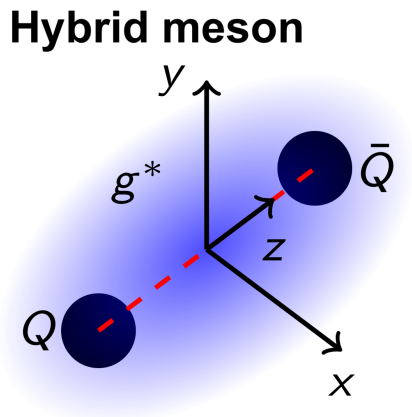
Hybrid static potentials at small quark-antiquark separations

Carolin Riehl, Marc Wagner

Asia-Pacific Symposium for Lattice Field Theory
August 7, 2020

Hybrid static potentials



Hybrid static potentials

- Computation of heavy hybrid meson masses in the Born-Oppenheimer approximation [1] [2] [3]
- Matching coefficients for potential Non-Relativistic QCD [4]

$\rightarrow$ so far based on lattice data at $r \geq 0.16\,\text{fm}$ [3] [5] [6]

$\Rightarrow$ New lattice results at r as small as $0.05\,\text{fm}$

[1] K. J. Juge, J. Kuti and C. J. Morningstar, Nucl. Phys. Proc. Suppl. 63, 326 (1998) [hep-lat/9709131]

[2] E. Braaten, C. Langmack and D. H. Smith, Phys. Rev. D 90, 014044 (2014) [arXiv:1402.0438 [hep-ph]]

[3] S. Capitani, O. Philipsen, C. Reisinger, C. Riehl and M. Wagner, Phys. Rev. D 99, no. 3, 034502 (2019) [arXiv:1811.11046 [hep-lat]]

[4] M. Berwein, N. Brambilla, J. Tarrus Castella and A. Vairo, Phys. Rev. D 92, 114019 (2015) [arXiv:1510.04299 [hep-ph]]

[5] K. J. Juge, J. Kuti, and C. Morningstar, Phys. Rev. Lett., 90, 161601 (2003), arXiv:hep-lat/0207004 [hep-lat].

[6] G. S. Bali and A. Pineda, Phys. Rev., D69, 094001 (2004), arXiv:hep-ph/0310130 [hep-ph]

Quantum numbers of static potentials

Quantum numbers Λ_η^ϵ $\quad e.g.\ \Sigma_g^+,\ \Pi_u,\ \Sigma_u^-$

$\Lambda = \Sigma, \Pi, ..$	orbital angular momentum along quark separation axis L_z
$\eta = u, g$	combination of parity and charge conjugation $P \circ C$
$\epsilon = +, -$	spatial inversion P_x

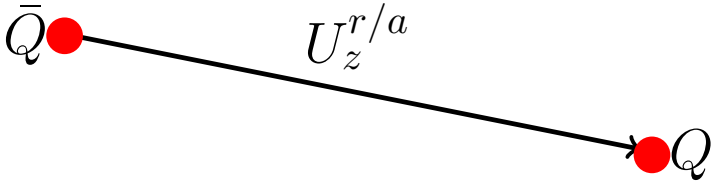


Figure: Σ_g^+

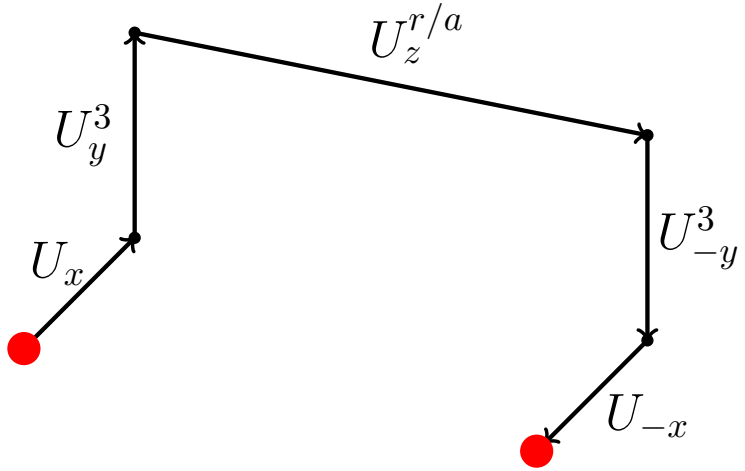
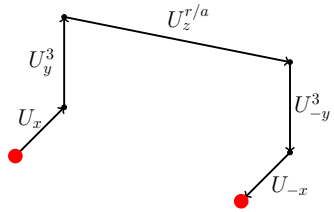


Figure: Π_u

Lattice setup

β	2.50	2.70	2.85
a [7]	0.077 fm	0.041 fm	0.026 fm

- $SU(2)$ gauge field configurations generated with a Monte Carlo heatbath algorithm
- optimized hybrid static potential creation operators [8]
  - *APE*-smearing of spatial links
    - $\alpha_{\mathrm{APE}} = 0.5$ and optimized N_{APE} for each lattice spacing
  - Multilevel algorithm [9]



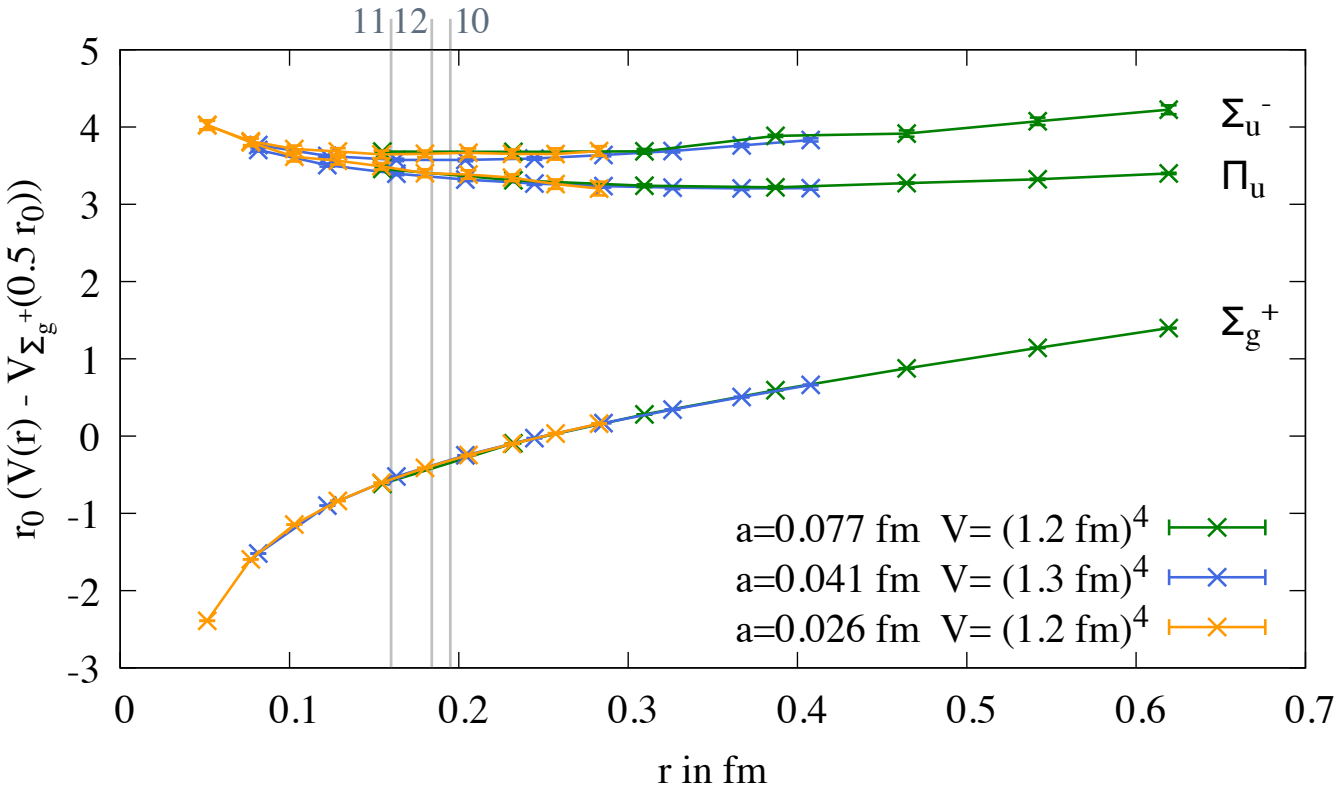
[7] T. Hirakida, E. Itou and H. Kouno, PTEP 2019 (2019) no.3, 033B01 [arXiv:1805.07106 [hep-lat]]

[8] S. Capitani, O. Philipsen, C. Reisinger, C. Riehl and M. Wagner, Phys. Rev. D 99, no. 3, 034502 (2019) [arXiv:1811.11046 [hep-lat]]

[9] M. Lüscher and P. Weisz, JHEP 09 (2001), 010 [arXiv:hep-lat/0108014 [hep-lat]

Lattice results for hybrid static potentials

- new lattice data at separations as small as $r = 0.052\,\text{fm}$
- previous lattice data at separations $r \geq 0.16\,\text{fm}$ [10] [11] [12]



[10] K. J. Juge, J. Kuti and C. J. Morningstar, Nucl. Phys. Proc. Suppl. 63, 326 (1998) [hep-lat/9709131]

[11] G. S. Bali and A. Pineda, Phys. Rev., D69, 094001 (2004), arXiv:hep-ph/0310130 [hep-ph]

[12] S. Capitani, O. Philipsen, C. Reisinger, C. Riehl and M. Wagner, Phys. Rev. D 99, no. 3, 034502 (2019) [arXiv:1811.11046 [hep-lat]]

Finite volume effects

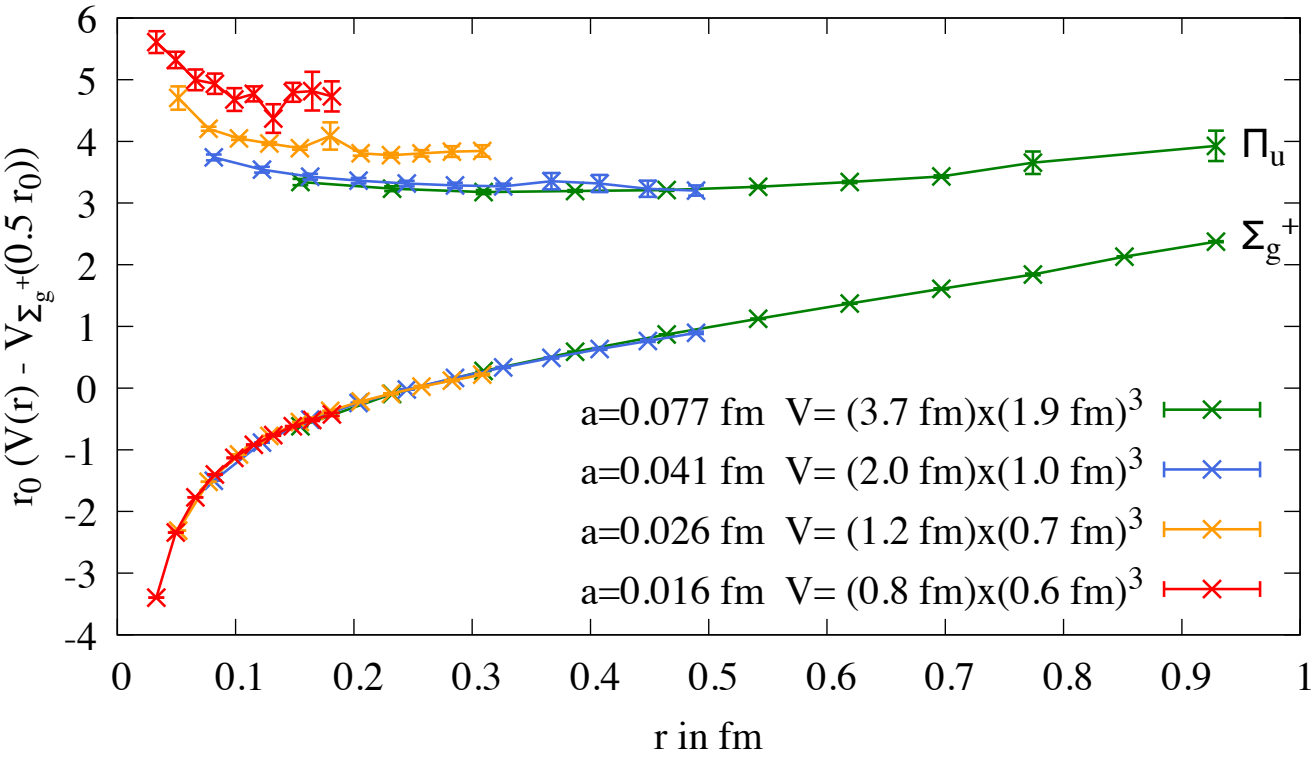
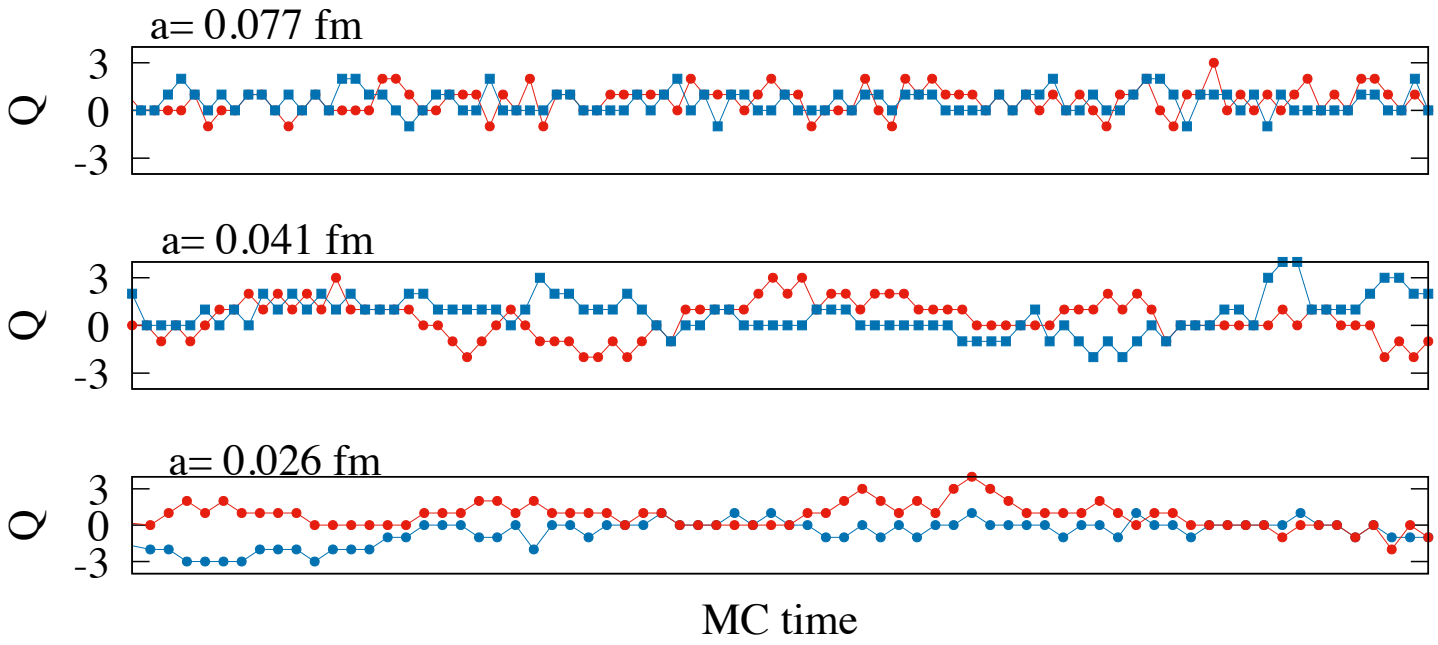


Figure: Static potential data for Σ_g^+ and Π_u at small lattice spacings and small spatial volumes.

$\rightarrow$ $(V_{\Pi_u} - V_{\Sigma_g^+})$ grows with decreasing L^3

Topological freezing

- expected when $a \to 0$
- Topological charge computed with simple clover-leaf discretization



- topological charge sectors are frequently changed by the algorithm at all lattice spacings

$\to$ no topological freezing

Glueball decay of hybrid static potentials

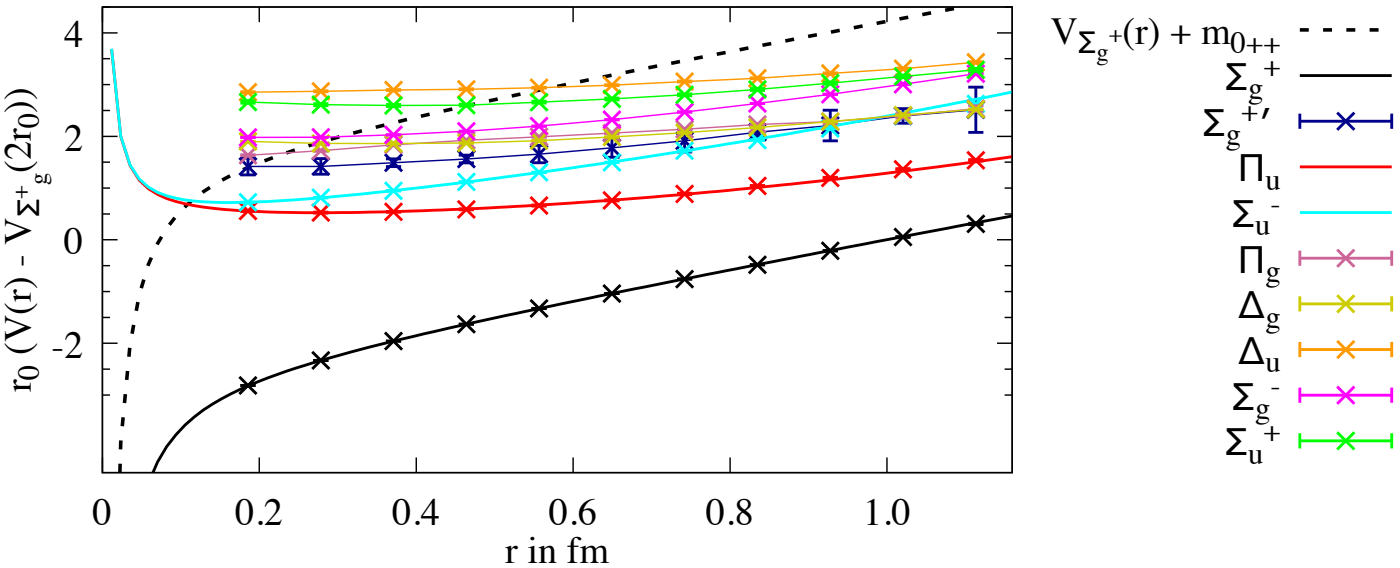


Figure: Threshold energy for a decay into the lightest glueball 0^{++} and hybrid static potentials[11].

Λ_η^ϵ	Π_u	Π_g	Δ_g	Δ_u	$\Sigma_g^{+\prime}$	Σ_u^+	Σ_u^-	Σ_g^-
r_{crit}/r_0	0.2	0.5	0.5	1.1	0.4	0.9	0.1	0.25

[11] S. Capitani, O. Philipsen, C. Reisinger, C. Riehl and M. Wagner, Phys. Rev. D 99, no. 3, 034502 (2019) [arXiv:1811.11046 [hep-lat]]

Possible decay of hybrid static potentials at small separations

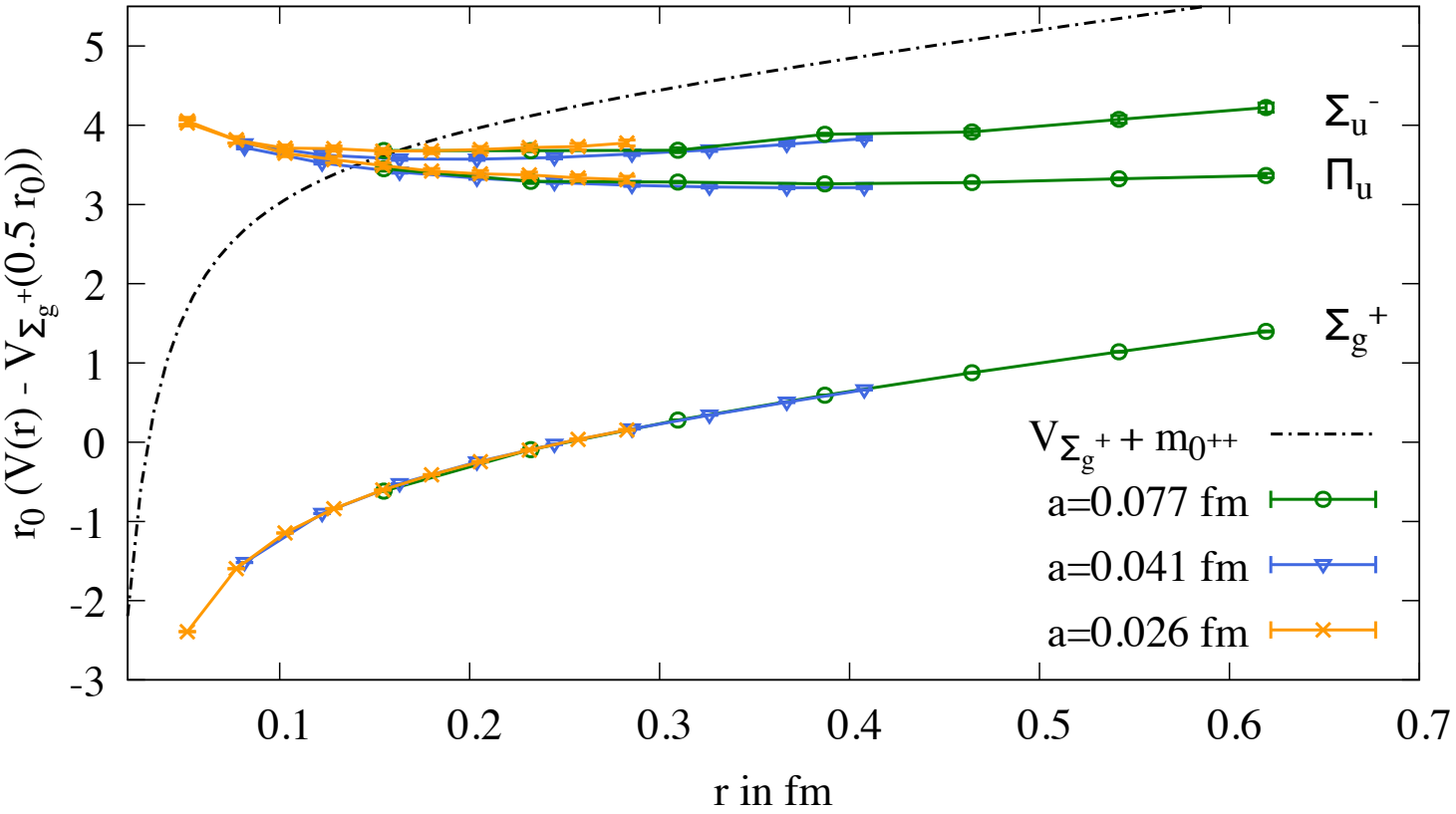


Figure: Threshold energy for a decay into the lightest glueball 0^{++}.

Possible quantum numbers

$$\mathcal{O}_{L_{z\eta}^{\epsilon}} = \frac{1}{2}\left(1 + \epsilon \mathcal{P}_x\right) \int \mathrm{d}^3 r \; e^{iL_z\varphi} f(r,z) \; \mathcal{O}_{\text{glueball}}(r,\varphi,z)$$

L_z	f	$\eta = (-1)^{L_z+f}$	ϵ	$L_{z\eta}^{\epsilon}$
0	1	-1	$+1$	Σ_u^+
0	2	$+1$	$+1$	Σ_g^+
1	1	$+1$	$+1$	Π_g^+
1	1	$+1$	-1	Π_g^-
1	2	-1	$+1$	Π_u^+
1	2	-1	-1	Π_u^-
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$

Table: Possible quantum numbers $L_{z\eta}^{\epsilon}$ with glueball 0^{++}.

Not possible with 0^{++}-glueball

$\Rightarrow$ $L_z = 0$ and $\epsilon = -$

$\rightarrow$ Σ_g^-, Σ_u^-

reason:

- $\mathcal{O}_{0^{++}} \xrightarrow{\mathcal{P}_x} \mathcal{O}_{0^{++}}$

Summary & Outlook

Summary

- Lattice results for ordinary and hybrid static potentials Σ_g^+, Π_u and Σ_u^- at three lattice spacings $a = 0.077\,\text{fm}, 0.041\,\text{fm}$ and $0.026\,\text{fm}$
- Excluded systematic errors from topological freezing and finite volume effects
- Glueball decay at short separations
  - Decay of Σ_g^- and Σ_u^- into $0^{++} + \Sigma_g^+$ not allowed

Outlook

- Hybrid static potentials $\Sigma_u^+, \Sigma_g^-, \Pi_g, \Delta_u, \Delta_g$ at small separations
- Computation of heavy hybrid meson masses