Mass of flavor singlet *uuddss* in QCD sum rules

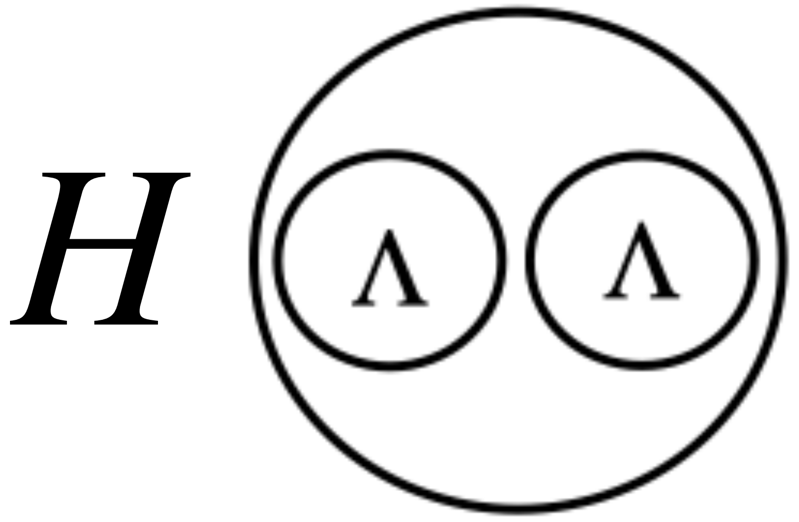
Zihui Wang (NYU)

APS April Meeting 2021

Based on work in progress with G. Farrar

Introduction

- Initial prediction of H-dibaryons @2.15 GeV by Jaffe (Jaffe 79)



- Not found by experiments by far; Lattice and other theoretical calculations vary a lot
- Farrar shows that a deeply-bound *uuddss (S)* < 2 GeV escapes all the previous experimental searches (Farrar 1708.08951)

S

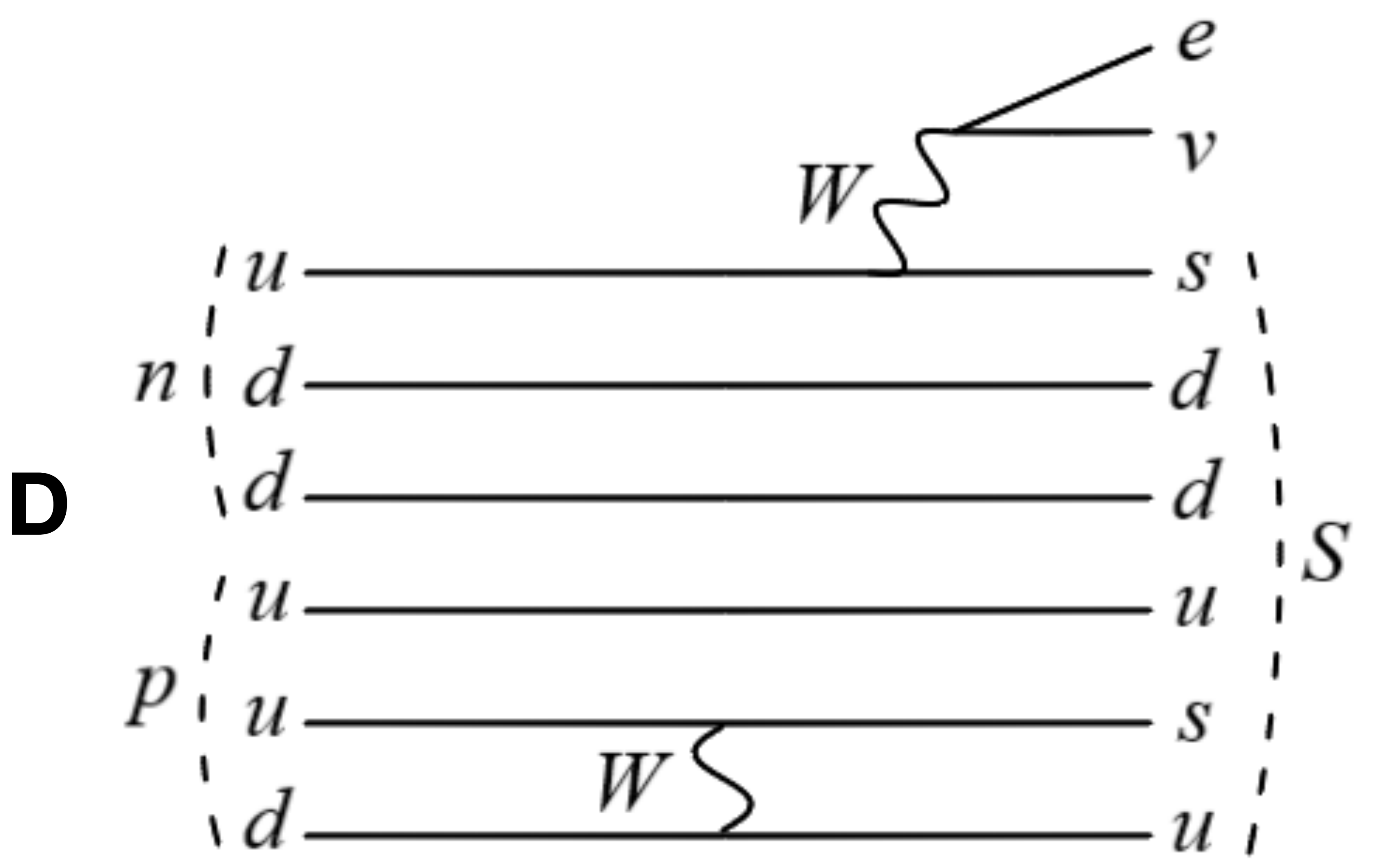
- Good dark matter particle candidate if exists

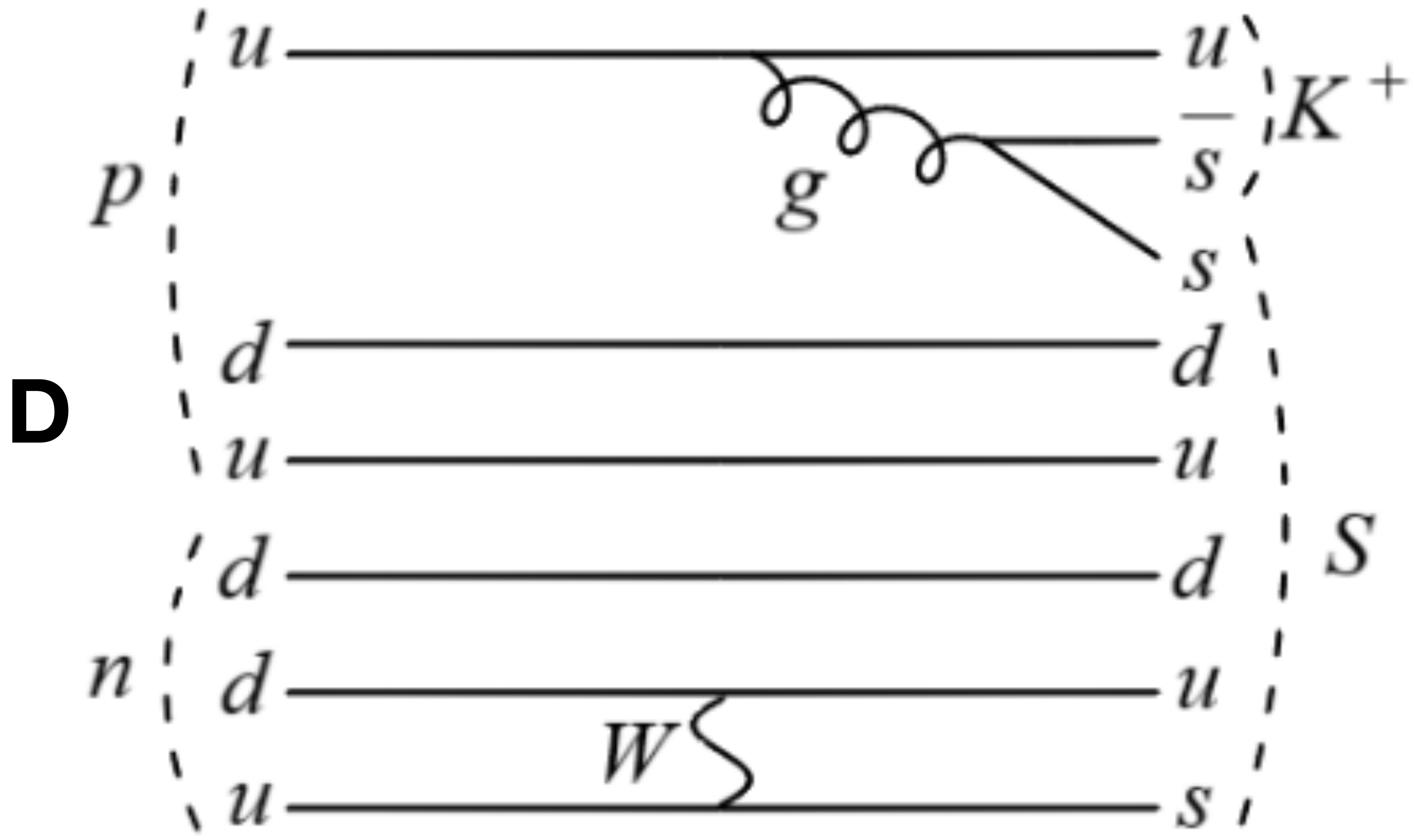
Farrar 1805.03723
Farrar, ZW, Xu 2007.10378

- This talk: study the mass of *S* with QCD sum rules

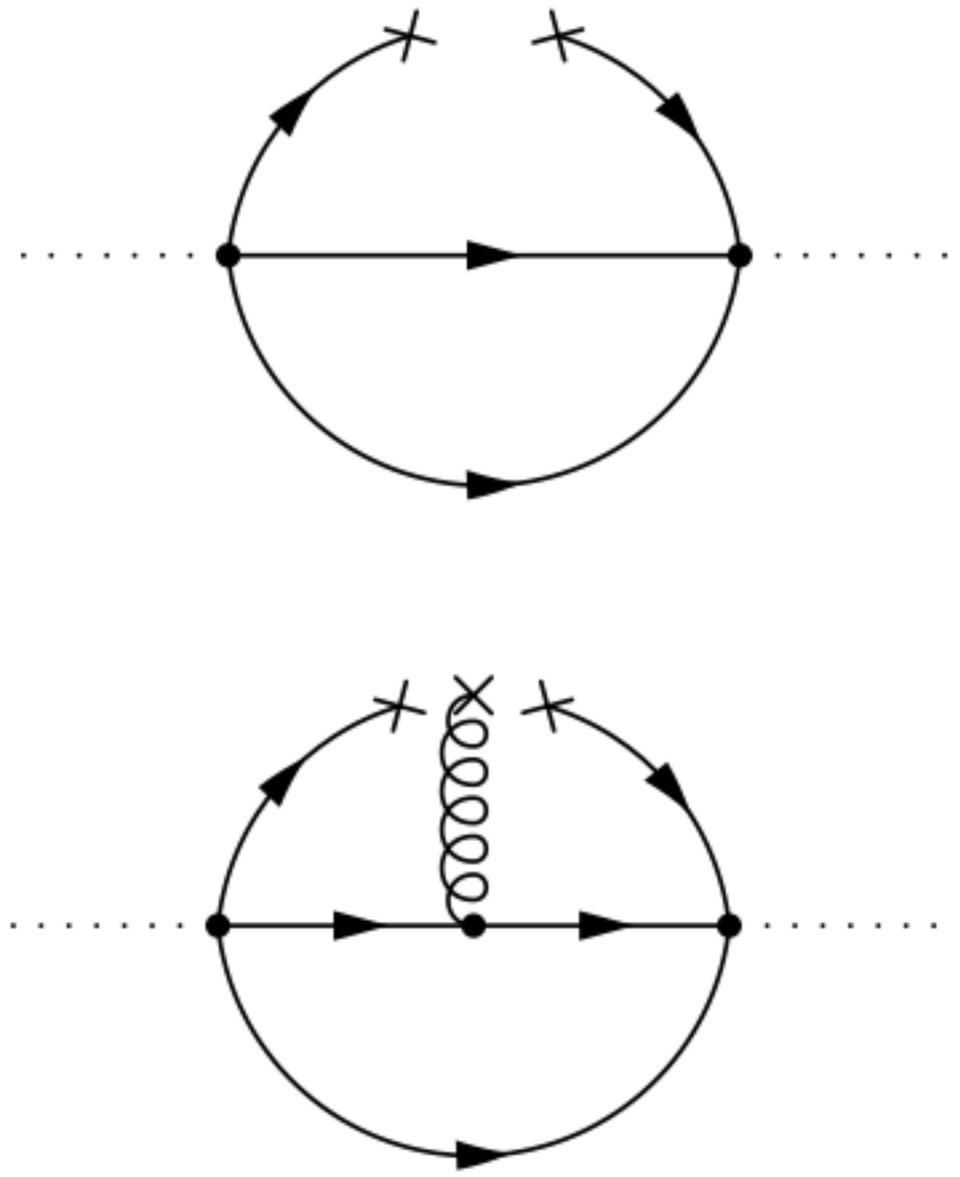
Constraint from deuteron stability

- To escape H-dibaryon searches: $m_S < 2\,\mathrm{GeV}$
- However, low mass destabilizes deuterons
- $m_S < 1.6\,\mathrm{GeV}$: severely constrained by heavy water tank @SNO (Farrar, ZW, Xu 2007.10378)
- $m_S < 1.4\,\mathrm{GeV}$: unacceptable. Deuterons decay via singly-weak processes





QCD sum rules



- Two point function evaluated by OPE, in terms of vacuum condensates of quarks and gluons

$$\Pi(p^2) = -i \int d^4x\, e^{ipx} \langle 0|TJ(x)J^\dagger(0)|0\rangle$$

- Spectral representation of the correlator separates the hadronic pole and continuum, equating hadron mass to $\langle \bar{q}q\rangle, \langle GG\rangle, \langle \bar{q}qG\rangle \ldots$

$$\Pi(p^2) = \int_0^\infty ds \rho(s)/(s - p^2 - i\epsilon) \qquad \rho(s) = f_0^2 \delta(s - m_0^2) + \Theta(s - s_0)\mathrm{Im}\,\Pi(s)$$

(Shifman-Vainshtein-Zakharov 79)
(Ioffe 81)

Need a current *J* consistent with the symmetries of *S*

Structure and symmetry of S

- Quantum numbers: baryon#=2, strangeness=-2, parity=+1; Same as H-dibaryons, but very different physics

S

Q=0, B=2, spin-0
Flavor singlet
(no pion coupling!)
m ~ 1.7-2 GeV

- Singlet under color SU(3) x spin SU(2) x flavor SU(3)
- Unique wavefunction dictated by Fermi statistics (Wintergerst)

$$|S\rangle = \frac{1}{24}\left(\epsilon_{ace}\epsilon_{bdf}\epsilon_{s_i s_m}\epsilon_{s_j s_k}\epsilon_{s_l s_n} - \epsilon_{abe}\epsilon_{cdf}\epsilon_{s_i s_m}\epsilon_{s_j s_l}\epsilon_{s_k s_n}\right) u^\dagger_{a,s_i} u^\dagger_{b,s_j} d^\dagger_{c,s_k} d^\dagger_{d,s_l} s^\dagger_{e,s_m} s^\dagger_{f,s_n} |\Omega\rangle$$

Color singlets Spin singlets

Prior works

- Kodama et al (94) performs sum rule analysis for H-dibaryons based on an analogy with deuterons $\rightarrow m_H = 2.2\,\mathrm{GeV}$
    - However, deuterons are spin-1 and loosely-bound
- Azizi at al (1904.09913) considers *S* as triple diquarks *(ud)(ds)(su),* they find $m_S = 1.2\,\mathrm{GeV}$ assuming a low continuum threshold
    - Excluded by deuteron stability. Would be a big problem for QCD!

Constructing the current *Js*

$$|S\rangle = \frac{1}{24}(\epsilon_{ace}\epsilon_{bdf}\epsilon_{s_i s_m}\epsilon_{s_j s_k}\epsilon_{s_l s_n} - \epsilon_{abe}\epsilon_{cdf}\epsilon_{s_i s_m}\epsilon_{s_j s_l}\epsilon_{s_k s_n})u^\dagger_{a,s_i}u^\dagger_{b,s_j}d^\dagger_{c,s_k}d^\dagger_{d,s_l}s^\dagger_{e,s_m}s^\dagger_{f,s_n}|\Omega\rangle$$

- Want a <u>scalar</u> current made of six quarks with <u>even parity</u>

- Only two ways of construction

Not a convenient decomposition to guarantee overall symmetry

1. Two color singlets: $J_S = \sum_{B_1 B_2} J^T_{B_1} C\gamma^5 J_{B_2}$
2. Three spin singlets: $J_S = \sum_{\text{flavor,color}} (q^T C\gamma^5 q)(q^T C\gamma^5 q)(q^T C\gamma^5 q)$ (scalar)^3

$$\left(+ \sum_{\text{flavor,color}} (q^T C q)(q^T C q)(q^T C\gamma^5 q) \right)$$ (pseudoscalar)^2(scalar)

$(\text{scalar})^3$

$$\sum_{\text{flavor,color}} (q^T C\gamma^5 q)(q^T C\gamma^5 q)(q^T C\gamma^5 q)$$

Zeroth order calculation:

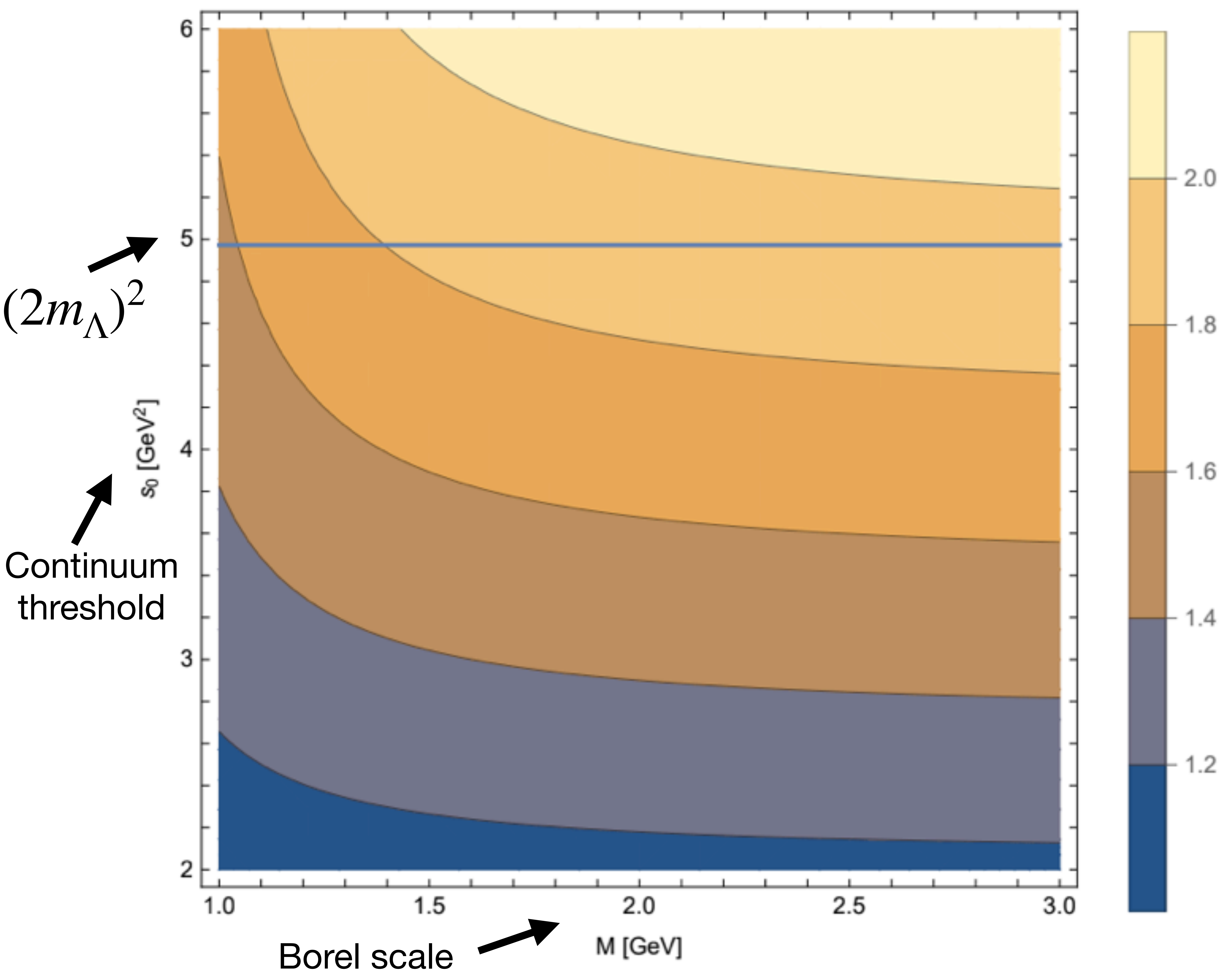
- Quark condensates only
- Massless quarks

With the physical threshold

$$s_0 = (2m_\Lambda)^2$$

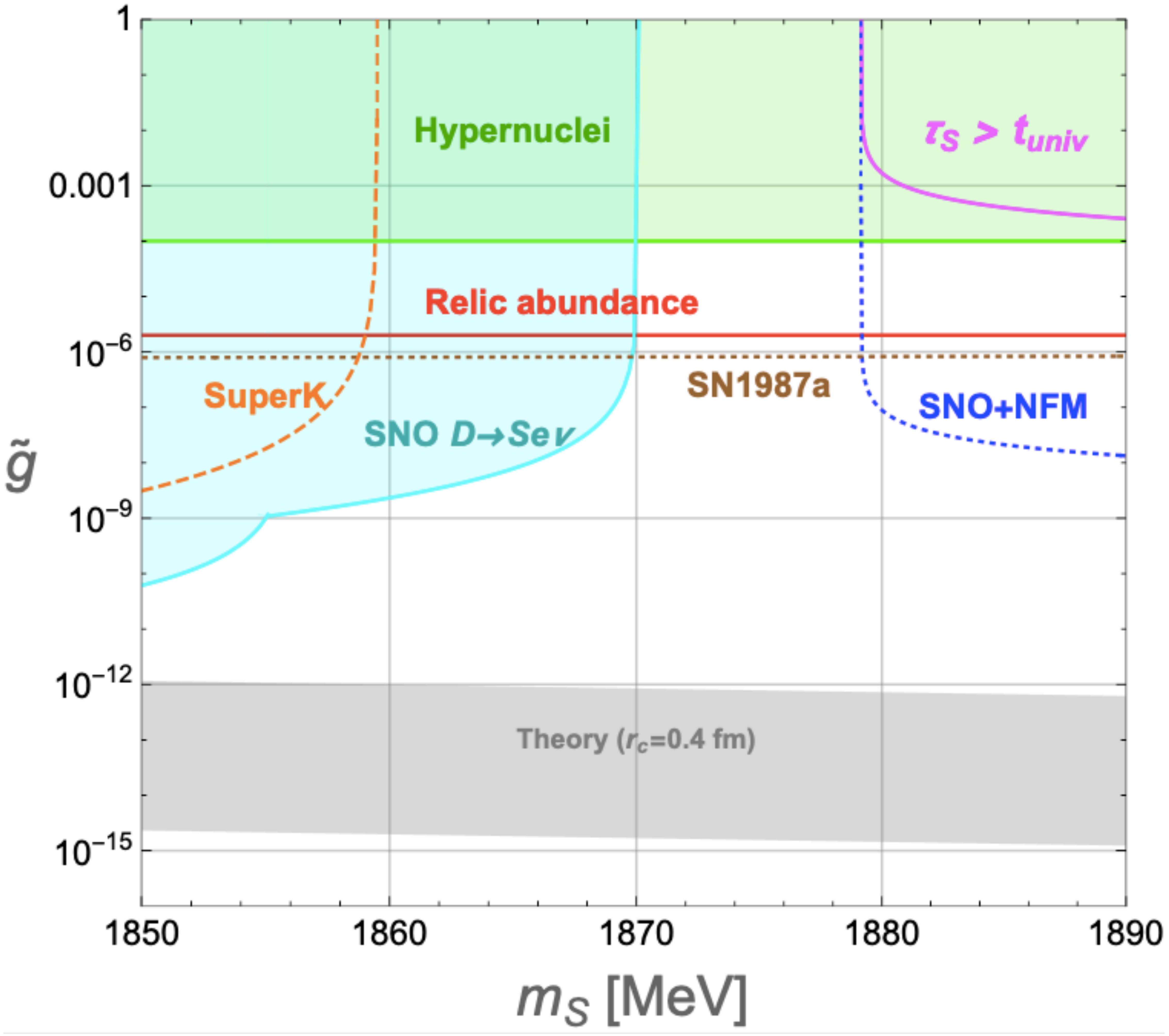
we predict $m_S = 1.5\text{-}1.9$ GeV

SU(3) breaking leads to extra ~200-300 MeV of mass



Summary

- Symmetries of S -> current J
- Sum rule analysis predicts a bound state, possibly < 1.9 GeV (need NLO calculation)
- Experimental constraints



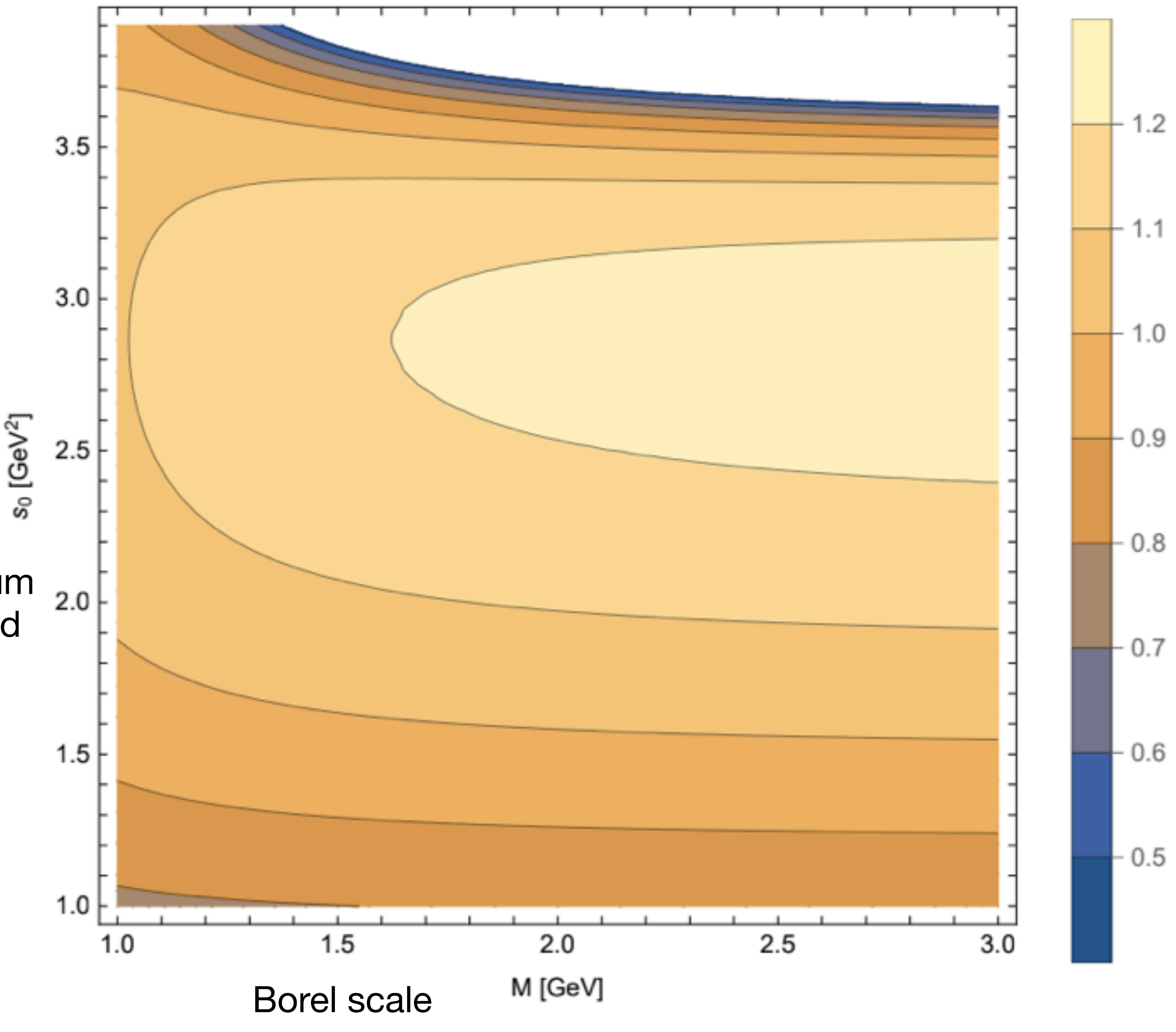
(Farrar, ZW, Xu 2007.10378)

$$\sum_{\text{flavor,color}} (q^T C q)(q^T C q)(q^T C \gamma^5 q)$$

Zeroth order calculation:

- Quark condensates only
- Massless quarks

Continuum threshold



Borel scale

Deeply-bound $m_S < 1.3\,\mathrm{GeV}$,
but nonexistent if threshold $s_0 > 4\,\mathrm{GeV}^2$