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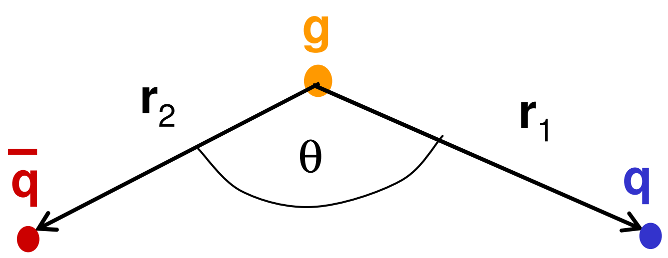
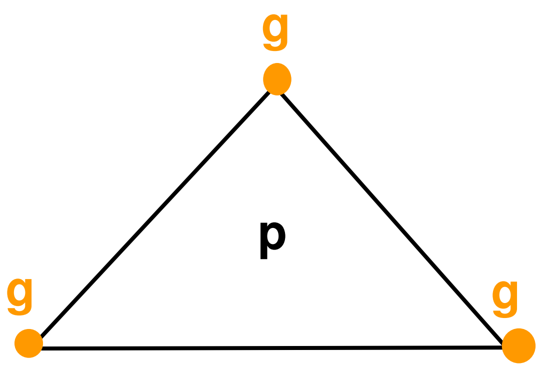
- Motivation
- The Wilson loops for GQQ and GGG
- Results for the Hybrid GQQ
- Results for the Glueball GGG

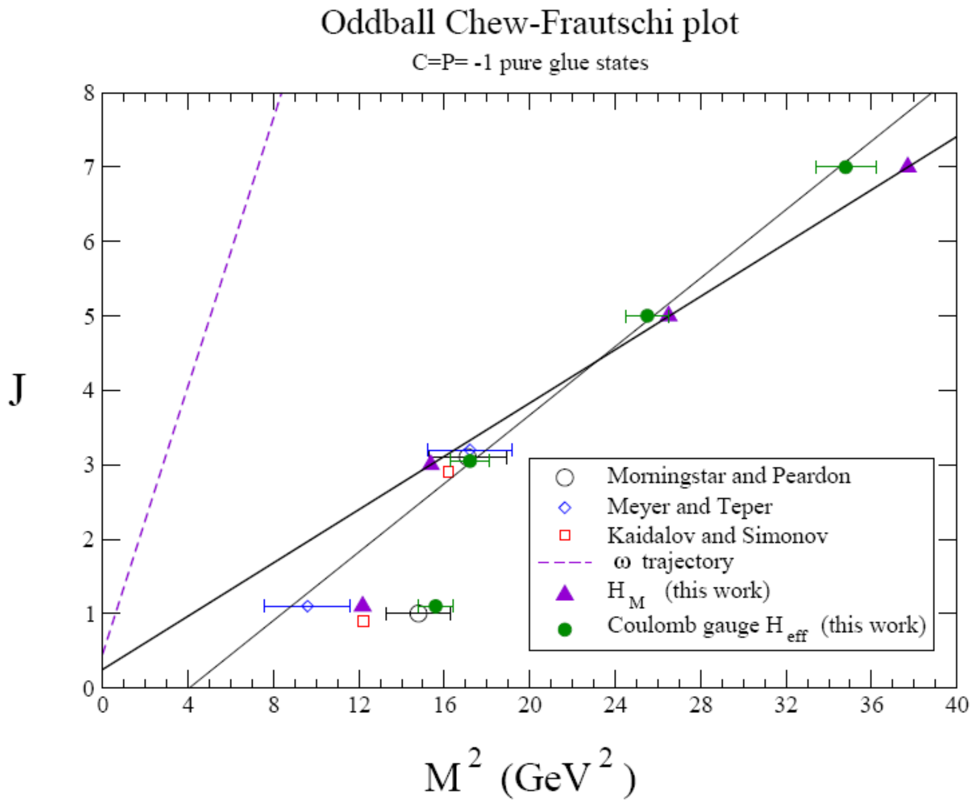
Utilizing Wilson Loops, we study the static potentials of GQQ and GGG





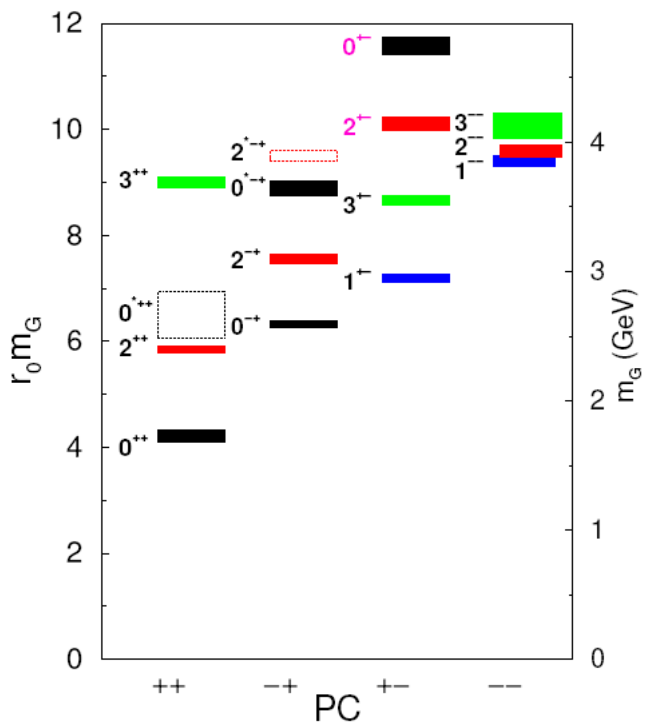
Motivation

The **experiments** BESIII at IHEP in Beijin, 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).

The **computations** of GQQ hybrids and GGG glueballs are performed,
- with constituent quark-gluon models, say for excited states,
- in Lattice QCD,



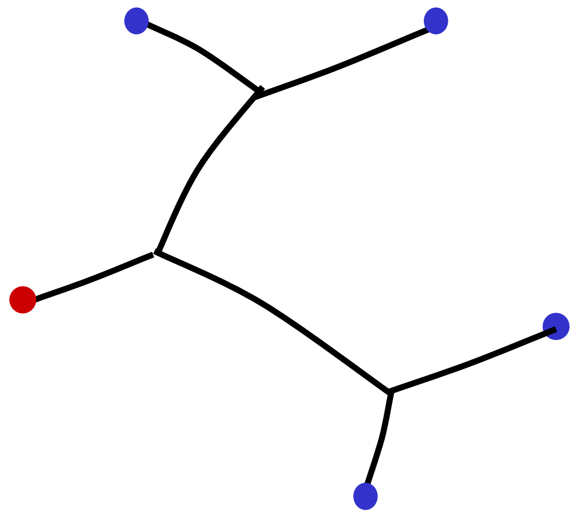
mass spectrum of glueballs in the pure SU(3)

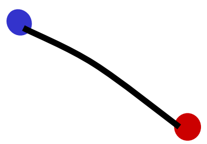
C. Morningstar and M. Peardon,
Phys. Rev. D **60**, 034509 (1999)

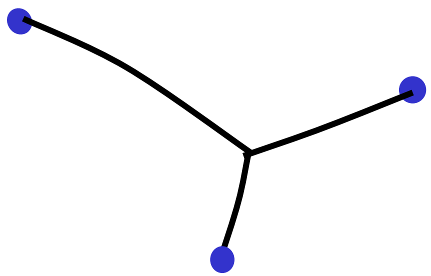
Motivation

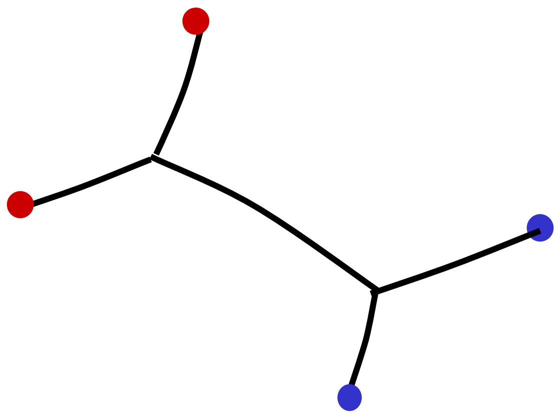
Previously, Static potentials have been studied in Lattice QCD to

- 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



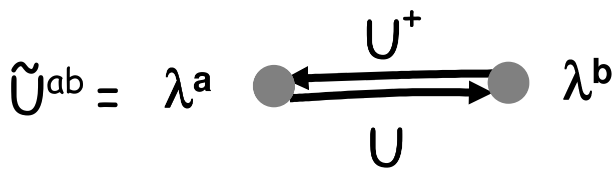




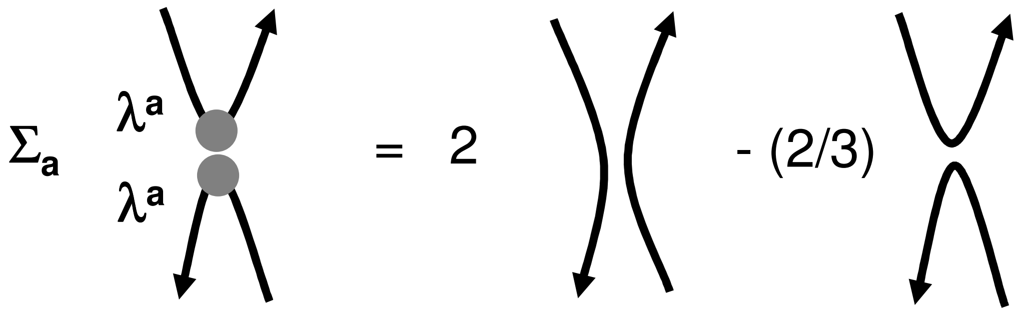


We utilize **Wilson loops** to measure the **static** potentials in Lattice QCD.

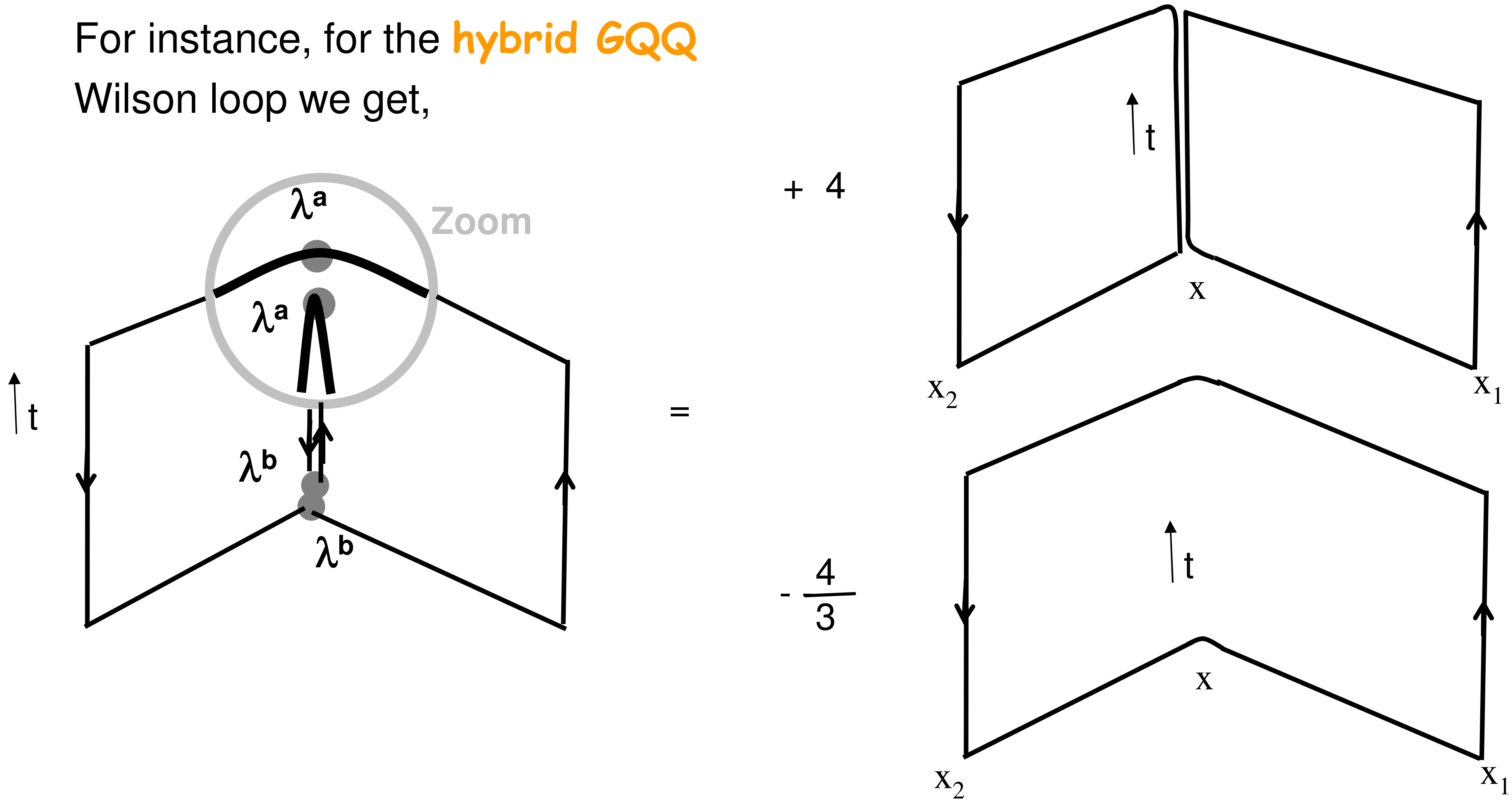
The positions of the quarks are connected by gauge paths composed of fundamental links, to maintain gauge invariance, while the positions of gluons are connected by adjoint paths,



The Fierz relation can be used to re-write the adjoint paths with fundamental paths.

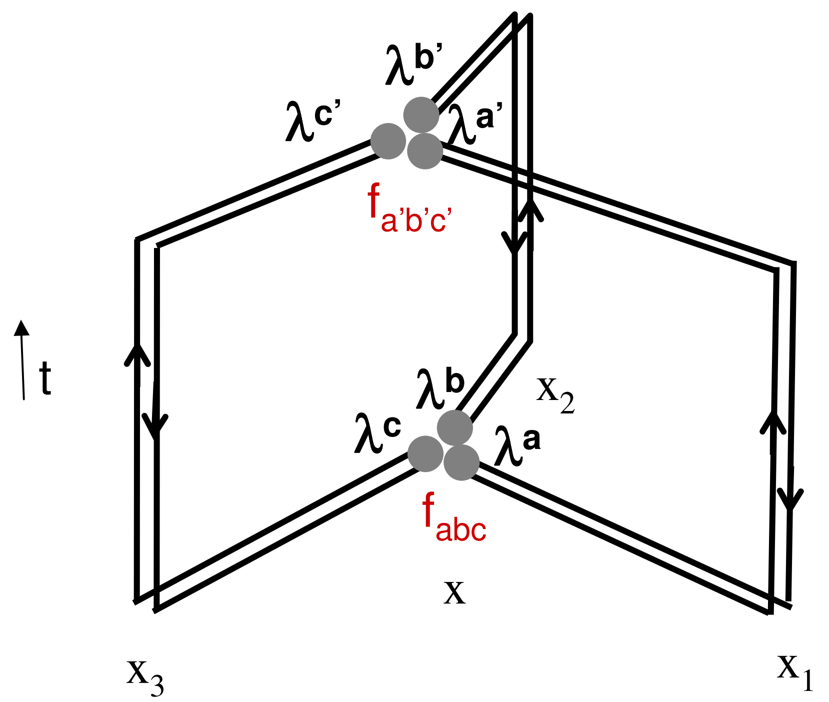


For instance, for the **hybrid GQQ** Wilson loop we get,

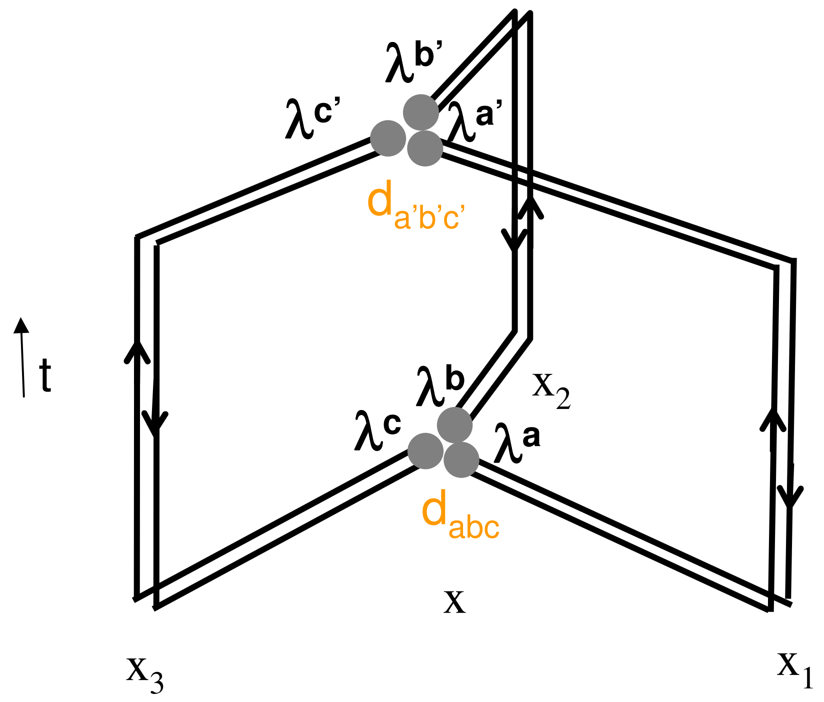


Whereas for the glueball GGG, we have two possible wavefunctions, **antisymmetric** or **symmetric**, with Wilson loops,

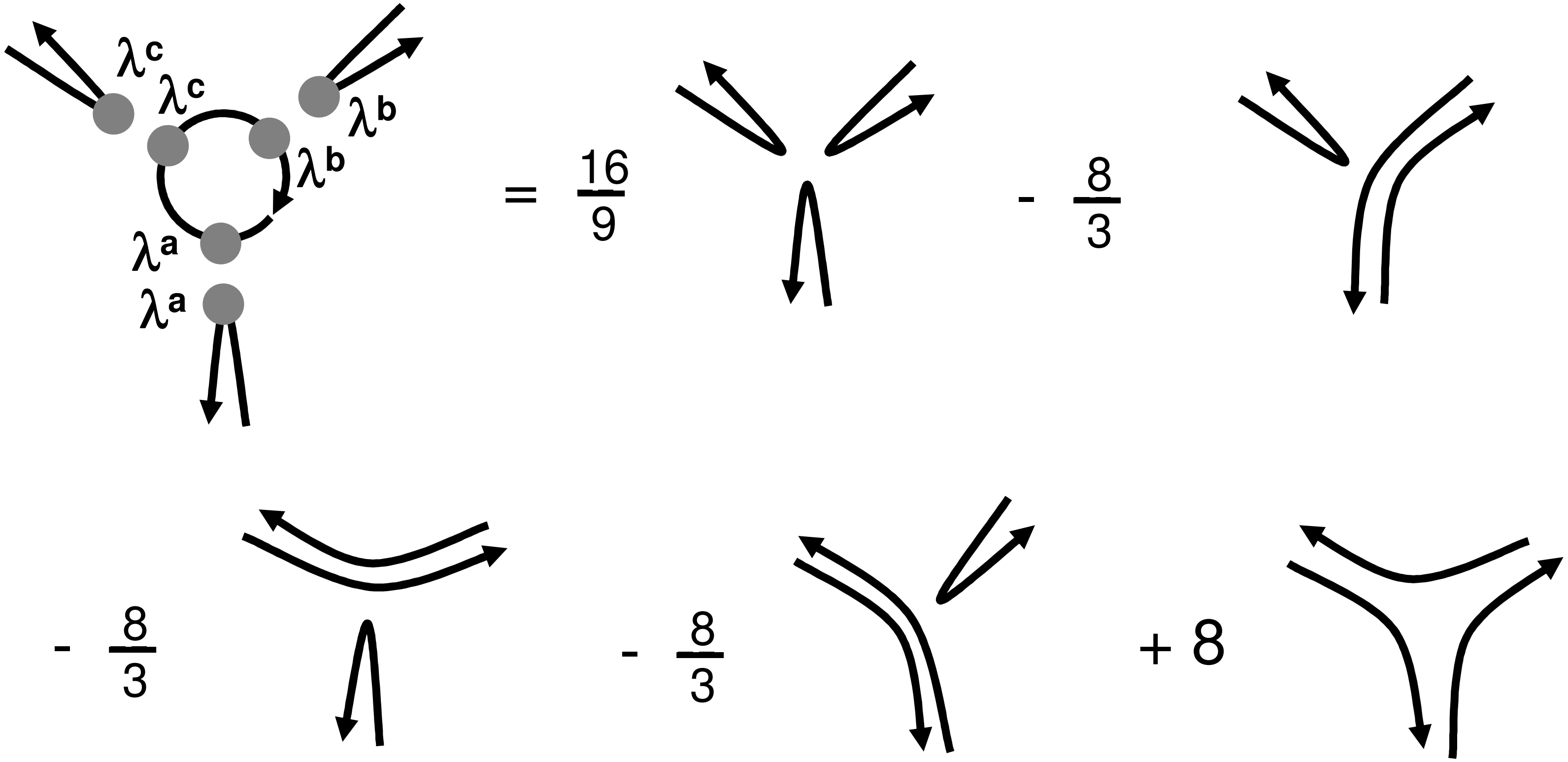
antisym.



symmetric

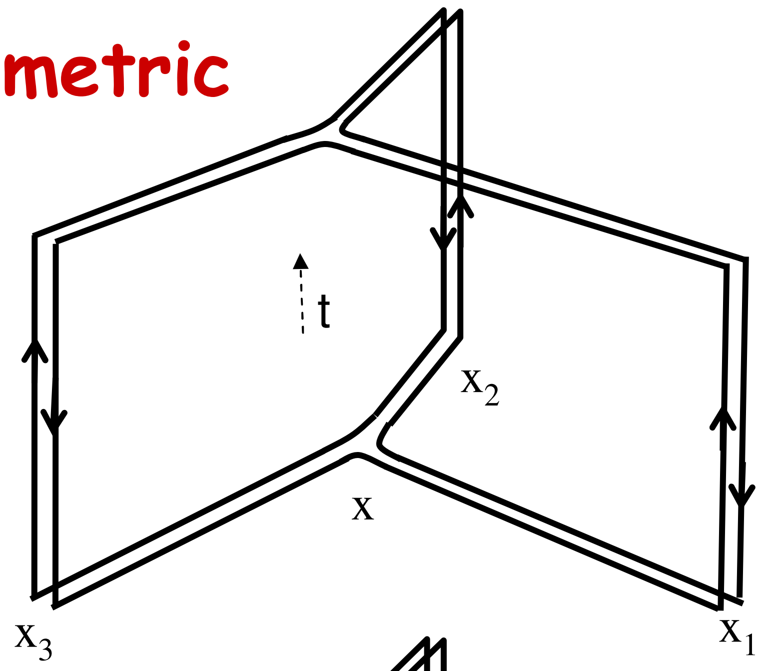


The two GGG Wilson loops can be rewritten with the Fierz relation,

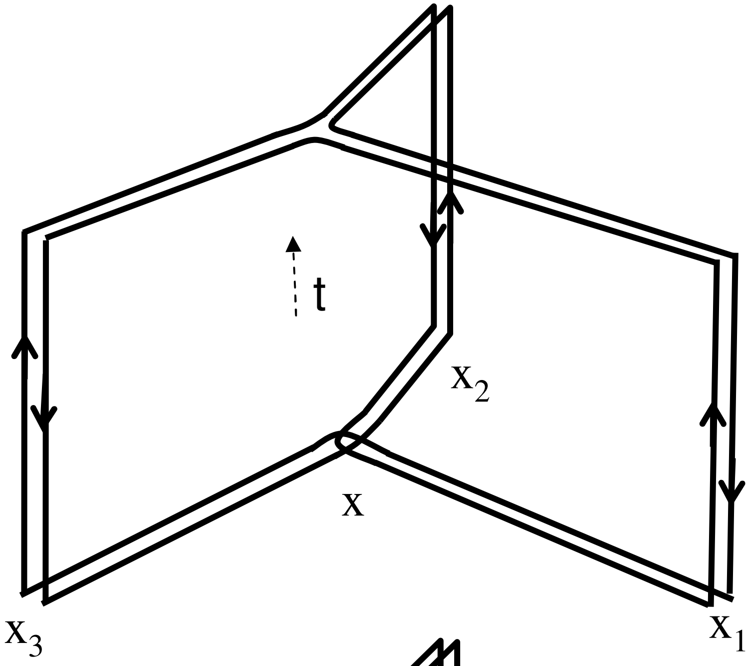


antisymmetric

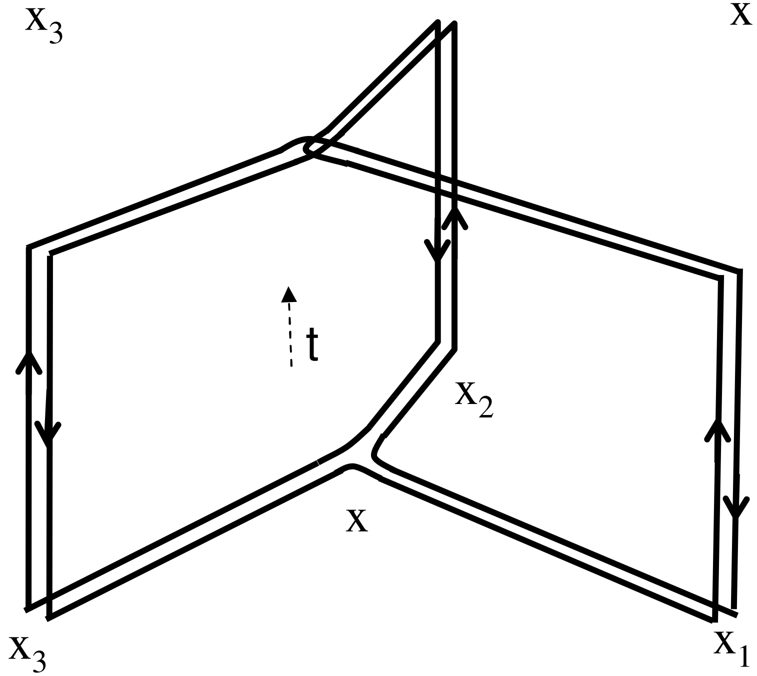
$W_{3g}{}^{A} = 4$



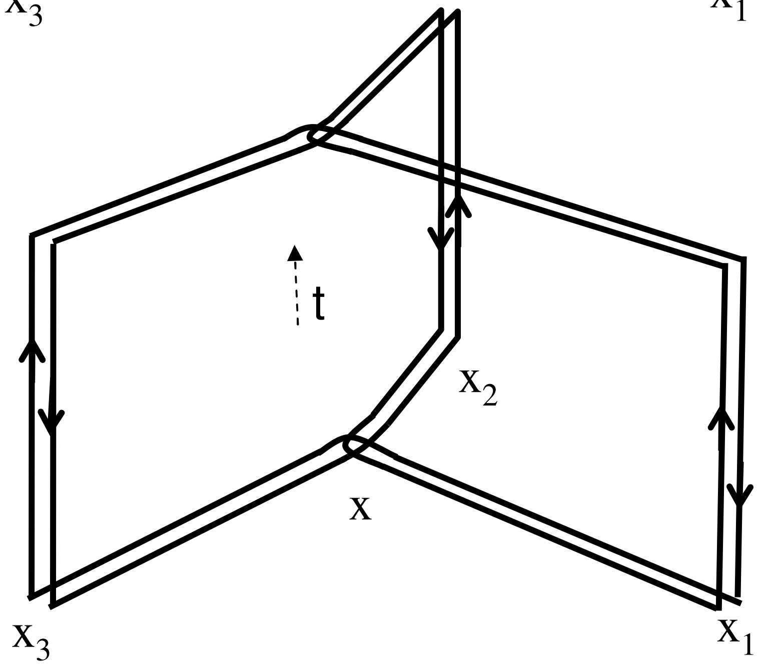
$- \ 4$



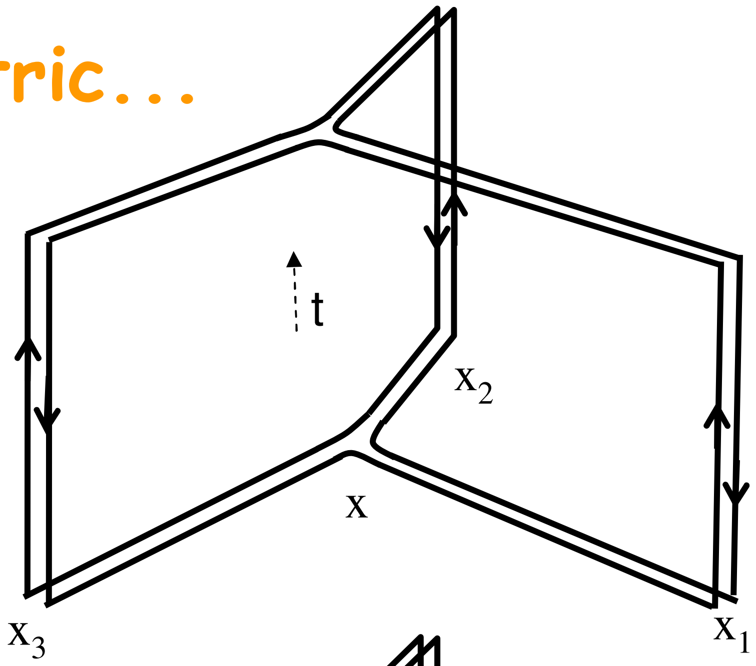
$- \ 4$

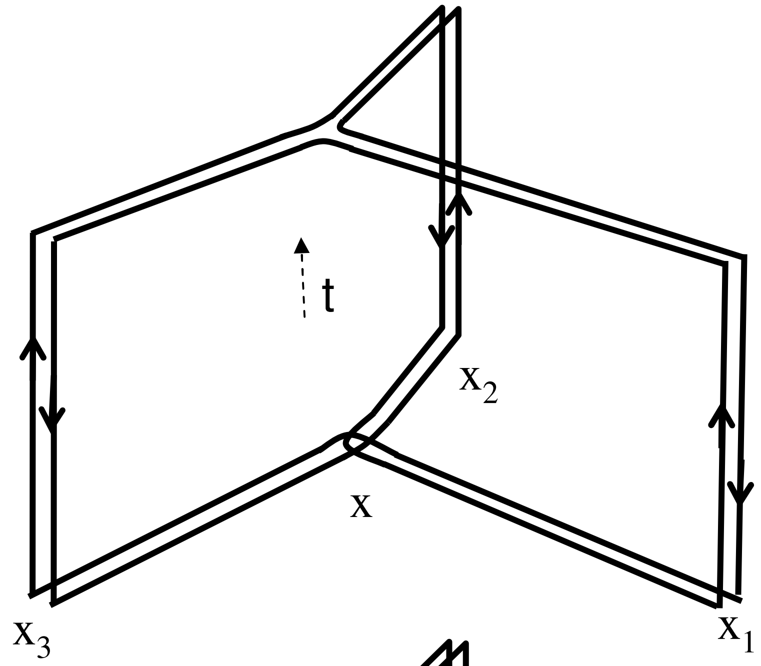


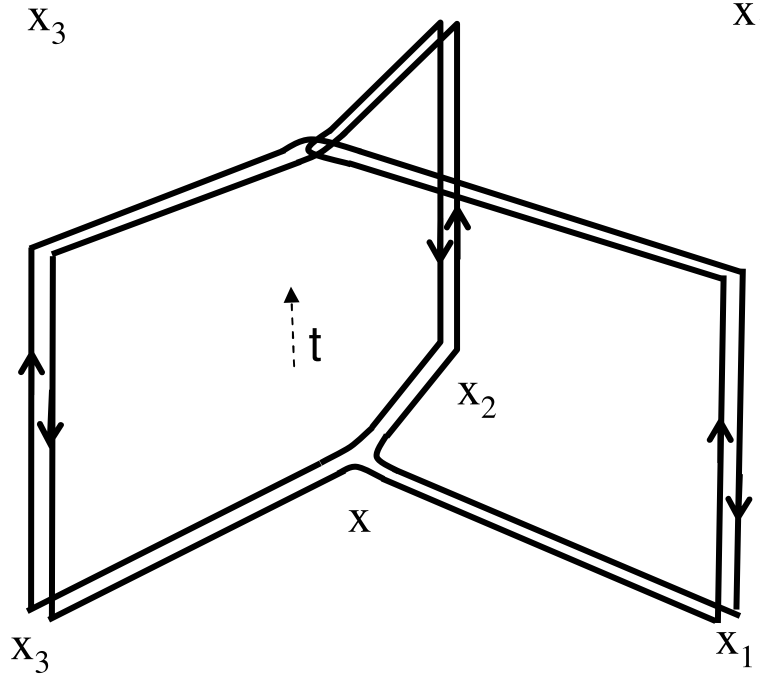
$+ \ 4$

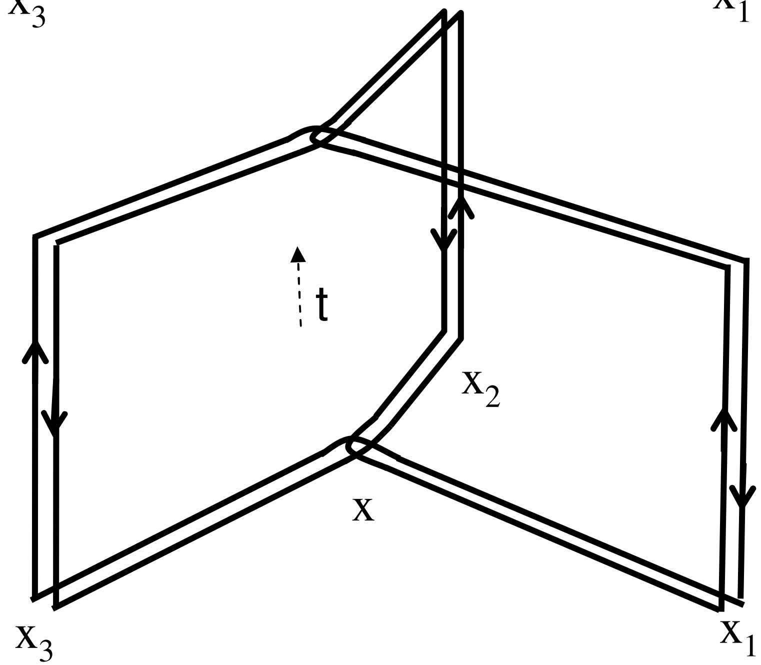


symmetric...

$W_{3g}{}^{S} = 4$ 

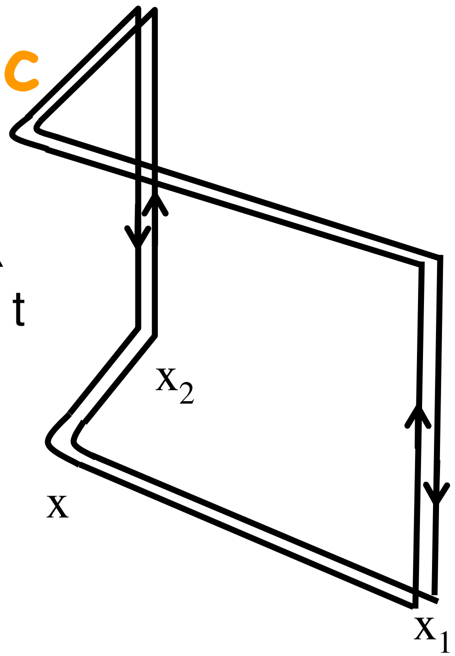
$+\ 4$ 

$+\ 4$ 

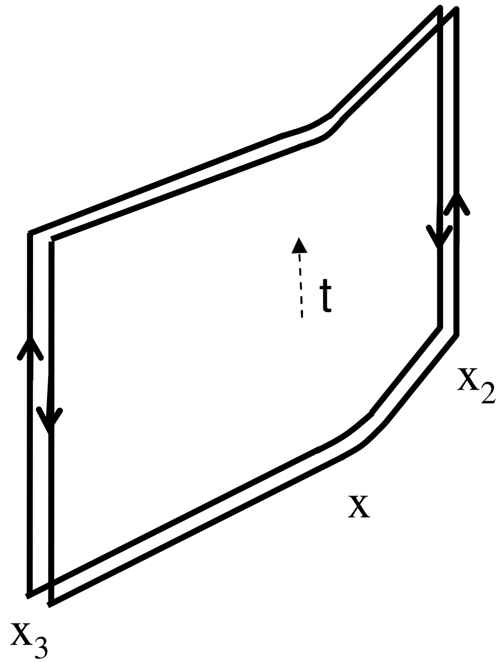
$+\ 4$ 

...symmetric

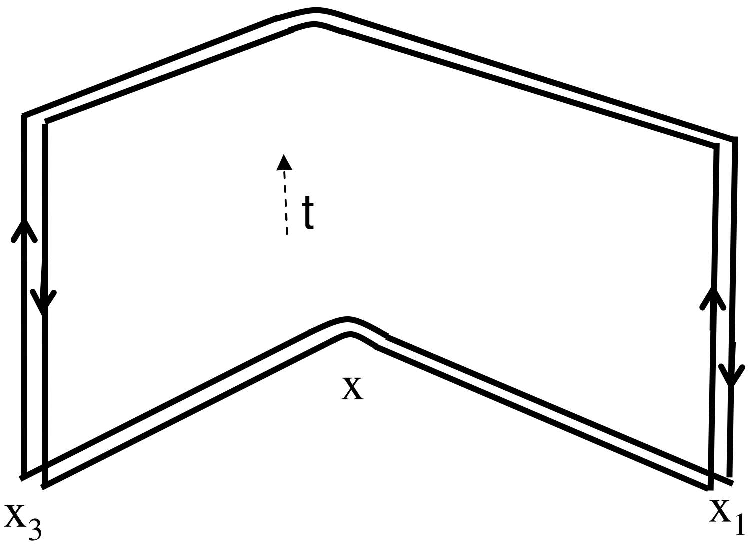
$-\frac{16}{3}$



$-\frac{16}{3}$



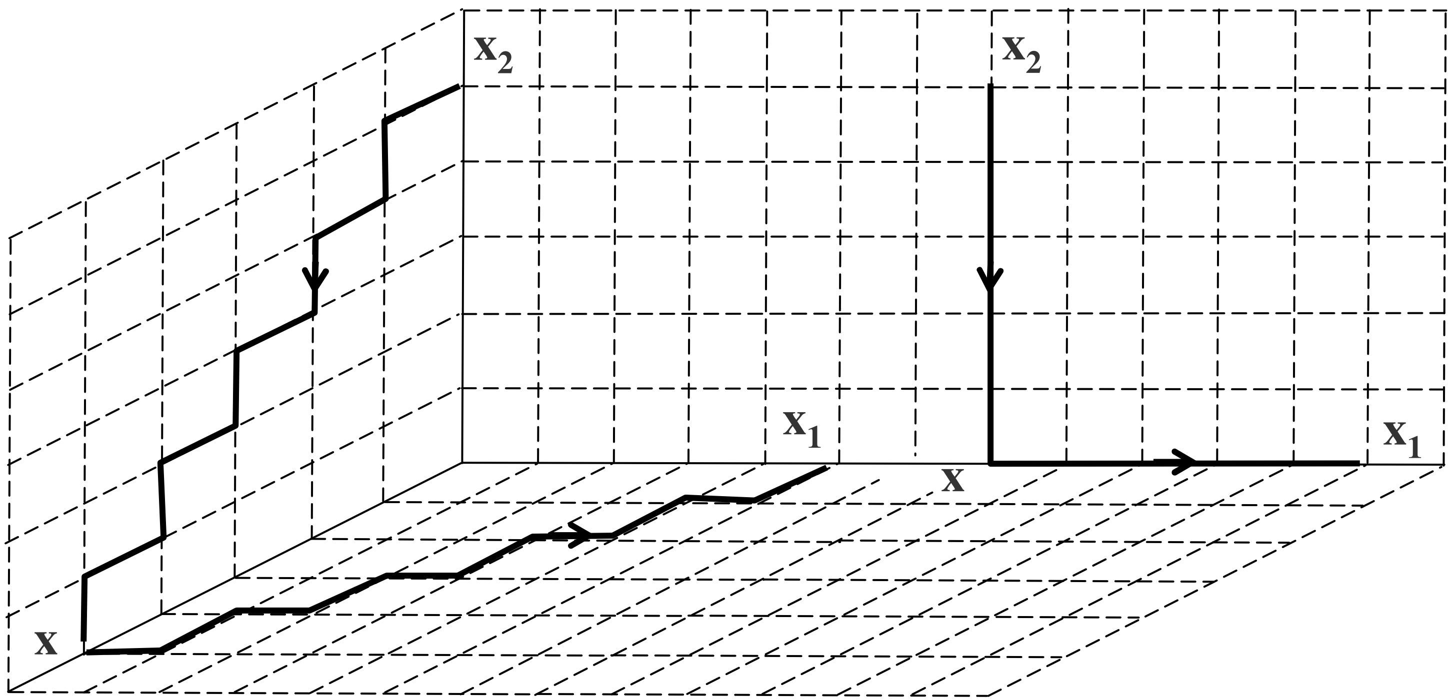
$-\frac{16}{3}$



$+\frac{32}{3}$

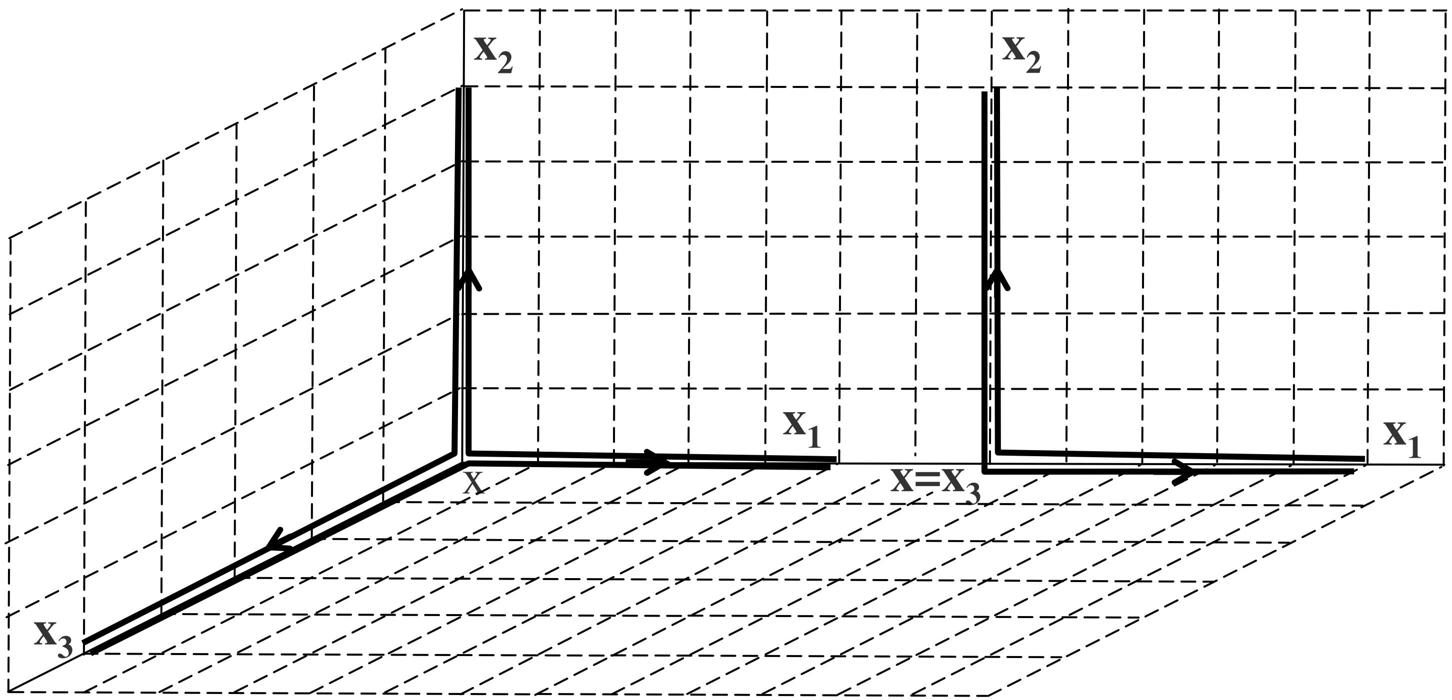
The Wilson Loops for GQQ and GGG

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

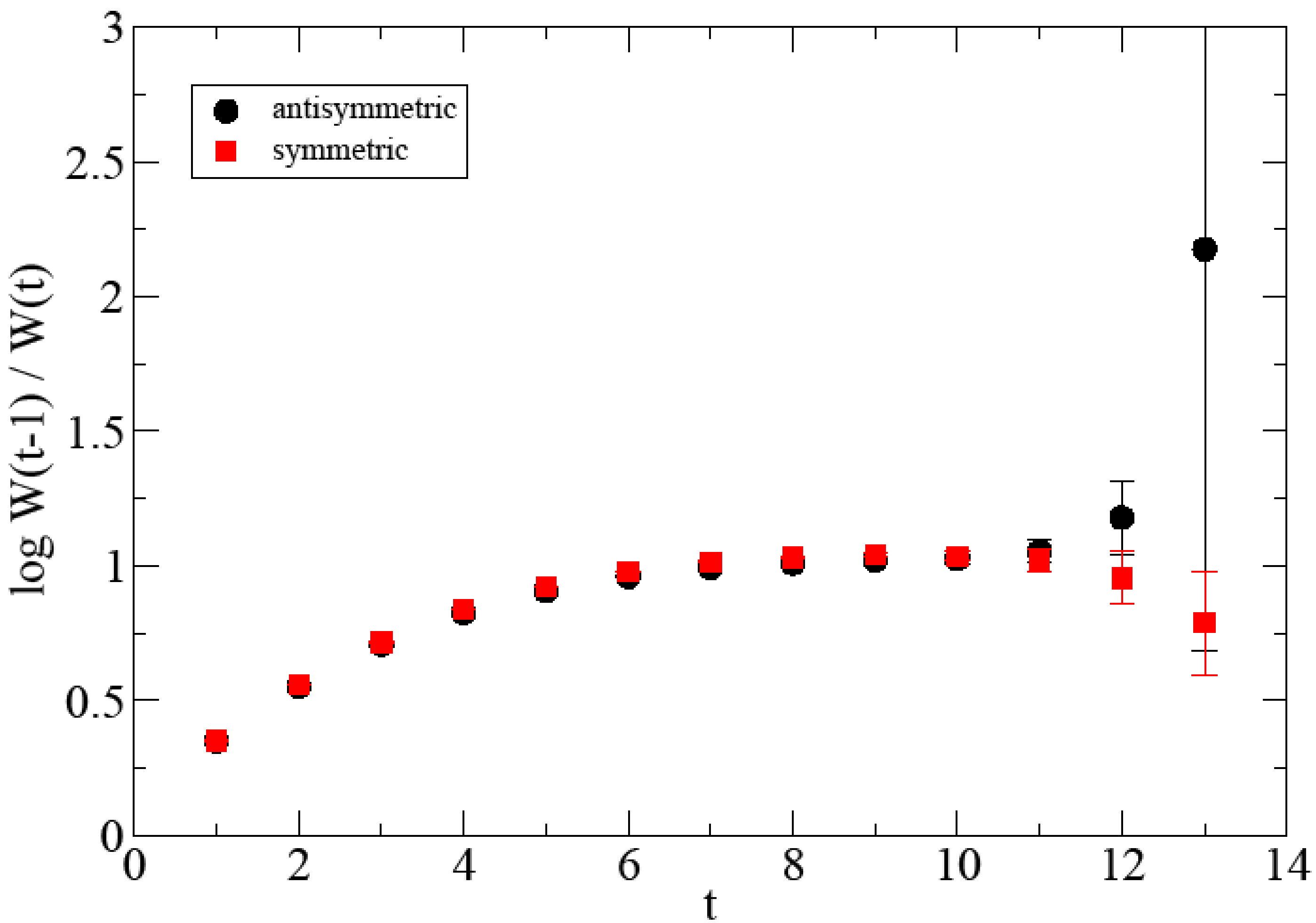


The Wilson Loops for GQQ and GGG

In what concerns the spatial geometry of the **GGG** we first use the simplest spatial paths



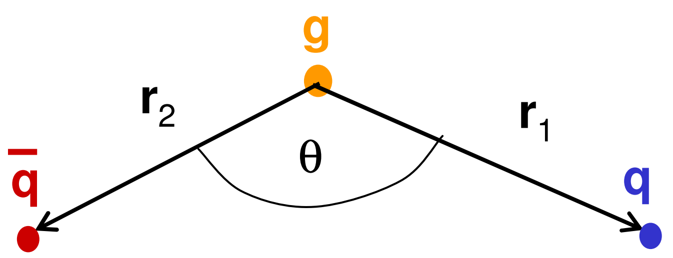
Then the **static potential** V is obtained fitting the exponential euclidian time t decay of the Wilson loop W, $W = cst.\ Exp\,(-V\ t)$



We compute the static potentials as a function of the **variables**,

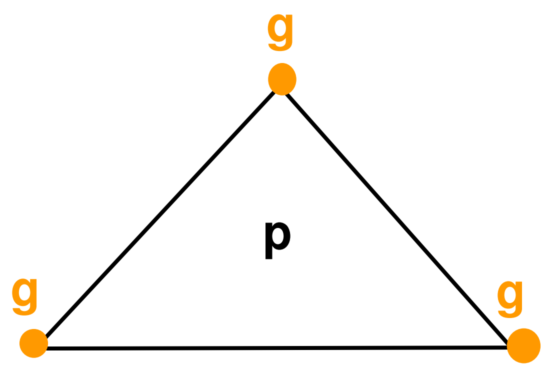
for the hybrid GQQ

distance r_1 , distance r_2 and angle θ



for the glueball GGG

perimeter p



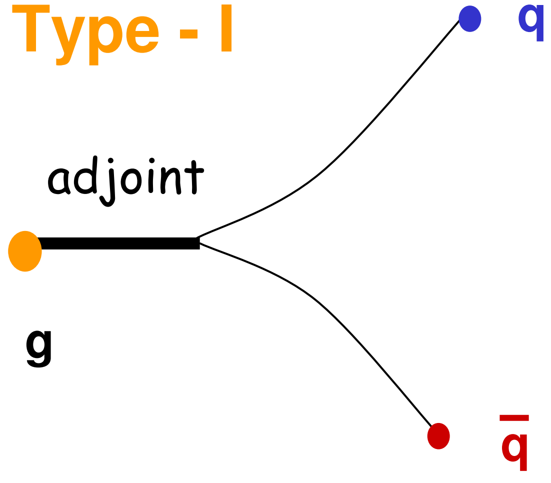
We want to compare with different **models of confinement**:

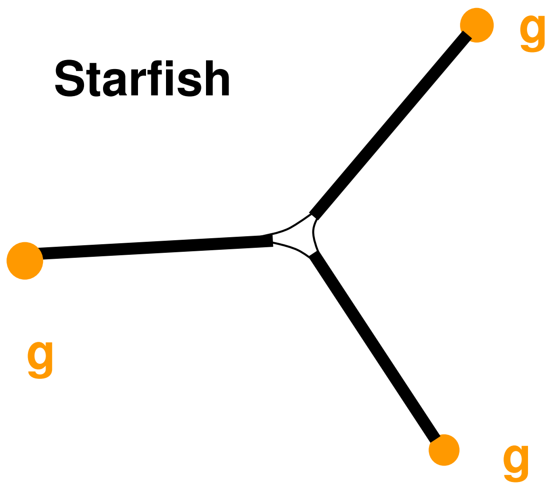
Casimir

The potentials are a sum of 2- body potentials,

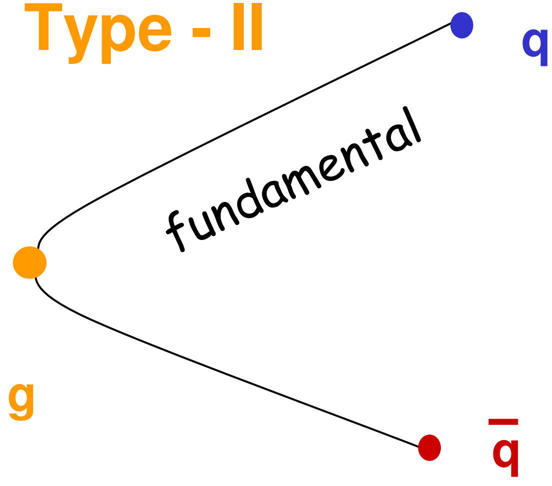
$V_{ij}\ \alpha\ \lambda_i . \lambda_j$

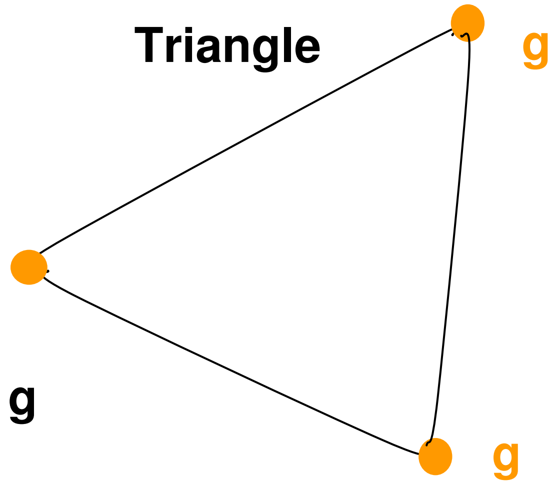
Type - I



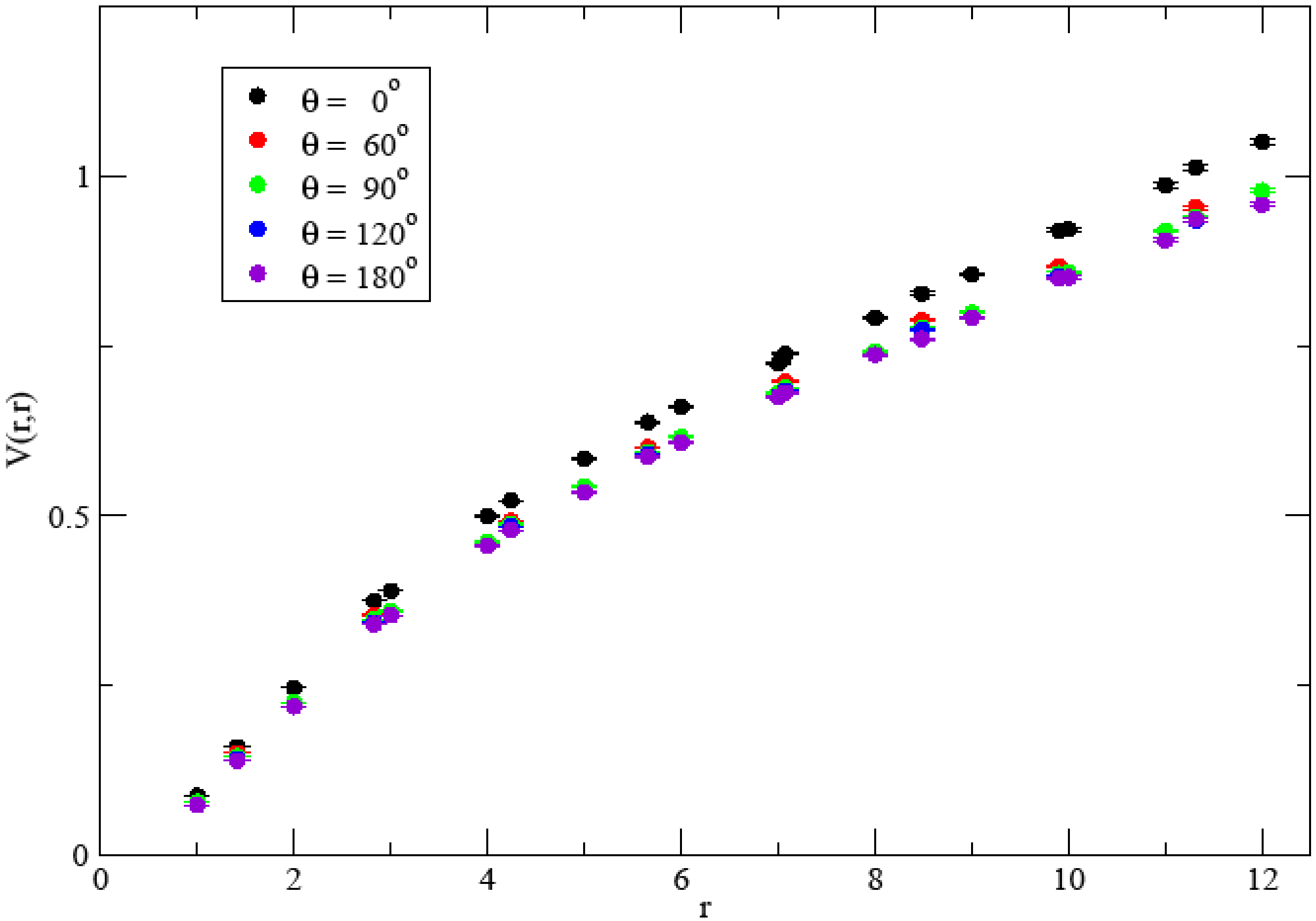


Type - II

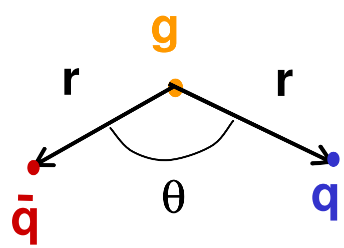




Results for the Hybrid GQQ

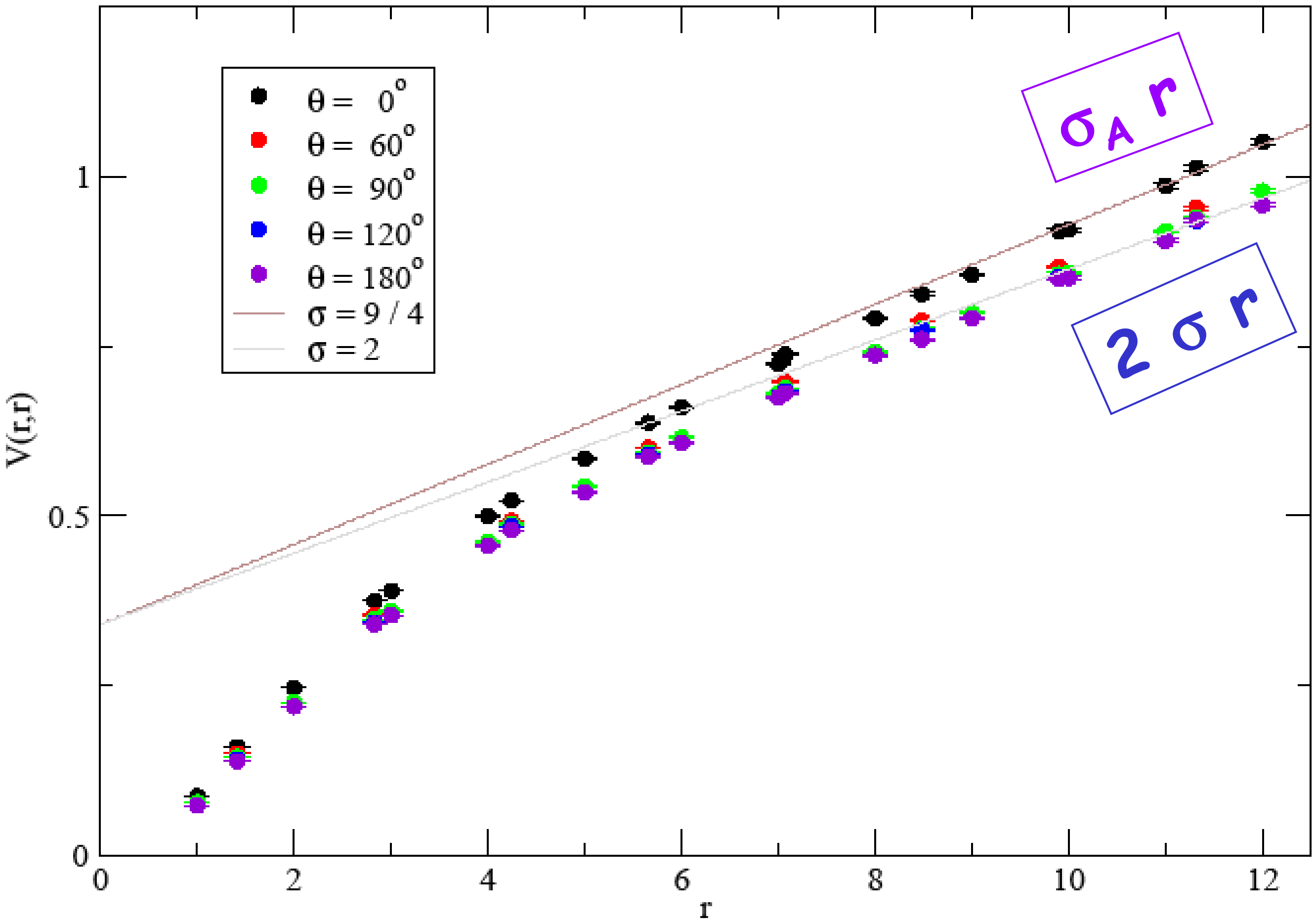


variables:

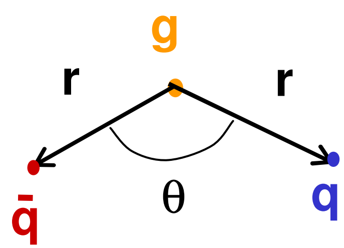


units: a = 0.072 fm   *($24^3 \times 48$, $\beta = 6.2$, 141 config.)*

Results for the Hybrid GQQ



variables:



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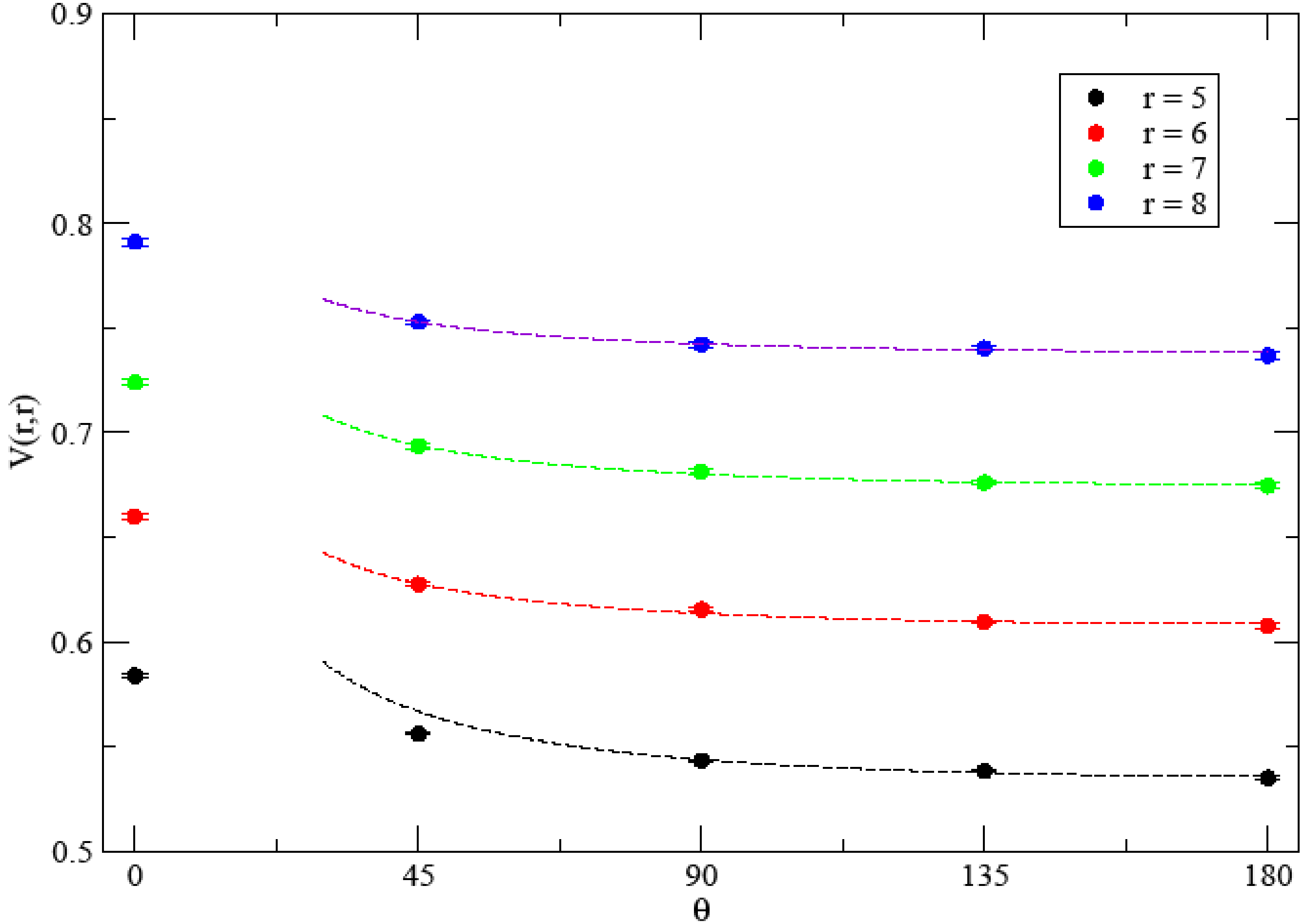
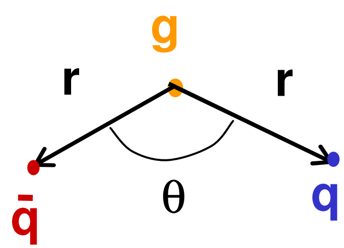
Results for the Hybrid GQQ

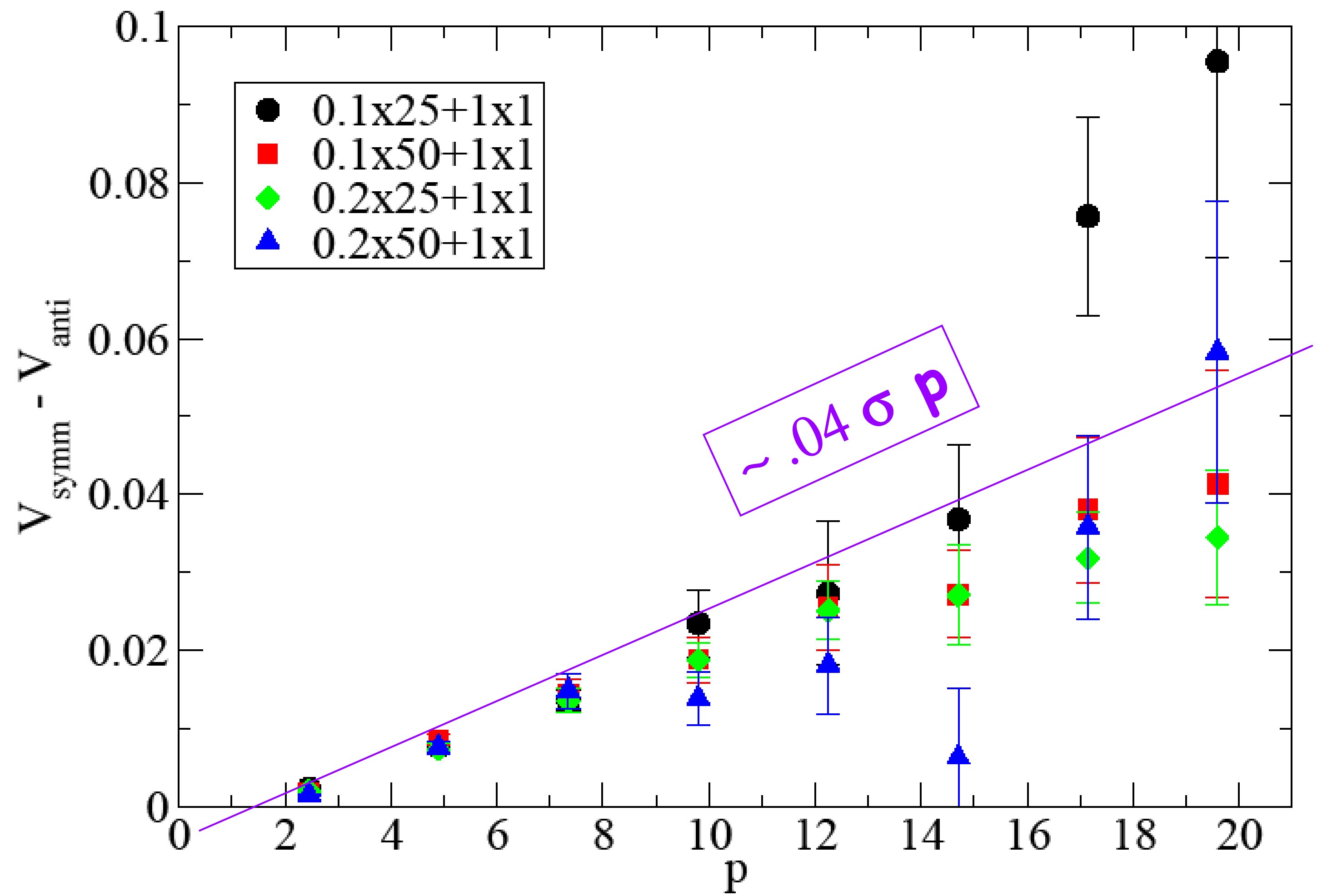


variables:

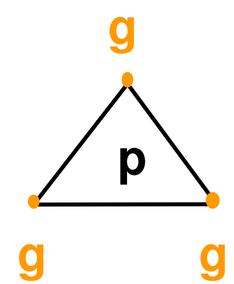


units: a = 0.072 fm   *($24^3 \times 48$, $\beta = 6.2$, 141 config.)*

Results for the Glueball GGG

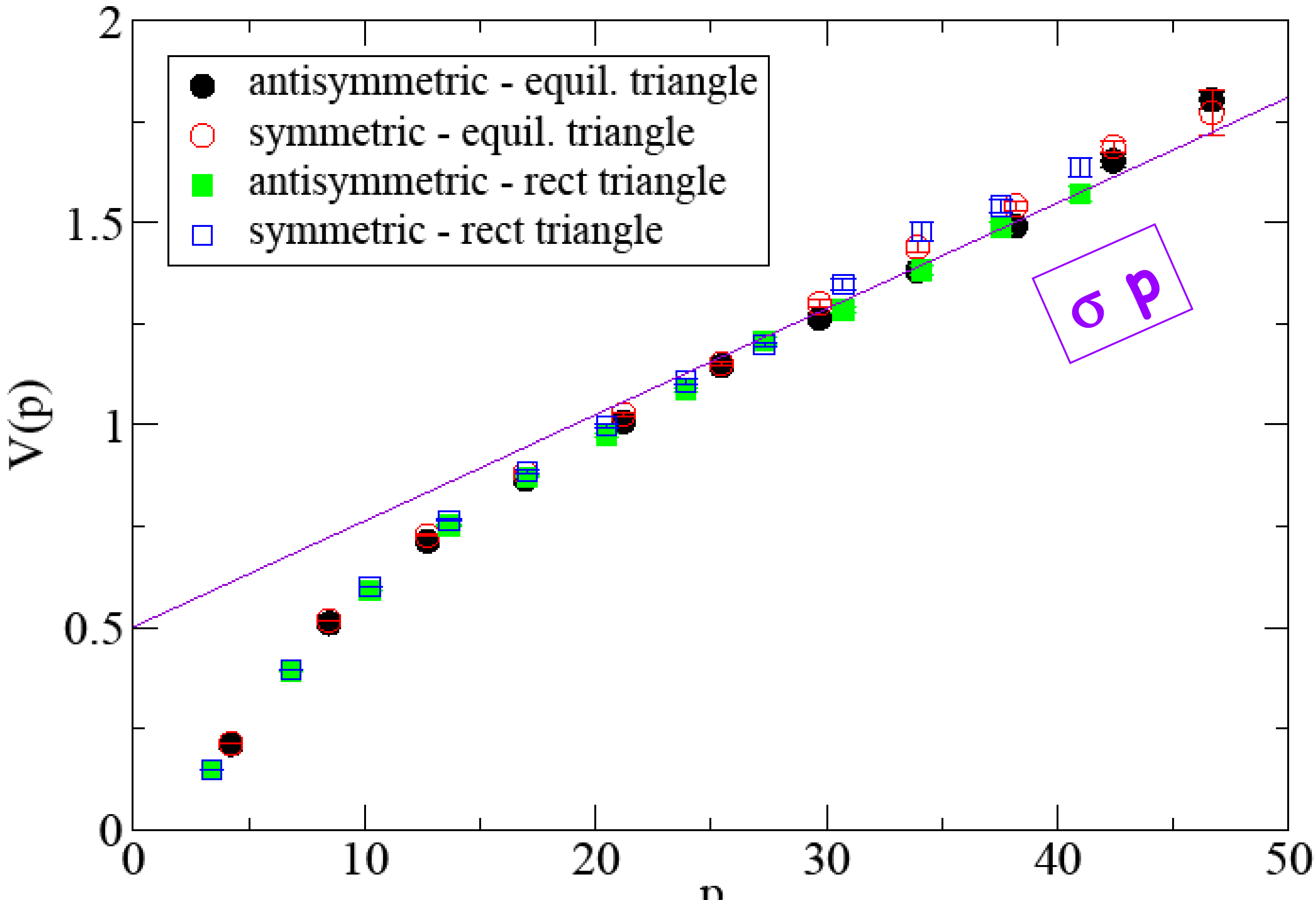


variables:

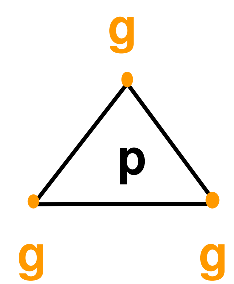


units: a = 0.072 fm   ($24^3 \times 48$, $\beta = 6.2$, 141 config.)

Results for the Glueball GGG



variables:



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

Conclusion & Outlook on GQQ and GGG

- The GQQ and GGG are confined by ***fundamental*** strings, as in a ***Type-I*** 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.

•P Bicudo, M Cardoso and O. Oliveira, PRD (r) 77, 091504 (2008), arXiv:0704.2156 [hep-lat].
•M Cardoso and P. Bicudo, arXiv:0807.1621 [hep-lat].

Please expect more results soon!