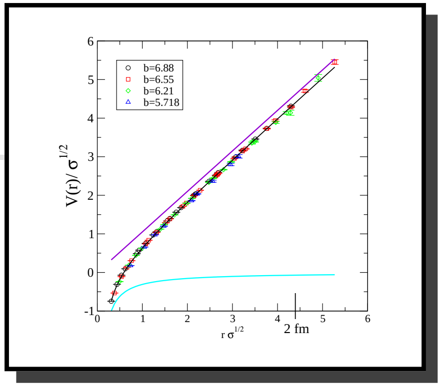

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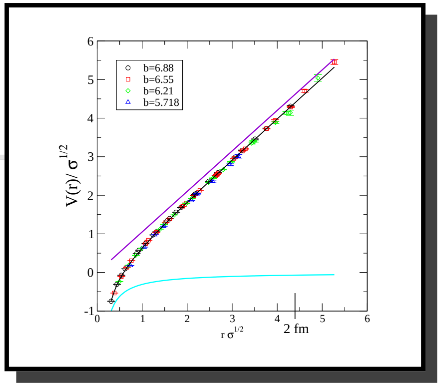

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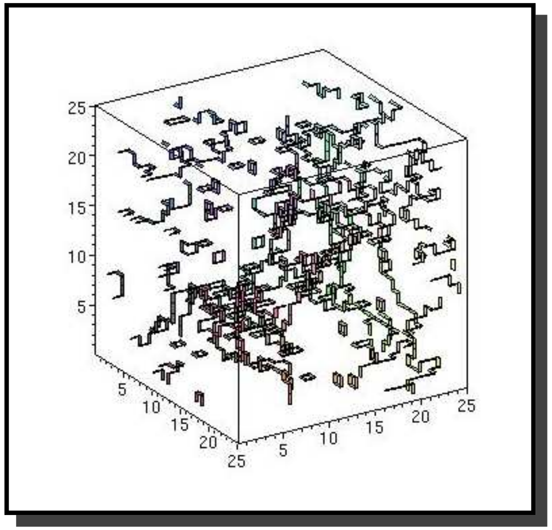
- The vortex picture:
  - ◇ SU(2) versus SU(3)
  - ◇ MCG versus LCG
  - ◇ relation to χSSB ?
  - ◇ open questions



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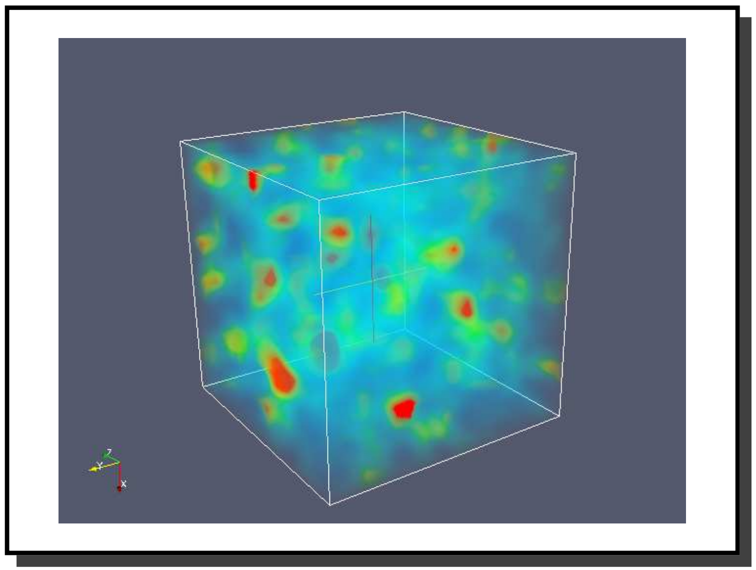
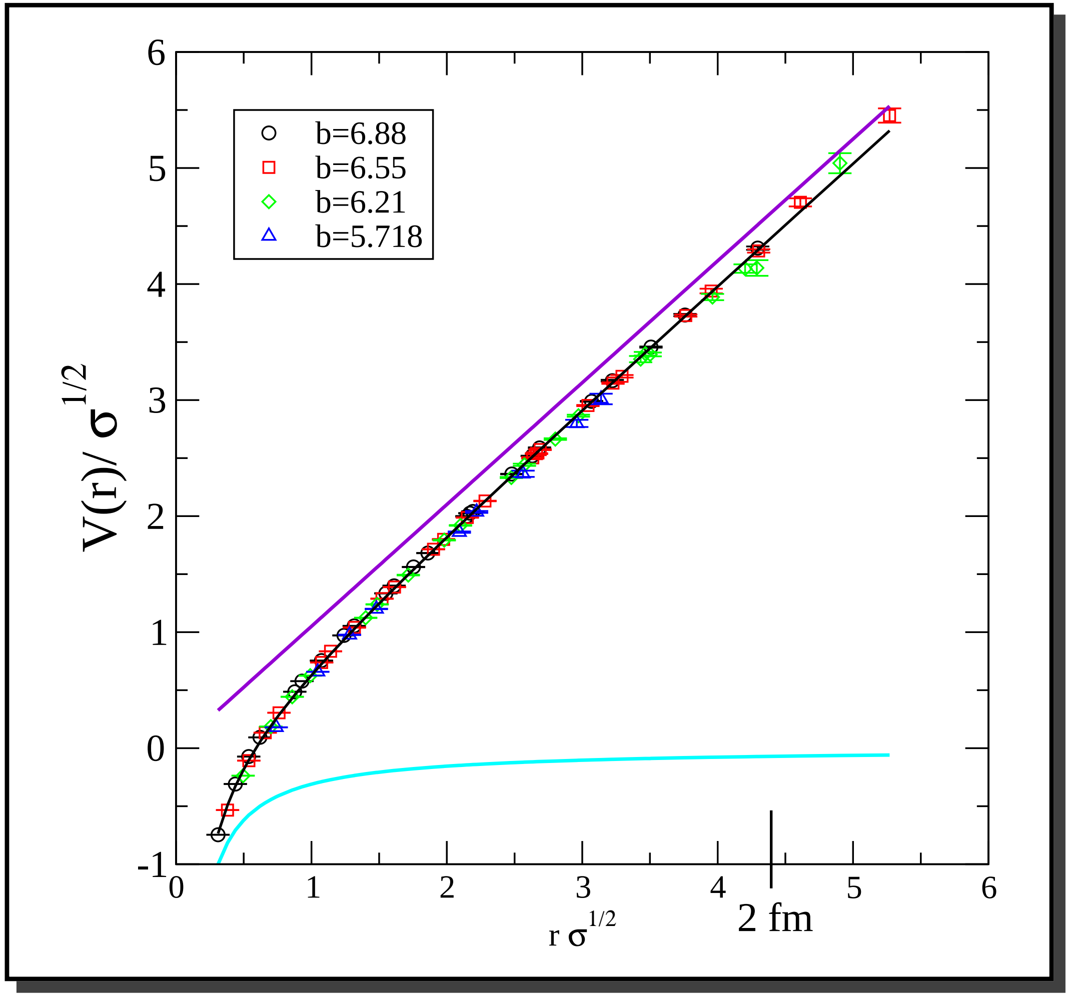
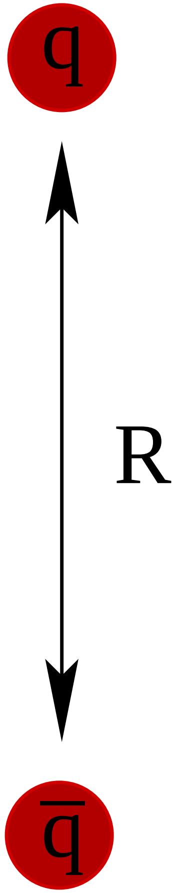
  - ▷ The Quark operator as low energy filter
    connection confinement $\leftrightarrow$ χSSB revisted
  - ▷ Entering the semi-classical regime
    without loosing confinement



Quark confinement:

Heavy quark anti-quark potential: $V(r) = \sigma r \; - \; \alpha / r$





(KL, improved SU(3) action, Phys. Rev. D76 (2007))

Origin of Confinement?

- Truncated set of DSEs (Landau gauge)

  $\Rightarrow$ IR enhanced ghost propagtor

  $\Rightarrow$ BRST quartet mechanism (Kugo-Ojima criterion)

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- Effective dofs acting as confiner

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- (Semi-)classical configurations:

  $F_{\mu\nu}$ field strength tensor
  $0 \leq (F - \widetilde{F})^2 = 2(FF - F\widetilde{F})$
  (anti-)selfdual configurations: $F[A] = \pm\widetilde{F}[A]$.
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Examples:

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't Hooft, PRL 37 (1976)
Calorons: Nahm (Proc. Trieste 1983)
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  Relation to confinement: ✔

  Dual Meissner Effect

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- (Centre) vortices

  Cornwall, Nucl. Phys. B157 (1979), Mack, PRL 45 (1980)
  Del Debbio, Faber, Greensite, Olejnik, Phys. Rev. D55 (1996)
  Relation to confinement: ✔

  Vortex Percolation

Origin of spont. chiral SSB?

Litmus paper for chiral SSB:

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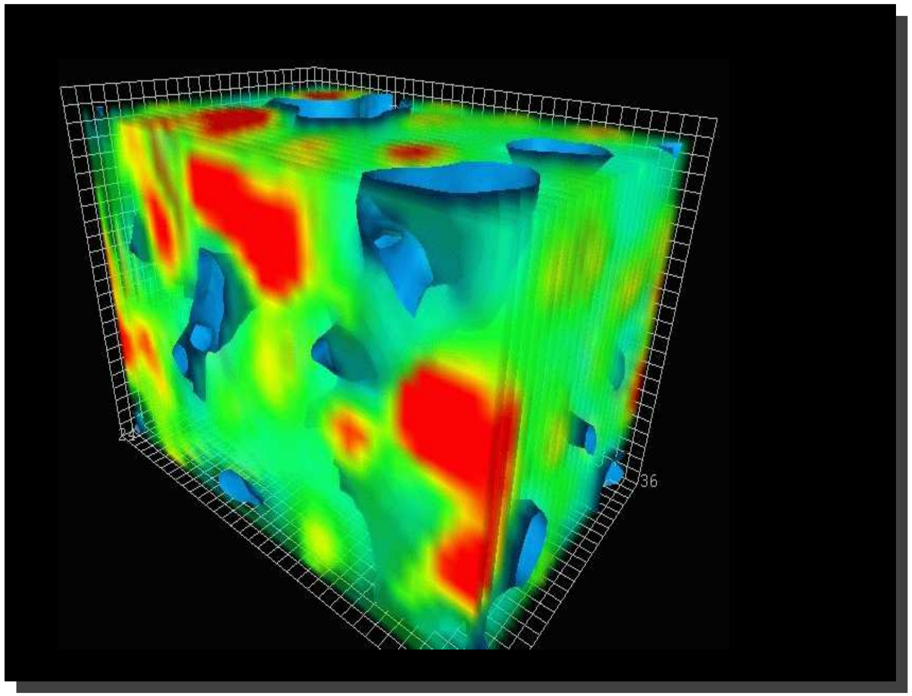
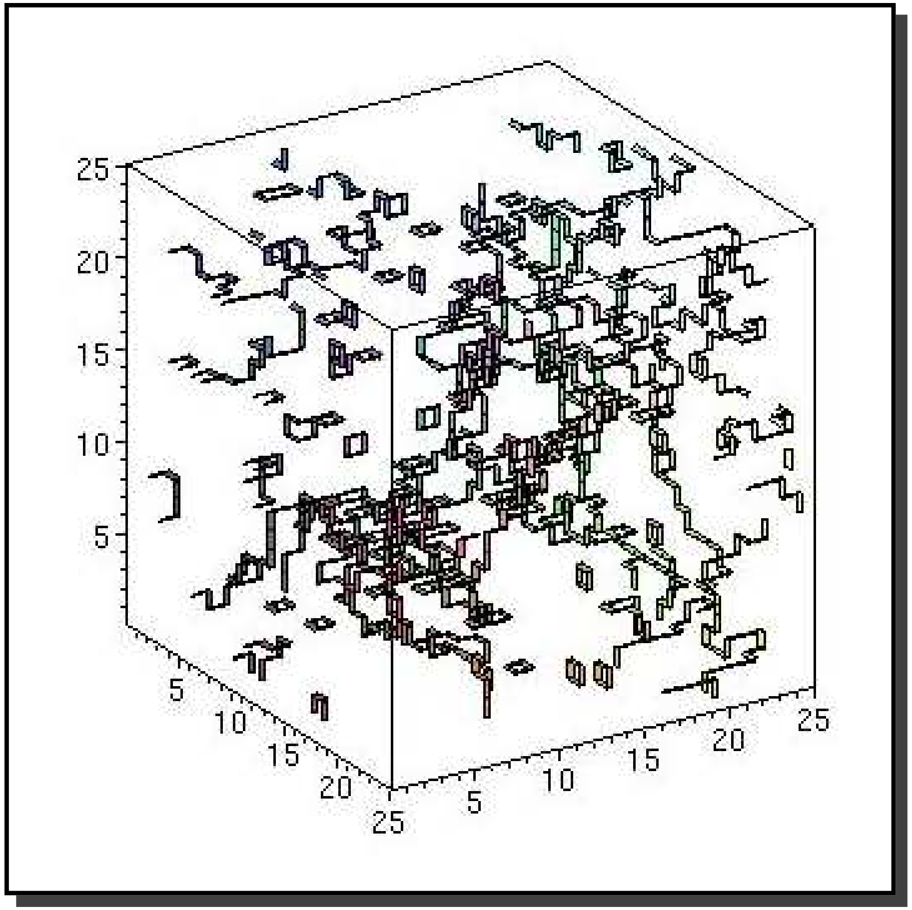
Vortices & spont. chiral SSB:

SU(2) action density

(CSSM, Adelaide)



vortex content

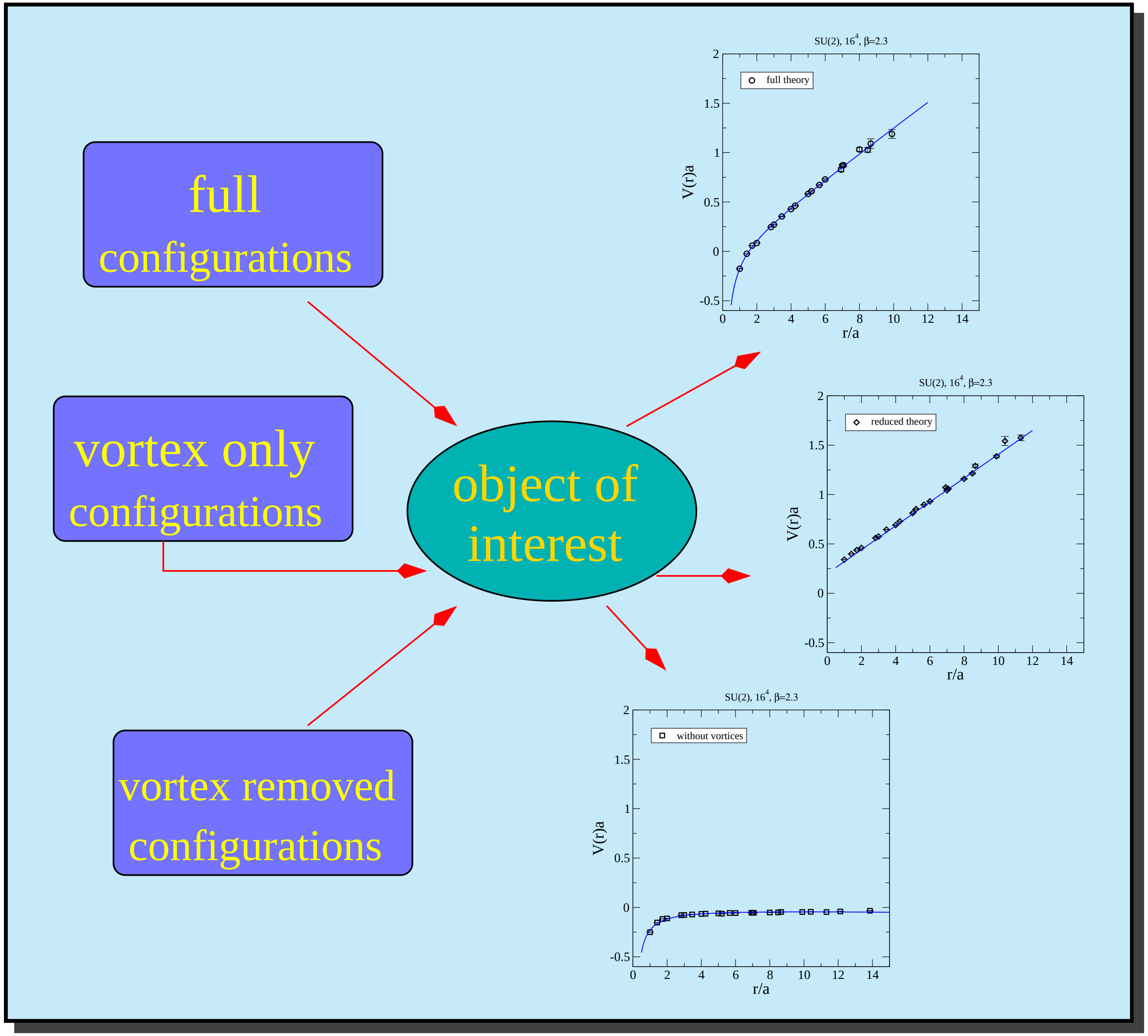


projection

[MCG, LCG,...]

Vortices & spont. chiral SSB:

Vortex methodology:



Vortices & spont. chiral SSB:

Object of interest: *chiral symmetry*

SU(2) YM theory

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- $\langle \bar{q}q \rangle = 0$ upon vortex removal

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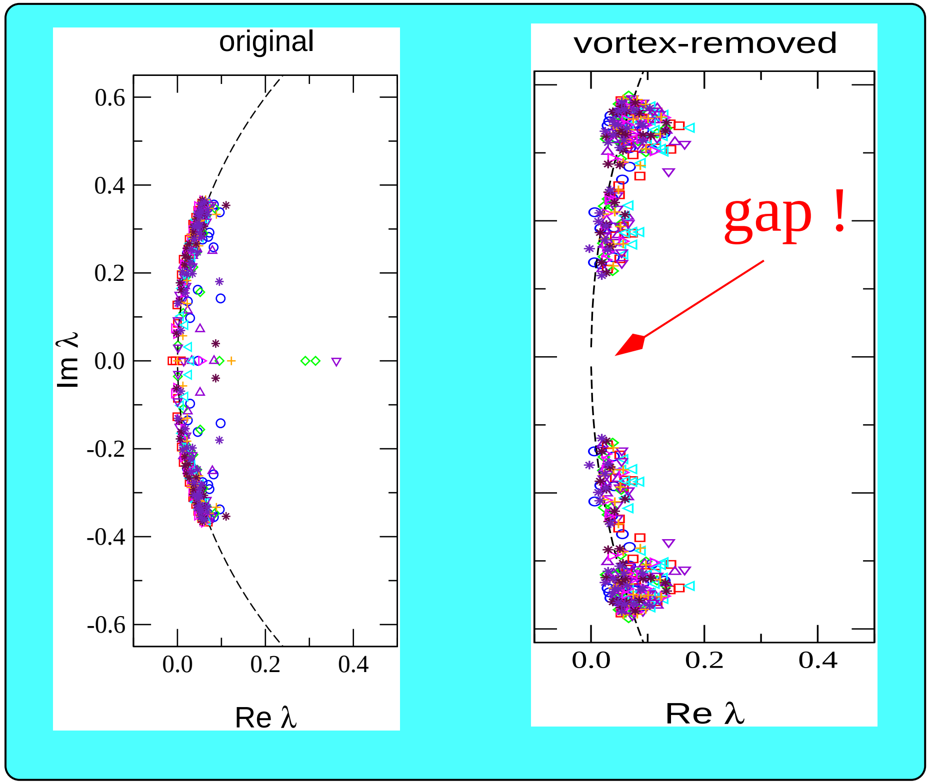

(Gattnar, Gattringer, Langfeld, Reinhardt, Schafer, Tok, NPB 716 (2005) 105)

Vortices & spont. chiral SSB:

- $\rho(0) = 0$ for vortex only configurations

`[staggered (asqtad) fermions needed]`

(Faber, Greensite, Heller, Hoellwieser, Olejnik
PRD 78 (2008) 054508.)

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- How is the quark propagtor affected by vortex removal? `[here: Landau gauge]`

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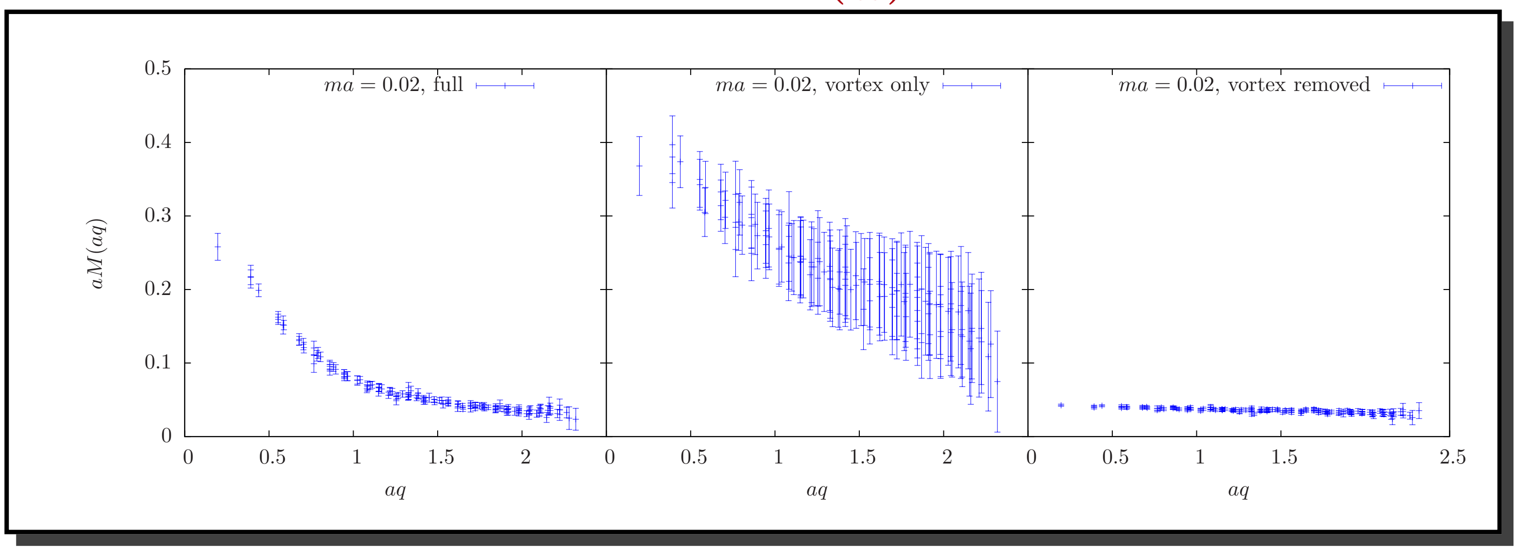

(Bowman, Langfeld, Leinweber, O'Cais, Sternbeck, von Smekal, Williams, PRD 78 (2008) 054509.)

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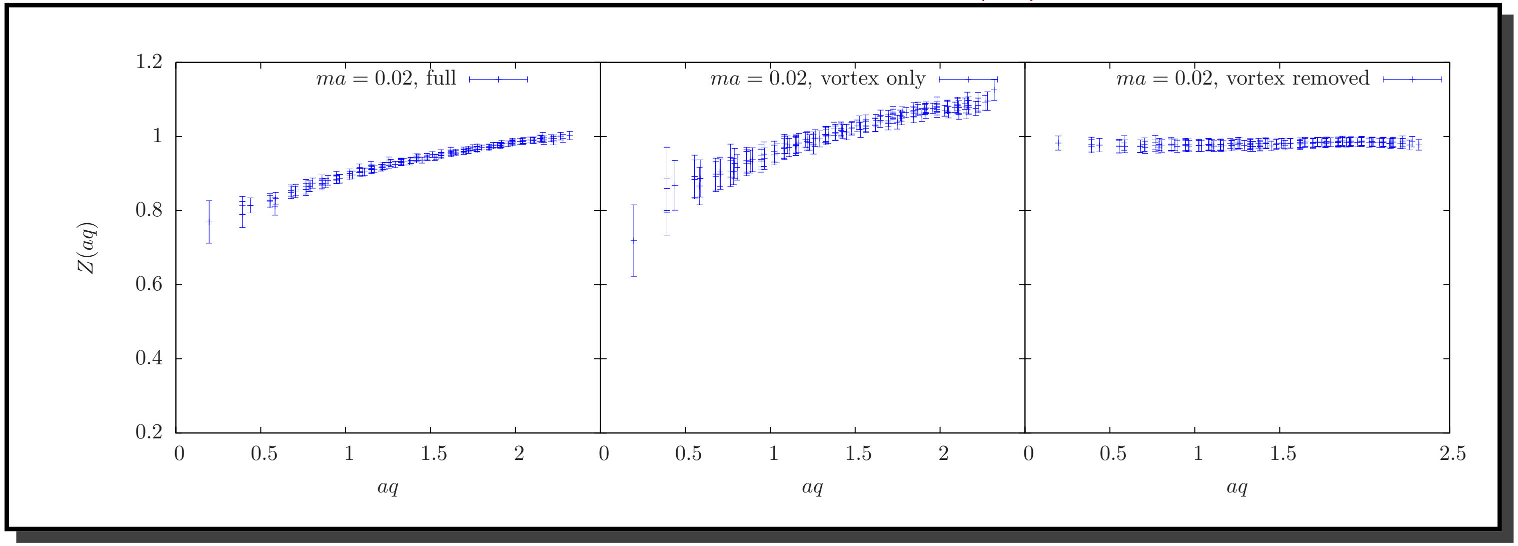

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- Confinement (Maximal Centre Gauge):
  vasnishing string tension upon vortex removal ✔
  only 62% string tension for vortex only configurations •
  vortex density physical: $\rho a^2 = \mathcal{O}(a^2)$ ✔
  [Langfeld, PRD 69 (2004) 014503]

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- Confinement (Laplacian Centre Gauge):
  vasnishing string tension upon vortex removal ✔
  only 100% string tension for vortex only configurations ✔
  vortex density un-physical: $\rho a^2 = \mathcal{O}(a)$ •
  [de Forcrand, Pepe, NPB 598 (2001) 557]
  [Langfeld, Reinhardt, Schafke, PLB 504 (2001) 338]

Vortices & spont. chiral SSB:

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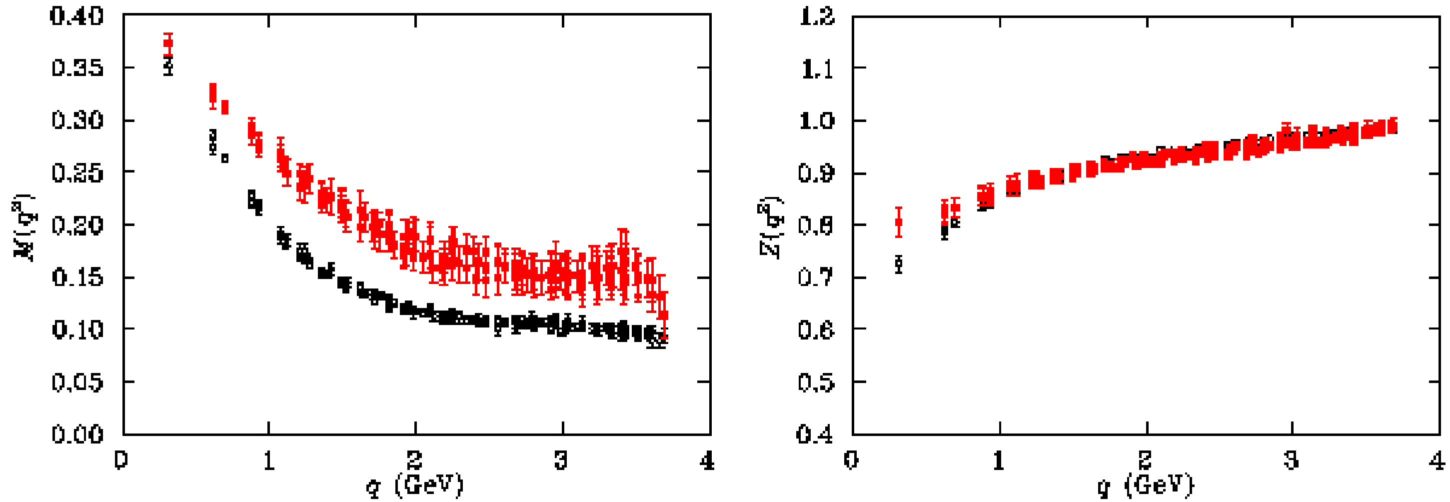

[Leinweber, Bowman, Heller, Kusterer, Langfeld, Williams, Nucl.Phys.Proc.Suppl.161 (2005) 130]

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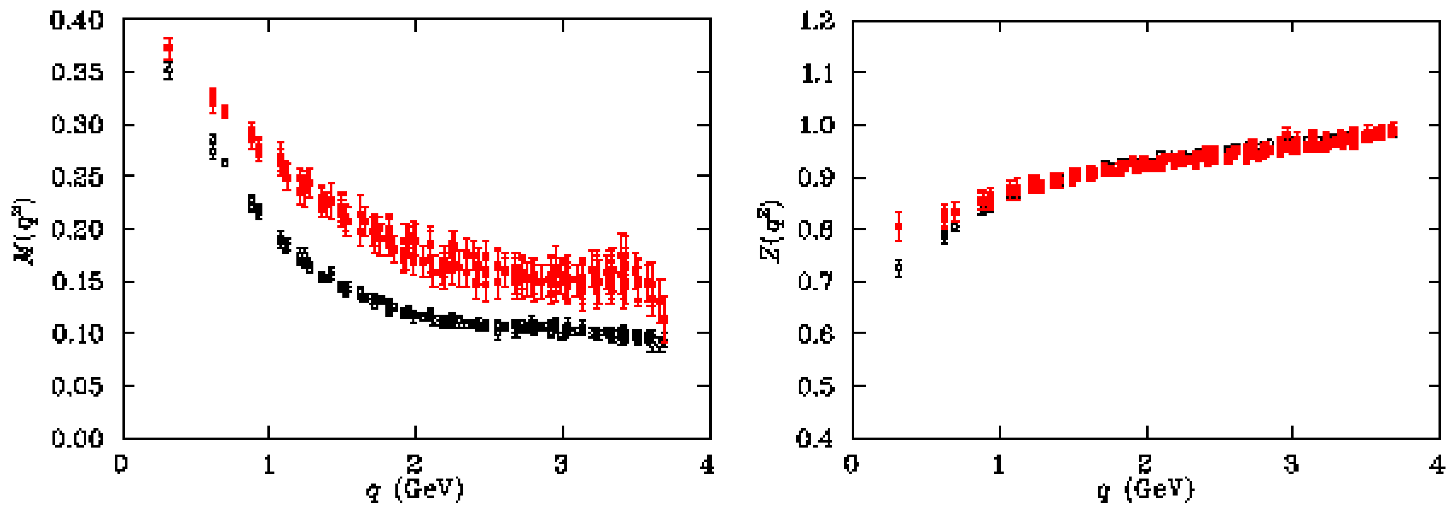

`[Leinweber, Bowman, Heller, Kusterer, Langfeld, Williams, Nucl.Phys.Proc.Suppl.161 (2005) 130]`

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SU(2) versus SU(3)

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- Laplacian centre gauge: (SU(2) and SU(3))
  too many vortices: $\rho a^2 = \mathcal{O}(a)$
  upon vortex removal:
  $\Rightarrow$ no asymptotic freedom anymore
  $\Rightarrow$ configurations too noisy

Unravelling the IR-regime:

. . . using low energy filters:

(i) eigenmodes of the quark propagator

(ii) confinement preserving cooling

Unravelling the IR-regime:

- eigenvalues and eigenfunctions:

$$D[U]\;\psi(x) = \lambda\;\psi(x)$$

$$D[{}^{\Omega}U]\;{}^{\Omega}\psi(x) = \lambda\;{}^{\Omega}\psi(x)$$

gauge invariant

$${}^{\Omega}\psi(x) = \Omega(x)\;\psi(x)$$

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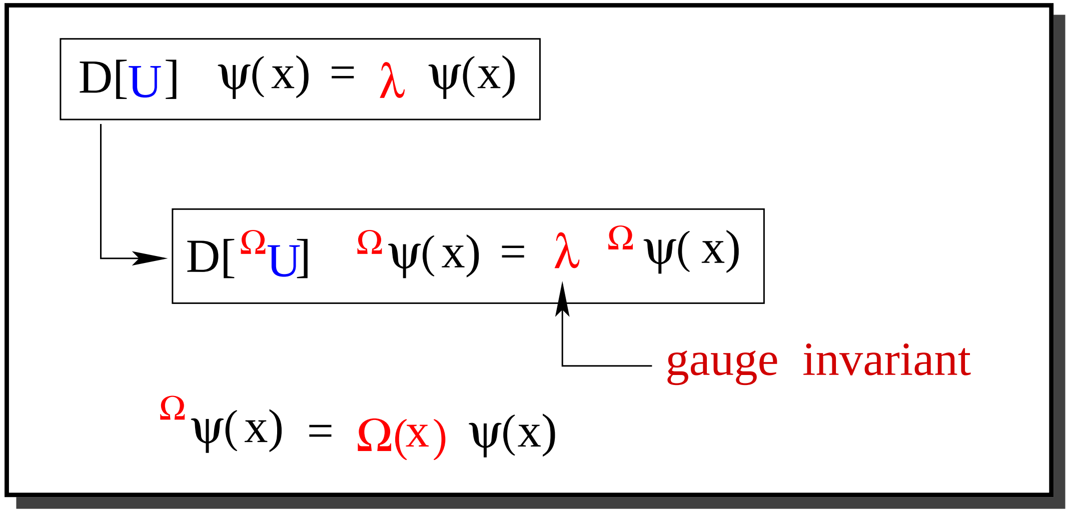

- Banks-Casher relation:
  $\rho(\lambda)\, d\lambda$: number of eigenvalues in $[\lambda, \lambda + d\lambda]$

$$\langle \bar{q} q \rangle = \pi\, \rho(0)$$

(gauge invariant statement)

Unravelling the IR-regime:

- confinement $\leftrightarrow$ chiral SSB revisited
  - low lying Diracmodes $\longrightarrow$ chiral SSB
  - $\langle$ Polyakov line $\rangle$ $\longrightarrow$ confinement

  $\Rightarrow$ re-construct $\langle P \rangle$ with Diracmodes!

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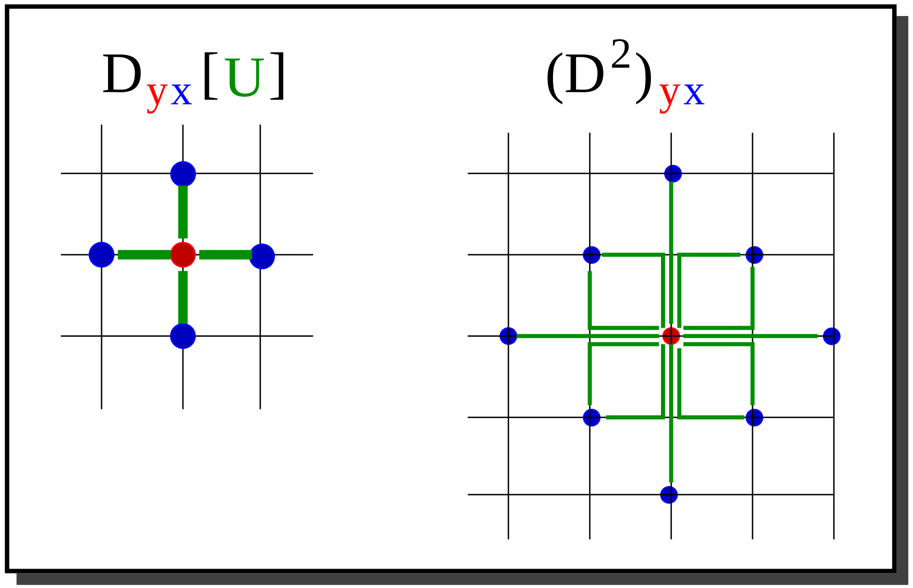
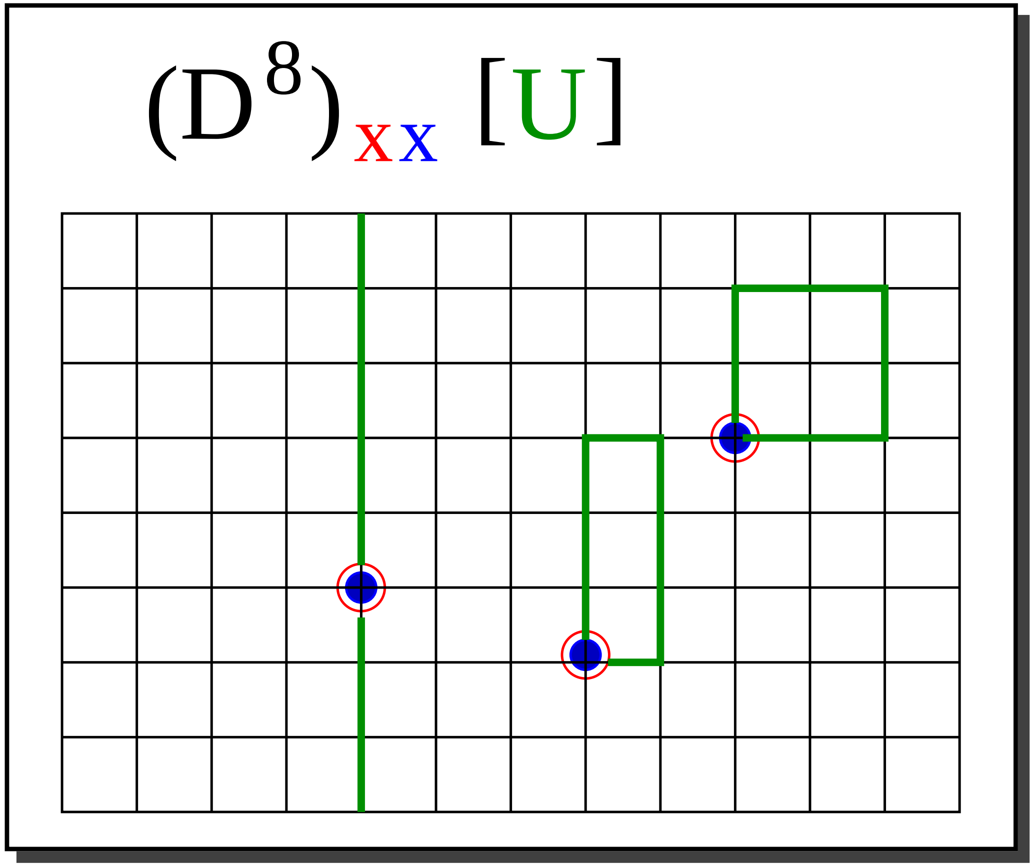


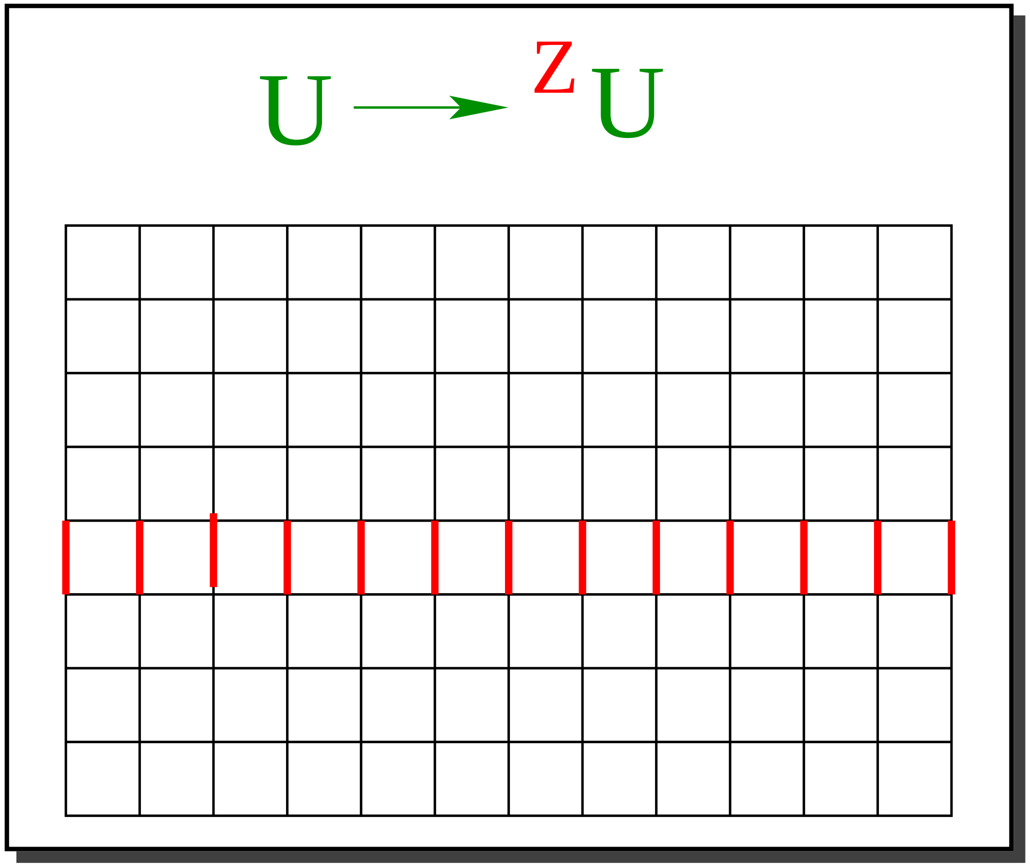
Unravelling the IR-regime:

- More powers of the quark operator:



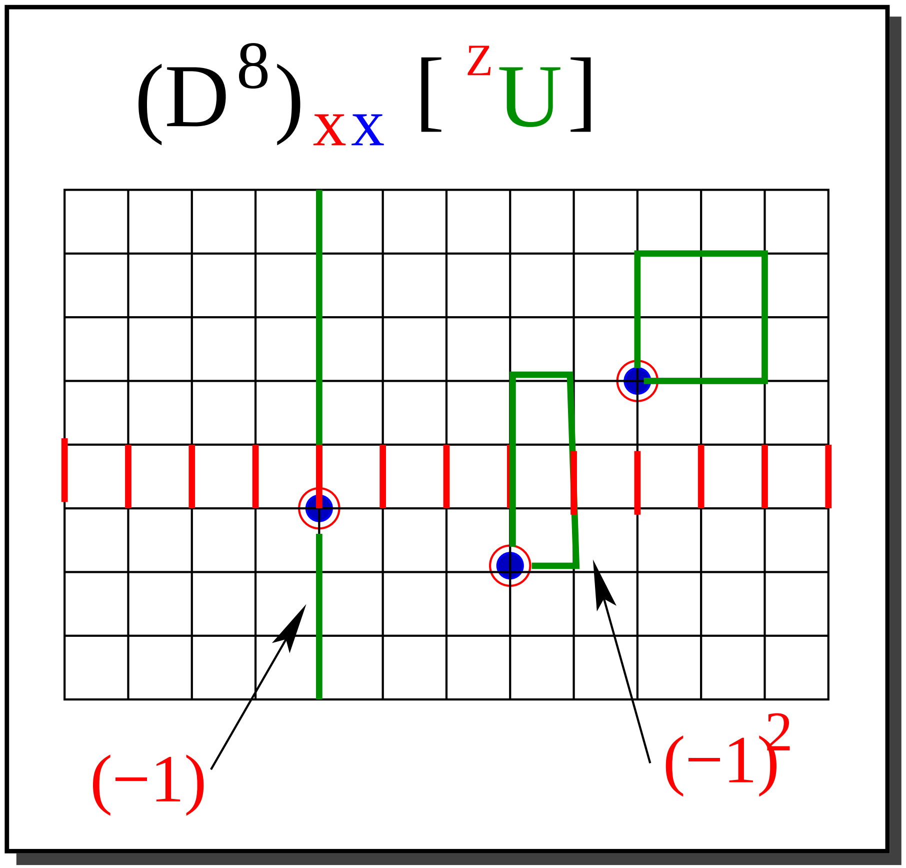
Unravelling the IR-regime:

- Change of the gluonic background field:



Unravelling the IR-regime:

- Impact on the quark operator?



$$P(x) \sim \mathrm{tr}\,(D^8)_{xx}\,[U] \; - \; \mathrm{tr}\,(D^8)_{xx}\,[{}^{z}U]$$

Unravelling the IR-regime:

- Define ...

$$\rho_n(x)[U] = \psi(x)\psi^\dagger(x)[U]$$

$$\boxed{P(x) = \sum_{\text{all n}} \left[\rho_n(x)[U]\lambda_n^{N_t} - \rho_n(x)[{}^zU]\,{}^z\lambda_n^{N_t} \right]}$$

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- applications:

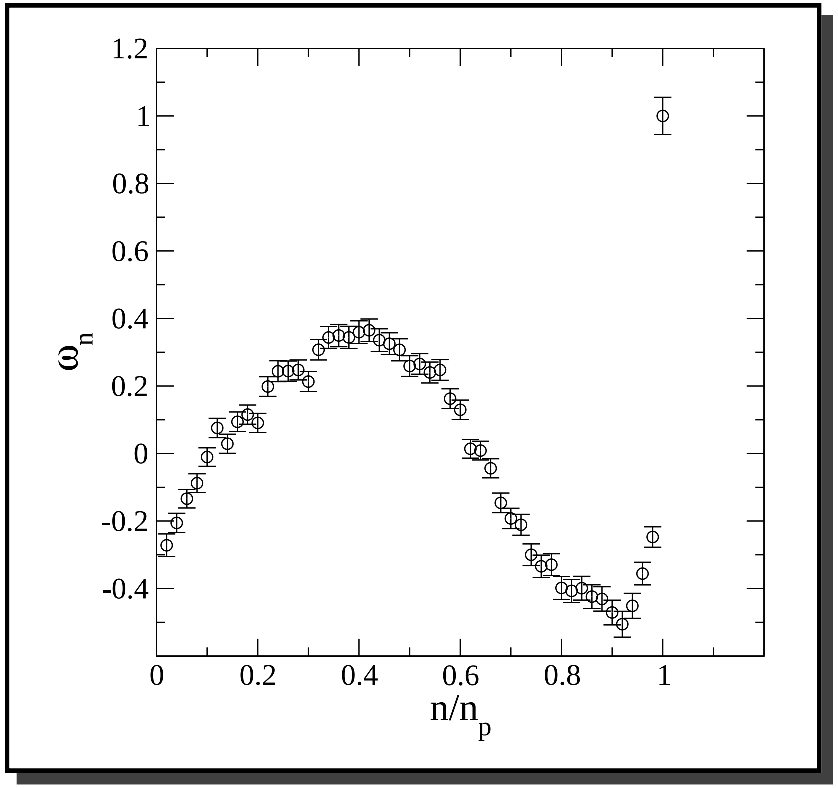
$$\left\langle P(x)P^\dagger(y) \right\rangle \longrightarrow V(|x-y|)$$

- Low energy (chiral) projection:

$$P_{\text{low}}(x) = \sum_{\text{low n}} \left[\rho_n(x)[U]\lambda_n^{N_t} - \rho_n(x)[^zU]\, {}^z\lambda_n^{N_t} \right]$$

Unravelling the IR-regime:

- Results: $\langle P \rangle$ is UV dominated



(Synatschke, Wipf, Wozar, PRD 75 (2007) 114003
(Synatschke, Wipf, Langfeld, PRD 77 (2008) 114018)

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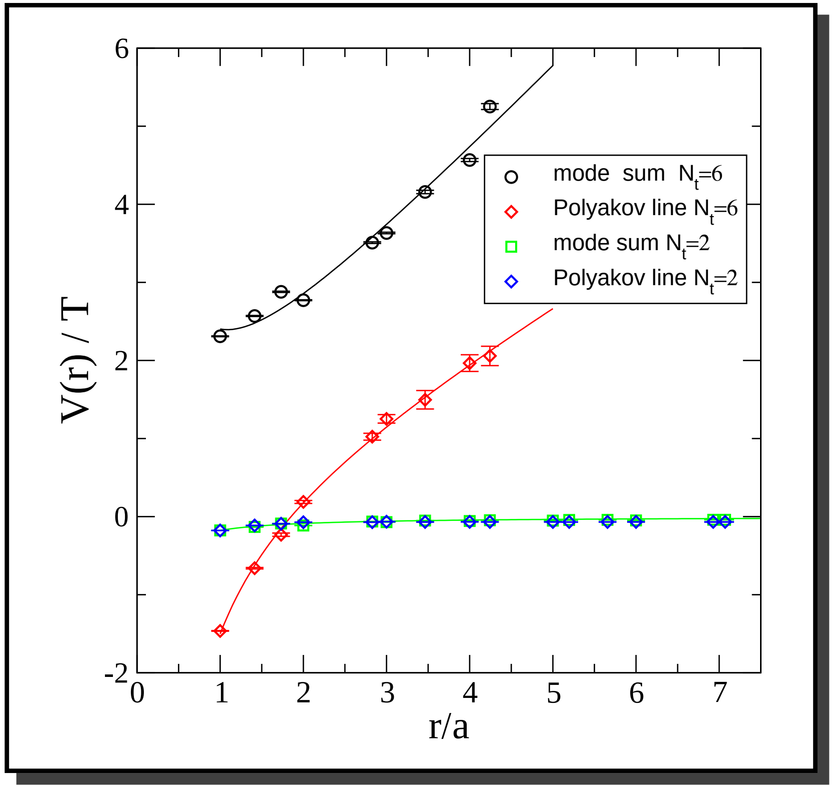
- confinement order parameter
  (caveat: non-local)

Unravelling the IR-regime:

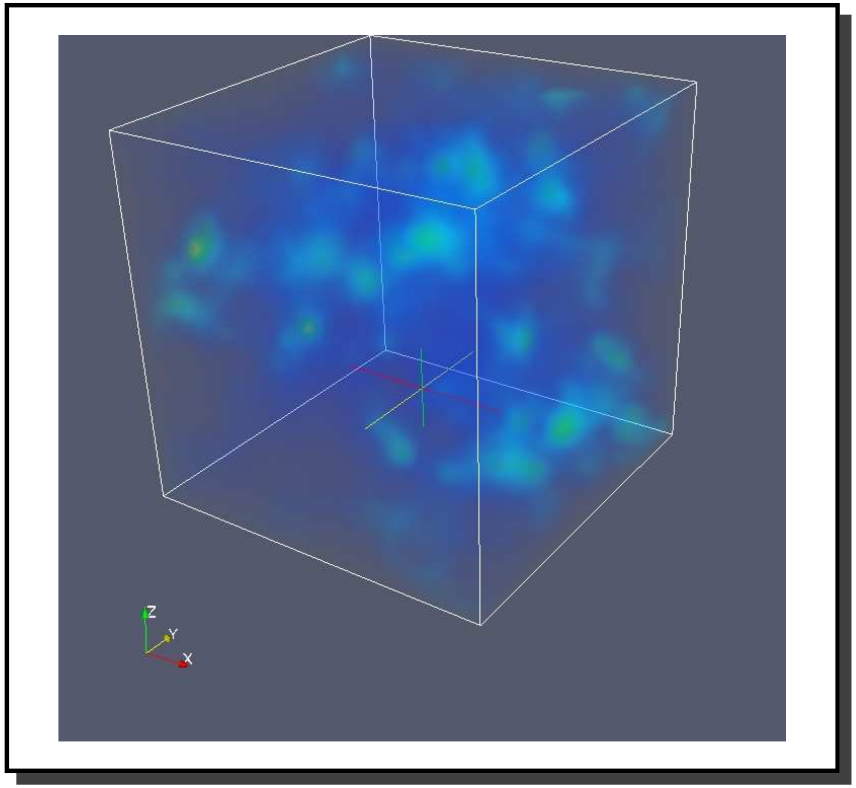
- Results: $V(|x-y|)$ is LOW modes dominated



(Synatschke, Wipf, Langfeld, PRD 77 (2008) 114018)

Unravelling the IR-regime:

- Results: visualise $\sum_{n=1}^{25} \rho_n(x)[U]\, \mathrm{e}^{-3\lambda_n^2}$



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  problem: cooling eliminates the string tension
- here: cool the configurations

  but keep the string tension!

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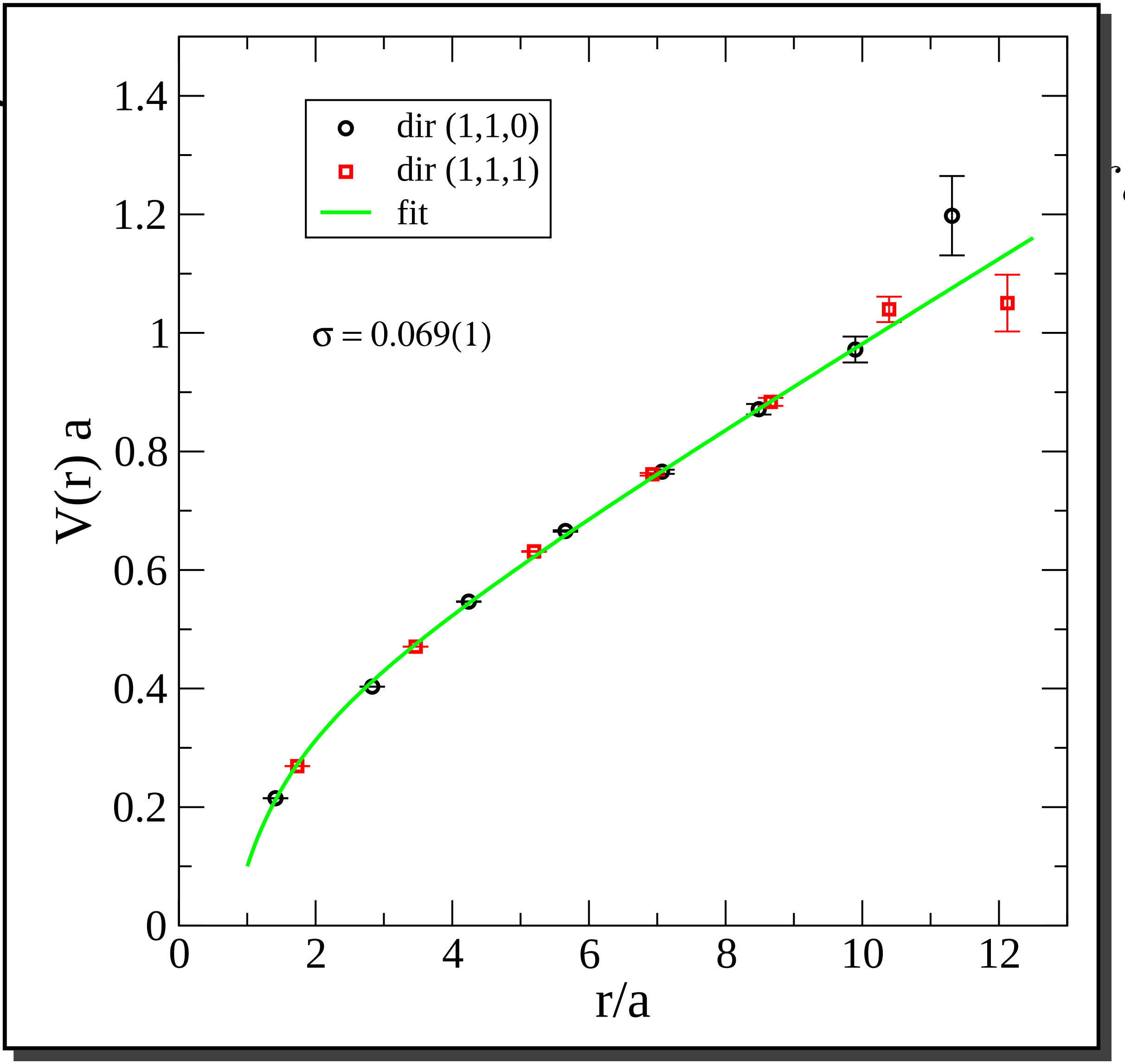
- consider: $W(r,T+a)/W(r,T) \approx \exp\{-V(r)a\}$
  keep it fixed for $r = r_c$

Unravelling the IR-regime:

- Numerical simulations:
  SU(2), 16^4 lattice, Wilson action, $\beta = 2.4$, $r_c = 3a$

Unravelling the IR-regime:

- Nu
  SU ... $r_c = 3a$



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  - caveats:

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- movie: action density

Conclusions:

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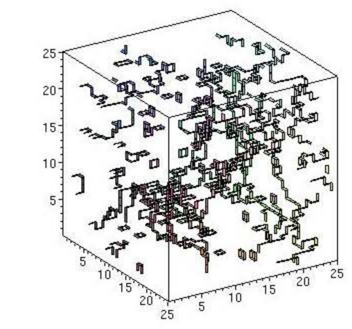
  SU(2): confinement, chiral SSB, ... ✔
  SU(3): more to understand ....



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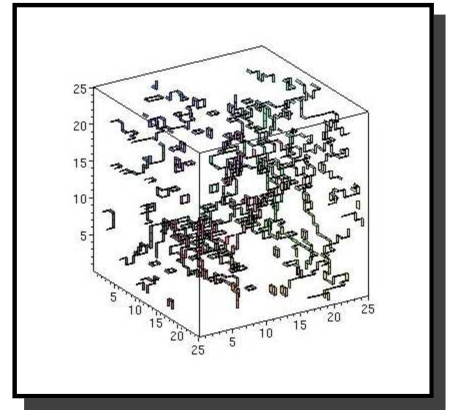
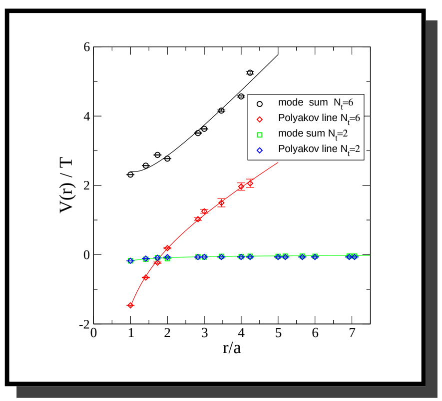
  SU(2): confinement, chiral SSB, ... ✔
  SU(3): more to understand ....



- Quark operator as low energy filter:
  low energy modes:



$\Rightarrow$ chiral SSB (Banks-Casher)

$\Rightarrow$ confinement

Conclusions:

- confinement and semi-classical config.

  $\Rightarrow$: cooling + confinement

  can we understand confinement
  in semi-classical approx (?)