Thermal production of sexaquarks in heavy ion collisions

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on behalf of

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Outline

I Introduction
II uuddss recent searches
III Thermal model results on uuddss
IV Summary, Conclusions and Outlook

H-uuddss

The uuddss dibaryon state has been initially proposed by Robert Jaffe (MIT) who made a bag model based calculations and predicted the so called H-dibaryon with a mass below 2m(Lambda) of about 2150 MeV and unstable.

R. L. Jaffe, Phys. Rev. Lett. **38**, 195 (1977)

The H dibaryon has been searched by several experiments without finding it.

B. H. Kim et al. (Belle), Phys. Rev. Lett. **110**, 222002 (2013), arXiv:1302.4028 [hep-ex].
J. Badier et al. (NA3), Z. Phys. **C31**, 21 (1986).
R. H. Bernstein, T. K. Shea, B. Winstein, R. D. Cousins, J. F. Greenhalgh, M. Schwartz, G. J. Bock, D. Hedin, and G. B. Thomson, Phys. Rev. **D37**, 3103 (1988).
J. Belz et al. (BNL-E888), Phys. Rev. Lett. **76**, 3277 (1996), [Phys. Rev.C56,1164(1997)], arXiv:hep-ex/9603002 [hep-ex].
A. Alavi-Harati et al. (KTeV), Phys. Rev. Lett. **84**, 2593 (2000), arXiv:hep-ex/9910030 [hep-ex].
H. Gustafson et al., Phys. Rev. Lett. **37**, 474 (1976).

S-uuddss

Recently a new possibility for the uuddss multiquark state has been proposed by Glennys Farrar (NYU) in which the uuddss is a state with small radius (0.1-0.4 fm) and mass below 2 GeV (so called Sexaquark).

Such a state could exist and could have escaped the experimental searches till now, since (depending on its mass) it can be absolutely stable or have a lifetime of the order of the age of the universe.

Such a stable state could be a candidate for Dark Matter, if produced out of the primordial Quark Gluon Plasma at the QCD phase transition from partons to hadrons.

G. R. Farrar, (2017), arXiv:1708.08951 [hep-ph] and
G. R. Farrar, (2018), arXiv:1805.03723 [hep-ph]

S-uuddss

The uuddss state can be maximally bound due to its symmetry.

Due to being a flavor singlet it does not bind to pions resulting in a compact configuration.

Assuming it can bind to lightest flavor singlet mesons like the f0 a radius of 0.1-0.3 fm is estimated.

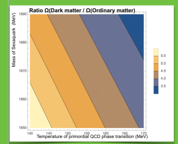
The different size of the S and baryons means that amplitudes involving the S and 2 baryons are strongly suppressed.

Lacking coupling via pions its interaction with matter is lower than that of ordinary hadrons supporting the hypothesis it can be a DM candidate.

G. R. Farrar, (2017), arXiv:1708.08951 [hep-ph] and
G. R. Farrar, (2018), arXiv:1805.03723 [hep-ph]

S-uuddss

Calculation of the ratio of Dark Matter (DM) to Ordinary Matter (OM) assuming production of S(uuddss) from the Quark Gluon Plasma at the early Universe at a temperature of 140-170 MeV is shown in figure below



y-axis: m(Sexaquark) in MeV
x-axis: Freeze out Temperature

The measured value for DM/OM of 5.3+- 0.1 is in the second from lightest band.

Therefore the assumption of the Sexaquark as DM candidate leads to agreement with the measured DM/OM ratio for masses below 1885 MeV and at freeze out T below 153 MeV.
However all values of the entire plot are within factor of 2 from the measured value

G. R. Farrar, (2017), arXiv:1708.08951 [hep-ph] and G. R. Farrar, (2018), arXiv:1805.03723 [hep-ph]

S-uuddss

The previous calculation of the ratio of Omega Dark Matter to Omega Ordinary Matter assuming a Sexaquark as DM candidate is valid for all forms of DM including equal u,d,s parts (like stable sexaquarks, quark nuggets or primordial black holes) or a combination of them.

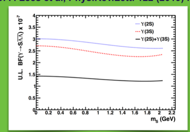
As a result the observed value of Omega(DM)/Omega(Matter) has been reproduced by assuming that DM is composed of equal number of u,d,s quarks

G. R. Farrar, (2017), arXiv:1708.08951 [hep-ph] and G. R. Farrar, (2018), arXiv:1805.03723 [hep-ph]

Experimental searches

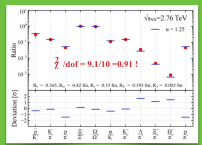
Even though not everyone agrees, its possible cosmological implications as DM candidate cannot be excluded and it has been recently searched in the BaBar experiment that set upper limits .

BABAR Coll. J. P. Lees et al, Phys.Rev.Lett. 122 (2019) no.7, 072002



90% confidence level upper limits on the branching fraction Upsilon(2S,3S) —> S + antiLambda + antiLambda as well as the combined sample

Hadron Resonance Gas Model (HRGM) with Induced Surface Tension EOS Results for LHC energy



Light (anti)nuclei are not included into fit

V.V. Sagun et al., Eur. Phys. J. A (2018) 54: 100

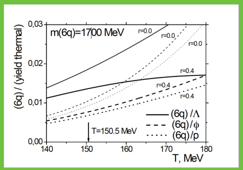
Radii are taken from the fit of AGS, SPS and RHIC data => single parameter Tcfo=150+-4MeV

Combined fit of AGS, SPS, RHIC and LHC data $\chi^2_{tot}/dof \simeq 64.8/60 \simeq 1.08$

K. A. Bugaev et al., Nucl. Phys. A970 (2018) 133-155 and references therein,
K. A. Bugaev et al., Universe 5 (2019) 63

Thermal production of S-uuddss in heavy ion collisions

PRELIMINARY



D. Blaschke et al, Int.J.Mod.Phys.A 36 (2021) 25, 2141005

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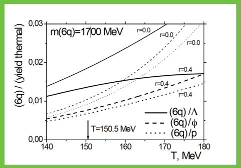
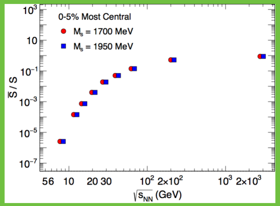
PRELIMINARY



D. Blaschke et al, Int.J.Mod.Phys.A 36 (2021) 25, 2141005

Antisexaquark to Sexaquark ratio vs collision energy in Au+Au collisions for two assumed masses



Thermal model calculation based on
S. Kabana, P. Minkowski, New J.Phys. 3 (2001) 4

Summary, Conclusions and Outlook

* In the framework of the thermal model by K. Bugaev et al, and of another thermal model by S. Kabana and P. Minkowski, we estimated ratios of Sexaquarks uuddss to hadrons.

* Sexaquarks are produced at relatively high rates, for vanishing and finite radius of 0.4 fm, and for masses of 1700 and 1950 MeV at the LHC.

* At T=170 MeV at LHC the ratio of thermal Sexaquark with mass 1950 GeV to thermal deuteron is about 0.45

* Antisexaquark ratios are shown here for the first time and are maximal at top RHIC energy and similar to LHC.