Excited QCD

Zakopane, February 8-14, 2009

Lattice QCD and Three-Body Exotic Systems in the static limit

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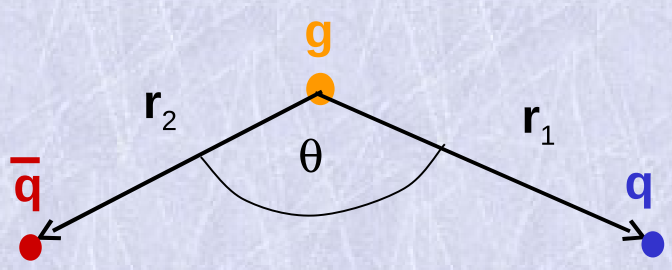
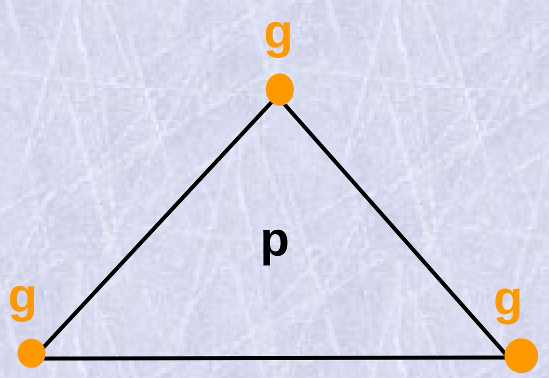
P Bicudo, M Cardoso and O. Oliveira, PRD (r) 77, 091504 (2008), arXiv:0704.2156 [hep-lat].

M. Cardoso and P. Bicudo, PRD 78, 074508,2008, arXiv:0807.1621 [hep-lat]

Static Exotic Potentials in lattice QCD

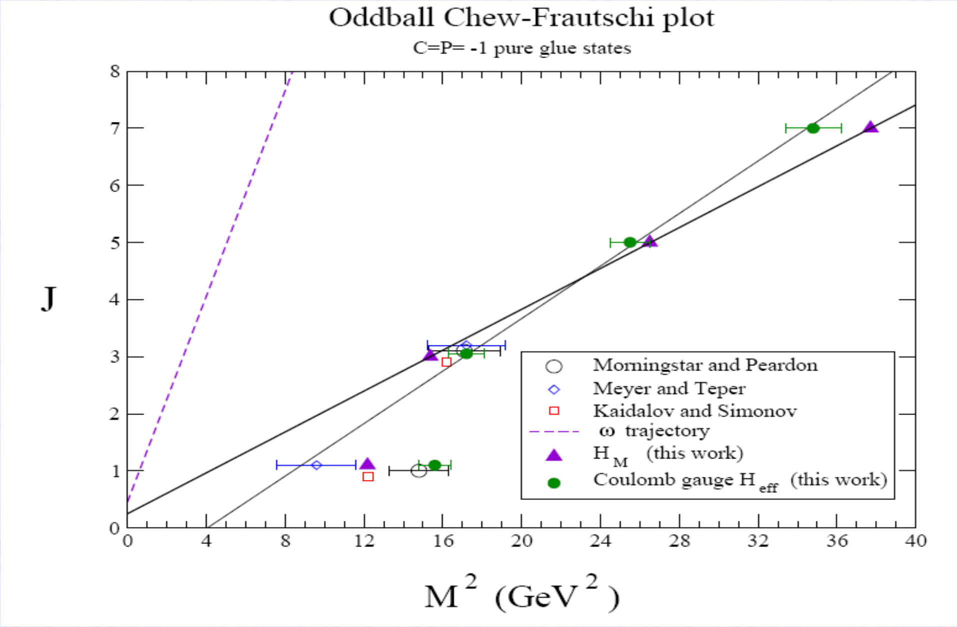
- Utilizing Wilson Loops, we study the static potentials of GQQ and GGG





Motivation

• The experiments BESIII at IHEP in Beijing, LHC at CERN, GLUEX at JLab and PANDA at GSI in Darmstadt, will scan the mass range of GQQ hybrids and GGG glueballs. The odderon might also depend on GGG glueballs…

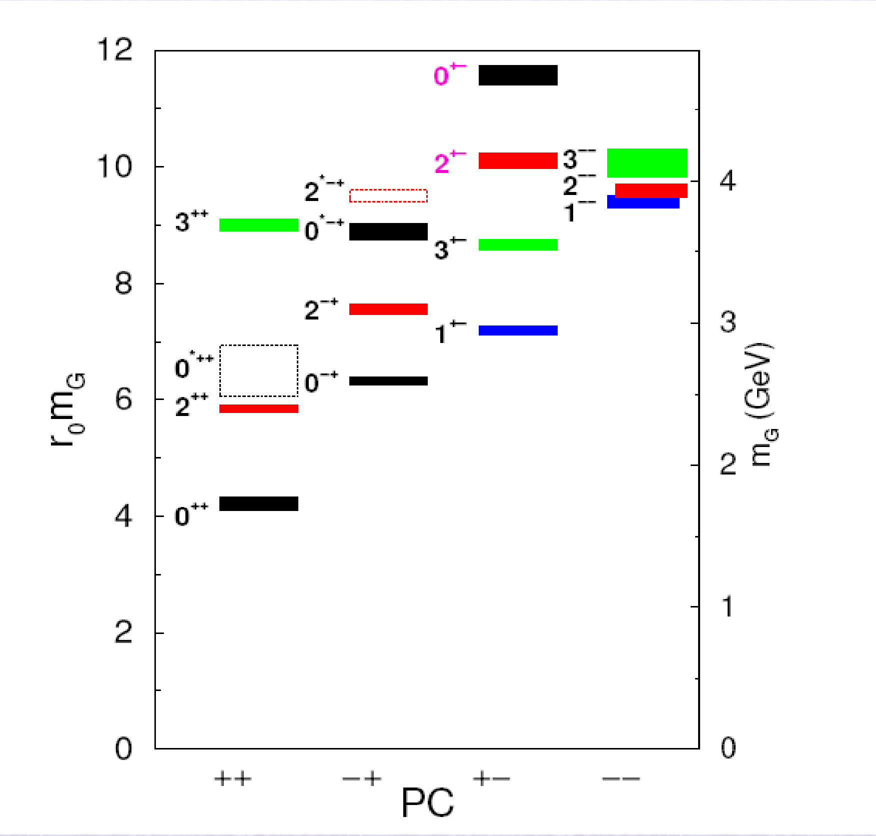


F. Llanes-Estrada, P. Bicudo and S. Cotanch, Phys.Rev.Lett.96, 081601(2006).

Motivation

- The computations of GQQ hybrids and GGG glueballs are performed:
  - With constituent quark-gluon models, say for excited states
  - In Lattice QCD

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



Motivation

Previously, Static potentials have been studied in Lattice QCD to

- be applied in constituent quark-gluon models
- understand confinement
- understand spin and temperature
- *mostly for* mesons, *some for* baryons, *a little for* tetraquarks, pentaquarks, 2-gluon glueballs…
- but not for GQQ hybrids and GGG glueballs

Wilson loops

- We use Wilson loops to get the static potential
- The quark lines correspond to fundamental paths, while the gluons lines correspond to adjoint paths:

$$\tilde{U}_{ab}=\frac{1}{2}\mathrm{Tr}\left(\lambda_a U \lambda_b U^{+}\right)$$

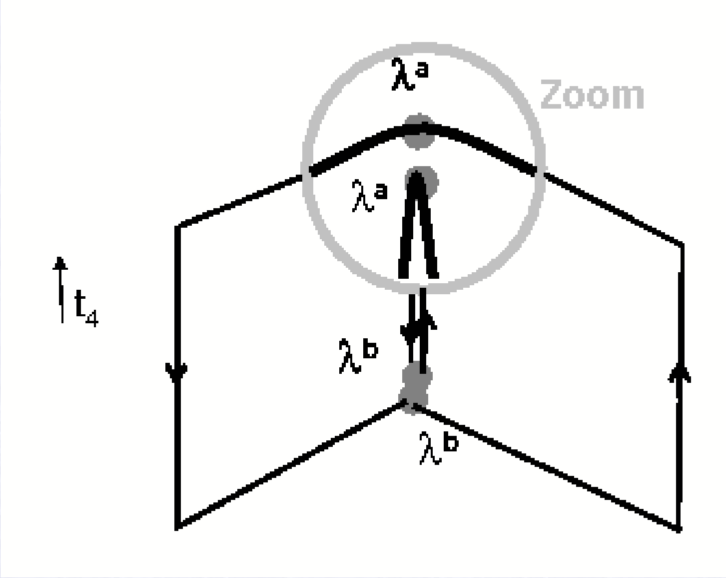
- We can use the Fierz relation to write the adjoint paths as fundamental paths:

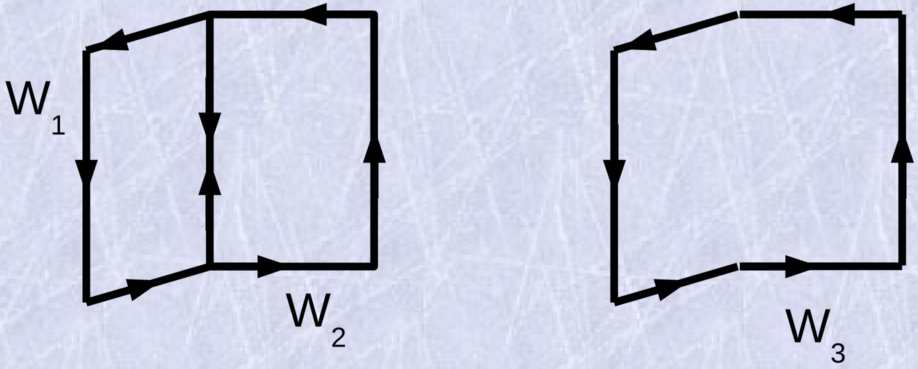
$$\sum_a \lambda_{ij}^a \lambda_{kl}^a = 2\,\delta_{il}\,\delta_{jk} - \frac{2}{3}\delta_{ij}\,\delta_{kl}$$

Hybrid meson Wilson loop

- For the hybrid gqq we have:

$$W_{qqg} = \mathrm{Tr}\left(X \lambda_a Y^{+} \lambda_b\right) \mathrm{Tr}\left(T \lambda_a T^{+} \lambda_b\right) = W_1 W_2 - \frac{1}{3} W_3$$





Three gluon Wilson loop

- For a three gluon glueball we have two possible color wavefunctions:
  - Antisymmetric: $|\psi^A\rangle = f_{abc}|a\, b\, c\rangle$
  - Symmetric: $|\psi^S\rangle = d_{abc}|a\, b\, c\rangle$
- Corresponding to opposite charge conjugation properties

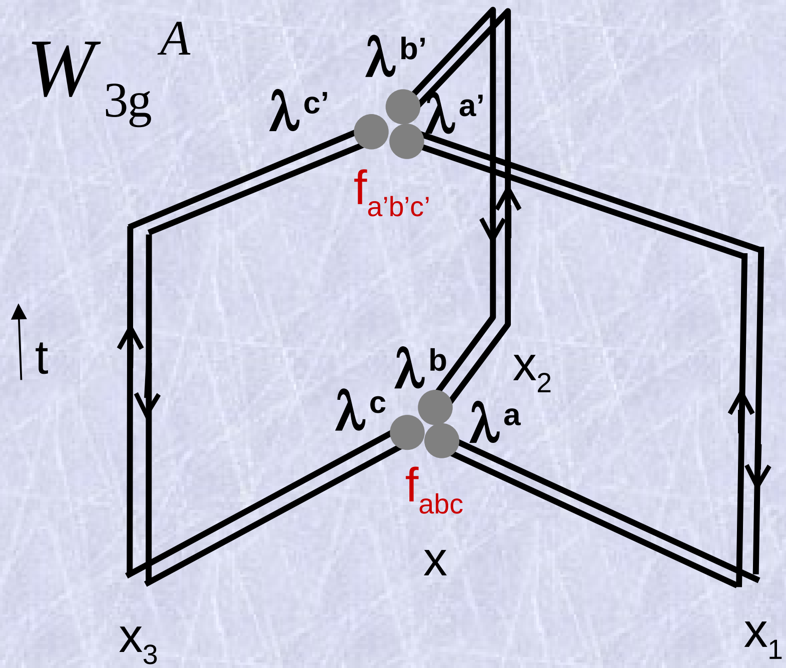
Three gluon Wilson loop

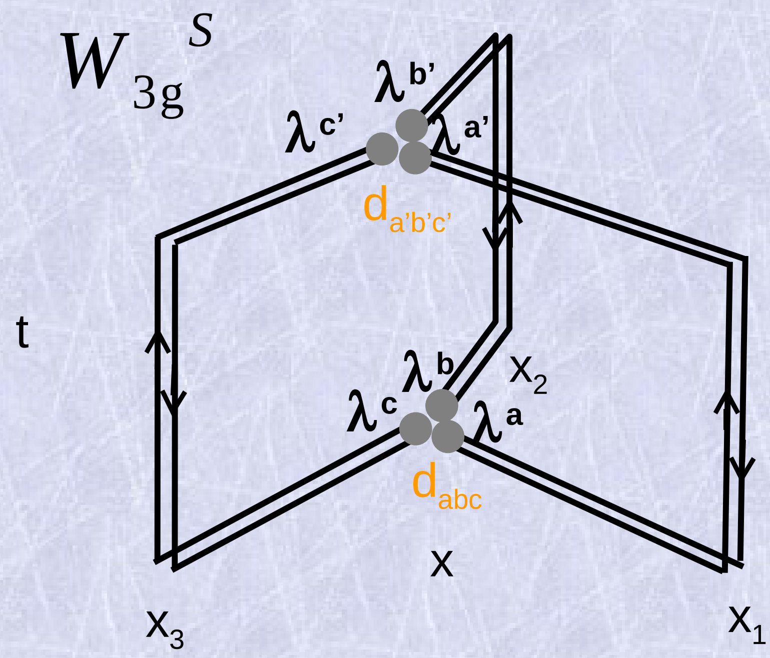
- Wilson loops given by:

$$W_{3g}^{A} = f_{abc} f_{a'b'c'} \tilde{X}^{aa'} \tilde{Y}^{bb'} \tilde{Z}^{cc'}$$

$$W_{3g}^{S} = d_{abc} d_{a'b'c'} \tilde{X}^{aa'} \tilde{Y}^{bb'} \tilde{Z}^{cc'}$$

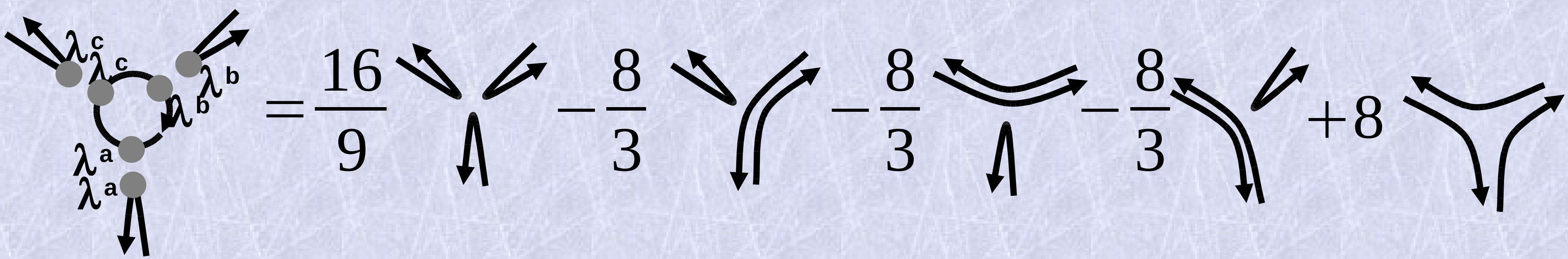
Antisymmetric **Symmetric**



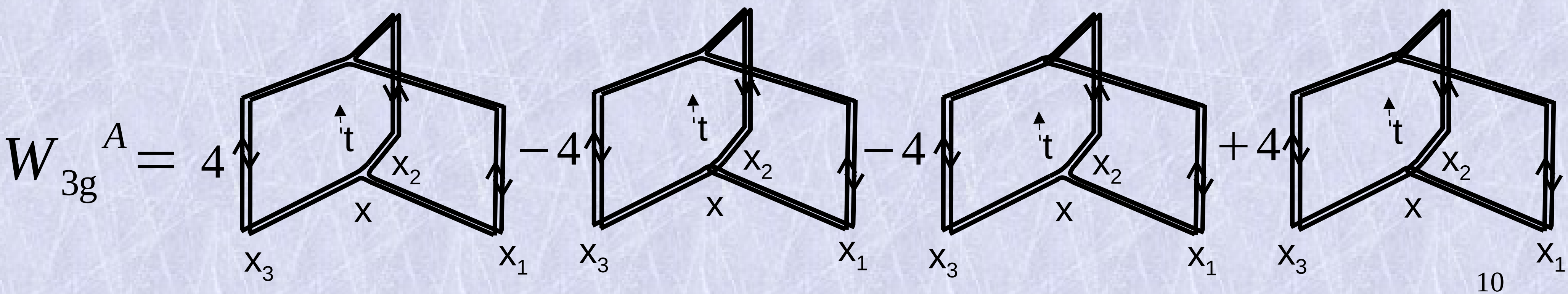


Three gluon Wilson loop

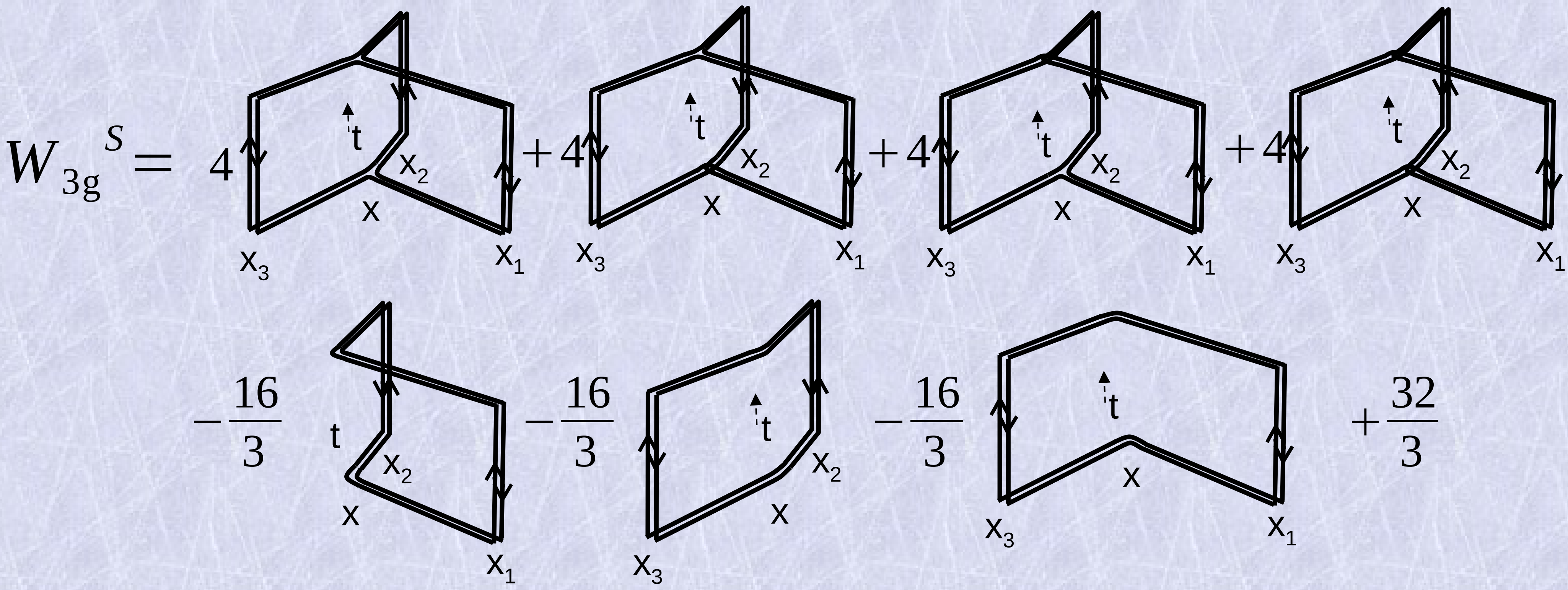
- The two GGG Wilson loops can be rewritten with the Fierz relation:



- We have

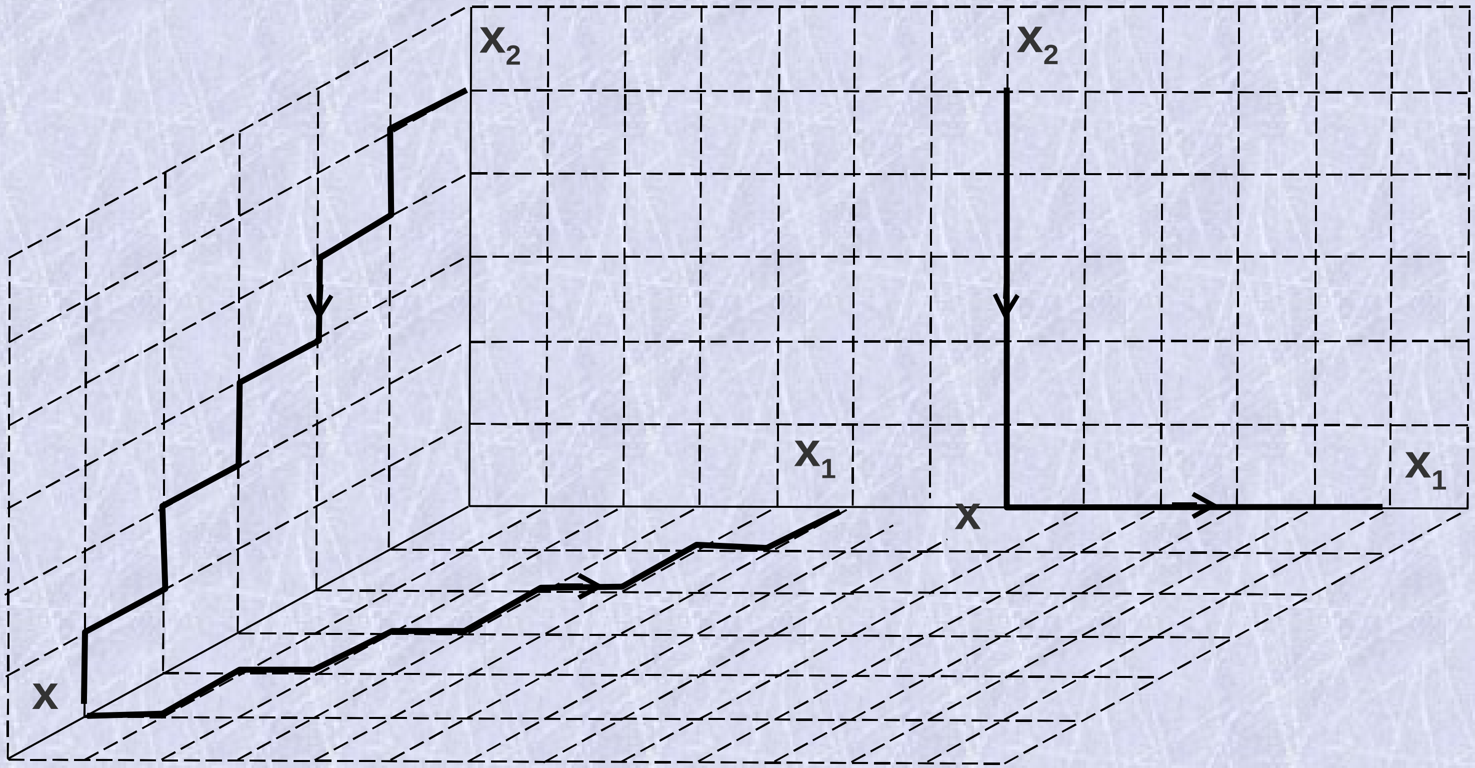


Three gluon Wilson loop



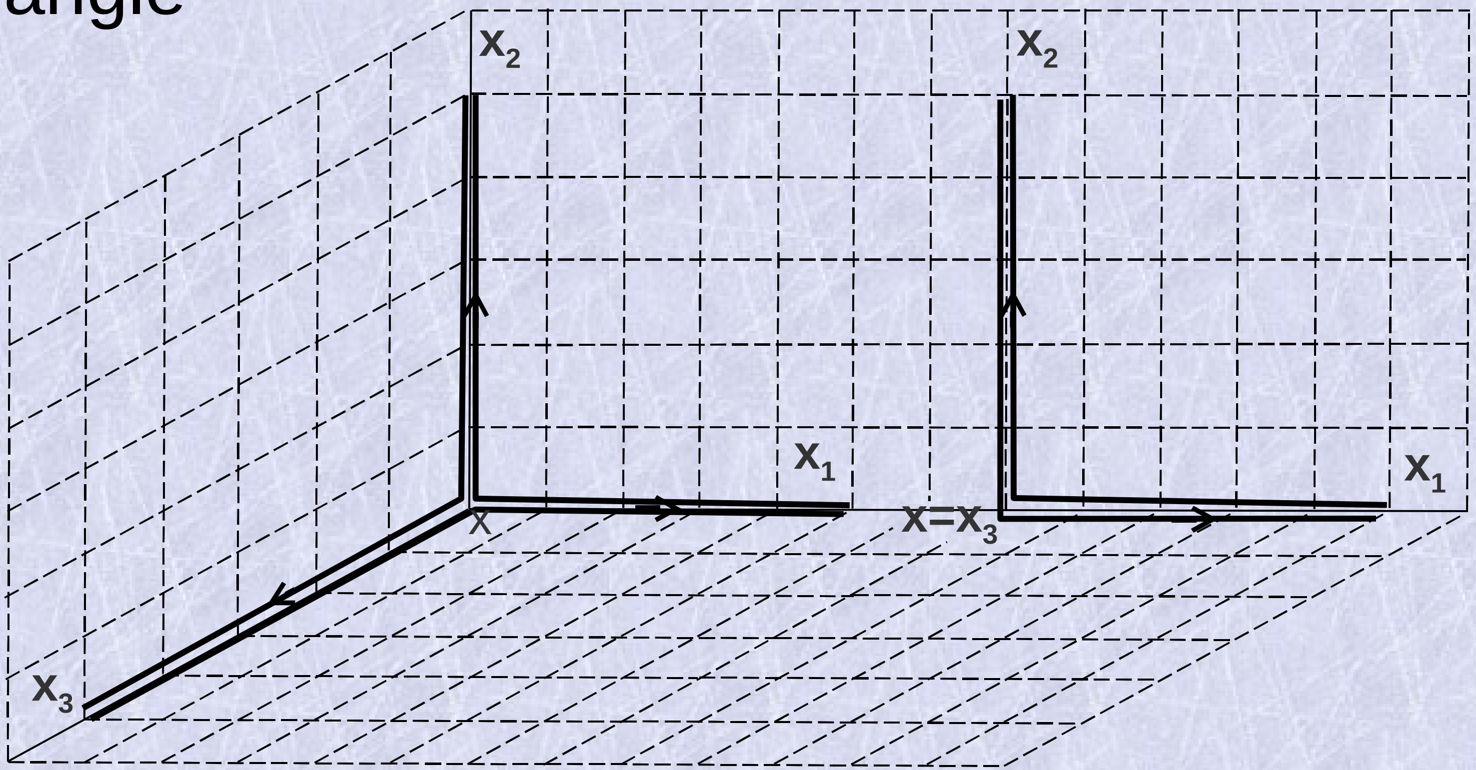
The Wilson Loops for GQQ and GGG

- The spatial paths we use for the GQQ include of-axis geometries,



The Wilson Loops for GQQ and GGG

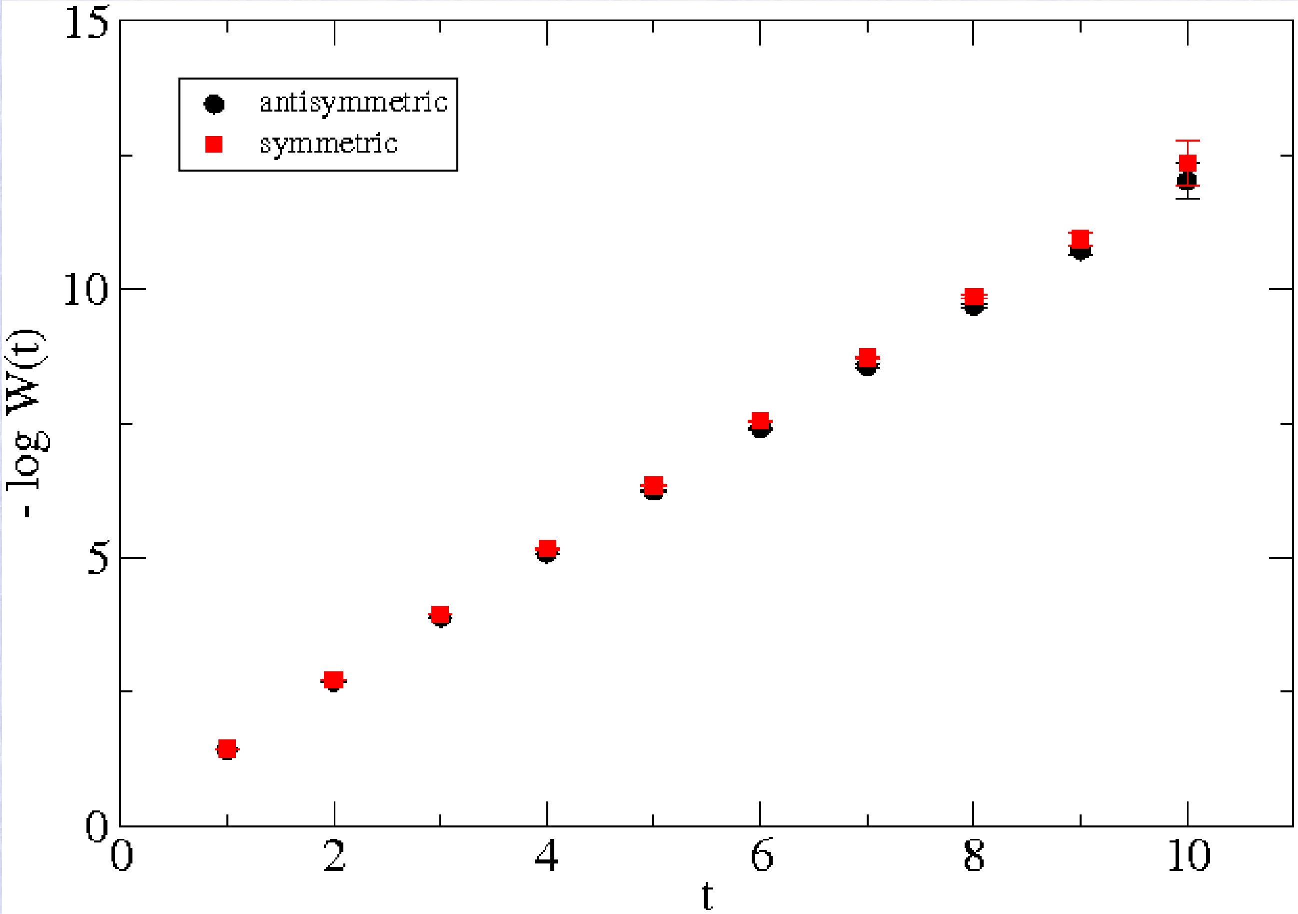
- We study two geometries
  - Equilateral Triangle
  - Rect Triangle



Static Potential

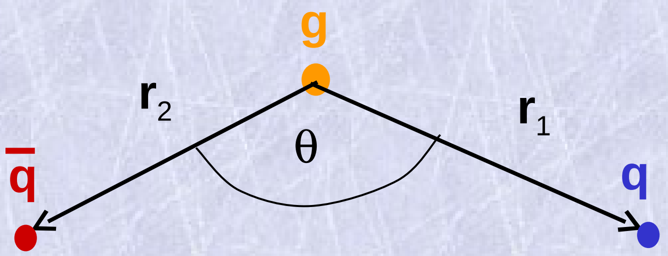
- Then the static potential V is obtained fitting the exponential euclidian time t decay of the Wilson loop W

$$W = cte\, e^{-V t}$$

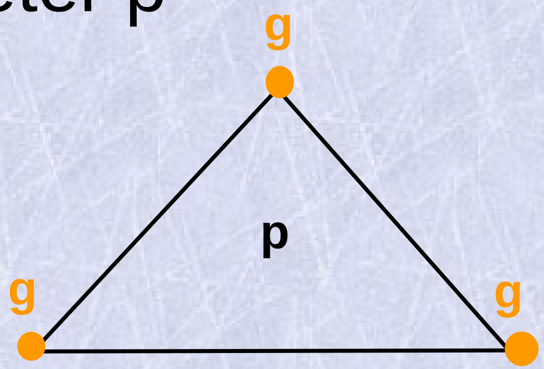


Results for the Hybrid GQQ

- We compute the potentials as a function of the variables:
  - For the hybrid gqq distance r_1 , distance r_2 and angle θ

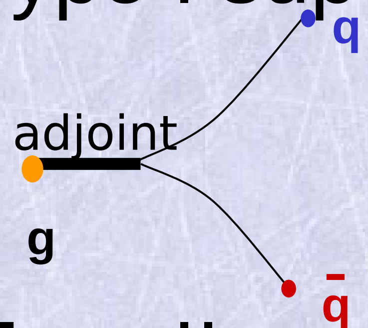


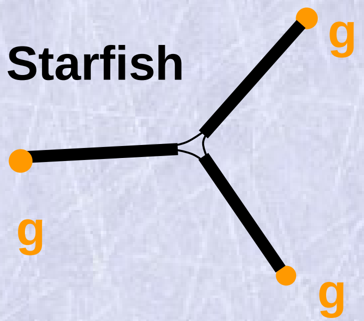
  - For the glueball ggg the perimeter p



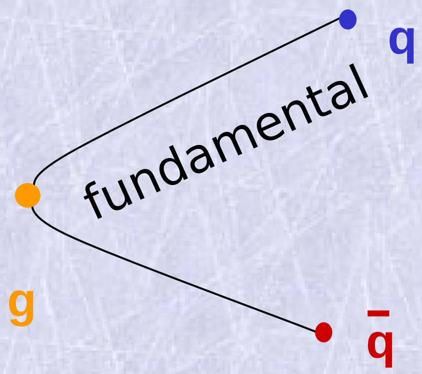
Models of confinement

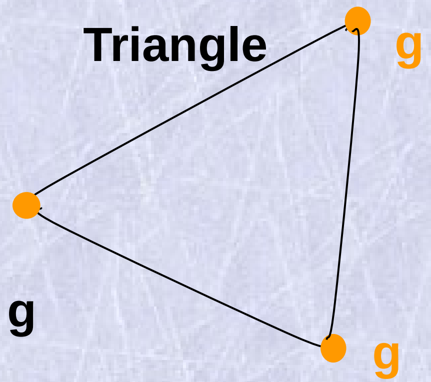
- We want to compare with different models of confinement:
  - Casimir scaling: Sum of two body potentials $V_{ij} \propto \lambda_i \cdot \lambda_j$
  - Type I superconductor:



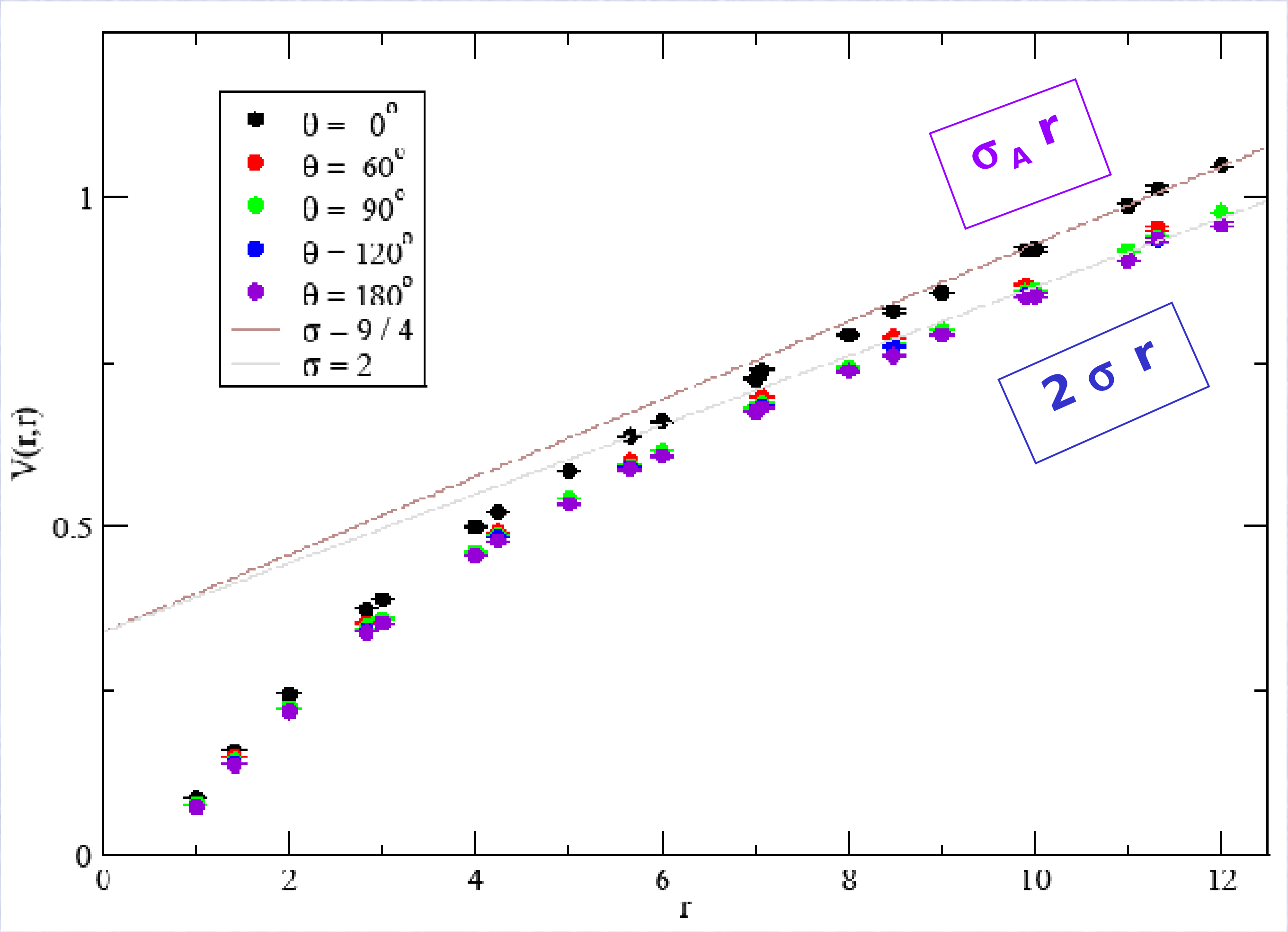


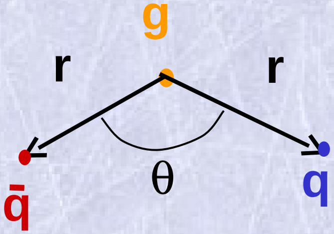
  - Type II superconductor:





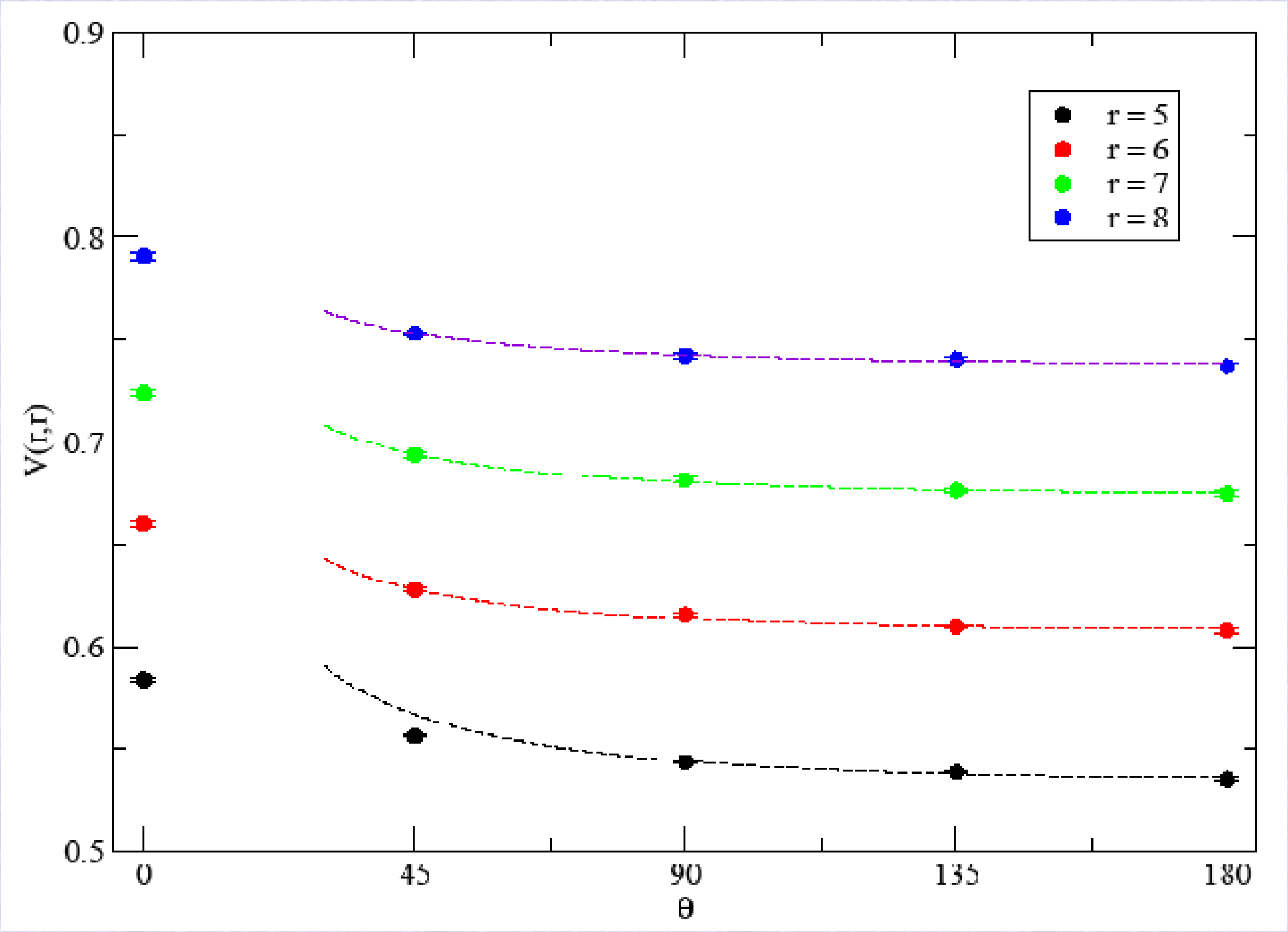
Results for the hybrid

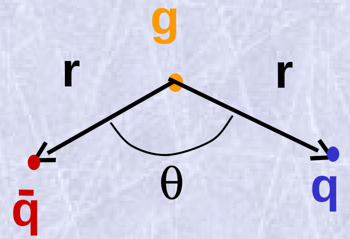




units: a = 0.072 fm *($24^3 \times 48$, $\beta = 6.2$, 141 config.)*

Results for the hybrid





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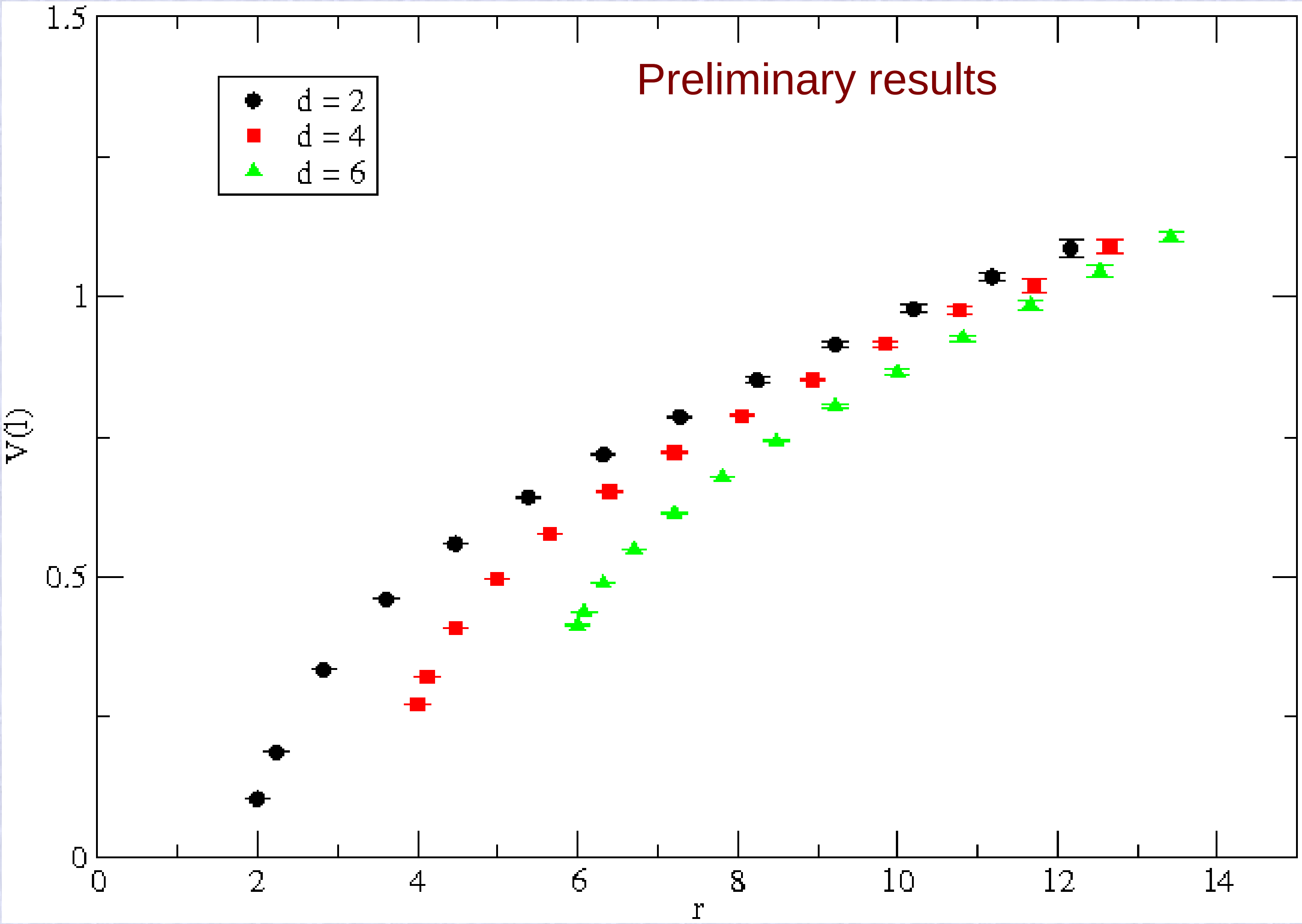

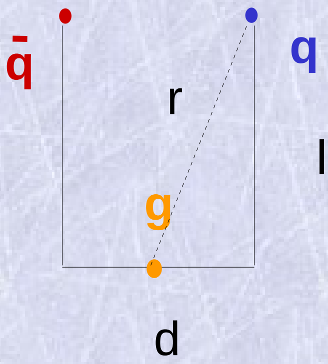

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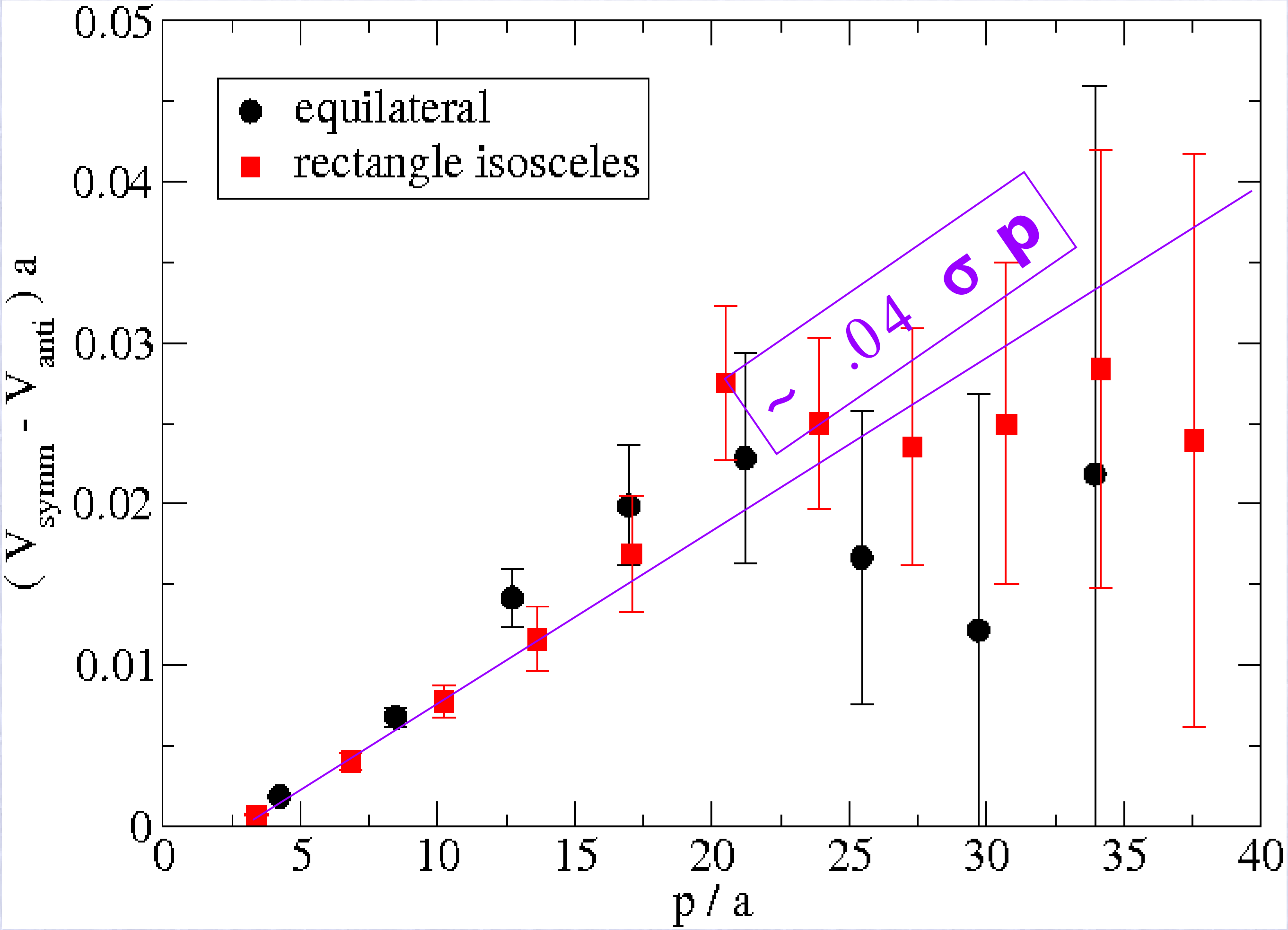
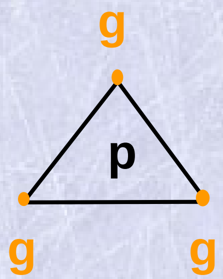
Results for the Glueball GGG





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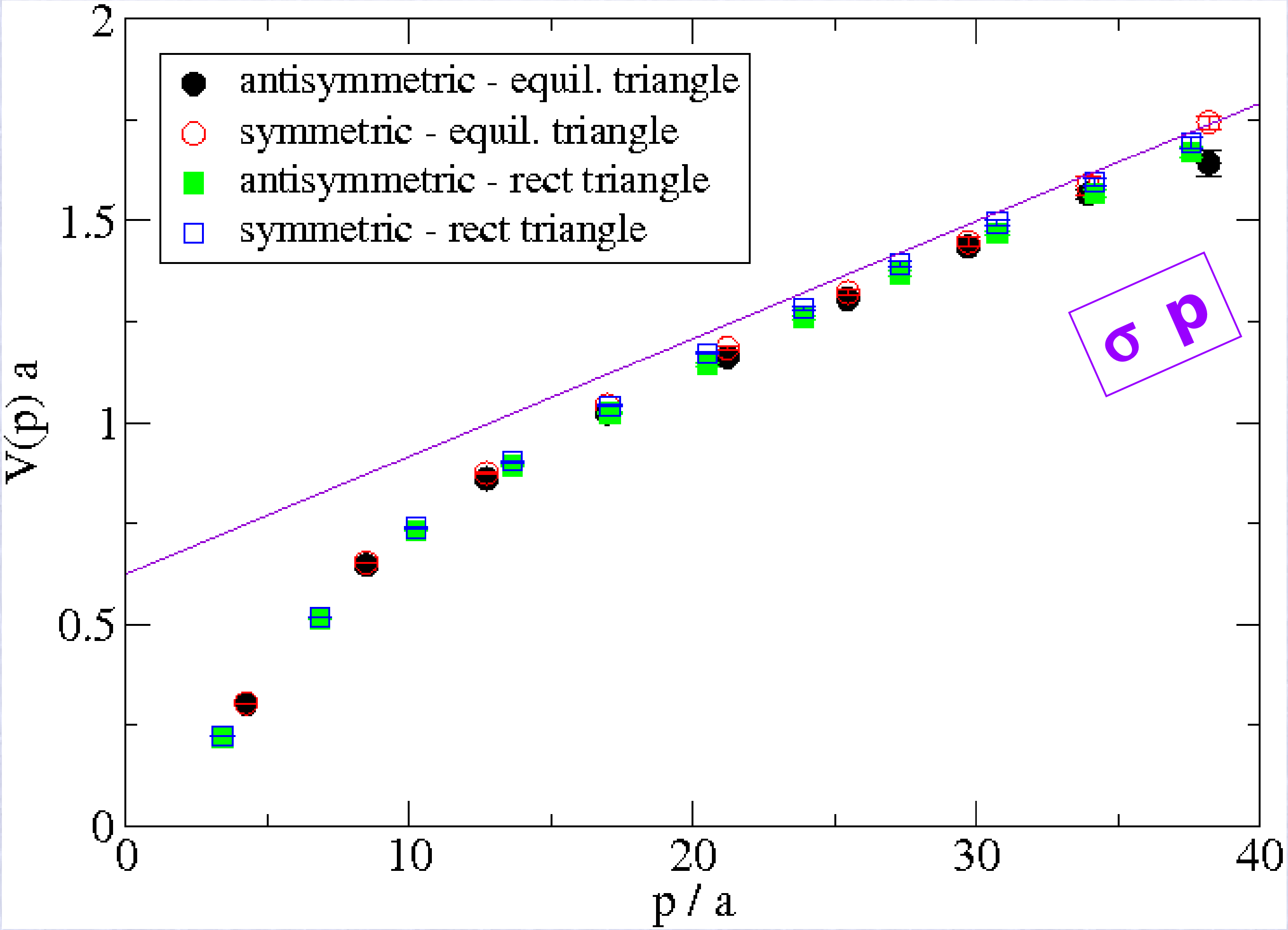
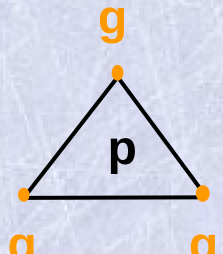
Results for the Glueball GGG





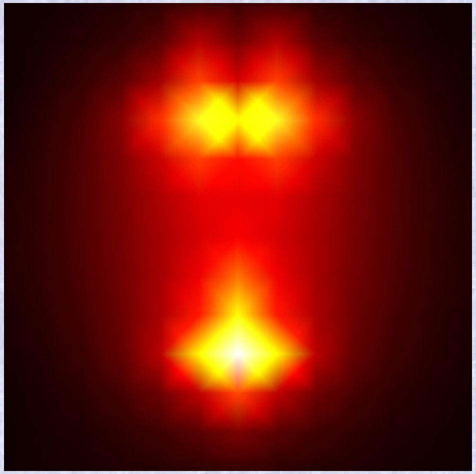
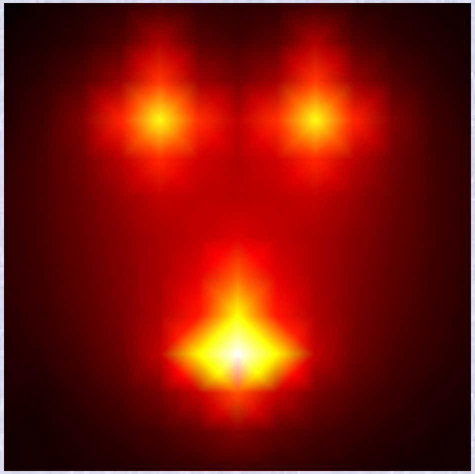
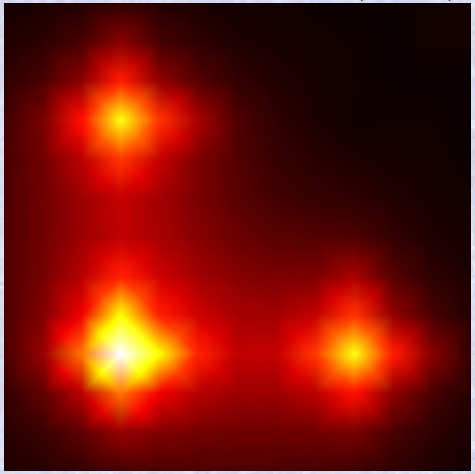
units: a = 0.072 fm *($24^3 \times 48$, $\beta = 6.2$, 141 config.)*

Conclusions

- The GQQ and GGG are confined by fundamental strings, as in a Type-II superconductor
  - although simple, this result matters for constituent quark-gluon models.
- The subtle nuances are:
  - in the GQQ, the 2 quark strings repel and when superposed they reproduce the Casimir scaling observed by G. Bali in GG,
  - In the GGG, the symmetric potential is slightly larger than the antisymmetric one. Both reproduce the GG potential when 2 G superpose.

Future Work

- Study the transition between the two regimes of confinement
- Study the Chromoeletric Field: $\langle E_i^2 \rangle = P_{0\mathrm{i}} - \dfrac{\langle W\, P_{0\mathrm{i}} \rangle}{\langle W \rangle}$

- Study longer distancies