SUNny gluonia as DM

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Lattice BSM, ANL; 04/21/16
[with Yue Zhang @ Caltech; arXiv:1602.00714]

outline

- **Intro …….**
- **Basic philos…..seek as simple a solution as possible**
- **Viable candidate?**
- **Naturally accounts**
- **Possible repercussions**
- **Future directions…..inc possible lattice studies**

Introduction + motivation

- **Preponderance of DM over matter is sometimes (often) used as a rationale to suggest that the underlying explanation for DM may well require considerable complexity i.e. much more complicated than theories of matter**

- **Pursue different philosophy:**
- **Explore as simple a solution as possible and introduce complexity if only if forced by experiments and observations**

SIMPLICITY IS OUR PRIORITY!

SU(N)…simplest theory with non-trivial mass scale

$$\mathcal{L} = -\frac{1}{4} H^a_{\mu\nu} H^{a\,\mu\nu}$$

Parameters: N, Λ

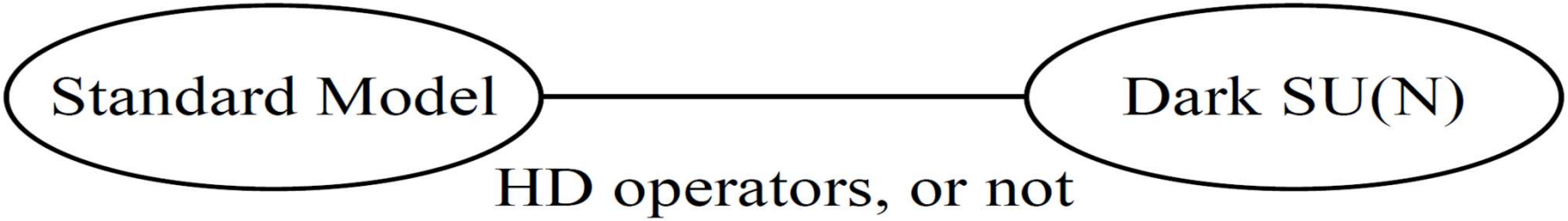
Implicit: θ [later]

IN FACT THIS THEORY IS SO SIMPLE AND SO ELEGANT, IT SEEMS DIFFICULT TO BELIEVE THAT NATURE DOES NOT MAKE USE OF IT!

Interactions

- **Gravitational for sure…….decays to gravitons**

- **With SM ….unavoidable via higher dimensional operators**



- **No compelling reason to think nature cares whether DM interacts with our detectors or not**

Decays to gravitons

$$\Gamma_\phi \sim m^5/M_{pl}^4 \sim \tau_U^{-1}(m/10^7\,\mathrm{GeV})^5$$

where $\tau_U = 10^{17}$ sec is the age of the universe

immediate consequences

- **The mentioned interactions likely *naturally* account for:**

- **Why it has been so difficult to detect DM in "direct detection experiments"**

- **Remarkably, the only compelling evidence of DM that so far we have is gravitational !**

Low lying spectrum

- Phenomenological models [Cornwall+AS'80] as well as lattice calculations [Morningstar + Peardon'99] 0++ and 0-+ as lightest states with masses ~Λ
- For N>> 1, lightest gluonia masses go as

$$(\alpha + \beta/N^2)\Lambda$$

See : Lucini + Teper '01; Lucini, Rago + Rinaldi, '10

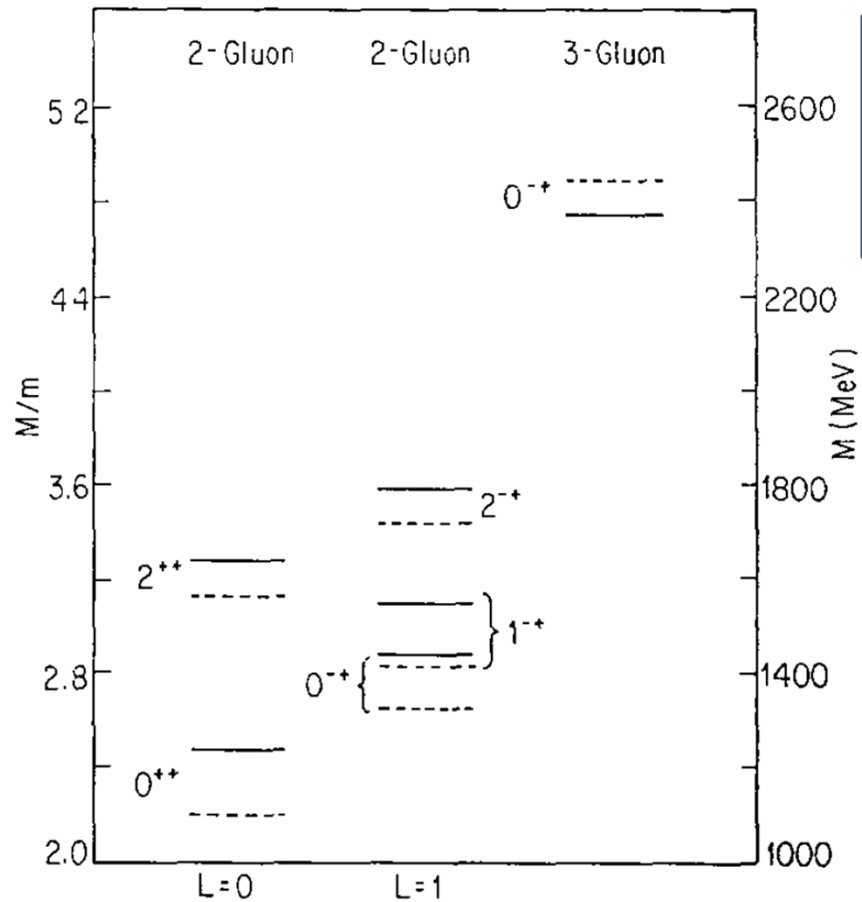


Fig. 3. Results of the numerical calculations. The scale on the left is in units of the gluon mass m; that on the right is in MeV, assuming m = 500 MeV. The solid lines refer to $s = 4m^2$ in the potential (6), and the dashed lines refer to a self-consistent determination of s.

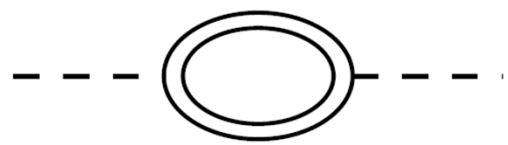
Cornwall + AS PLB'83

Interactions of dark [SUN] gluonia

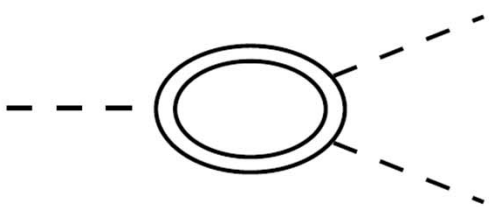
- Scalar potential:

$$V(\phi) = \frac{1}{2}m^2\phi^2 + \frac{1}{3!}\lambda_3\phi^3 + \frac{1}{4!}\lambda_4\phi^4 + \frac{1}{5!}\lambda_5\phi^5 + \cdots$$

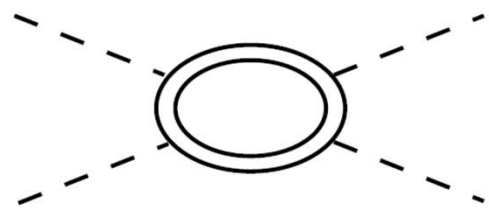
Power counting in the large N limit



$\phi \sim \sqrt{N}$



$\lambda_3 \sim \frac{m}{N}$



$\lambda_4 \sim \frac{1}{N^2}$

Constraints due structure formation I

- **2 to 2 elastic scattering of gluonia:**

  $\sigma \sim 1/m^2N^2$

- **For this DM to address the core/cusp problem of dwarf galaxies**:

$$0.1\,\mathrm{cm}^2/\mathrm{gram} < \sigma_{2\to 2}/m < 10\,\mathrm{cm}^2/\mathrm{gram}$$

$$m \sim 0.1\,\mathrm{GeV} \cdot N^{-4/3}$$

||

- **Interactions also allow 3=>2 inelastic annihilation**

  3=>2 reaction rate, Γ (3=>2) ~ $(n_\phi)^2$ σ (3=>2) with

  σ (3=>2) ~$1/m^5N^2$

- **The 3=>2 process tends to make ϕ relativistic & warmer until there gets to be balance with the reverse 2=>3 rate**
- **The final DM relic density is given by value of n_ϕ at the decoupling of the 3=>2 annihilation**

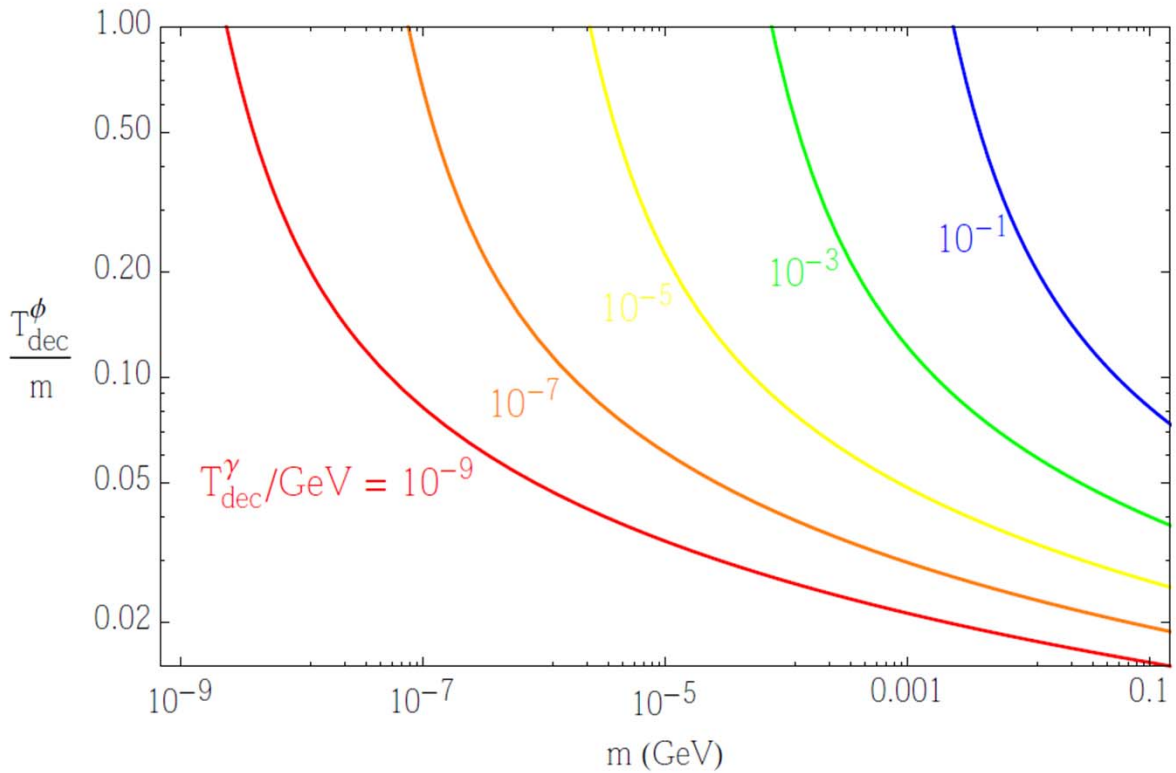
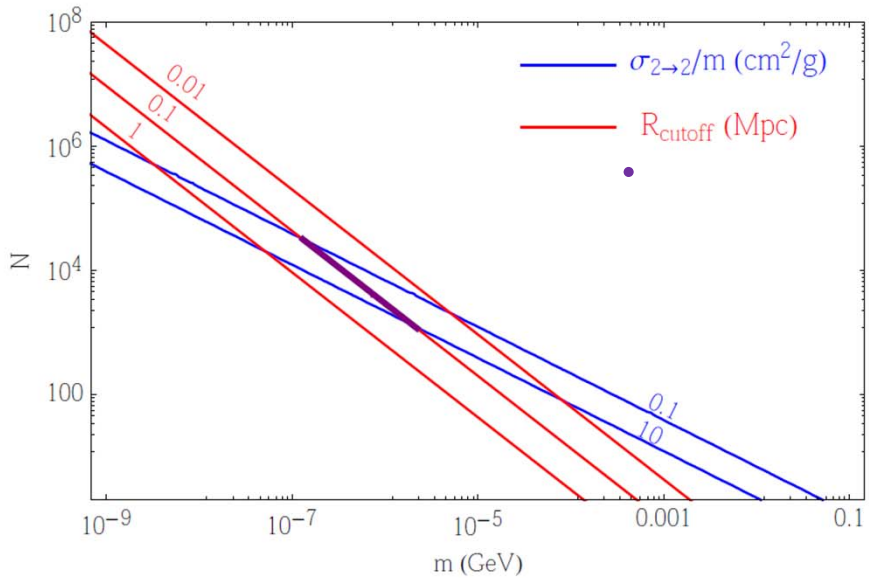


FIG. 2. Ratio of temperature T_ϕ to the mass m of ϕ particles at the decoupling of $3 \to 2$ annihilation that could give the correct dark matter relic density. The curves correspond to different photon temperatures (T^{γ}_{dec}) at this epoch. Roughly, T_ϕ is only one order of magnitude below the mass, and the ϕ particles remain heated before the decoupling.



For SI + WARM

$10^{-4} \lesssim m \lesssim 10^{-2}$ MeV

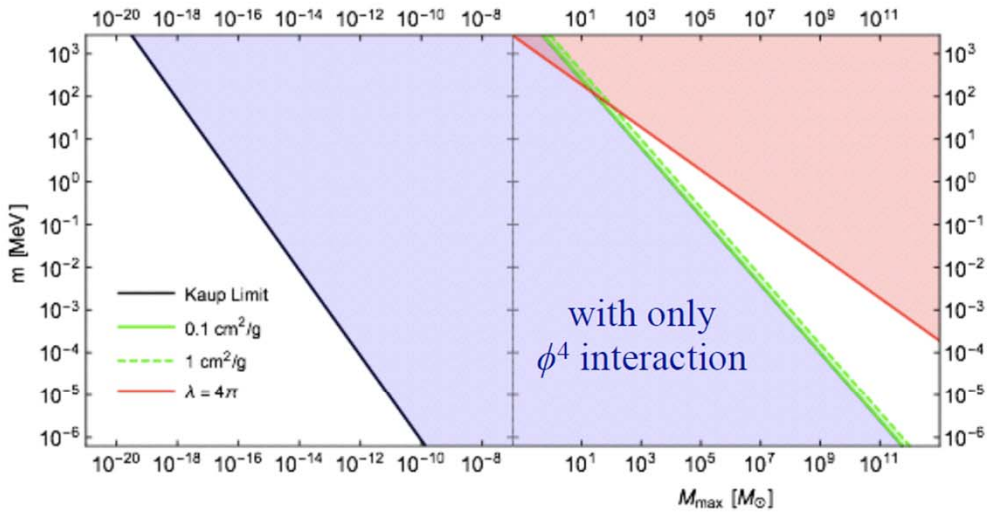
$10^5 \lesssim N \lesssim 10^3$

FIG. 1. The parameter space of m versus N where the lightest hidden glueball could be a self-interacting and/or warm DMC. The two blue curves correspond to constant values of DM self interaction cross section, $\sigma_{2\to2}/m = 0.1, 10\,\mathrm{cm}^2/\mathrm{gram}$, respectively. Self-interacting DM lives between the blue curves. The red curves correspond to constant values of damping scale in the power spectrum, $R_{\mathrm{cutoff}} = 0.01, 0.1, 1\,\mathrm{Mpc}$, respectively. Warm DM lives along the middle red curve. The glueball dark matter can be both self-interacting and warm at the intersection of the two regions (thick purple curve).

More Gravitational Effects

Gravitation: BEC of dark glueball yields macroscopic dark stars.

Repulsive interaction ($\lambda_4 > 0$) could leads to lensing effects.



SI+W DMC
⇒
$10^6 \to 10^8 \odot$

Further work in progress to explore more general potentials.

Eby, Kouvaris, Nielsen, Wijewardhana (1511.04474)

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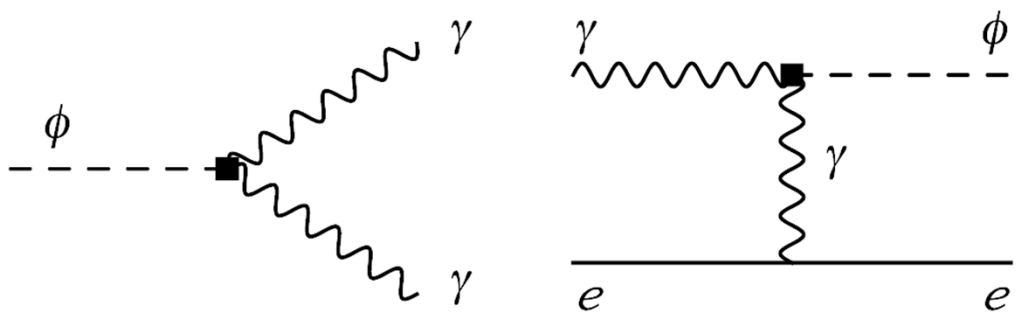
Interactions with the SM via HDO

$$\mathcal{L}_{int} = (1/M^n) H_{\mu\nu} H^{\mu\nu} \mathcal{O}_{SM}$$

$$\mathcal{L}_{int} = \frac{1}{M^4} H_{\mu\nu} H^{\mu\nu} \left(F_{\alpha\beta} F^{\alpha\beta} \right) \rightarrow \frac{N m^3}{M^4} \phi F_{\alpha\beta} F^{\alpha\beta}$$



~EW

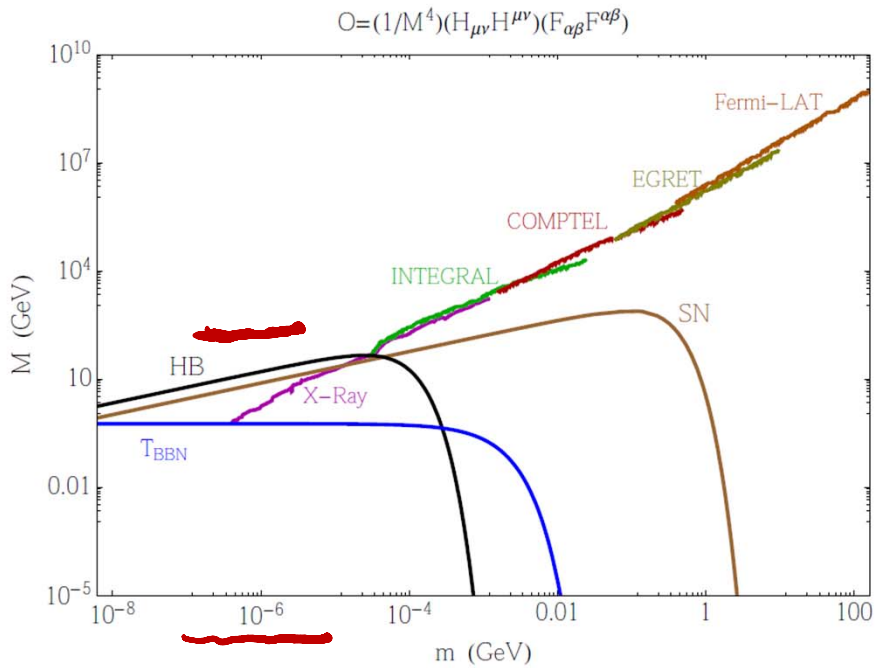


FIG. 3. Lower bounds on the cutoff scale M. Cosmic ray photon observations constrains glueball dark matter decay into photons, and from right to left, the curves correspond to constraints from Fermi-LAT, EGRET, COMPTEL, INTEGRAL, X-ray. The black (brown) solid curve is the lower bound on M from the energy loss argument of HB (SN). The blue curve represents the requirement that the hidden sector is not thermalized with the SM sector below the BBN temperature.

Implications of $\theta H \widetilde{H}$

- This can generate an effective interaction with the SM

$$(1/M^4)(H\widetilde{H})(G\widetilde{G})$$

=> $$\theta_{\rm QCD} G\widetilde{G}$$

$$\theta_{\rm QCD} \sim (m/M)^4 \theta$$

$< 10^{-3}$ automatically satisfied

Using nedm bound of 10 -26 em => $\theta_{\rm QCD} \lesssim 10^{-13}$.

Theta SUN ~ O(1) cannot be ruled out !
Possibly interesting implications

Key questions for NP studies

- **Potential for s s scattering, attractive or repulsive?**
- **pp…..?**

- **Key to BEC into Dark SUN-onia stars**
- **Could lead to gravitational lensing**
- **Possibly different pattern of gravitational waves**

FOR QCD SOME STUDIES

Glueball-glueball scattering in a constituent gluon model

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Abstract. In this work we use a mapping technique to derive in the context of a constituent gluon model an effective Hamiltonian that involves explicit gluon degrees of freedom. We study glueballs with two gluons using the Fock-Tani formalism. In the present work we consider two possibilities for 0^{++}: (*i*) as a pure $s\bar{s}$ and calculate, in the context of a quark interchange picture, the cross-section; (*ii*) as a glueball where a new calculation for this cross-section is made, in the context of the constituent gluon model, with gluon interchange.

arXiv 0407114

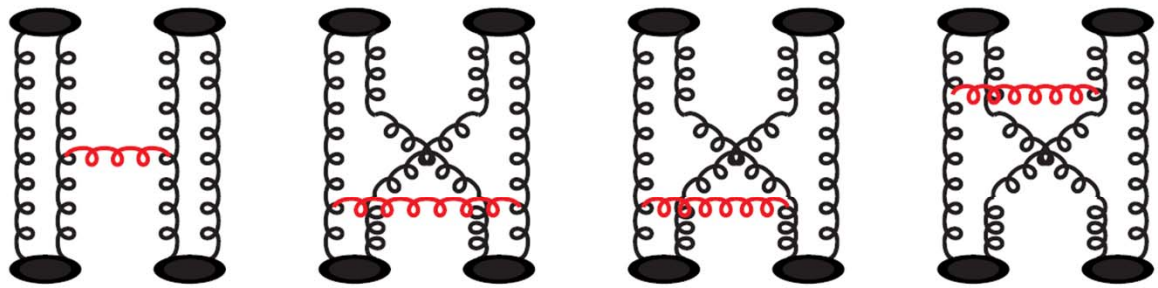
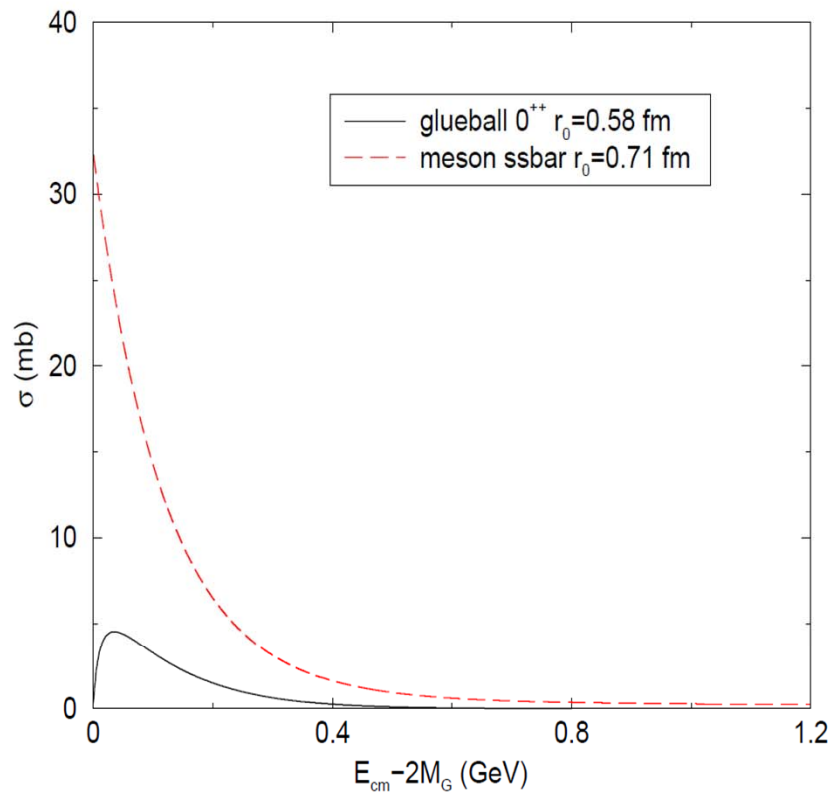


FIGURE 1. Diagrams representing the scattering amplitude h_{fi} for glueball-glueball interaction wi constituent gluon interchange.

1 glum exch pot. model... rather naive?



0^{++} possibly repulsive?

FIGURE 2. Cross-section comparison for 0^{++} with the following parameters $\beta = 0.1$, $\lambda = 1.8$, $k = 0.21$, gluon mass $m = 0.6$ GeV. The $s\bar{s}$ quark model parameters: $m_q = 0.55$ GeV, $\alpha_s = 0.6$.

A well known study in QCD is ππ scattering

- In fact this is part of the RBC-UKQCD major project, K=> ππ and ε' and in particular for ε'

scattering phases of ππ are very important.

See [CU] thesis of Qi Liu [2012] and Daiqiang Zhang [2015] and in progress

- See also E. Shabalin, arXiv:1511.00498 who uses ChiPT.
- Scattering length for I=2 is + → repulsive
- And for I=0 is - → attractive

Summary & Outlook

- **SUN pure gauge theory provides a strikingly simple and viable DMC…[It'd be a bit surprising if nature does not make use of its simplicity]**
- **It provides a natural set up for accounting for the only compelling evidence, i.e. gravitational, that we have so far**
- **It also readily explains why direct detections so far have been giving null results**
- **Non-perturbative studies of this fascinating theory are called for, esp $\emptyset\emptyset \Rightarrow \emptyset\emptyset$ ….is it attractive or repulsive for low lying gluonia?**
- **Exciting possibility of BEC and gigantic SUN Dark "stars" of 10^6 to 10^8 solar masses leading to enhanced lensing effects!**