Exotic hadron predictions in heavy ion collisions

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on behalf of

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Outline

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III Thermal model results on uuddss

IV Summary, Conclusions and Outlook

I Introduction

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-uudds

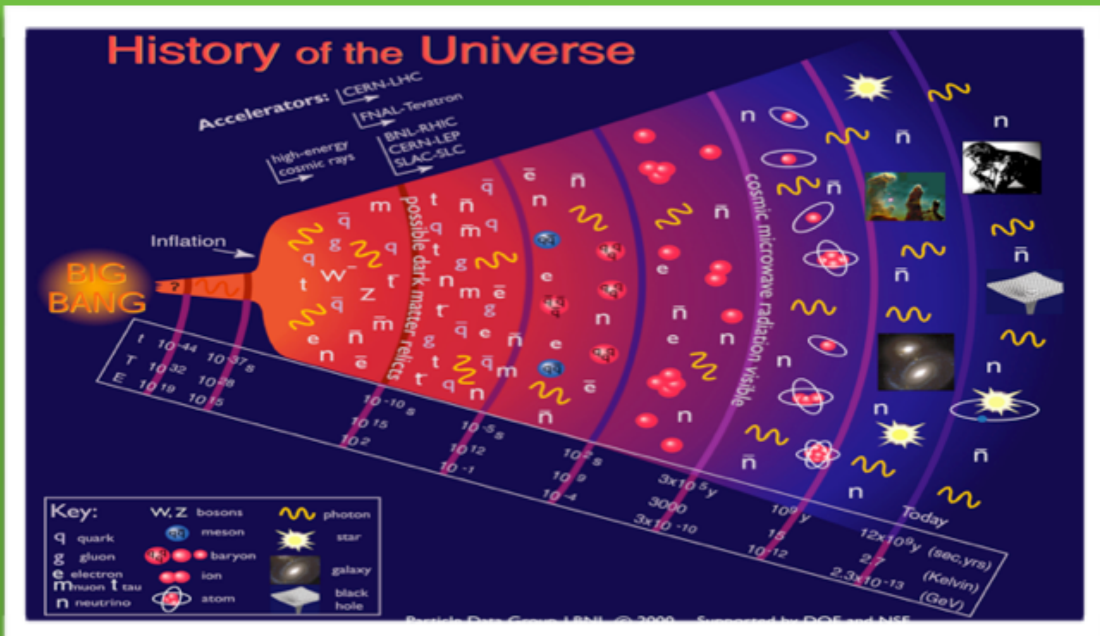
Recently a new possibility for the uuddss multiquark state has been proposed by Glennys Farrar (NYU) in which the uuddss is a state with small radius (0.1-0.4 fm) and mass below 2 GeV (so called Sexaquark).

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]

The QCD phase transition

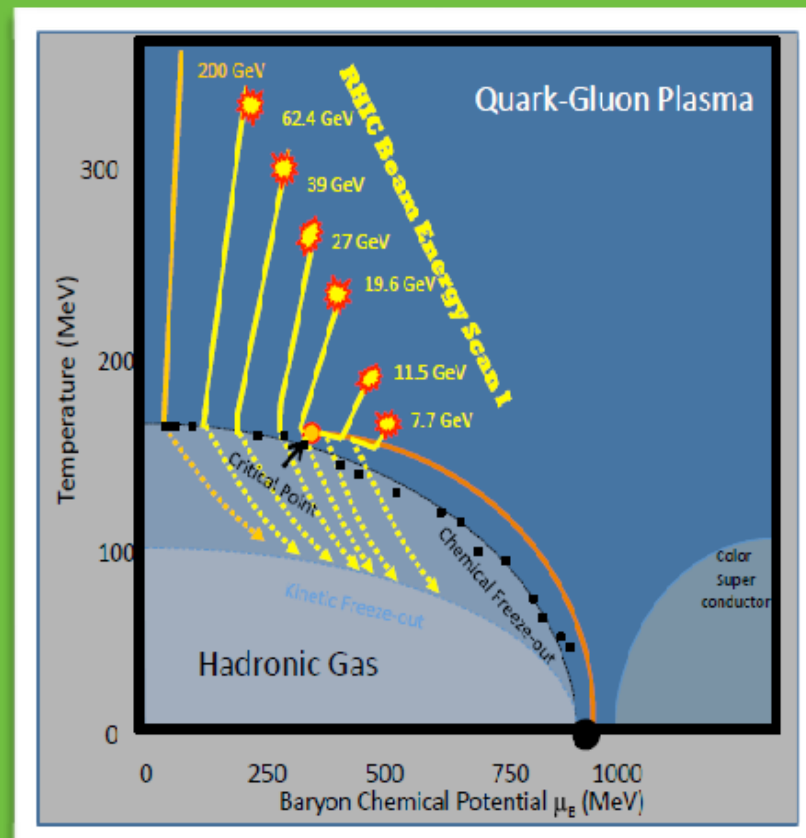


The transition from quarks and gluons to hadrons is believed that took place few 10-6 sec after the Big Bang

Lattice QCD predicts at zero baryon density a crossover with a pseudocritical temperature

Tc~156.5+/-1.5 MeV

(**A. Bazanov et al,** Phys. Lett. B \textbf{795}, 15-21 (2019).)



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.

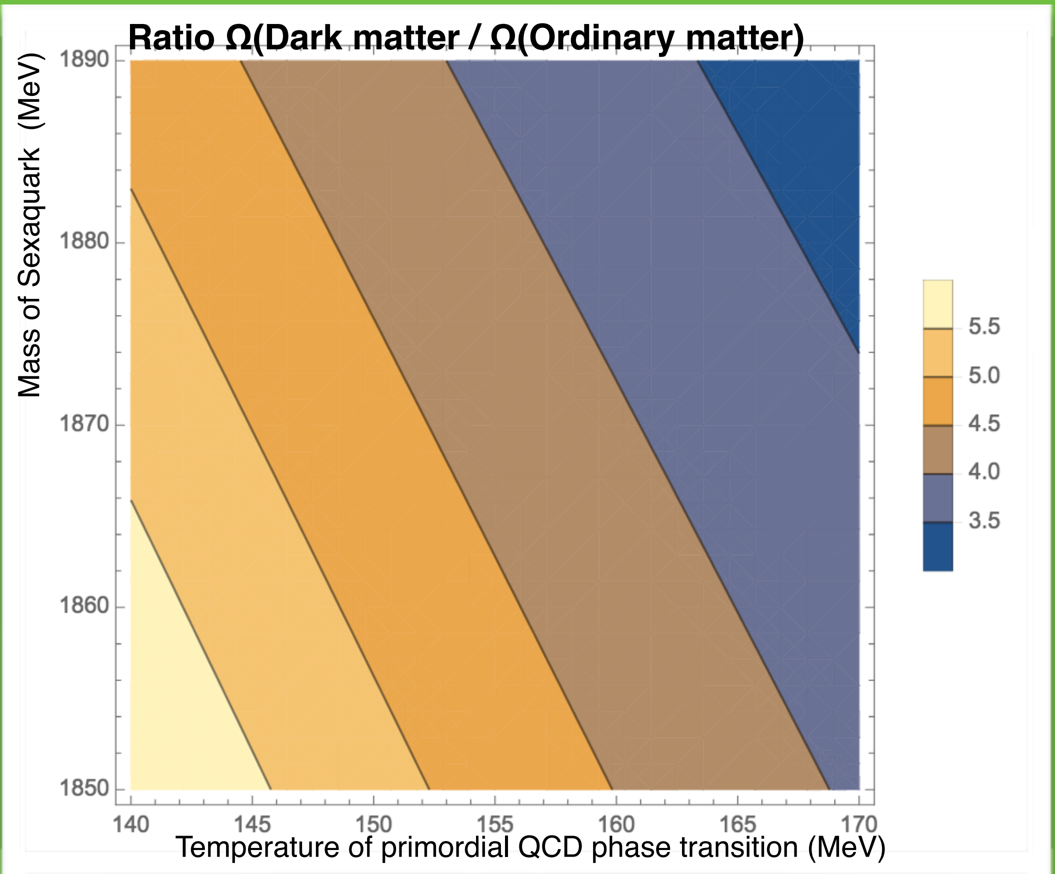
The different size of the S and baryons means that amplitudes involving the S and 2 baryons are strongly suppressed.

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]

II uuddss recent searches

Methods

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

One proposed method to observe the S-uuddss is via the Upsilon decay in Upsilon factories, namely as missing mass due to the S or anti-S production in association with di-anti-Lambda or di-Lambdas

$$\Upsilon \ [\to \text{gluons}] \to S\,\bar{\Lambda}\,\bar{\Lambda} \ \text{ or } \bar{S}\,\Lambda\,\Lambda \ + \text{pions and/or } \gamma$$

Other possibility that can be used is the following:

$$\bar{S} + N \to \bar{\Xi}^{+,0} + X, \text{ with } \bar{\Xi}^{+,0} \to \bar{\Lambda}\pi^{+,0} \,\&\, \bar{\Lambda} \to \bar{p}\pi^{+}$$
$$\text{or } \bar{S} + N \to \bar{\Lambda} + K^{+,0} + X. \quad (2)$$

Kolb and Turner

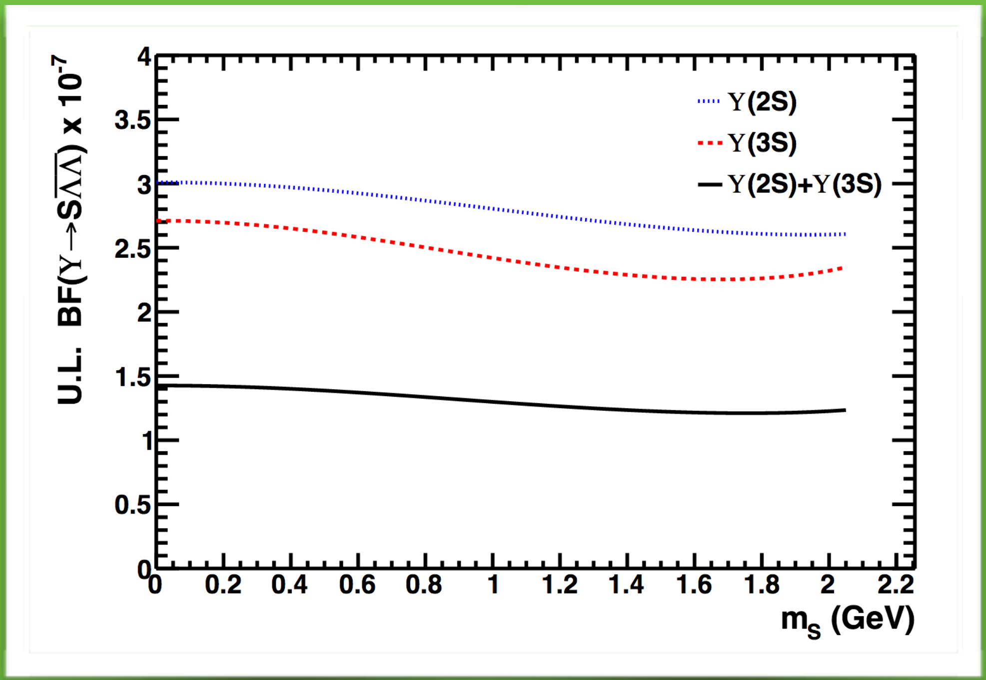
Kolb and Turner argue that the Sexaquark abundances will freeze out at about Temperature of 10 MeV following decrease in number of Lambdas and very small abundance of S-uuddss remain at that Temperature.

E. Kolb, M. Turner,Phys.Rev. D99 (2019) no.6, 063519

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

Experimental searches

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

In conclusion, we performed the first search for a stable $uuddss$ configuration in Υ decays. No signal is observed, and 90% CL limits on the combined $\Upsilon(2S,3S) \to S\bar{\Lambda}\bar{\Lambda}$ branching fraction of $(1.2-1.4)\times 10^{-7}$ are derived for $m_S < 2.05\,\mathrm{GeV}$. These results set stringent bounds on the existence of a stable, doubly strange six-quark state.

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

The predicted inclusive branching fraction of S in Upsilon decays is of the order ~10^{-7}. and the exclusive to inclusive ratio for Upsilon decay is typically <~ 10^{-4}, so no exclusive signal would have been expected at the level of sensitivity of BABAR which is 10^{-7} in the exclusive channel.

Thermal production of S-uuddss in heavy ion collisions

Thermal models can successfully describe hadron production in heavy ion collisions at high energy.

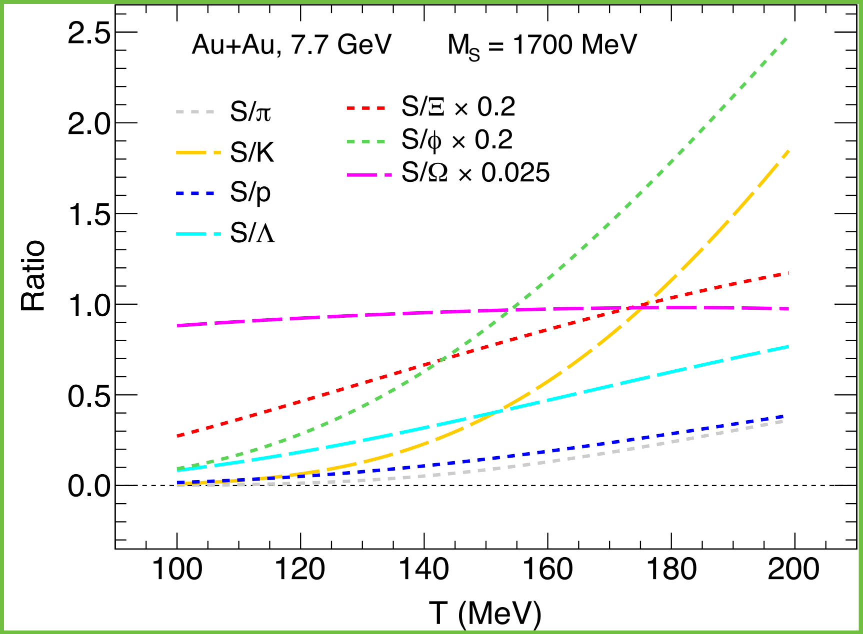
We use a model that has proven to describe particle production with a thermal assumption very successfully, in order to predict abundance of Sexaquarks in heavy ion colisions at RHIC.

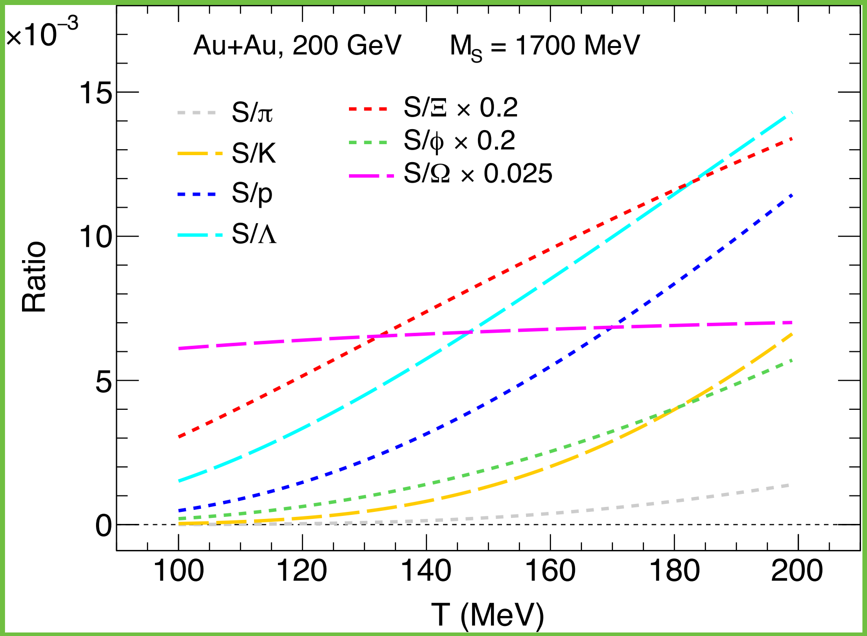
Model: Sonja Kabana and Peter Minkowski
New Journal of Physics, Volume 3, January 2001

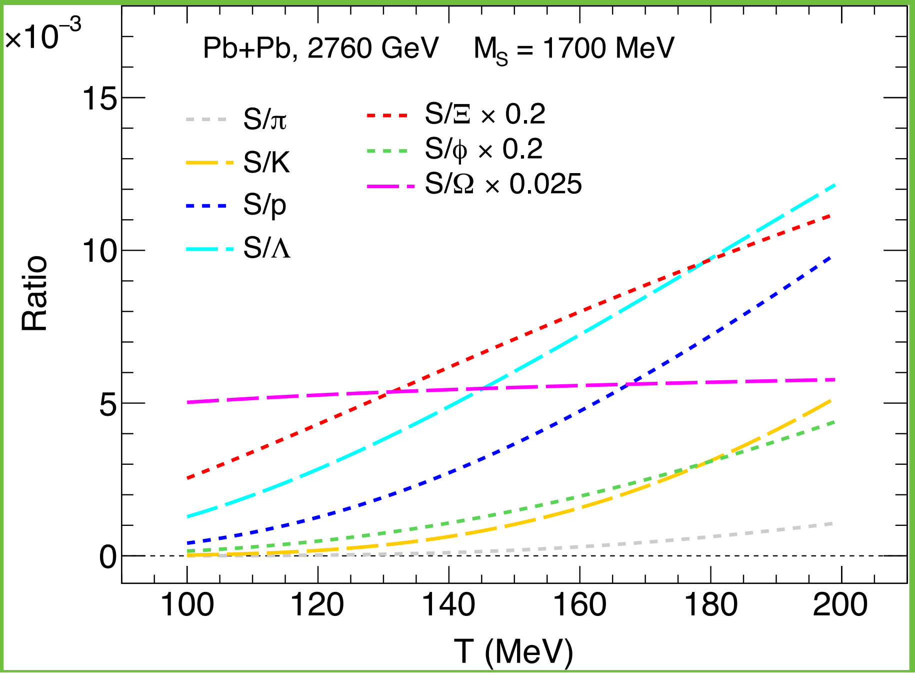
III Thermal model results on uuddss

Predictions for Au+Au collisions at RHIC for R=0

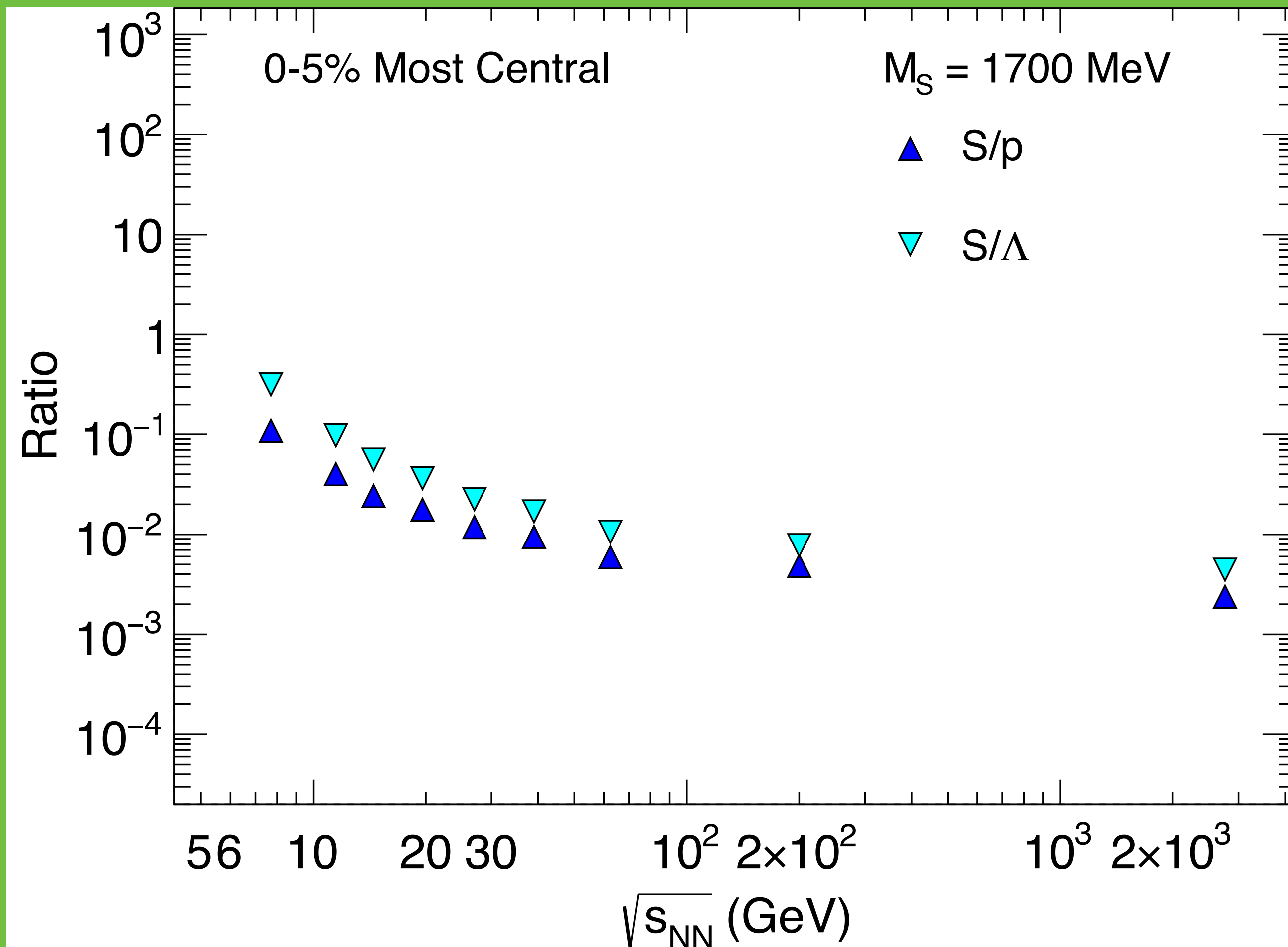
Temperature dependence of sexaquark ratios at 1700 MeV in Au+Au at 3 energies





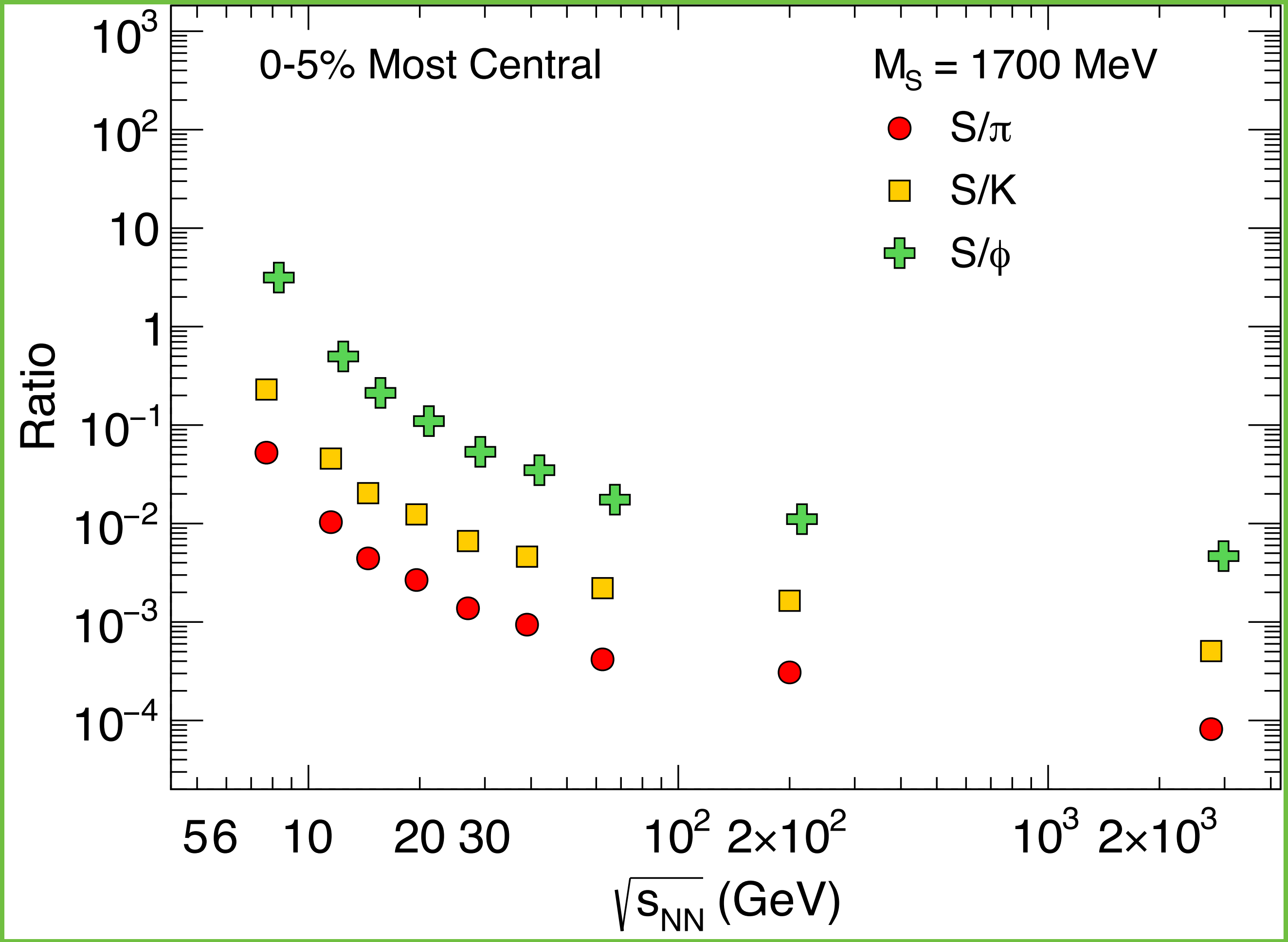


Sexaquark ratios to protons and Lambdas in Au+Au collisions as a function of collision energy for mass 1700 MeV

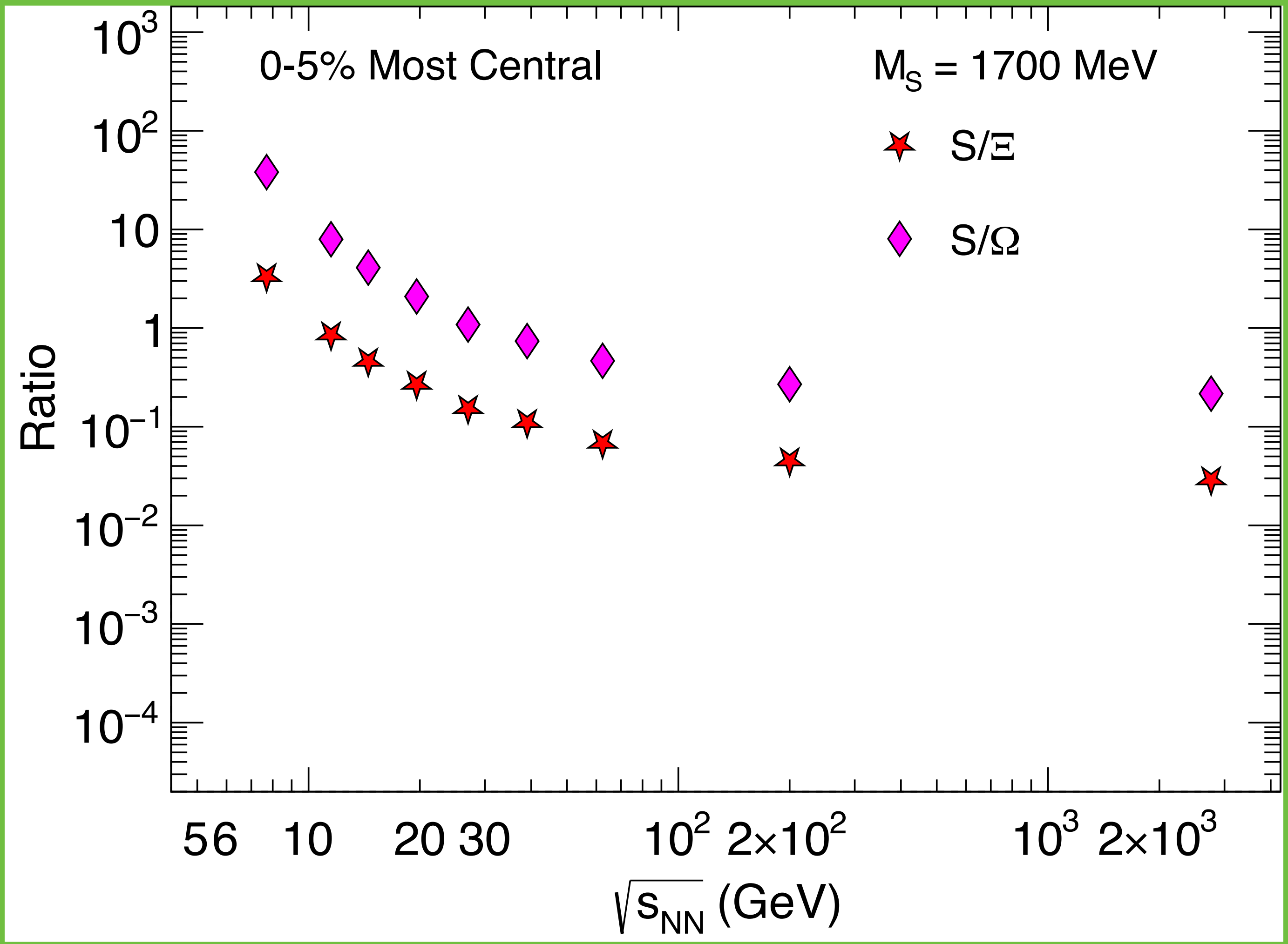


Promising for FAIR and NICA

Sexaquark ratios to mesons in Au+Au collisions as a function of collision energy for mass of 1700 MeV



Sexaquark ratios to strange baryons in Au+Au collisions as a function of collision energy for mass of 1700 MeV



IV Summary, Conclusions and Outlook

Summary, Conclusions and Outlook

* In the framework of the thermal model by S. Kabana and P. Minkowski, we estimated for the first time ratios of Sexaquarks uuddss to hadrons at RHIC.

* Sexaquarks are produced at relatively high rates, especially at very low energy where NICA and FAIR will measure in the future.

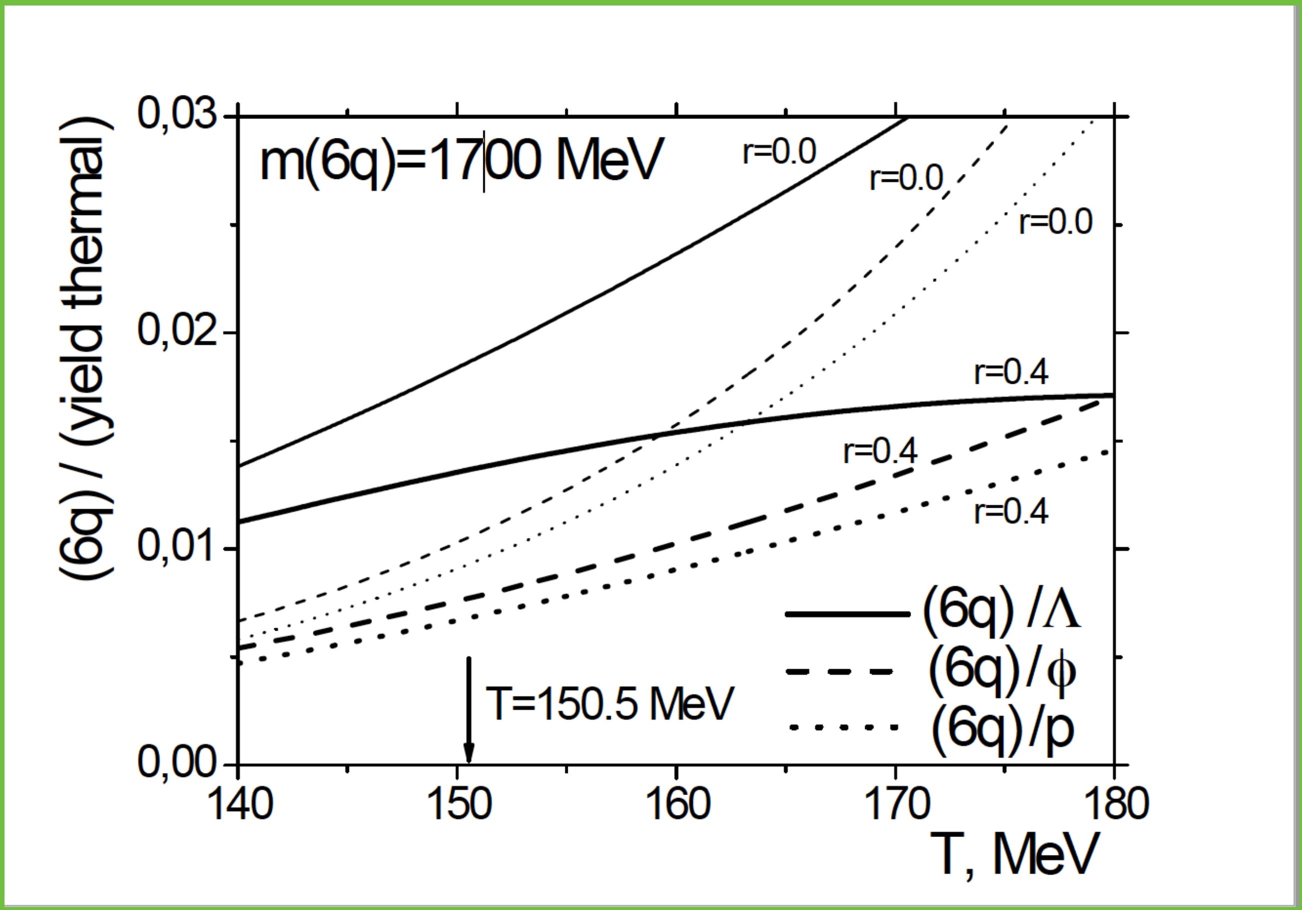
Thank you very much

Backup slides

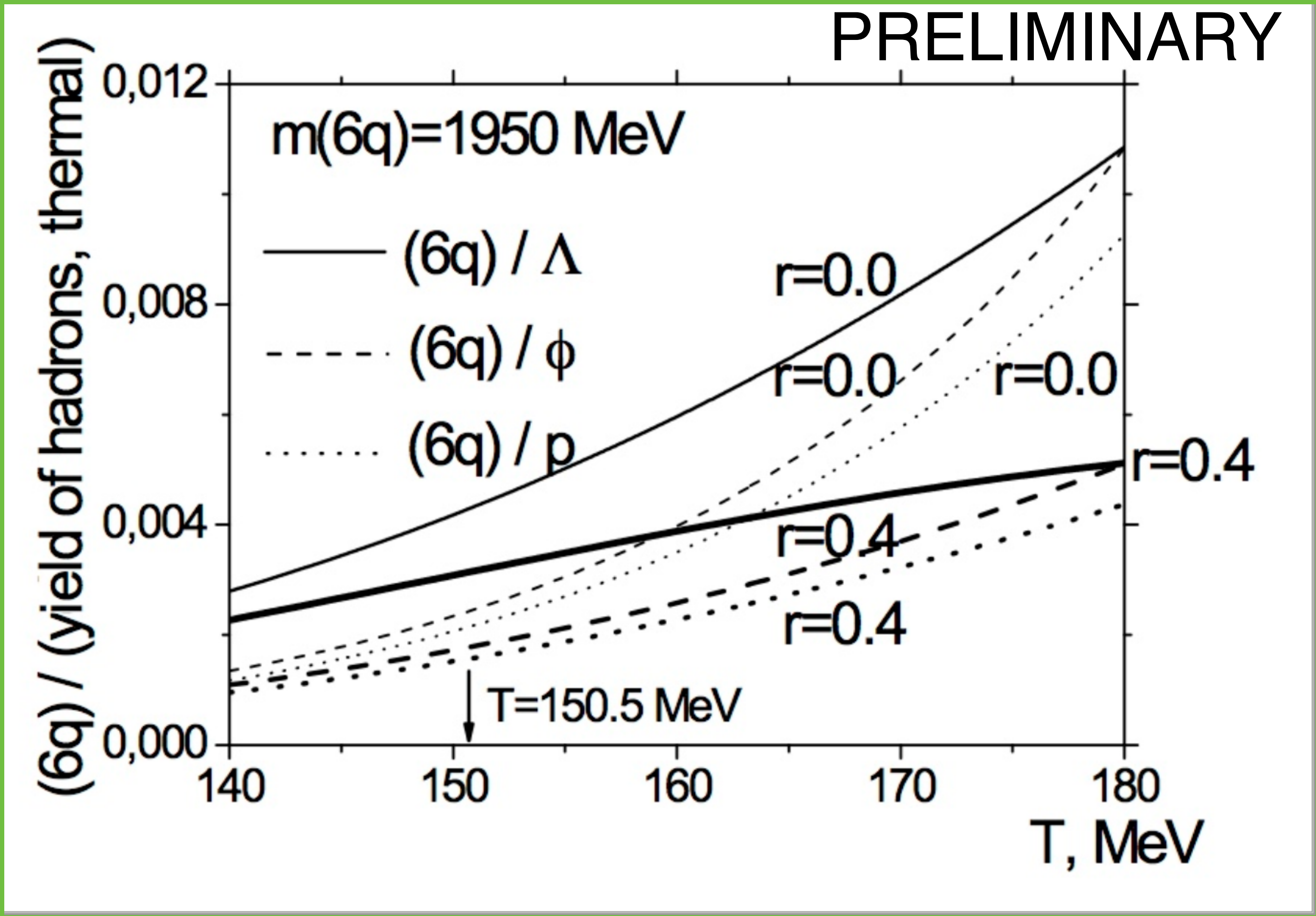
Predictions for LHC Pb+Pb

Thermal production of S-uuddss in heavy ion collisions

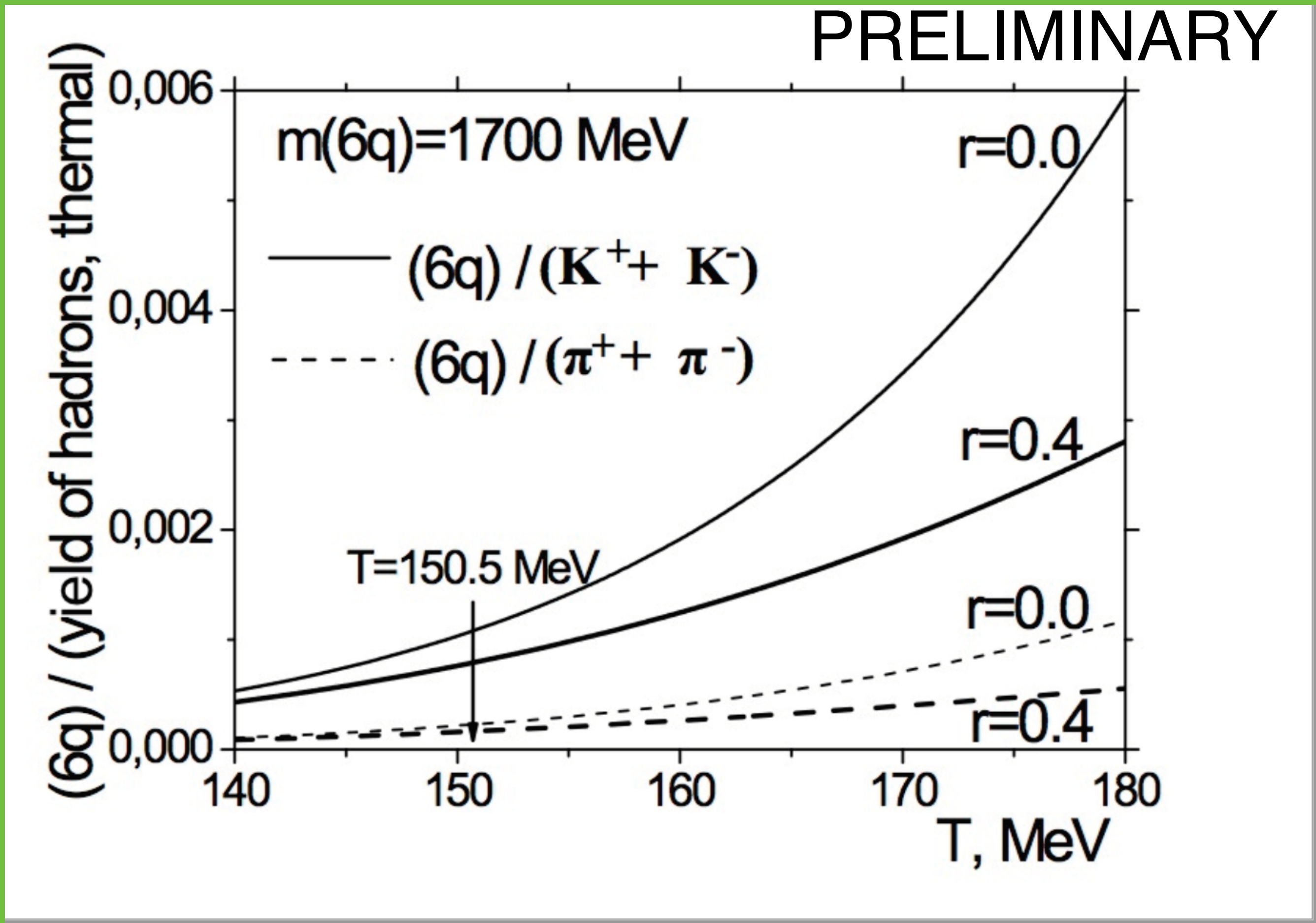
PRELIMINARY



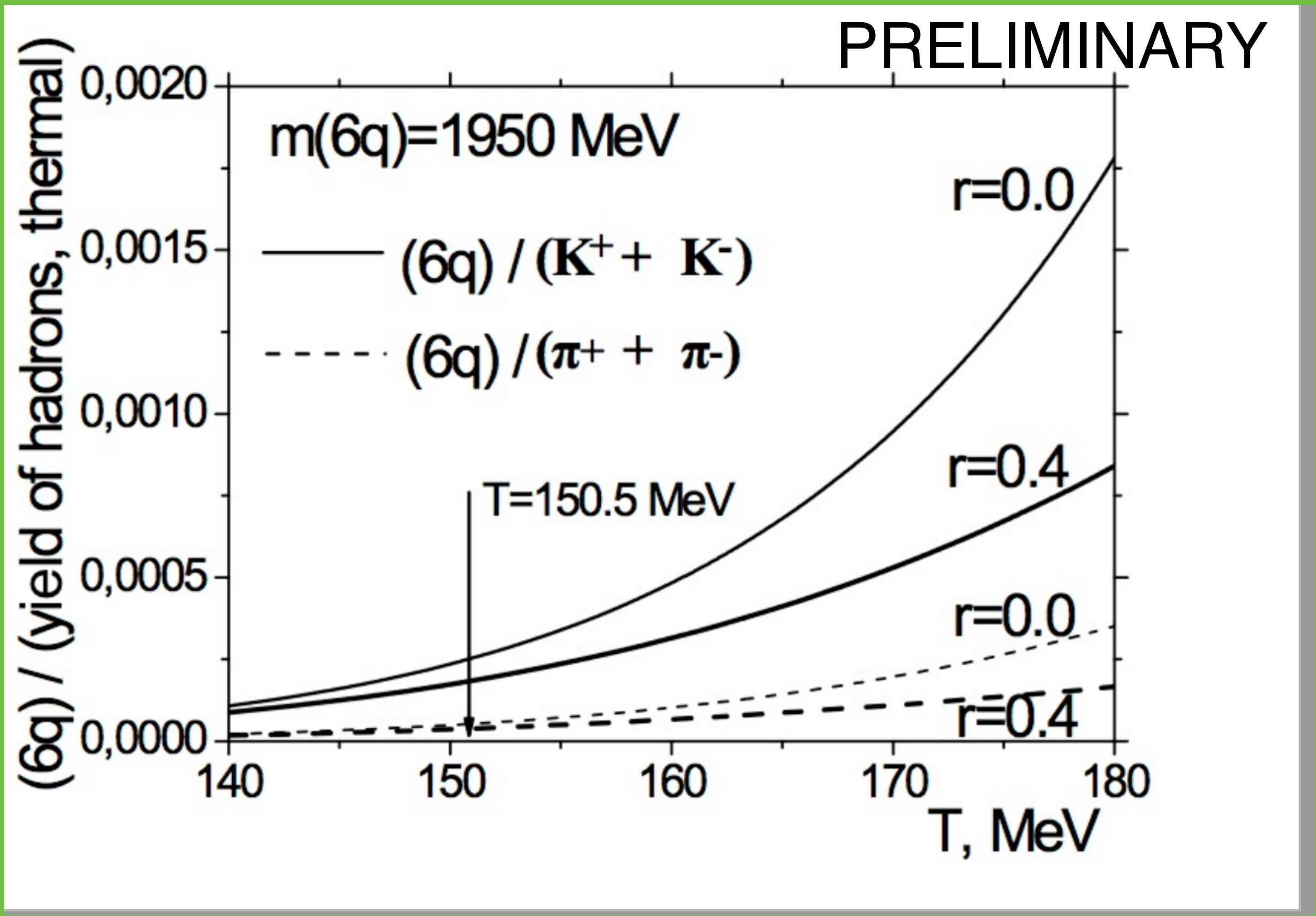
Thermal production of S-uuddss in heavy ion collisions



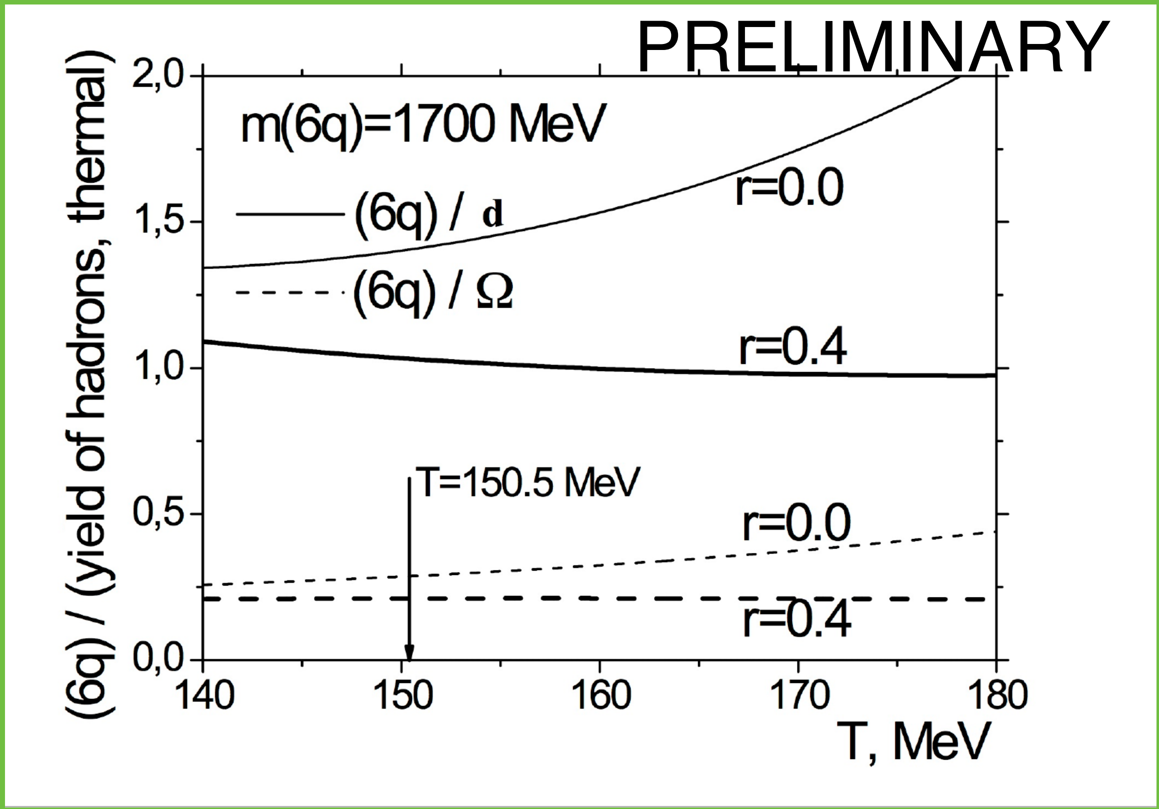
Thermal production of S-uuddss in heavy ion collisions



Thermal production of S-uuddss in heavy ion collisions

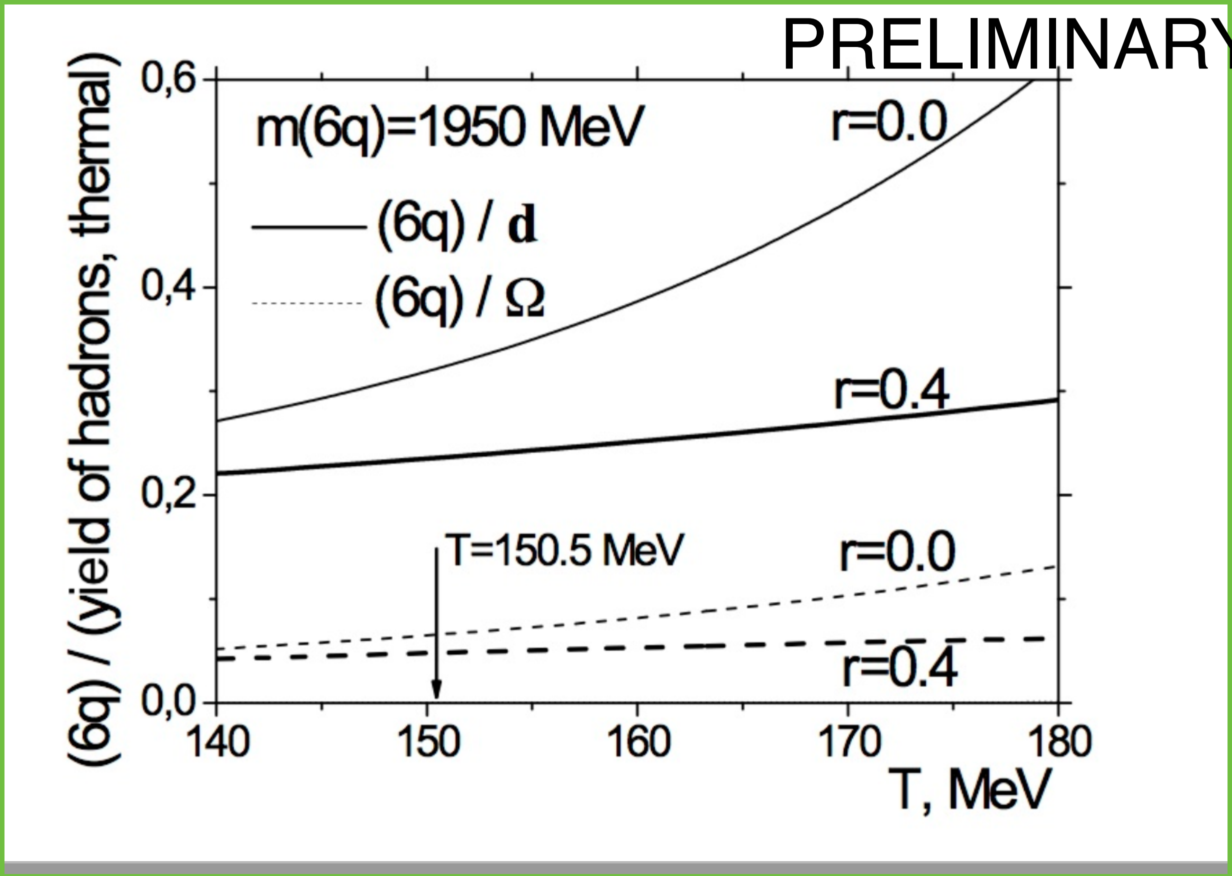


Thermal production of S-uuddss in heavy ion collisions



ICNFP 2019, D. Blaschke et al.

Thermal production of S-uuddss in heavy ion collisions



Hadron Resonance Gas Model (HRGM) with multi-component hard-core repulsion (MHRGM)

- Fit gives T~ 151+-7 MeV and chi^2/DOF=0,8

K.A. Bugaev et al. / Nuclear Physics A 970 (2018) 133–155

Pb+Pb
sqrt(s)= 2.76 TeV

with hard-core radii

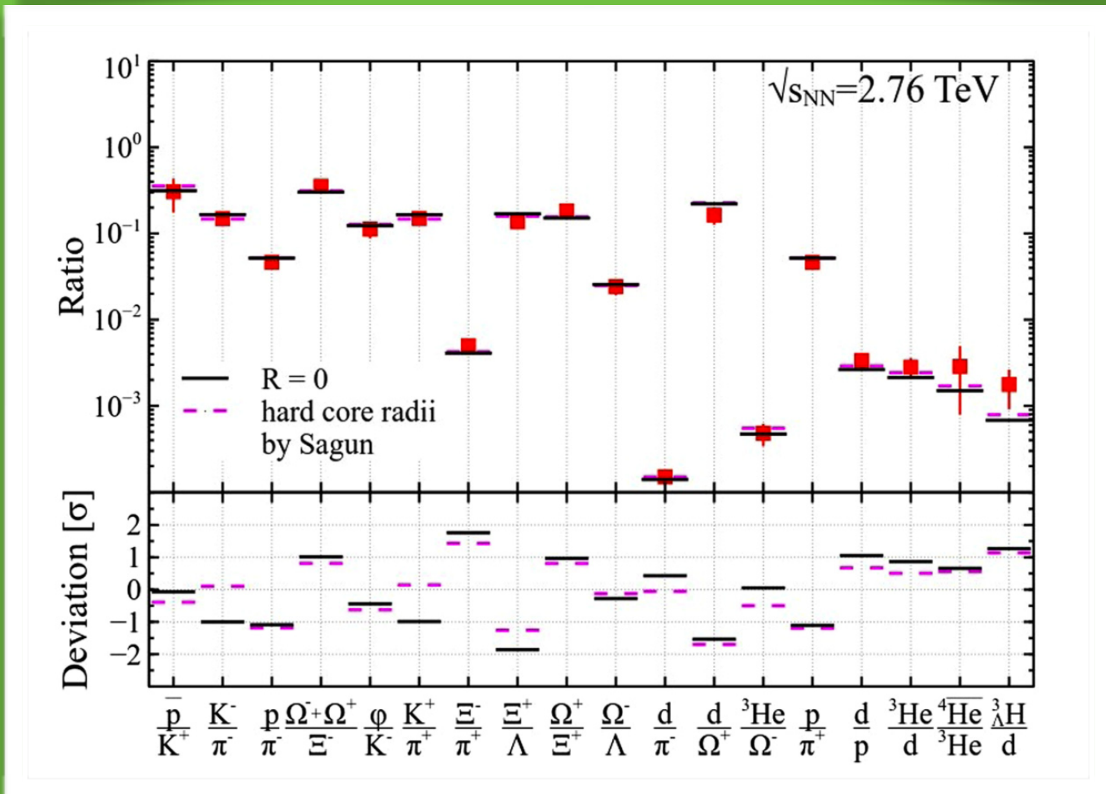
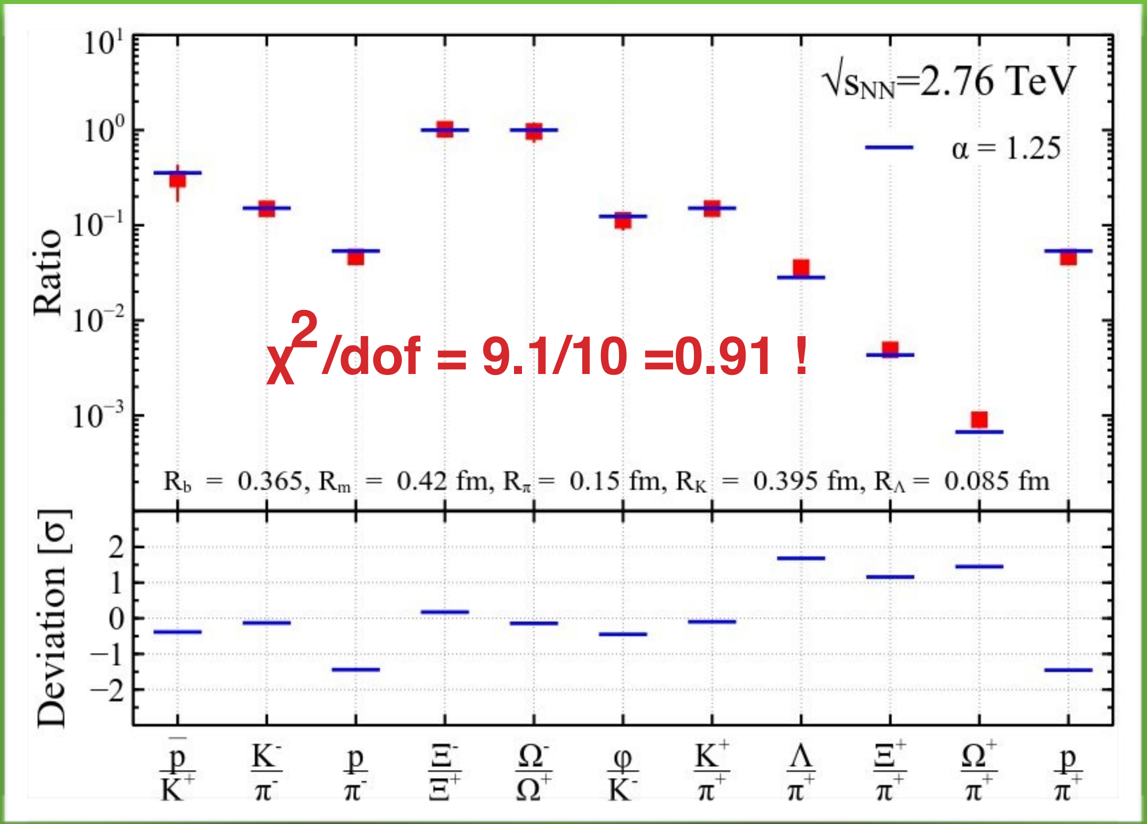


Fig. 3. The full set of ALICE data (see Table 2) was fitted by the MHRGM with the hard-core radii taken from Ref. [5] with the CFO temperature $T_{CFO} \simeq 151 \pm 7$ *MeV and* $\chi^2/ndf \simeq 13.827/17 \simeq 0.8$. *For a comparison the ideal gas fit results are also shown which correspond to* $T_{CFO} \simeq 148 \pm 7$ *MeV and* $\chi^2/ndf \simeq 19.63/17 \simeq 1.15$. The upper panel shows the fit of the ratios, while the lower panel shows the deviation between data and theory in units of estimated error.

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