Dynamical quarkonia suppression in a realistic AA background

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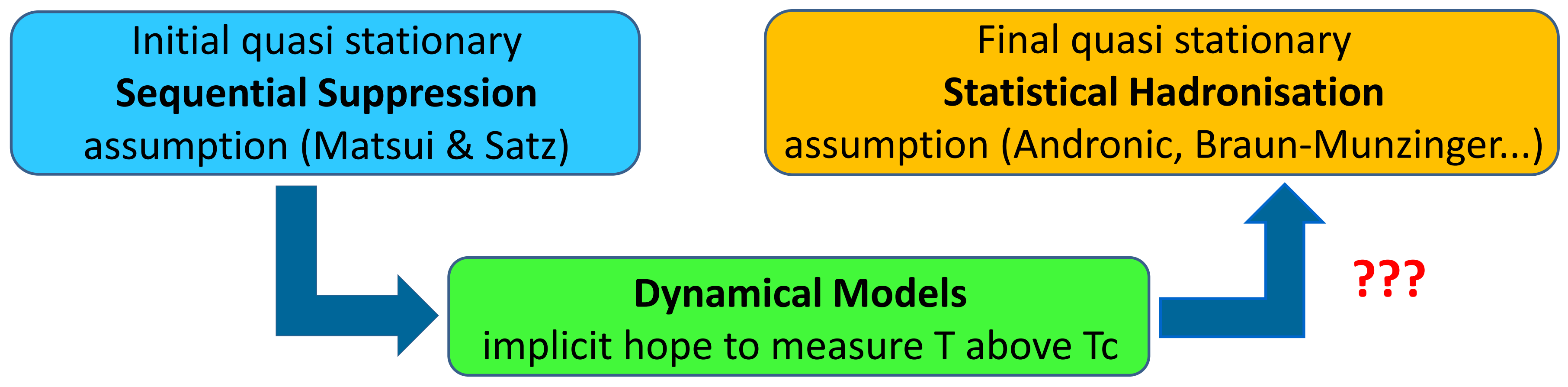
Abstract: The suppression of the quarkonium states in AA collisions, observed at RHIC and LHC, is one of the most convincing evidence for the creation of the Quark Gluon Plasma (QGP). The precise survival of excited states vs ground states could even allow to measure the temperature reached in those collisions. In our contribution, we address the question of charmonium and bottomonium dissociations resorting to a dynamical approach: the non-linear Schroedinger-Langevin equation (SLE).
In this scheme, a time-dependent real potential reflects the Debye-screening of the heavy quark/antiquark pair self interaction, while a fluctuation/dissipation mechanism expresses its hard interactions with the QGP. The SLE enables to treat transitions to open quantum states and between bound states, which play an important role for excited state final populations. It allows to consider a realistic compact initial state, made of a linear superposition of eigenstates and to preserve quantum coherence and unitarity in the time-evolution of a pair. In a stationary QGP, our SLE naturally leads to asymptotic distributions of the states following correct statistical weights, which allows to make the link with models based on the hypothesis of statistical recombination. This sanity check is a unique feature of our approach. We present the suppression prediction resulting from the SLE embedded in the state-of-the-art EPOS QGP background. The pT and centrality dependences of the yields are discussed both for RHIC and LHC energies.

1. Motivation

Quarkonia modeling in QGP

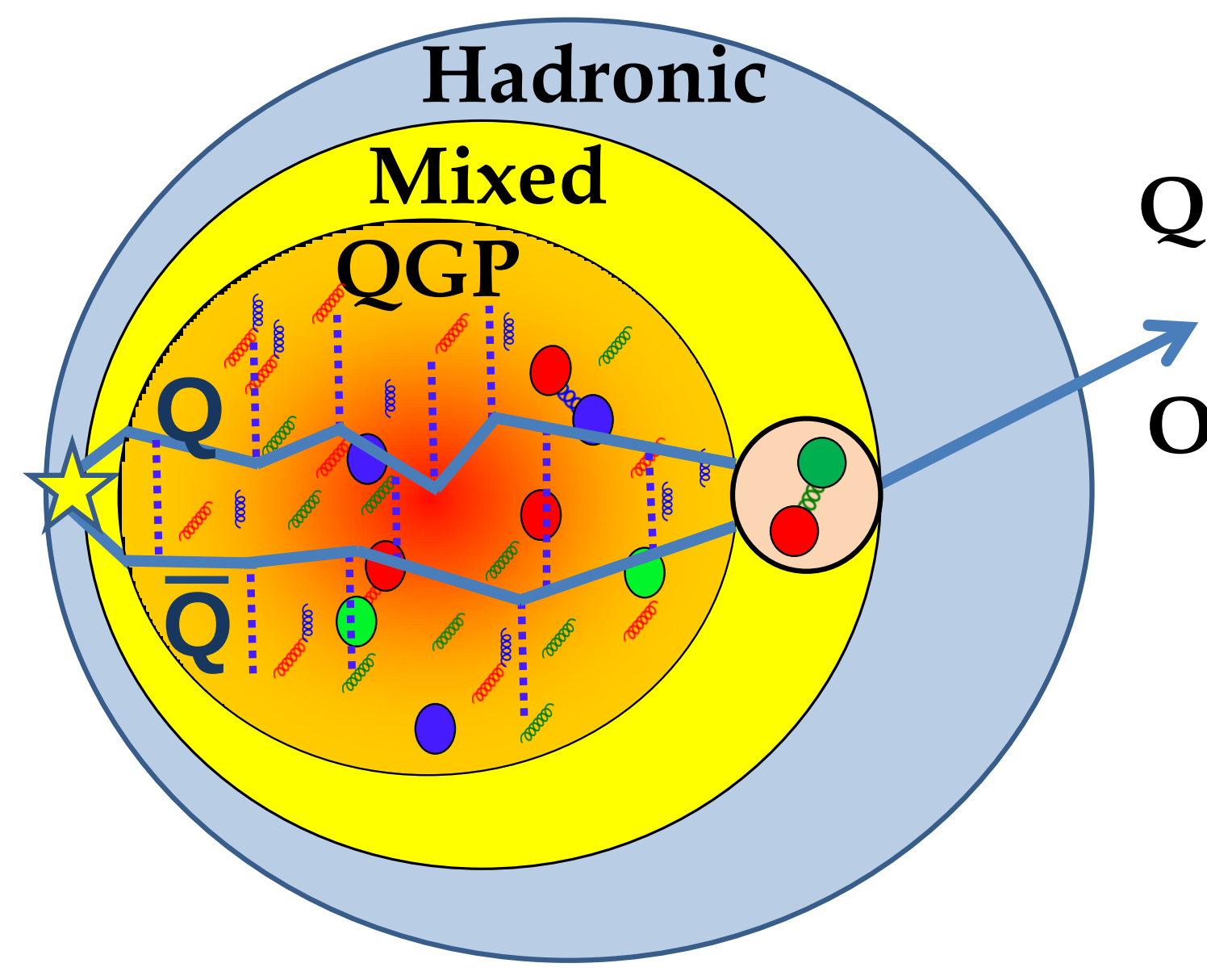


Initial quasi stationary **Sequential Suppression** assumption (Matsui & Satz)

Final quasi stationary **Statistical Hadronisation** assumption (Andronic, Braun-Munzinger...)

Dynamical Models implicit hope to measure T above Tc

???



Quarkonium
?
Open meson

only resolved at the end of the evolution

very complicated QFT problem at finite T(t) !!!

Beware of quantum coherence during the whole evolution
=> Need for quantum treatment ♥
=> A dynamical and continuous picture of the dissociation, recombination, energy exchanges and transitions to other bound states

2. Model

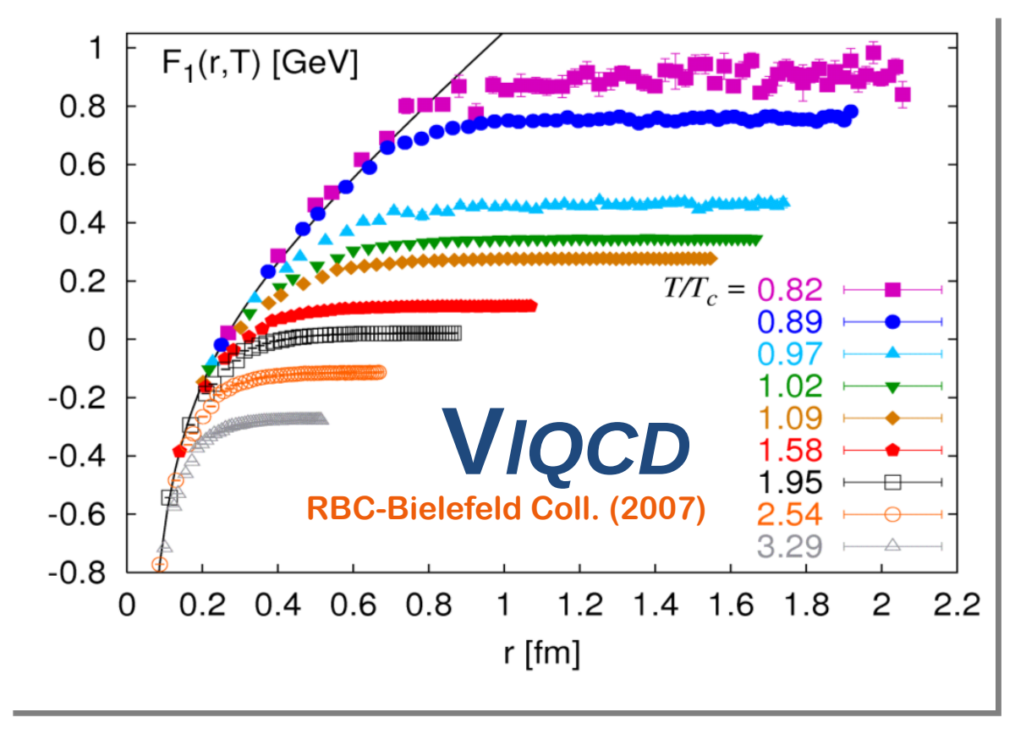
$Q\bar{Q}$ pair inner dynamics with Schrödinger-Langevin equation …

An effective equation of the open quantum system framework

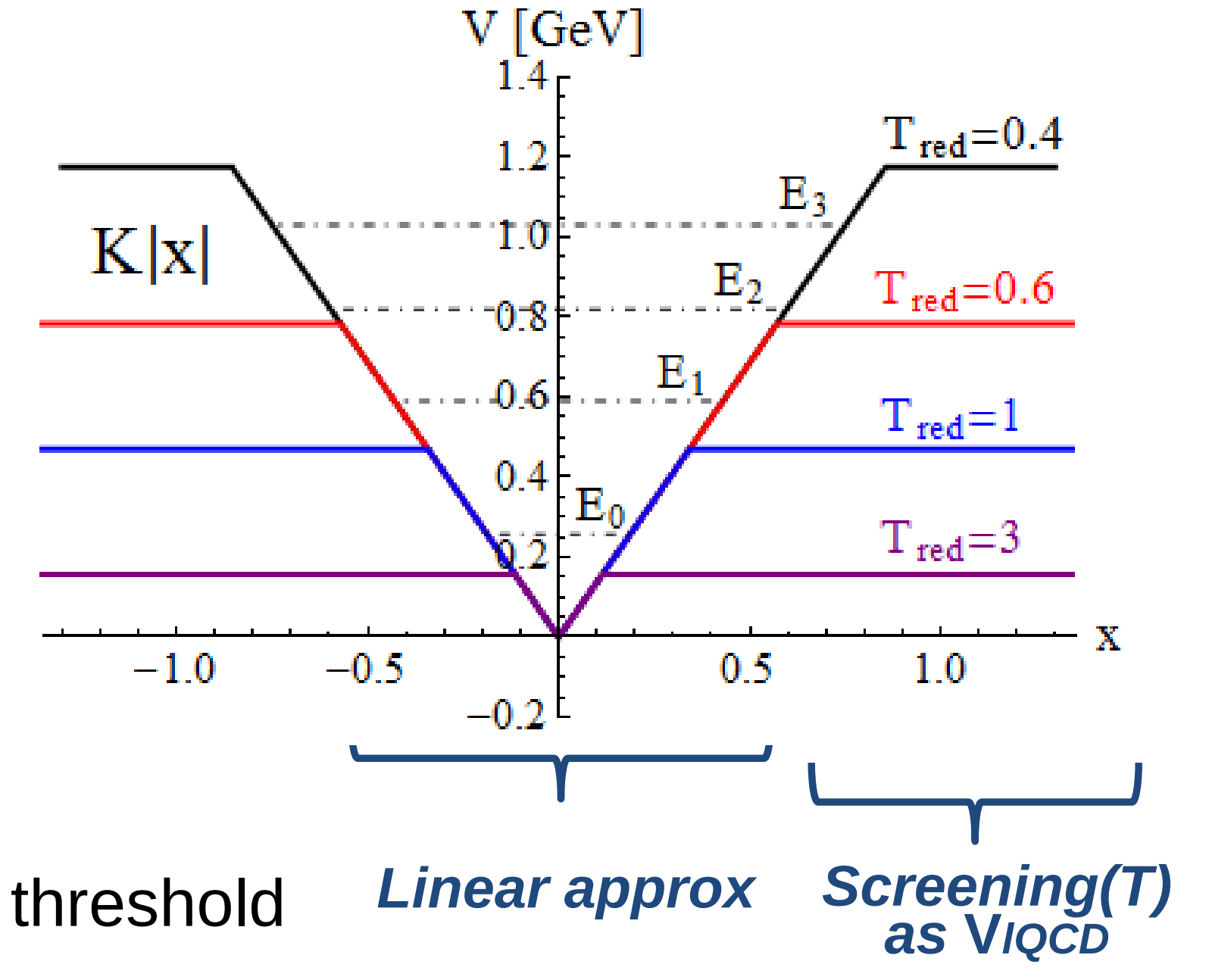
Kostin The J. of Chem. Phys. 57(9):3589–3590, (1972); Garashchuk et al. J. of Chem. Phys. 138, 054107 (2013)

$$i\hbar\frac{\partial\Psi_{Q\bar{Q}}(\mathbf{r},t)}{\partial t} = \Big(\underbrace{\hat{H}_{\mathrm{MF}}(\mathbf{r},t)}_{\text{MF}} - \underbrace{\mathbf{F}(t)\cdot\mathbf{r}}_{\text{Fluctuations}} + \underbrace{A\left(S(\mathbf{r},t)-\langle S(\mathbf{r},t)\rangle_{\mathbf{r}}\right)}_{\text{Friction/dissipation}}\Big)\Psi_{Q\bar{Q}}(\mathbf{r},t)$$

✓ Mean Field: In general, should be taken from lattice-QCD



1D → simplification



Parameters (K, Vmax) chosen to reproduce quarkonium spectrum + $B\bar{B}$ or $D\bar{D}$ threshold

✓ Fluctuations: F(t) taken as a classical stochastic force scaled such as to obtain $T_{QGP} = T_{Q\bar{Q}}$

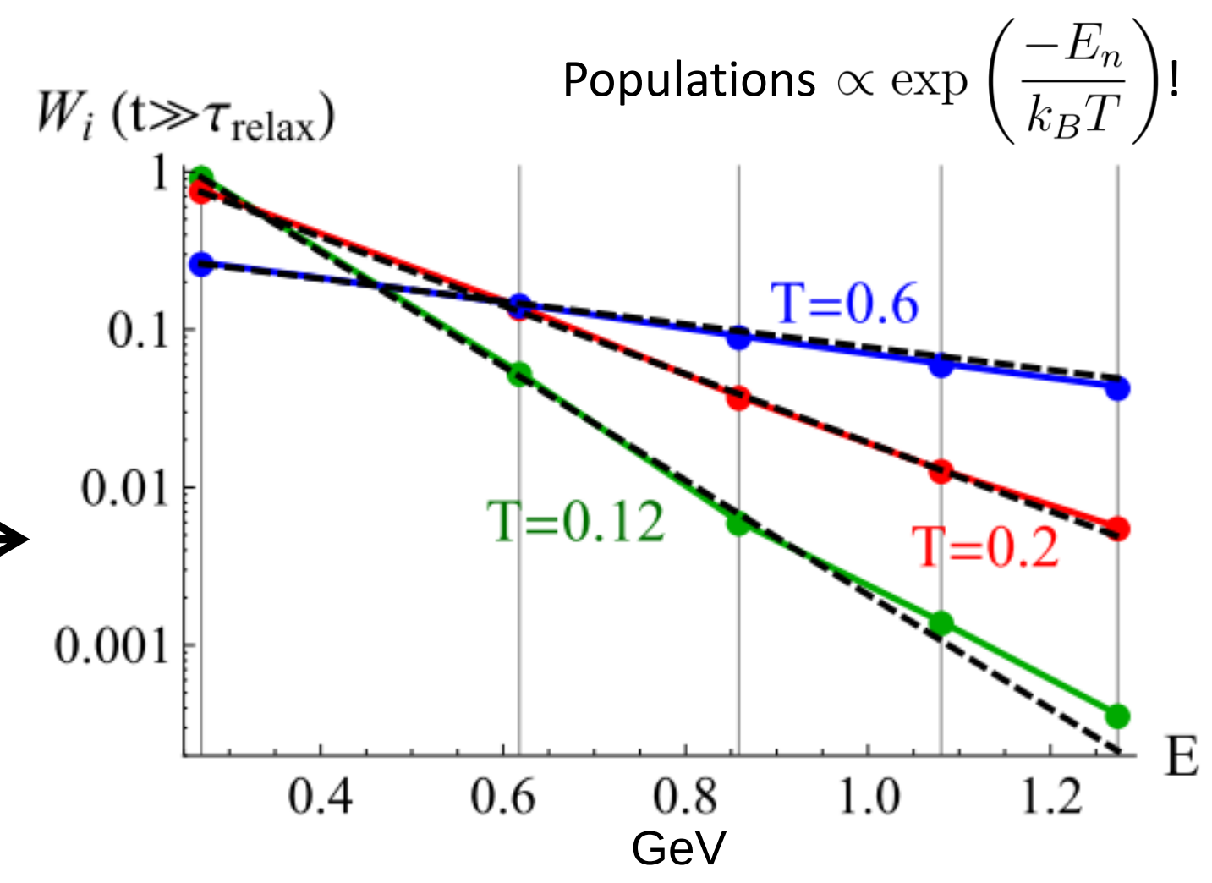
✓ Dissipation (real and ohmic): with A(T) α T^2 the Drag coefficient and $S(\mathbf{r},t) = \arg\big(\Psi_{Q\bar{Q}}(\mathbf{r},t)\big)$ brings the system to the lowest state

Some properties :

- ➢ Unitarity and Heisenberg principle satisfied
- ➢ Gradual evolution from pure to mixed states
- ➢ Mixed state observables from statistics

$$\Big\langle\langle\psi(t)|\hat{O}|\psi(t)\rangle\Big\rangle_{\mathrm{stat}} = \lim_{n_{\mathrm{stat}}\to\infty}\frac{1}{n_{\mathrm{stat}}}\sum_{r=1}^{n_{\mathrm{stat}}}\langle\psi^{(r)}(t)|\hat{O}|\psi^{(r)}(t)\rangle$$

- ➢ Leads to local « thermal » distributions ⟶
  => *a unique feature of our approach !*
- ➢ « Easy » to implement numerically



Refs: arXiv:1504.08087, arXiv:1601.01443

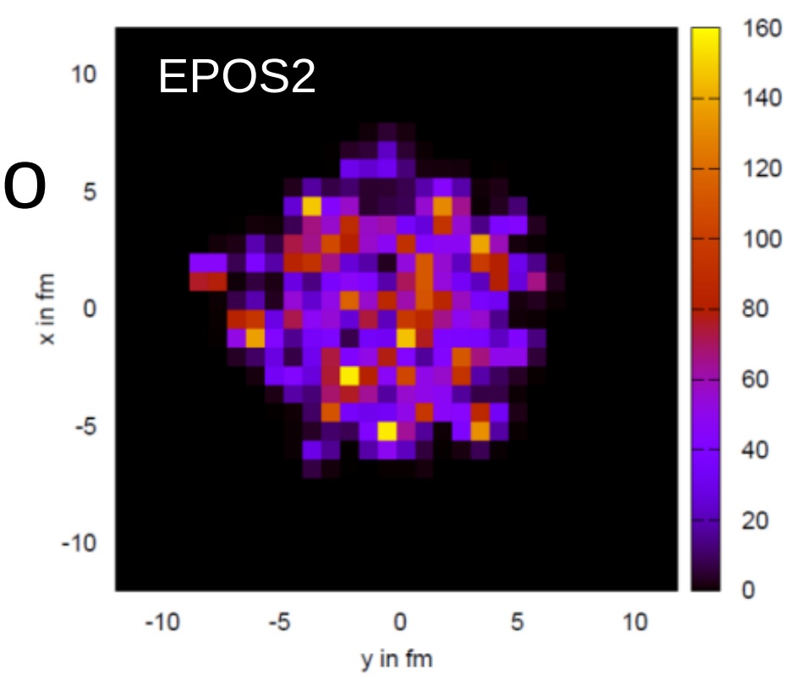
Initial $Q\bar{Q}$ wavefunction ?

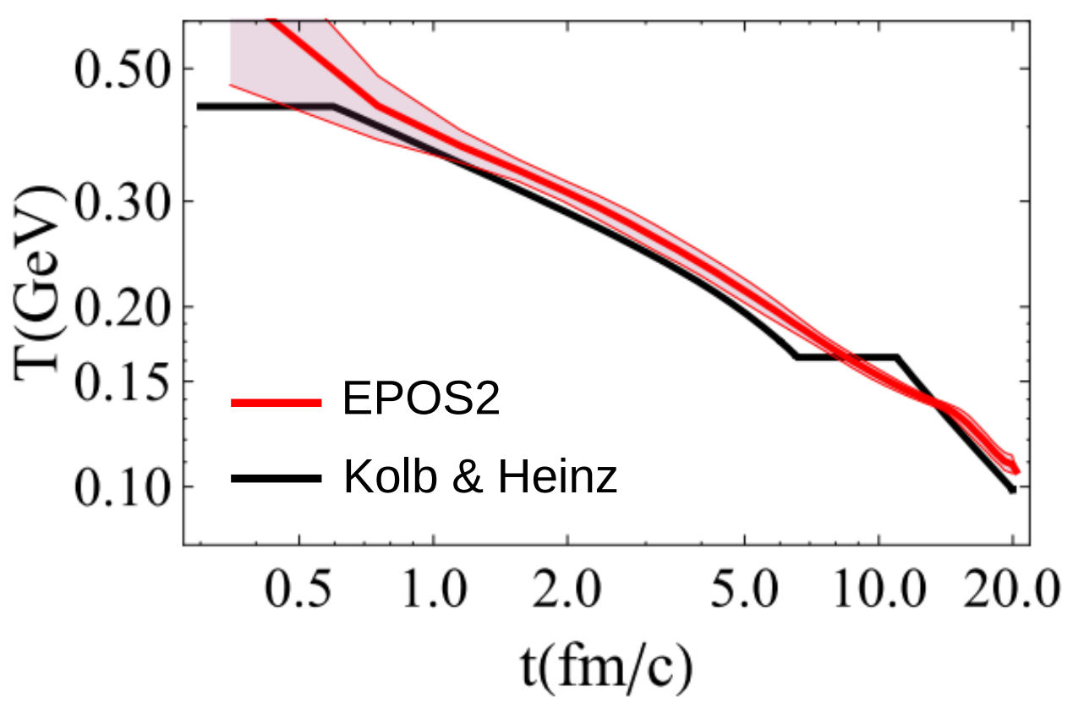
The $Q\bar{Q}$ pairs are produced at the very beginning, however, state formation times are subject to debate => we test the two extrem behaviours: either

- ➢ the $Q\bar{Q}$ pair is fully decoupled into eigenstates: $\psi_{Q\bar{Q}}(t=0)=\psi_i(T=0)$
- ➢ the $Q\bar{Q}$ pair is not decoupled: $\psi_{Q\bar{Q}}(t=0)$="a mixture of Gaussian S and P components" tuned to obtain correct feed-downs and production ratios.

… on the top of a QGP background

- ➢ QGP background:
  - ✓ At RHIC (Au+Au, 200 GeV): Kolb & Heinz isotropic ideal hydro
  - ✓ At LHC (Pb+Pb, 2.76 TeV): *EPOS2* -> very good model for heavy ion collisions with initial fluctuations T(x,t) and ideal hydro



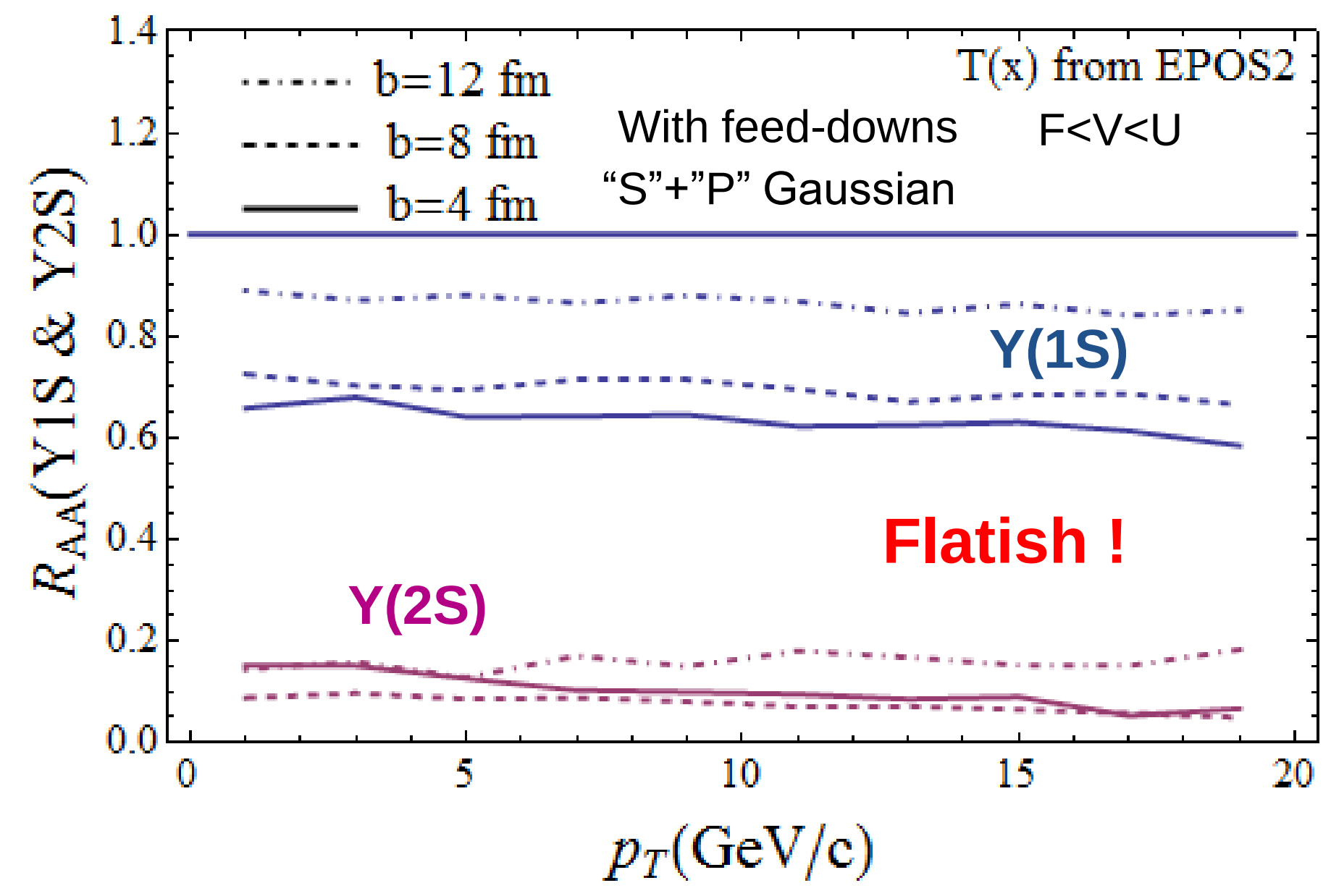


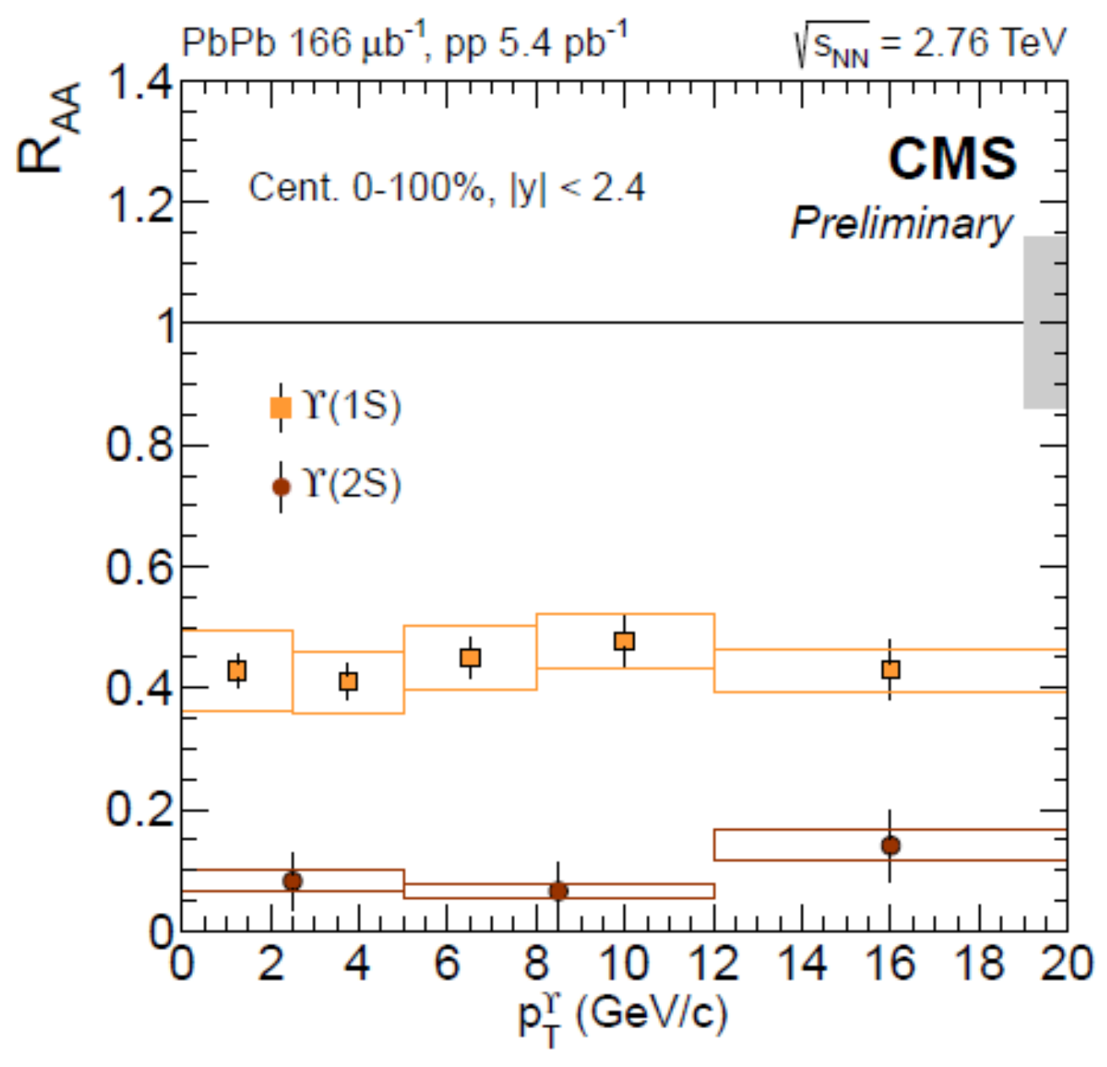
- ➢ $Q\bar{Q}$ pair initial positions given by Glauber model
- ➢ $Q\bar{Q}$ center of mass dynamics: along straight lines with no energy loss
- ➢ $Q\bar{Q}$ pairs: assumed to be color singlets
- ➢ No cold nuclear matter effects and no statistical recombinations considered
- ➢ Observables: « survivance » : $S_i(t) = W_i(t)/W_i(t=0)$,
  where W_i is the « weight » (population) $W_i(t) = |\langle\Psi_i(T=0)|\Psi_{Q\bar{Q}(t)}\rangle|^2$.

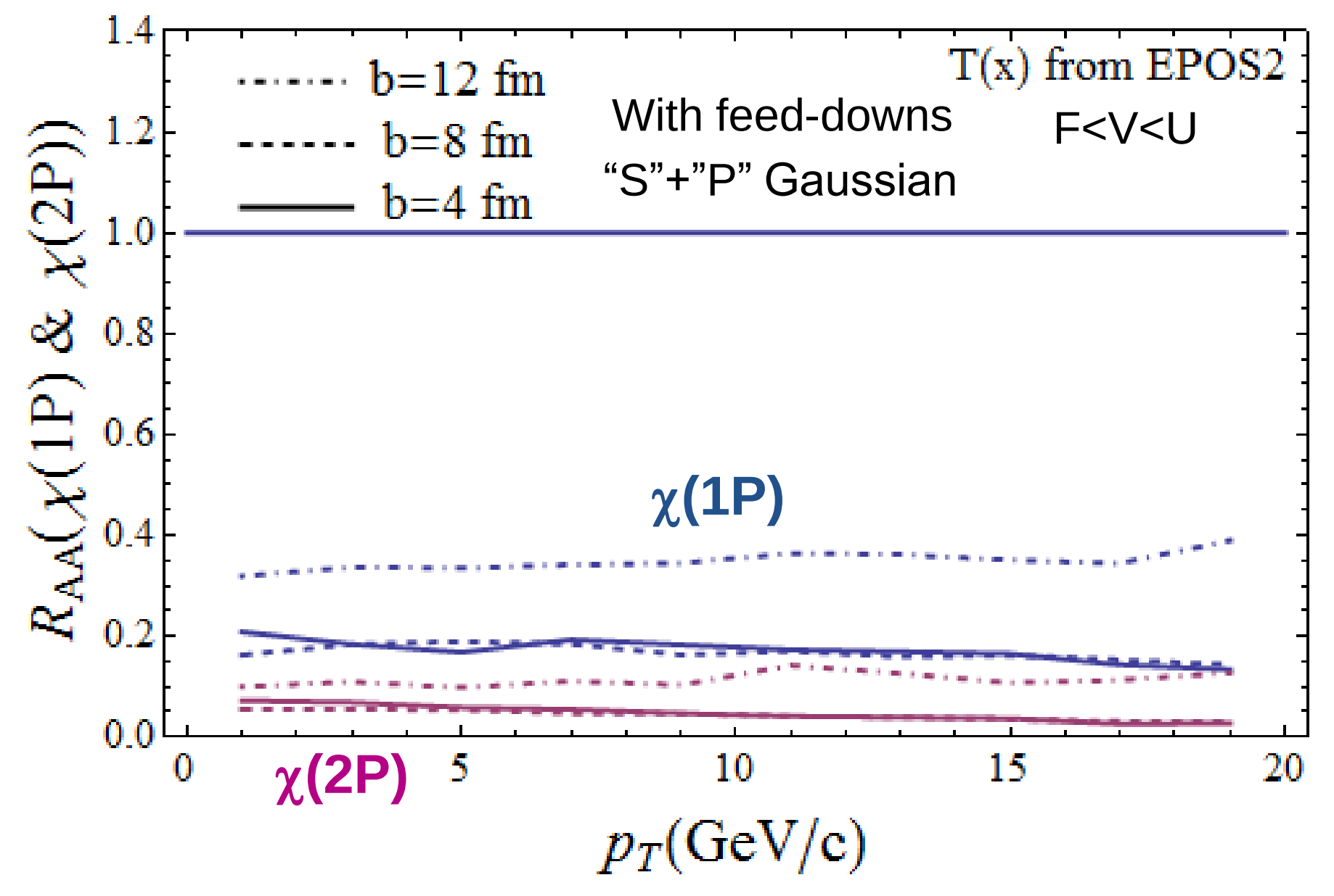
Freeze out values convoluted with p_T-y spectra => R_{AA}

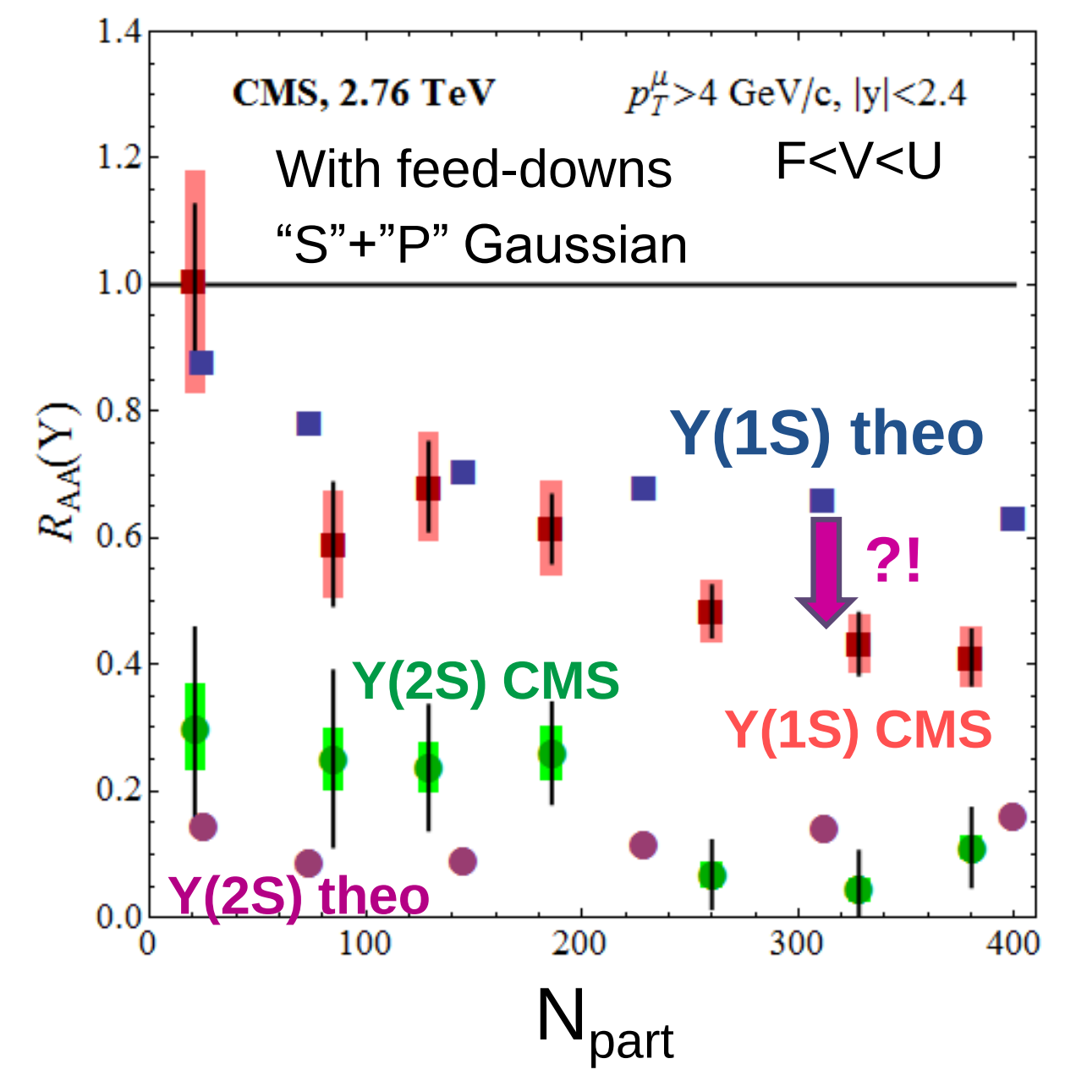
3. Results

LHC (2.76 TeV)

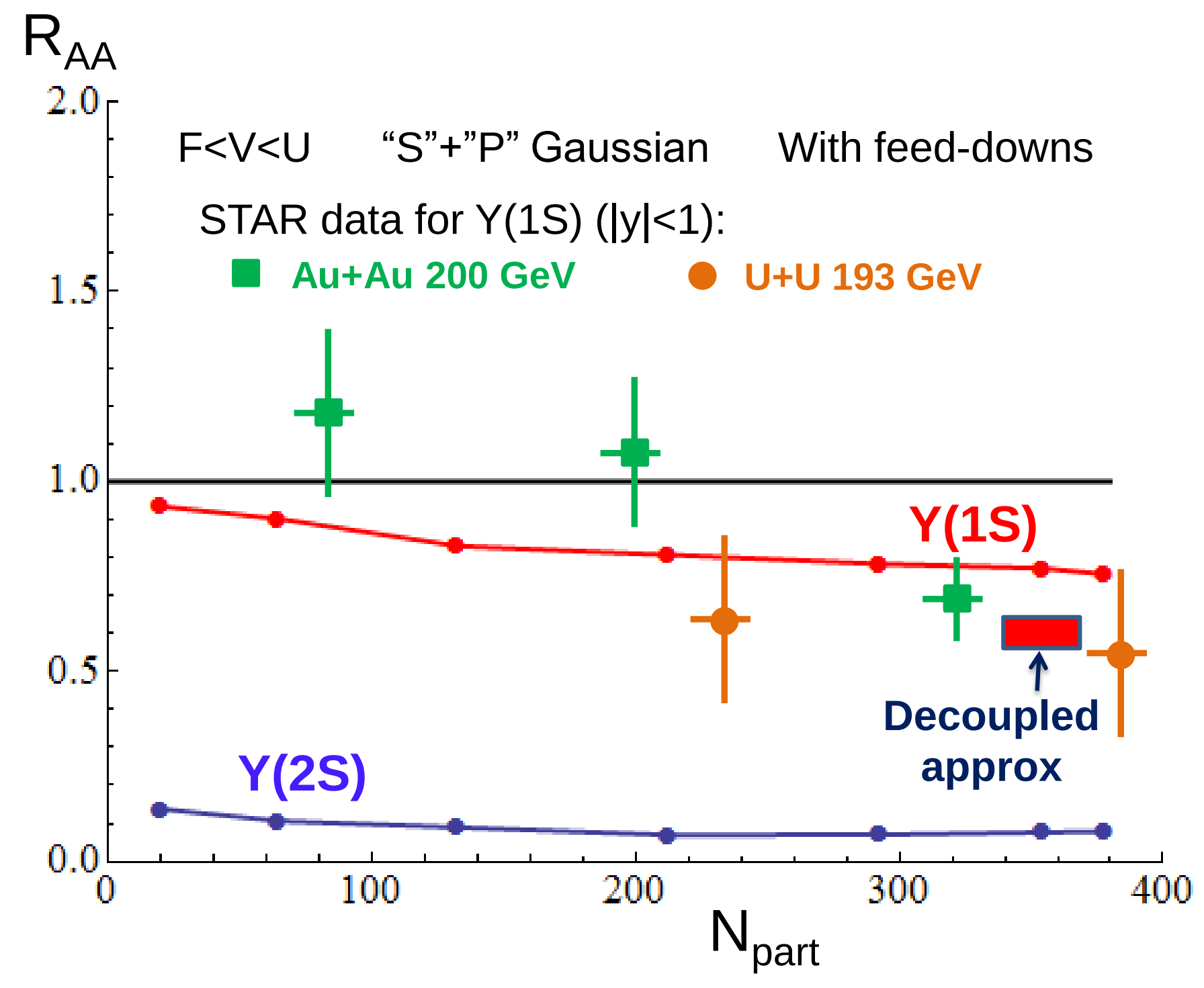


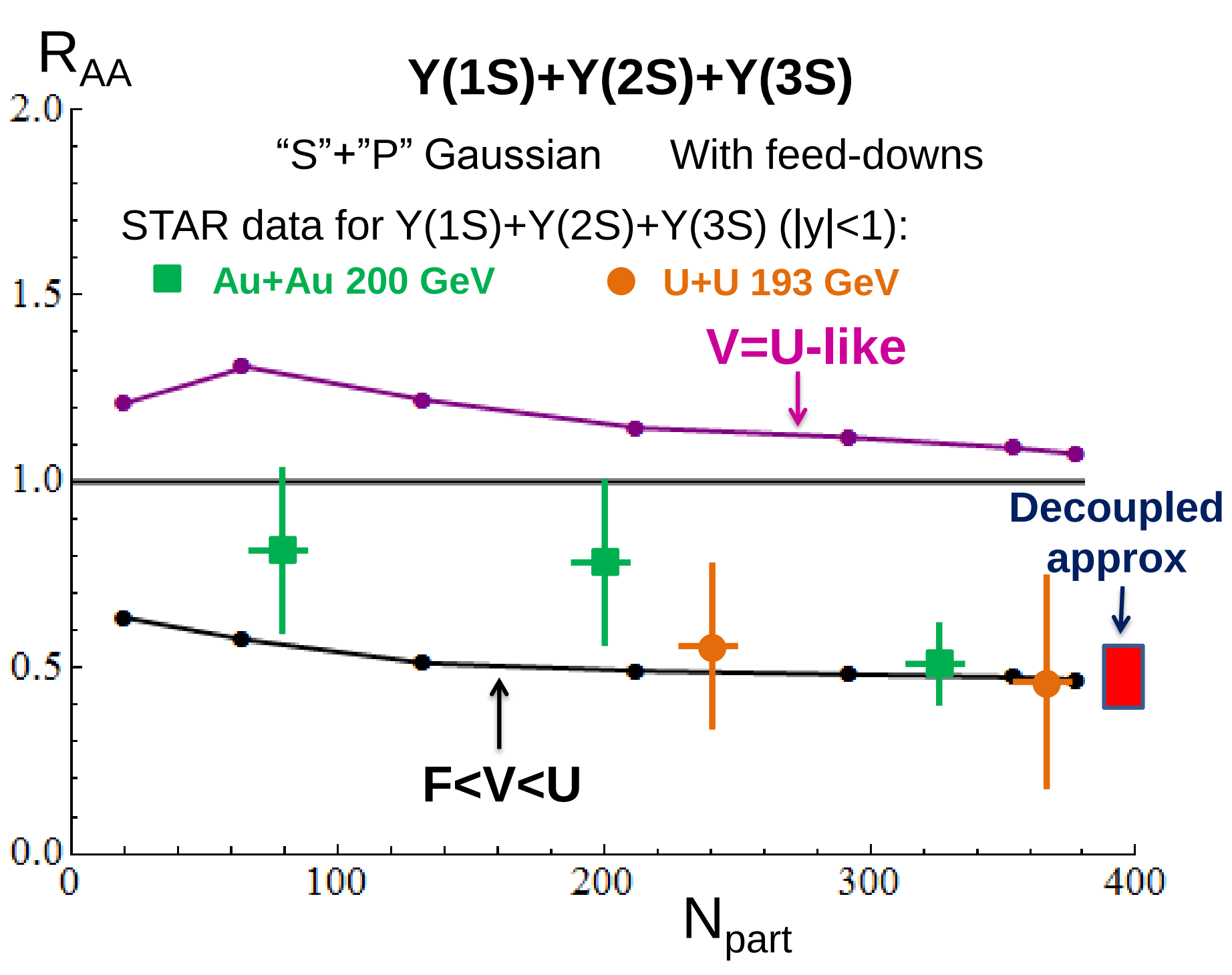






RHIC (200 GeV)





Refs: arXiv:1611.06499v1, arXiv:1004.0805, nucl-th/0305084, CMS PAS HIN-15-001 (2015), STAR arXiv:1509.05359

Conclusion:
- Both screening and thermal effects are important !
- Reproduce experimental trends provided F<V<U potential is chosen
- Some lack of suppression in most central events (CNM ?)

Future:
- Use state of the art hydro and include cold nuclear matter effects
- 3D internal dof and use of genuine lQCD potential => more reliable results
- Make contact with other models (link statistical hadronization / dynamical models)