[199/118]

Feb, 2013

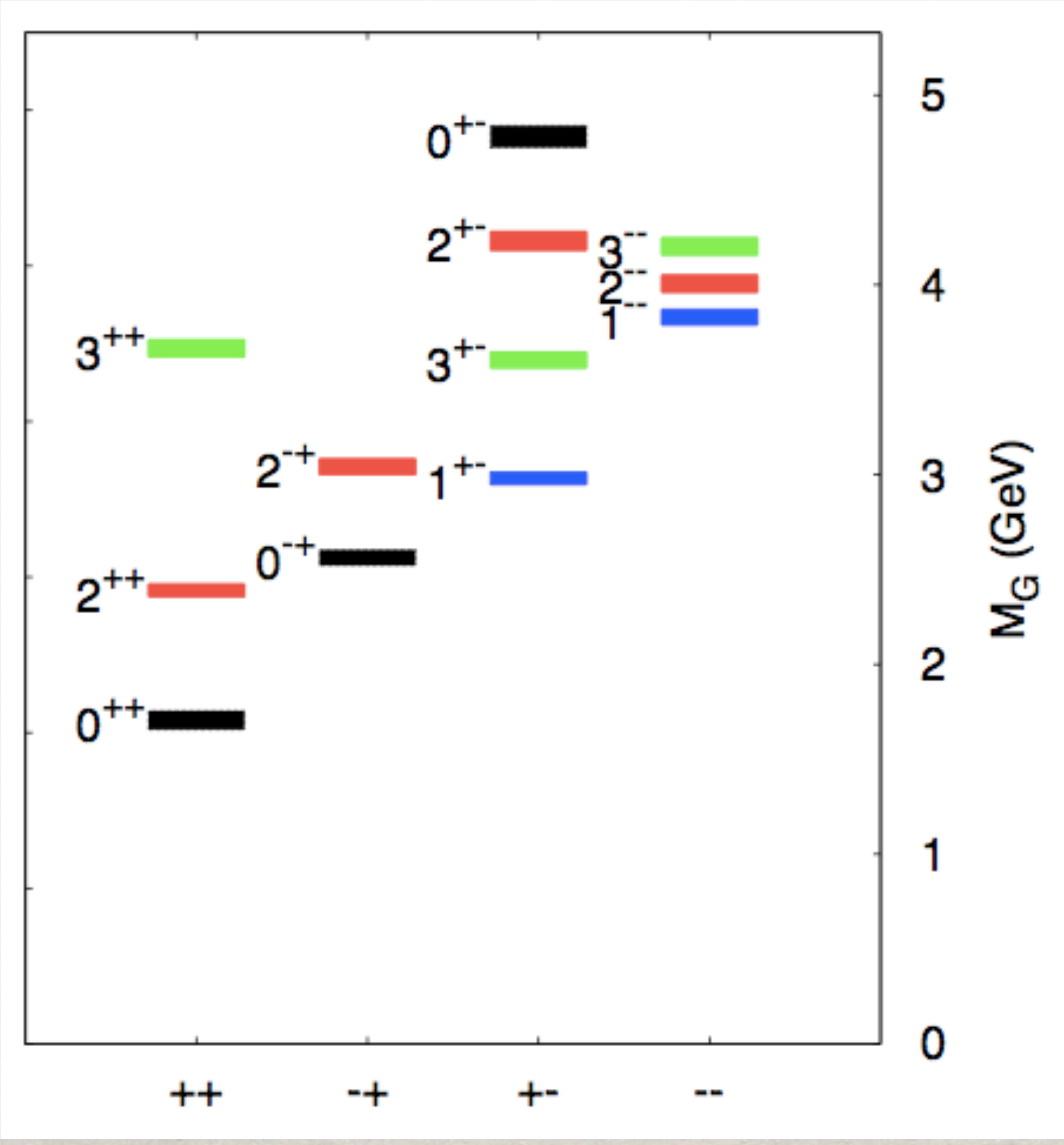
eQCD, Sarajevo

GLUEBALLS IN THE BETHE-SALPETER FORMALISM

Eric Swanson

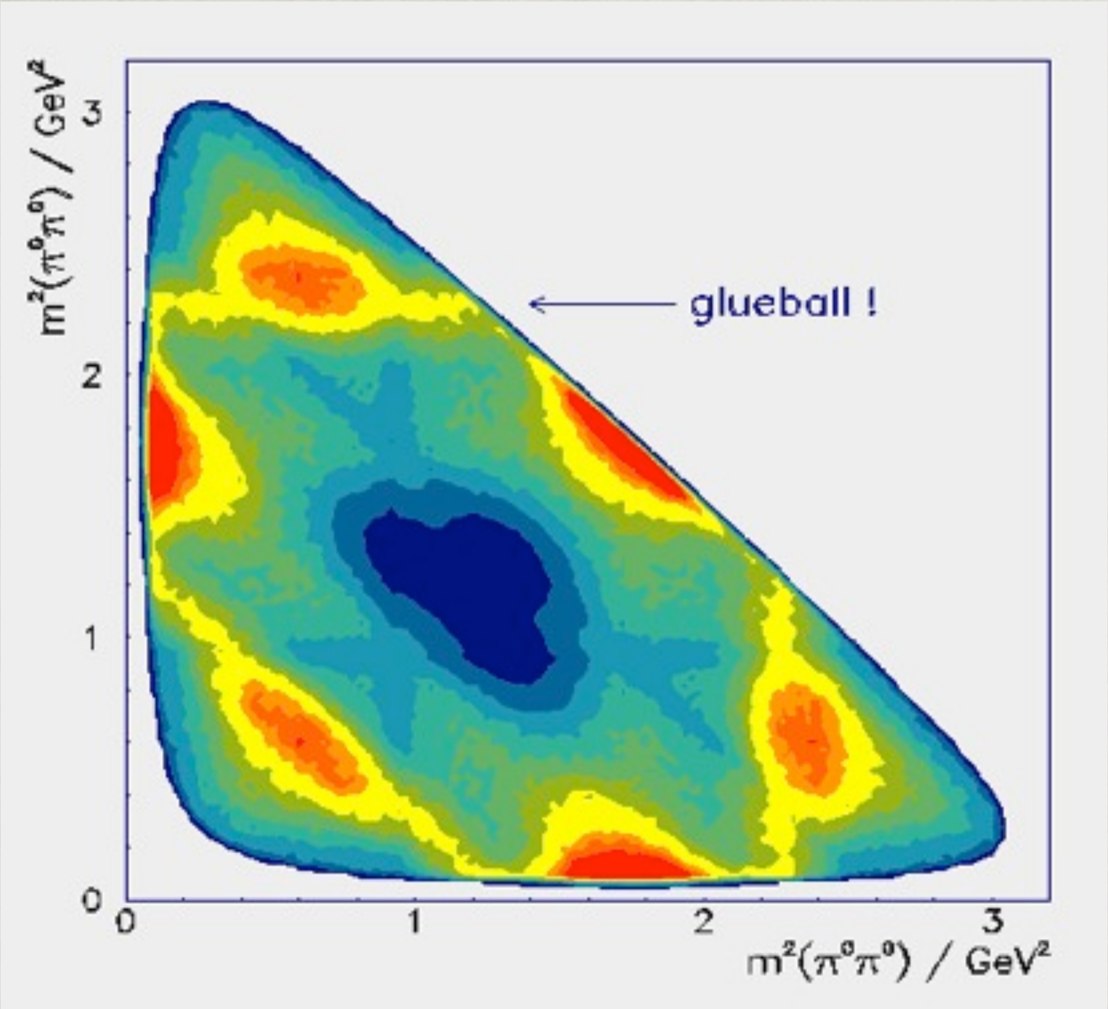
LATTICE RESULTS

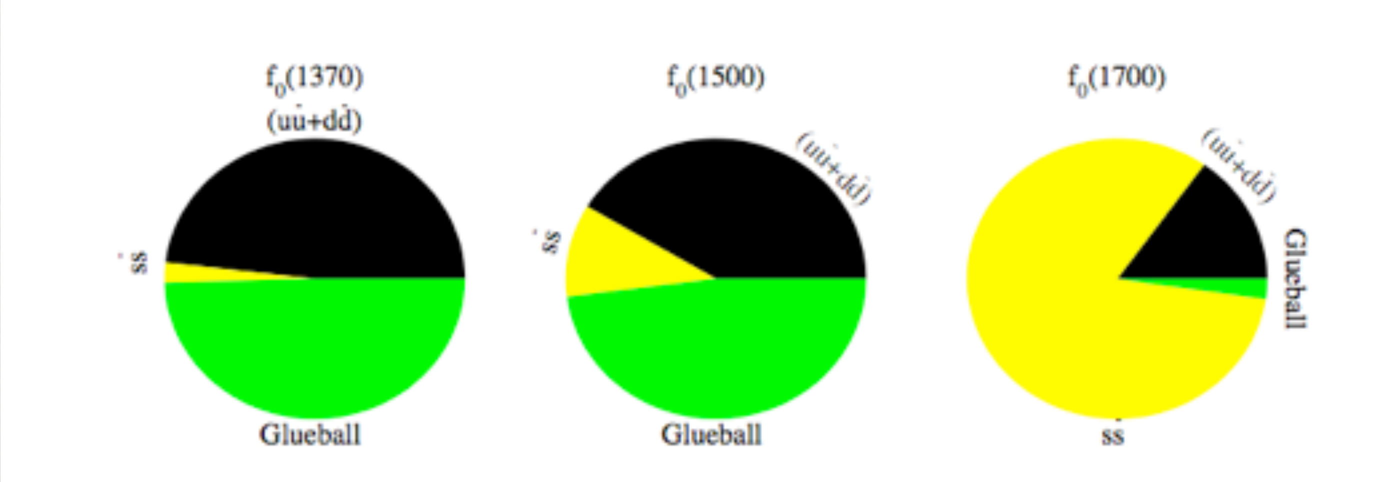
Y. Chen et al., Phys. Rev. D73, 014516 (2006).



EXPERIMENT

$$f_0(1500) \quad IJ^{PC} = 0\,0^{++}$$

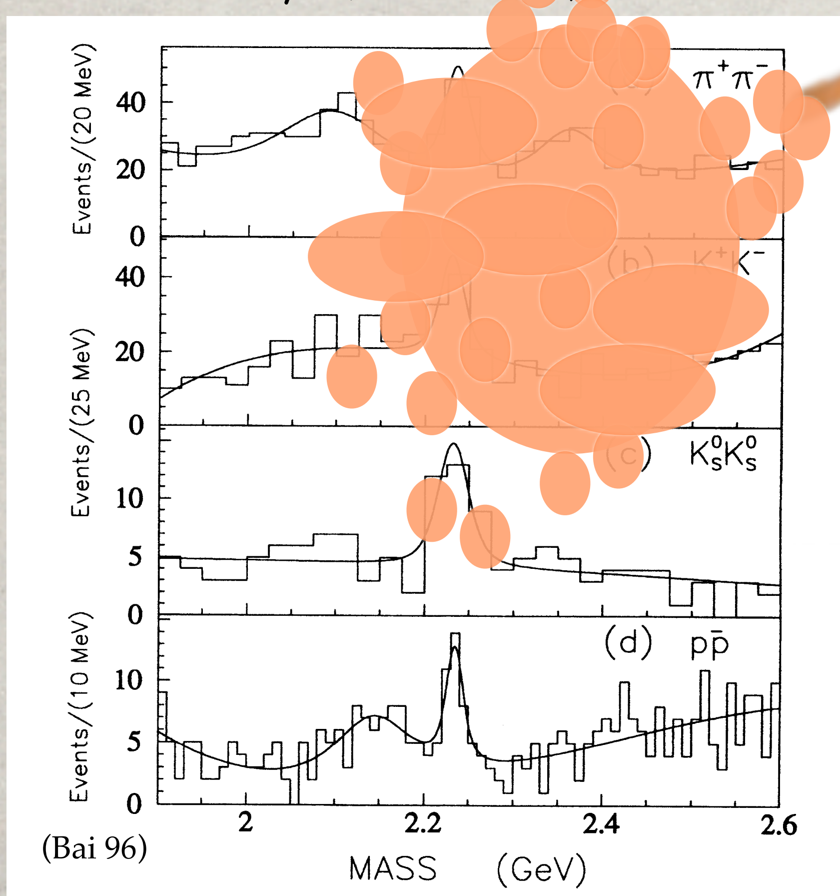




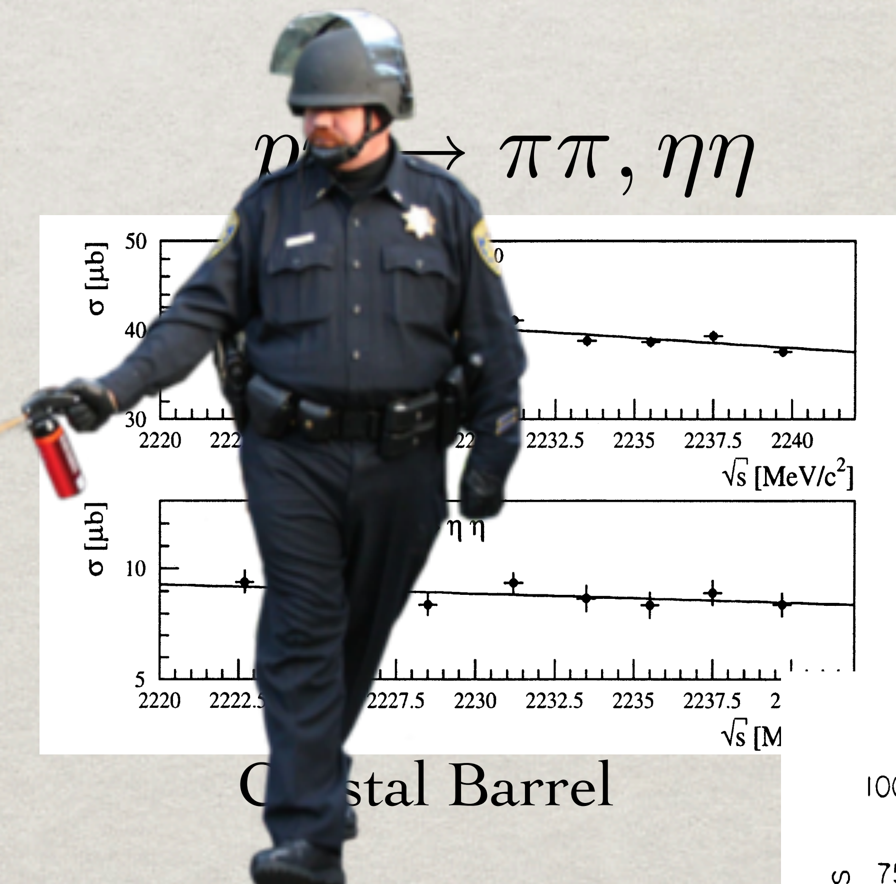
EXPERIMENT

$$\xi(2230) \quad J = 2$$

$J/\psi \to \gamma h$

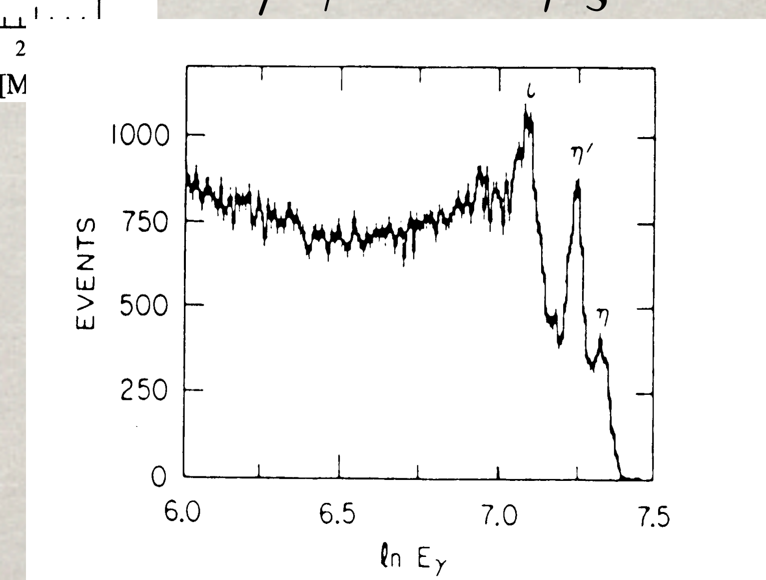


$p\bar{p} \to \pi\pi, \eta\eta$



Crystal Barrel

$J/\psi \to \gamma\xi$



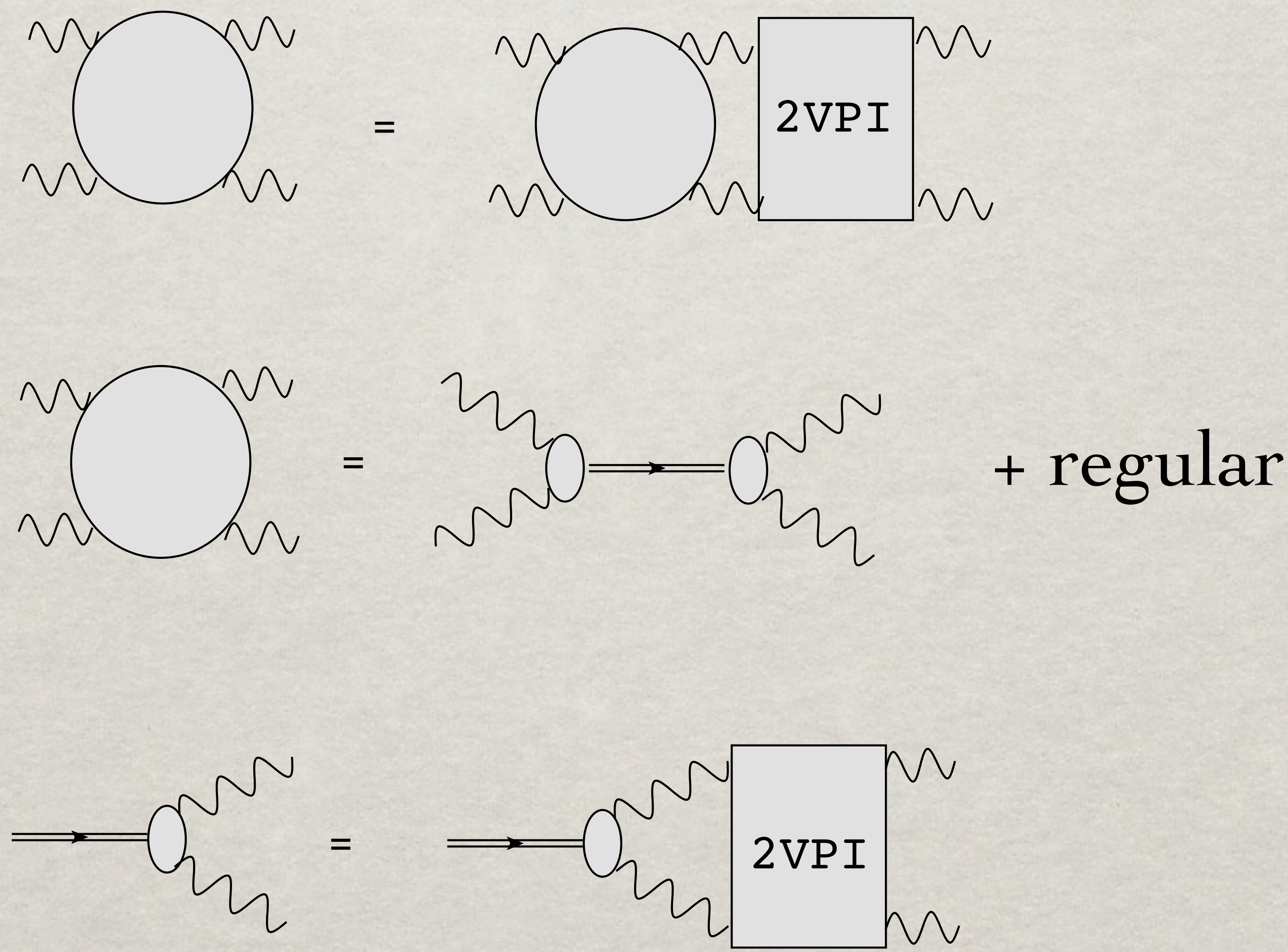
Crystal Ball

BETHE-SALPETER FORMALISM

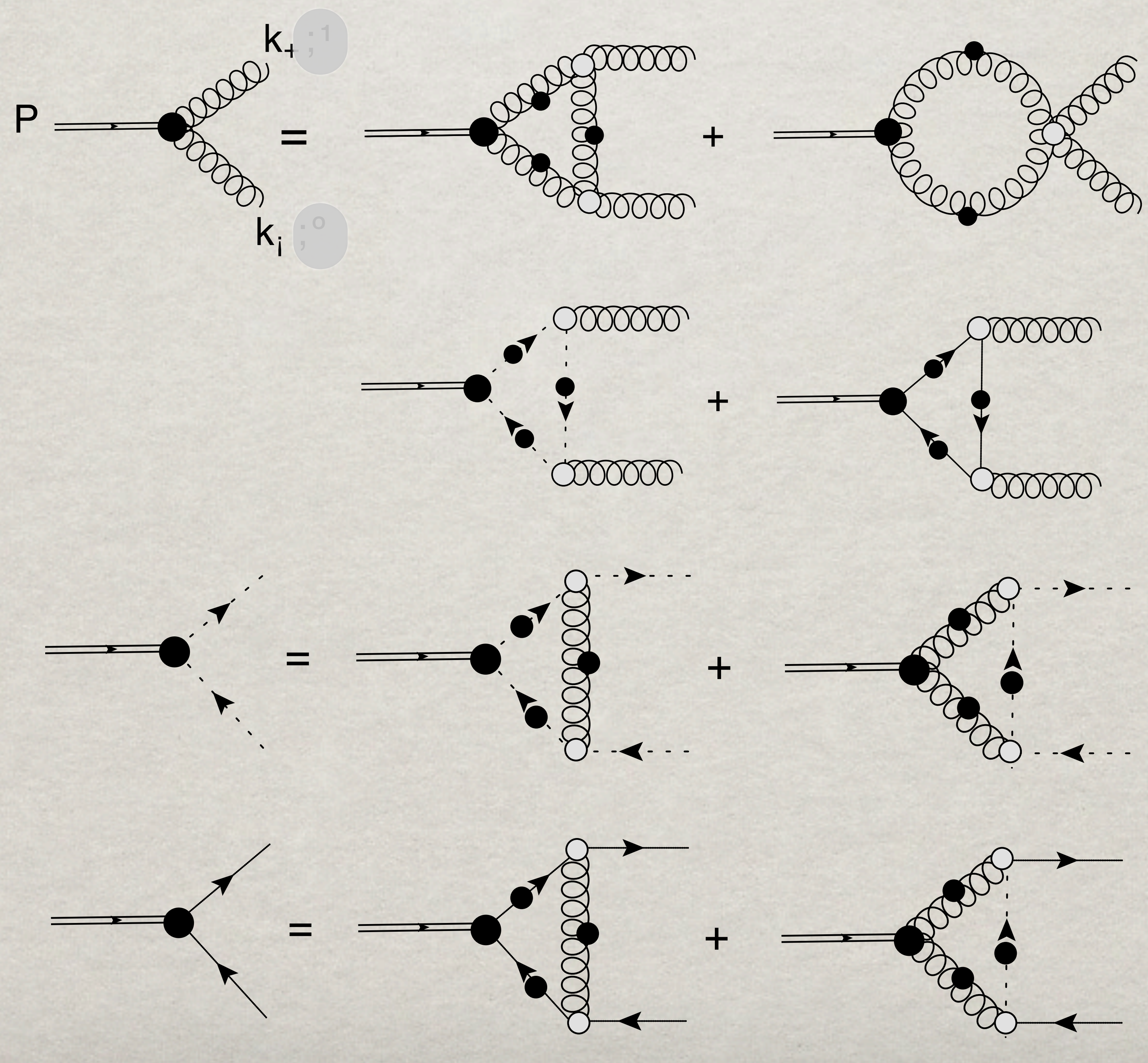
J. Meyers and E.S. Swanson, PRD [arxiv:1211.4648]

R. Alkofer and L. von Smekal, Phys. Rept. **353**, 281 (2001).

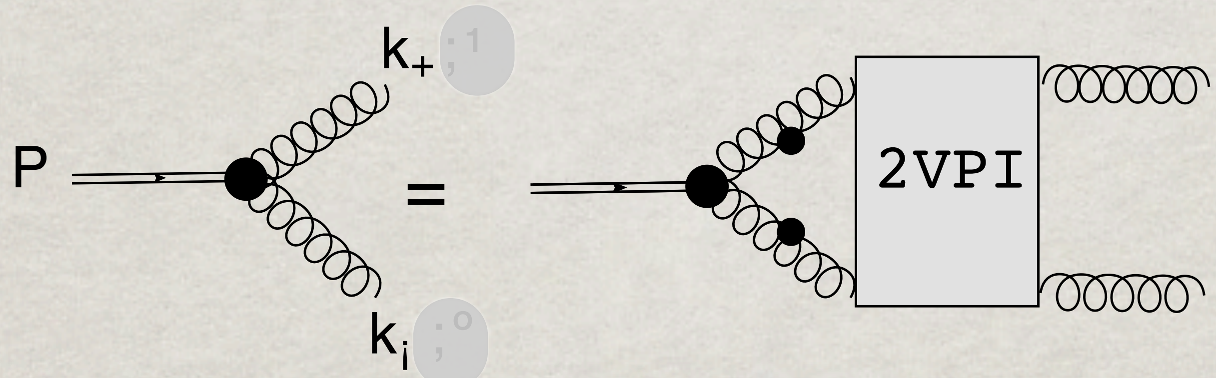
BETHE-SALPETER FORMALISM

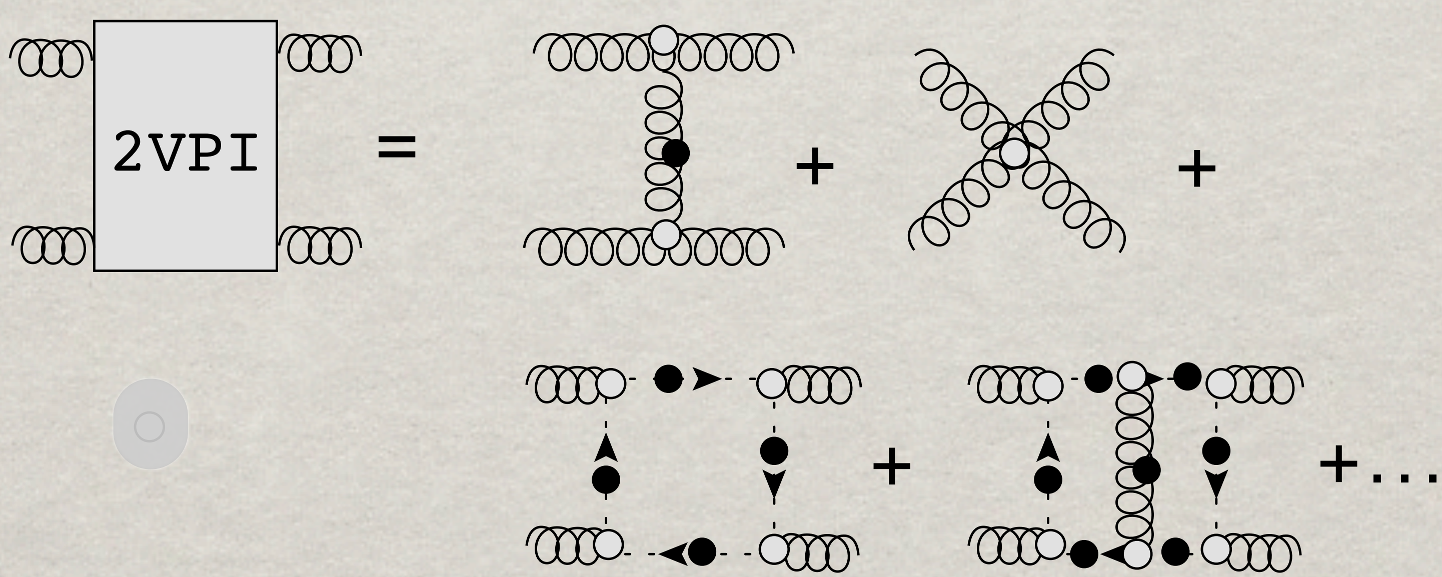


BETHE-SALPETER FORMALISM



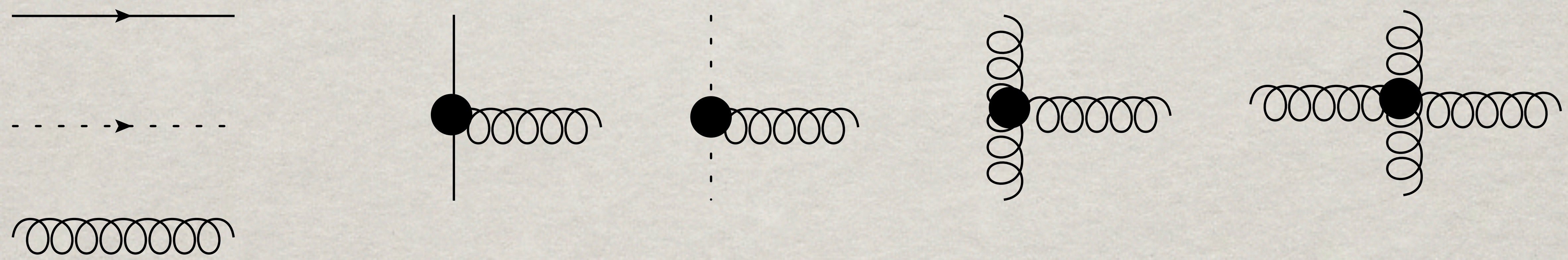
BETHE-SALPETER FORMALISM





BETHE-SALPETER FORMALISM

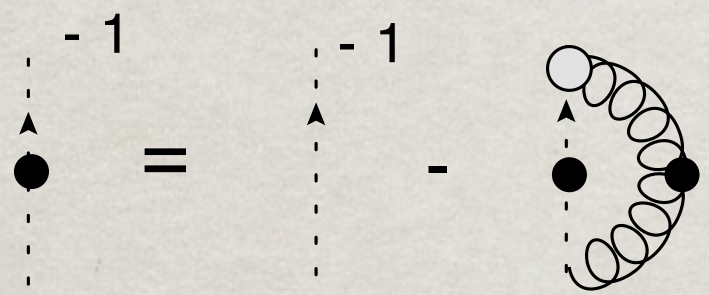
required elements:



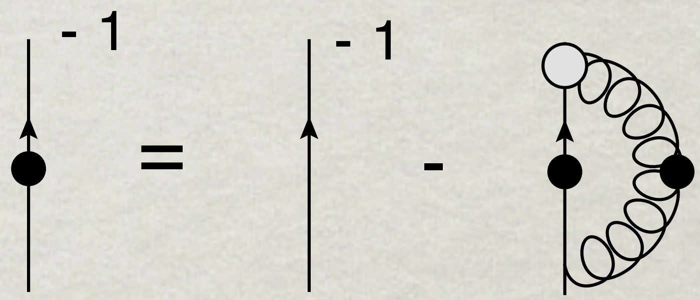
GAP EQUATIONS

GAP EQUATIONS

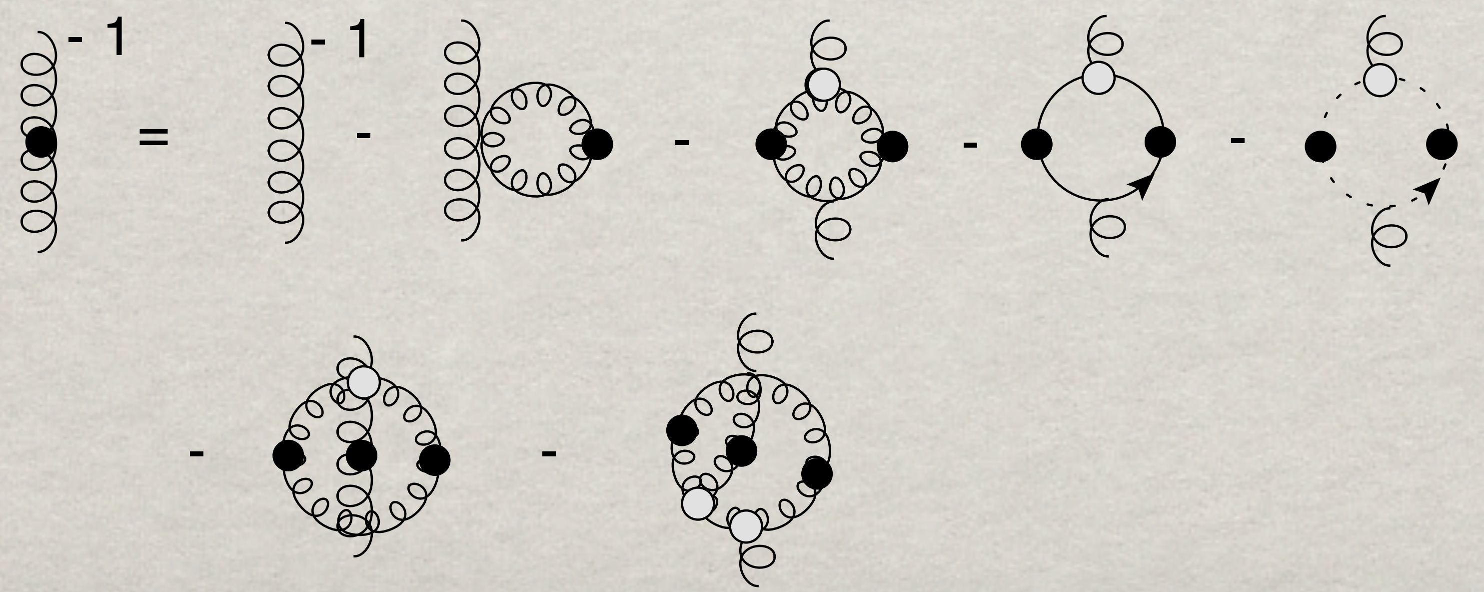
ghost



quark



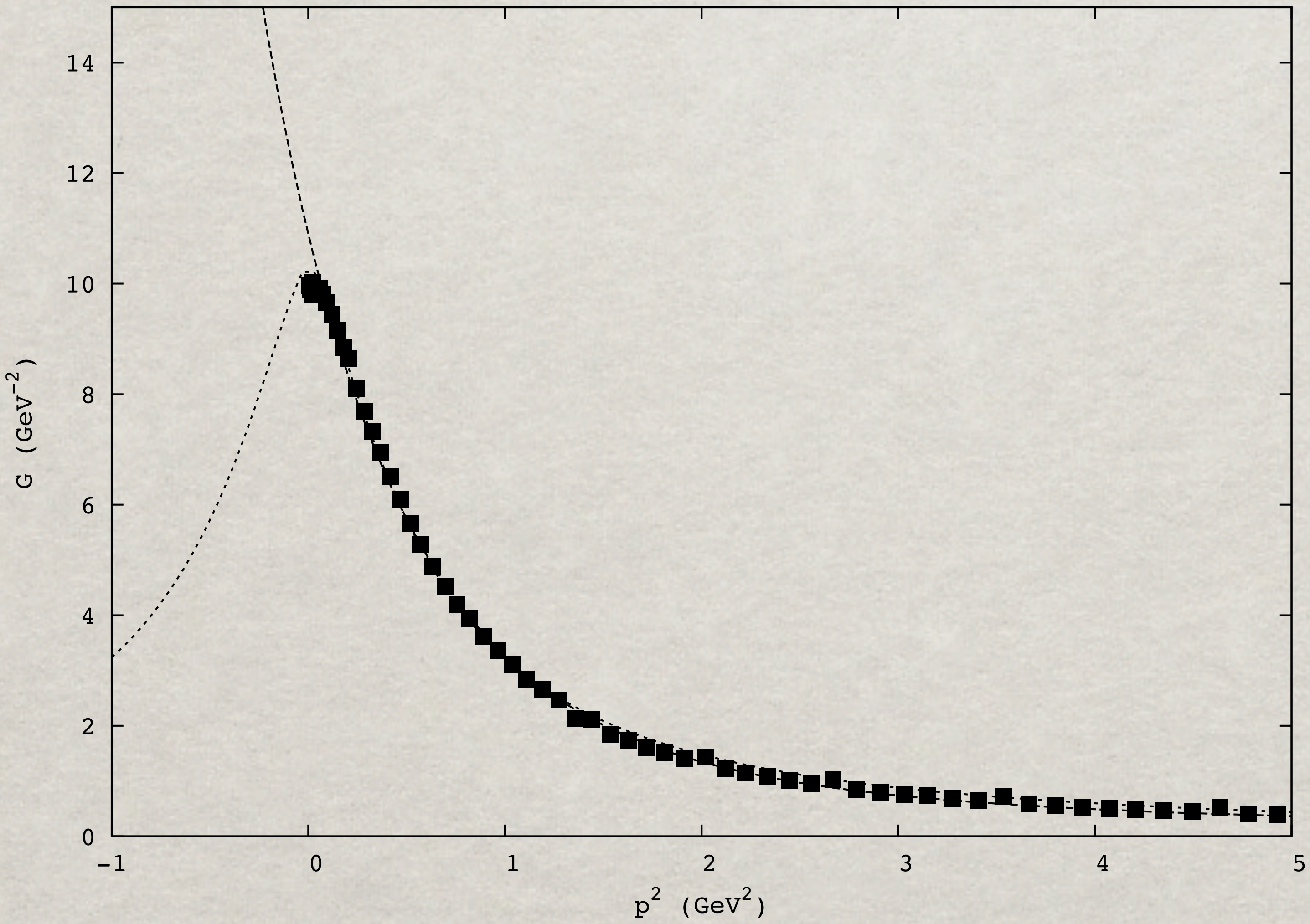
gluon



GAP EQUATIONS

gluon propagator:

$$D_{\mu\nu}(k) \equiv -i\left(g_{\mu\nu} - \frac{k_\mu k_\nu}{k^2}\right)\cdot G(k) - i\xi\frac{k^\mu k^\nu}{k^4+i\epsilon}$$



I.L. Bogolubsky, E.M. Ilgenfritz, M. Muller-Preussker and A. Sternbeck, Phys. Lett. **B676**, 69 (2009)

GAP EQUATIONS

vertices:

various models taken from

A.C. Aguilar and J. Papavassiliou, Phys. Rev. D**83**, 014013 (2011)

L. von Smekal, A. Hauck, and R. Alkofer, Ann. Phys. **267**, 1 (1998)

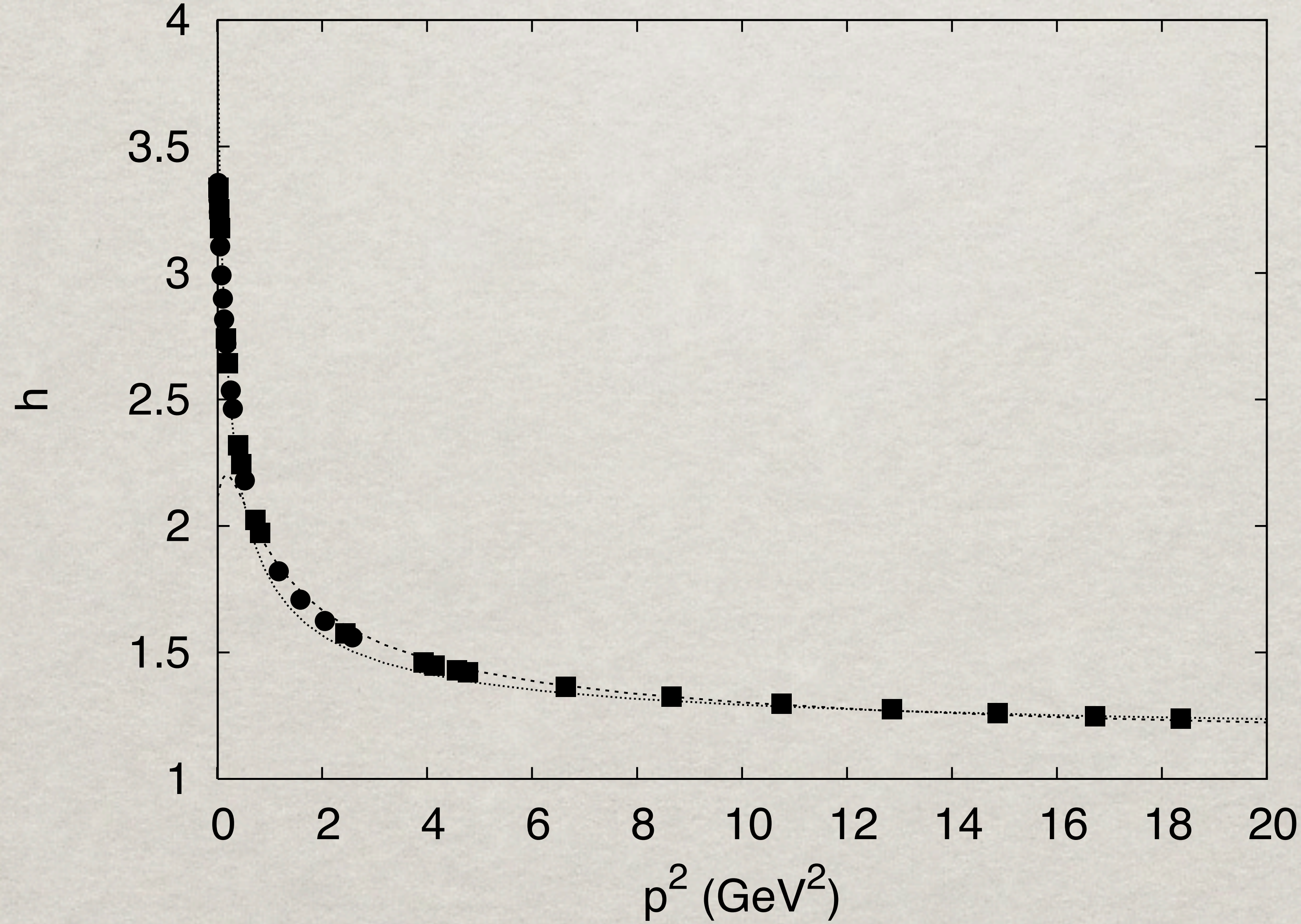
M.R. Pennington and D.J. Wilson, Phys. Rev. D**84**, 119901 (2011)

attempt to take into account Slavnov-Taylor identities, multiplicative renormalisability, etc

GAP EQUATIONS

results: ghost

$$H(q) \equiv i\delta^{ab}\,\frac{h(q)}{q^2}$$



I.L. Bogolubsky, E.M. Ilgenfritz, M. Muller-Preussker and A. Sternbeck, Phys. Lett. **B676**, 69 (2009)

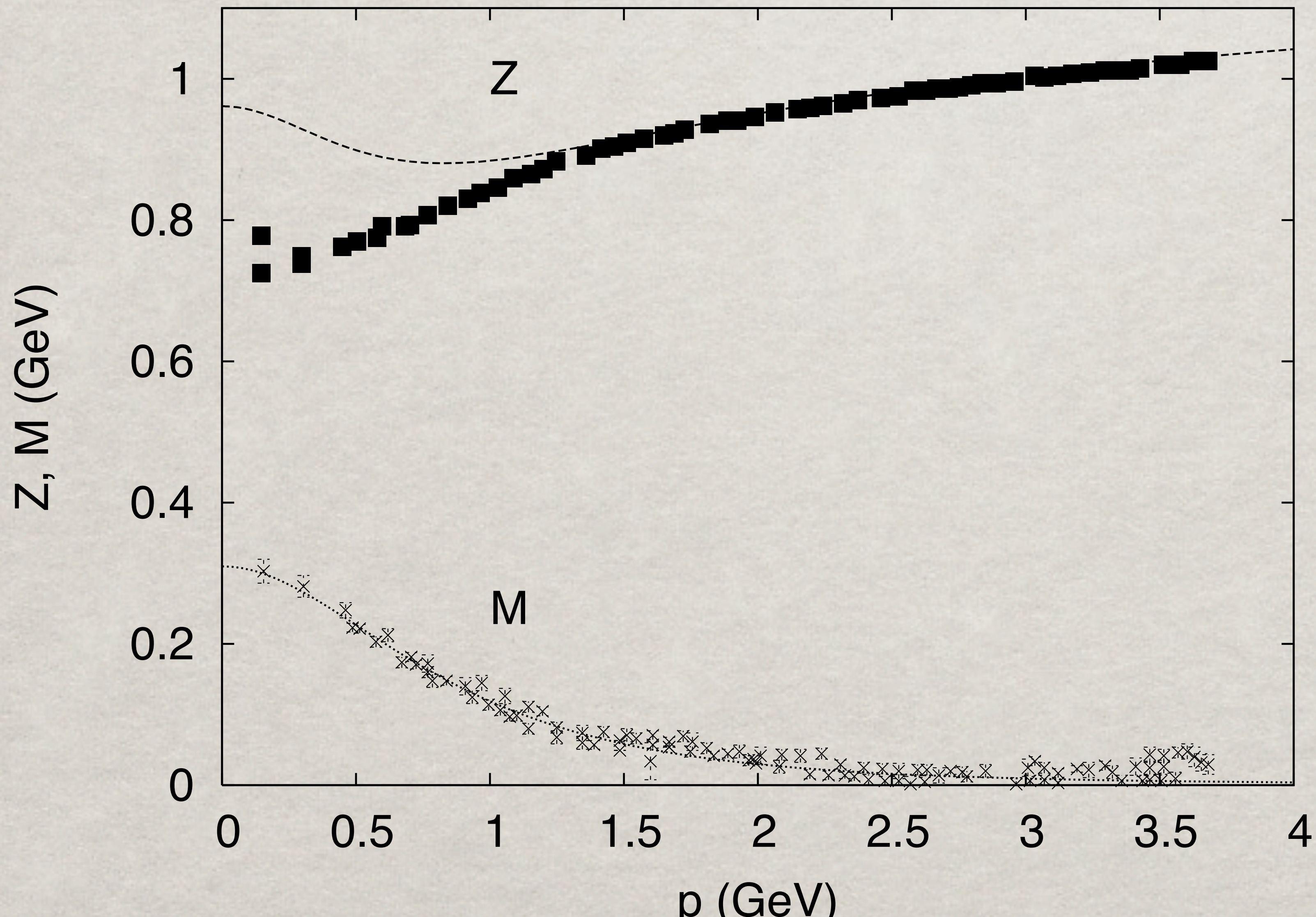
GAP EQUATIONS

results: quark

$$f_\pi = 240 \text{ MeV}$$

$$\langle\bar{\psi}\psi\rangle(1 \text{ GeV}) = (-251 \text{ MeV})^3$$

$$S(k) = i\frac{Z(k)}{\not{k} - M(k)}$$



P.O. Bowman et al., Phys. Rev. **D71**, 054507 (2005).

GLUEBALL EQUATIONS

Bethe-Salpeter equations

$$
\begin{aligned}
\chi_{\mu\nu}(k_+,k_-) &= ig^2 N \int \frac{d^4q}{(2\pi)^4}\, \chi_{\alpha\beta}(q_+,q_-)\, \mathcal{C}^{\alpha\beta}_{..\mu\nu}\, G(q_+)G(q_-) \\
&+ ig^2 N \int \frac{d^4q}{(2\pi)^4}\, \chi_{\alpha\beta}(q_+,q_-)\, \mathcal{T}^{\alpha\beta}_{..\mu\nu}(q,k;P)\, G(q_+)G(q_-)G(Q) \\
&+ ig^2 N \int \frac{d^4q}{(2\pi)^4}\, \chi(q_+,q_-)\, \mathcal{G}_{\mu\nu}(q,k;P)\, H(q_+)H(q_-)H(Q) \\
&- \frac{g^2}{2} \int \frac{d^4q}{(2\pi)^4} \mathrm{tr}\left[\gamma_\mu S(q_+) \mathbb{X}(q_+,q_-) S(-q_-)\gamma_\nu S(Q)\right]\, h^n(k_+)h^n(k_-)\bar{A}(Q,q_+)\bar{A}(Q,q_-) \\
&+ \text{crossed} \qquad (1)
\end{aligned}
$$

$$
\begin{aligned}
\chi(k_+,k_-) &= ig^2 N \int \frac{d^4q}{(2\pi)^4}\, \chi(q_+,q_-)\, \mathcal{H}(q,k;P)\, H(q_+)H(q_-)G(Q) \\
&+ ig^2 N \int \frac{d^4q}{(2\pi)^4}\, \chi_{\alpha\beta}(q_+,q_-)\, \mathcal{B}^{\alpha\beta}(q,k;P)\, G(q_+)G(q_-)H(Q) \qquad (2)
\end{aligned}
$$

$$
\begin{aligned}
\mathbb{X}(k_+,k_-) &= g^2 C_F \int \frac{d^4q}{(2\pi)^4} \gamma_\alpha S(-Q)\gamma_\beta G(q_+)G(q_-)\chi_{\alpha\beta}(q_+,q_-)h^n(q_+)h^n(q_-)\bar{A}(Q,k_+)\bar{A}(Q,k_-) \\
&+ ig^2 C_F \int \frac{d^4q}{(2\pi)^4} \gamma_\mu S(q_+)\mathbb{X}(q_+,q_-)S(-q_-)\gamma_\nu G(Q)P_{\mu\nu}(Q)\, h^{2n}(Q)\, \bar{A}(k_+,q_+)\, \bar{A}(k_-,q_-) \qquad (3)
\end{aligned}
$$

Bethe-Salpeter equations

$$\mathcal{C}^{\alpha\beta\mu\nu} = 2g^{\mu\nu}g^{\alpha\beta} - g^{\alpha\nu}g^{\beta\mu} - g^{\alpha\mu}g^{\beta\nu}$$

$$\mathcal{T}_{\alpha\beta\mu\nu} = P^{\gamma\gamma'}(Q)\, V_{\alpha\mu\gamma}(q_+, k_+)\, V_{\beta\nu\gamma'}(q_-, k_-)$$

$$P^{\gamma\gamma'}(Q) = g^{\gamma\gamma'} - \frac{Q^\gamma Q^{\gamma'}}{Q^2}$$

$$\begin{aligned} V_{\alpha\mu\gamma}(q_+, k_+) \quad = \quad & A_+(q_+, k_+, q_+ - k_+)g^{\alpha\mu}(q_+ + k_+)^\gamma + \\ & +A_+(k_+, q_+ - k_+, q_+)g^{\mu\gamma}(q_+ - 2k_+)^\alpha + \\ & +A_+(q_+ - k_+, q_+, k_+)g^{\gamma\alpha}(k_+ - 2q_+)^\mu . \end{aligned}$$

Bethe-Salpeter equations

$$\mathcal{G}^{\mu\nu} = \left(q_+^\mu \frac{h(k_+)}{h(q_+)} + Q^\mu \left(\frac{h(k_+)}{h(Q)} - 1 \right) \right) \left(Q^\nu \frac{h(k_-)}{h(Q)} - q_-^\nu \left(\frac{h(k_-)}{h(q_-)} - 1 \right) \right)$$

$$\mathcal{H} = P_{\mu\nu}(Q) k_+^\mu k_-^\nu \cdot \left(\frac{h(Q)}{h(k_+)} + \frac{h(Q)}{h(q_+)} - 1 \right) \cdot \left(\frac{h(Q)}{h(k_-)} + \frac{h(Q)}{h(q_-)} - 1 \right)$$

$$\mathcal{B}^{\alpha\beta} = -k_+^\alpha k_-^\beta \cdot \left(\frac{h(q_+)}{h(Q)} + \frac{h(q_+)}{h(k_+)} - 1 \right) \cdot \left(\frac{h(q_-)}{h(Q)} + \frac{h(q_-)}{h(k_-)} - 1 \right)$$

Bethe-Salpeter equations

impose transversality and parity

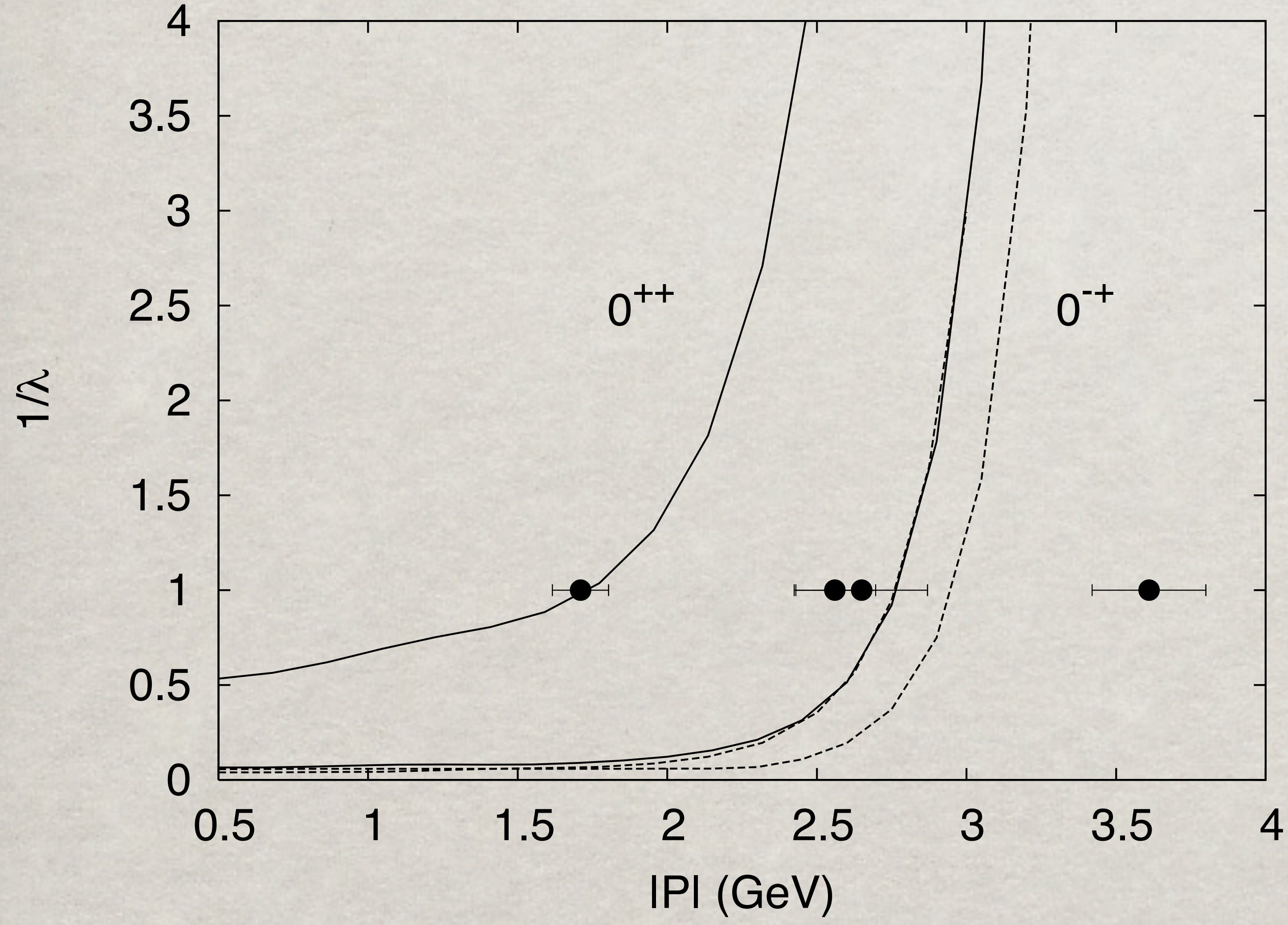
$$\chi_R^{\mu\nu}(k_+, k_-) = \epsilon(\mu,\nu) \cdot \Pi_R \cdot \chi_R^{\mu\nu}(\tilde{k}_+, \tilde{k}_-)$$

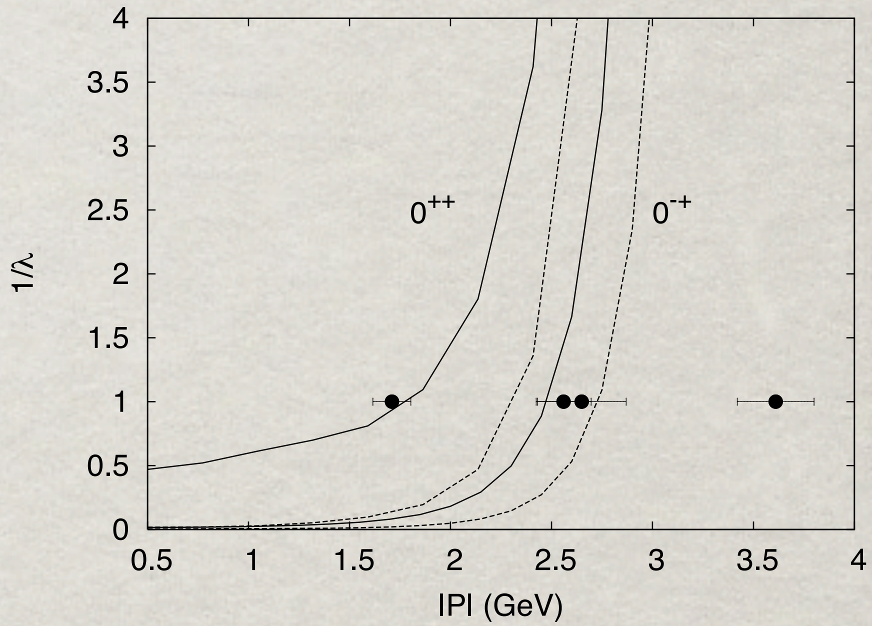
$$\chi^{\mu\nu}(k_+, k_-) = A_0 g^{\mu\nu} + A_1 k_+^\mu k_+^\nu + A_2 k_-^\mu k_-^\nu + A_3 k_+^\mu k_-^\nu + A_4 k_-^\mu k_+^\nu + A_5 \epsilon^{\mu\nu\alpha\beta} k_{+\alpha} k_{-\beta}$$

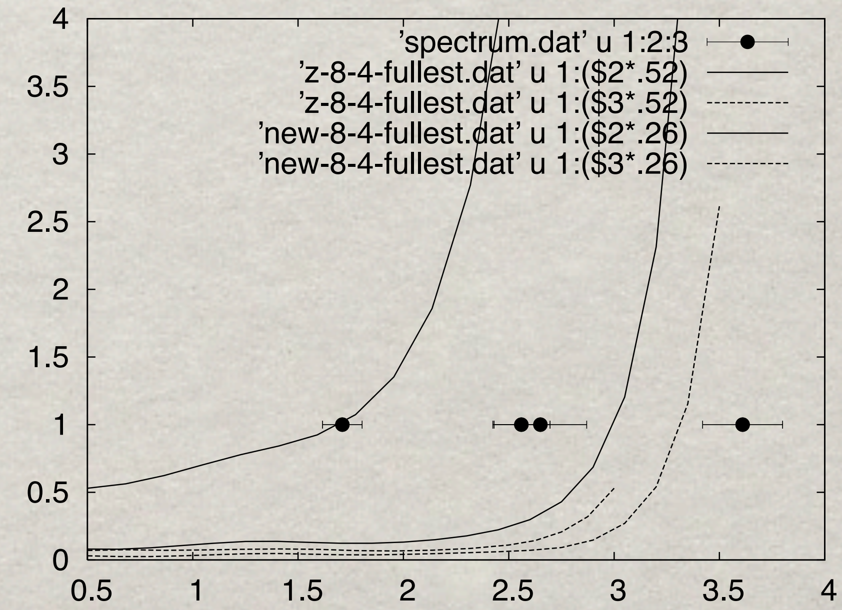
$$\chi^{\mu\nu}(k_+, k_-) = \epsilon^{\mu\nu\alpha\beta} k_\alpha P_\beta F(k, P) \quad [0^{-+}]$$

$$\chi^{\mu\nu}(k_+, k_-) = A(k, P) A^{\mu\nu} + B(k, P) B^{\mu\nu} \quad [0^{++}]$$

Bethe-Salpeter equations







CONCLUSIONS

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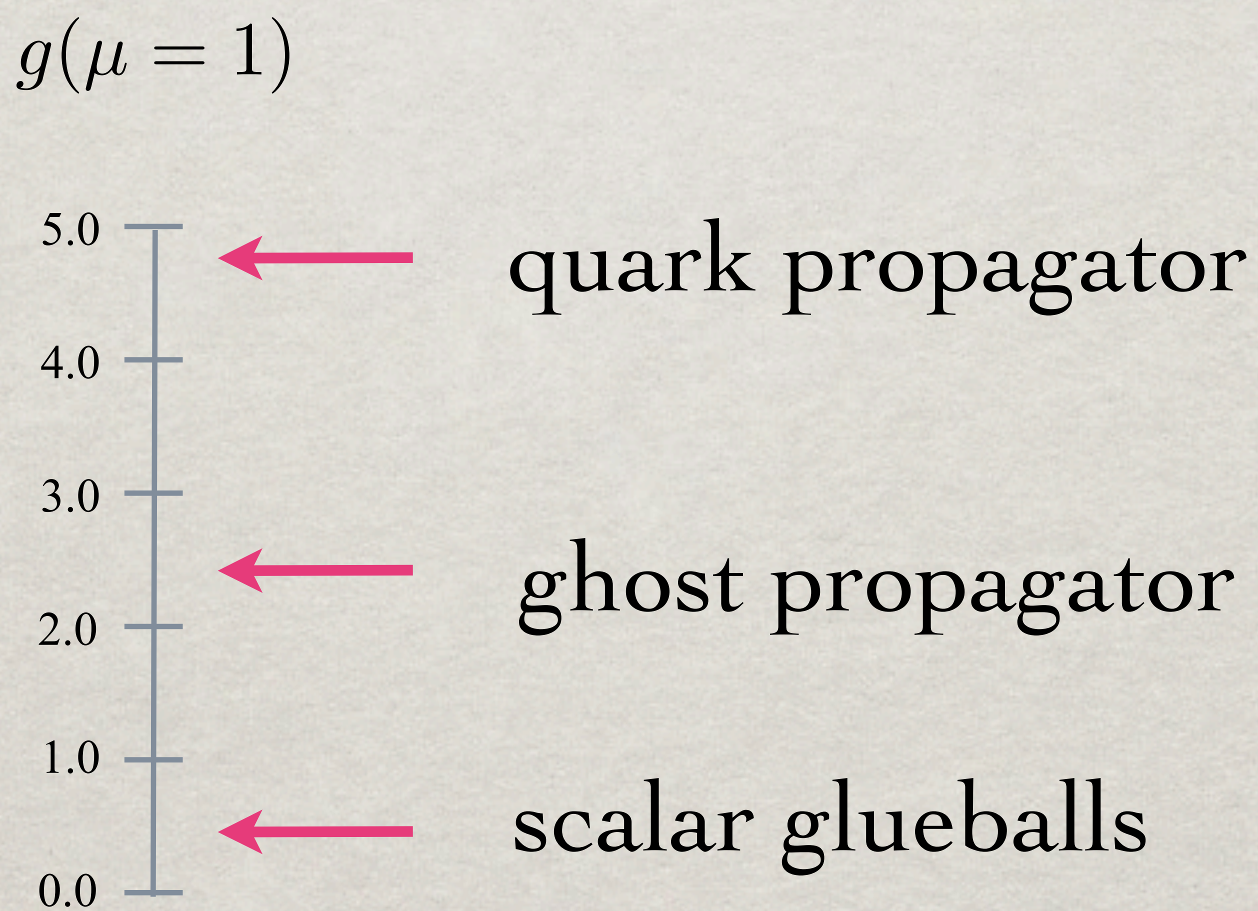
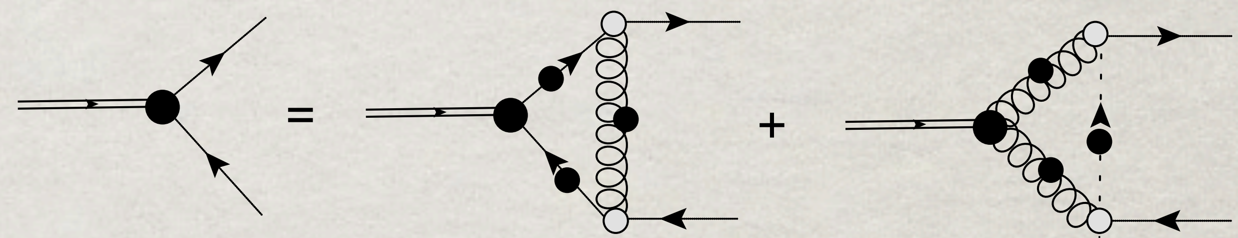


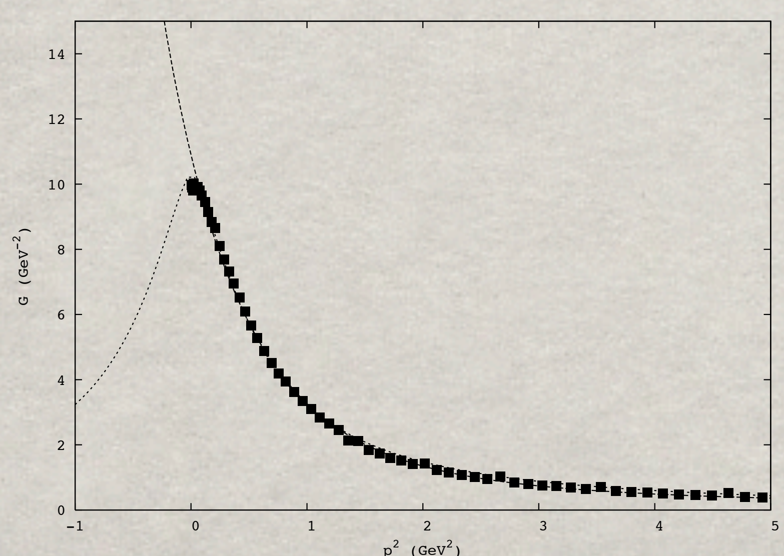
CONCLUSIONS

Wilson loop



the Bethe-Salpeter equation simplifies in the heavy quark limit

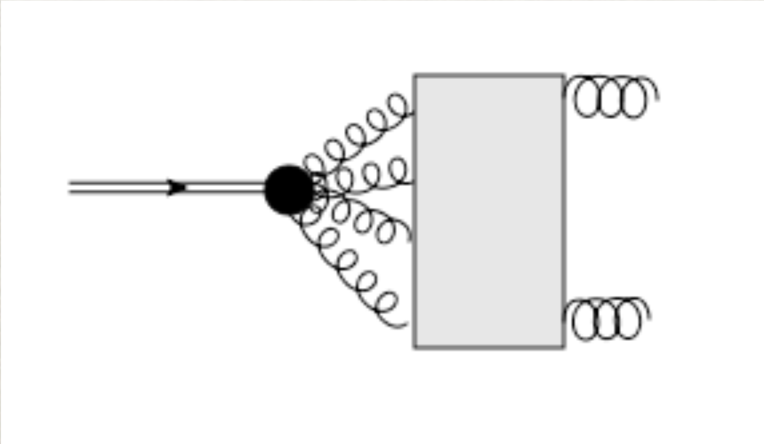
$$V \to -iG(-\vec{p}^2)$$



[screened Coulomb with log corrections]

CONCLUSIONS

- kernel structure
- instantons
- reggeons
- flux tubes
- N-ality confinement
- pomeron



CONCLUSIONS

- this methodology is in its infancy -- it will likely require sophisticated modelling
- the importance of topological vacuum effects and multigluon dynamics may be revealed.
- PANDA@GSI, JLab, BESIII, superB, LHCb provide hope for progress

✢ ÆRIC MEC HEHT GEWYRCAN