DYNAMICAL QUARKONIA SUPPRESSION WITH THE SCHROEDINGER LANGEVIN EQUATION… A POSSIBLE WAY TO MAKE A STEP TOWARDS PRECISION PHYSICS ?

Pol B Gossiaux & Roland Katz

Precision Spectroscopy of QGP Properties with Jets and Heavy Quarks
INT Seattle (USA)
01/06/2017

Subatech and TOGETHER Pays de la Loire

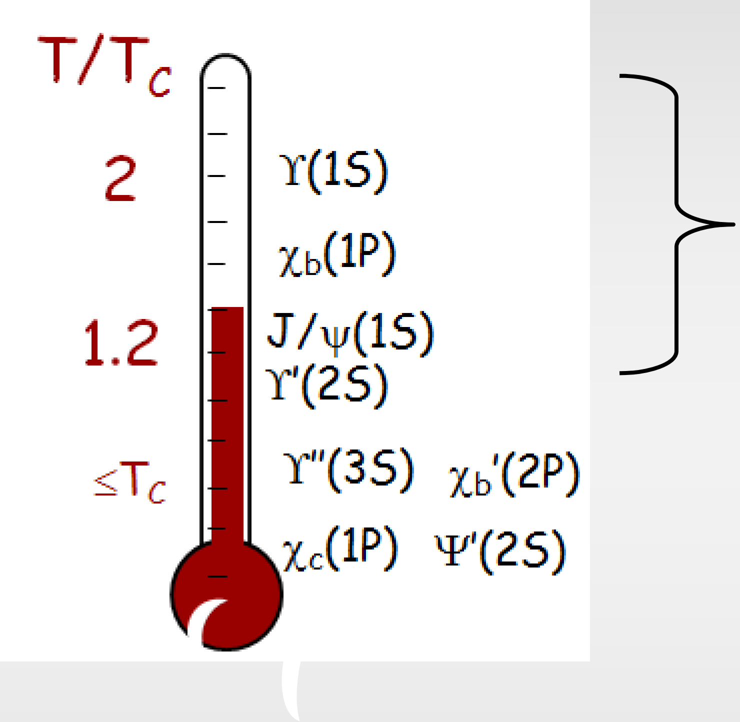
Schematic view

Sequential Suppression in the Thermal-Stationary assumption
(Matsui & Satz 86)

Quarkonia in Stationary QGP

QGP

Thermometer



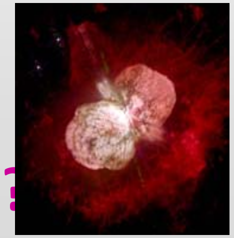
“robust”

states

Indeed observed at SPS (CERN) and RHIC (BNL) experiments. However:

- alternative explanations, lots of unknown (also from theory side)
- less suppression at LHC

•Time dependent quarkonia formation in evolving medium ?

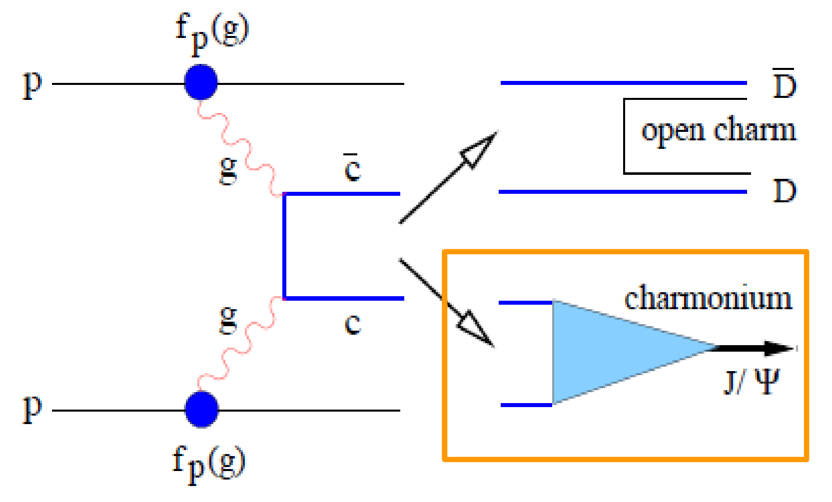


Schematic view

Sequential Suppression in the Thermal-Stationary assumption
(Matsui & Satz 86)

Sequential Suppression in a thermal quasi-stationary assumption
(SPS)

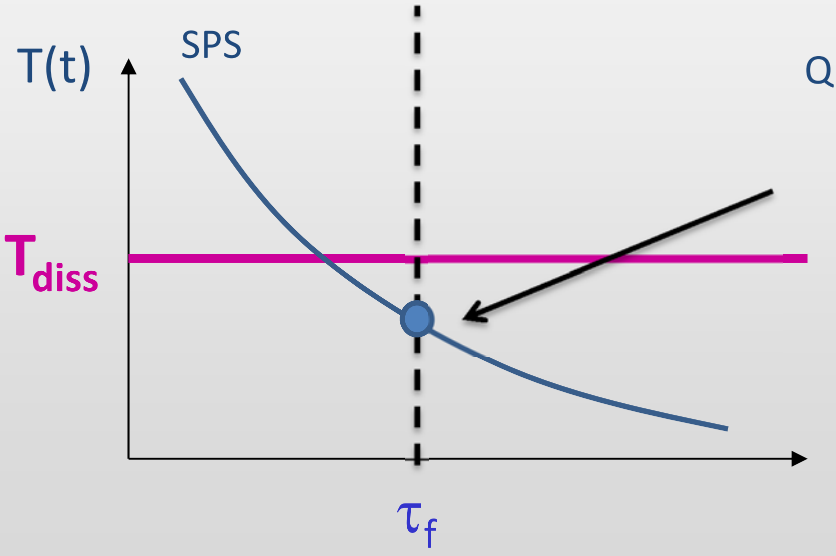
Dynamical version of the sequential suppression scenario



a) In vacuum: Quarkonia are formed after some "formation time" τ_f (typically the Heisenberg time), usually assumed to be independent of the surrounding medium

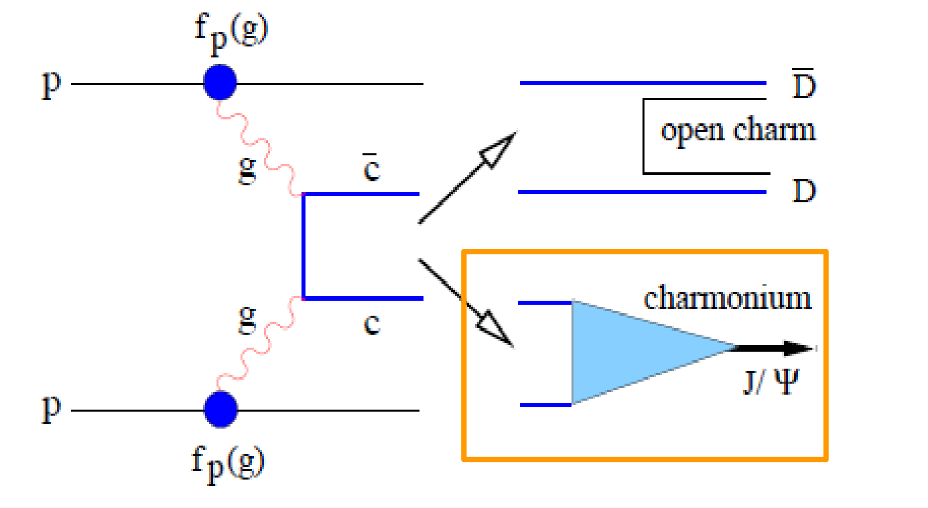
Standard folklore of sequential suppression: b.1) If $T(\tau_f,x_0)<T_{diss}$ the quarkonia is indeed created (as in vacuum)

Local temperature in the medium



Quarkonia state formed as in the vacuum

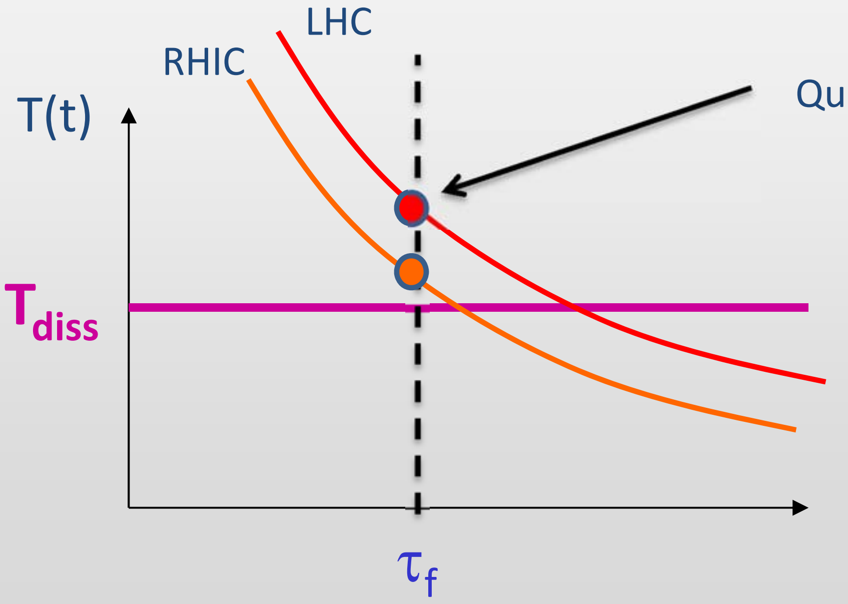
Dynamical version of the sequential suppression scenario



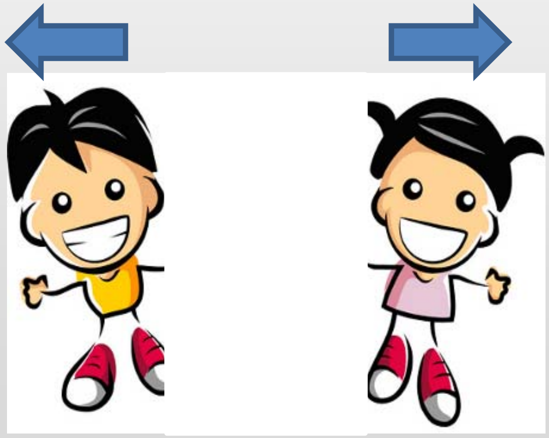
a) In vacuum: Quarkonia are formed after some “formation time” τ_f (typically the Heisenberg time), usually assumed to be independent of the surrounding medium

Standard folklore of sequential suppression: b.2) If $T(\tau_f,x_0)>T_{diss}$ the quarkonia is NOT created (Q-Qbar pair is “lost” for quarkonia production)

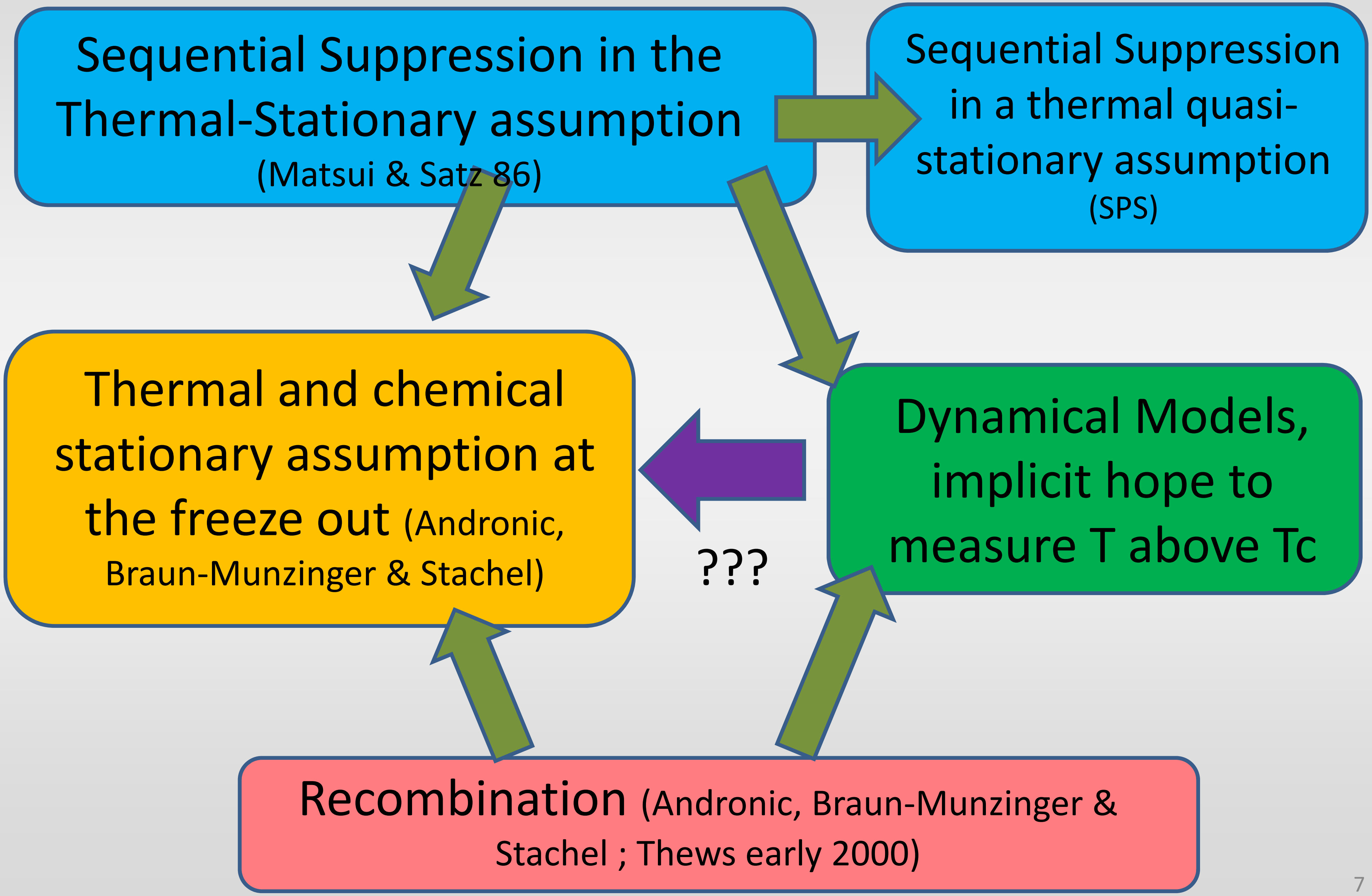
Local temperature in the medium



Quarkonia state “suppressed”



Schematic view



Sequential Suppression in the Thermal-Stationary assumption (Matsui & Satz 86)

Sequential Suppression in a thermal quasi-stationary assumption (SPS)

Thermal and chemical stationary assumption at the freeze out (Andronic, Braun-Munzinger & Stachel)

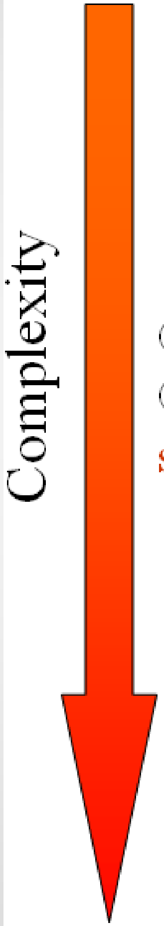
???

Dynamical Models, implicit hope to measure T above Tc

Recombination (Andronic, Braun-Munzinger & Stachel ; Thews early 2000)

Not all equal !!!

Recombination: hierarchy of approaches…

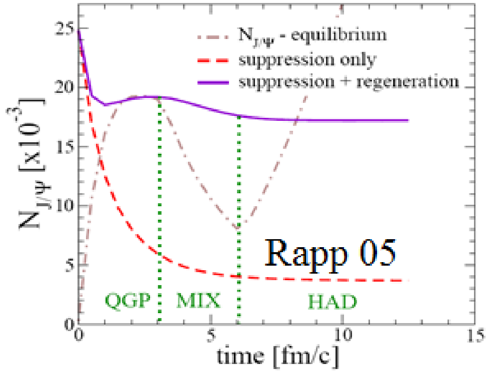


Statistical weights (at transition). no detailed dynamics. ☹ assumes all time scales are small vs. transition time. ☺ simple to deal with. PBM, Stachel & Andronic; Gorenstein, Kostyuk;…

Rate equations: $$\frac{dN_\Psi}{dt} = -\Gamma_\Psi \left(N_\Psi - N_\Psi^{eq}\right)$$

☺ Might contain the essential physics at a global level.

☹ Model of $f_c(x,p)$ needed. ☹ no possibility of studying diff. spectra. Grandchamp, rapp and Brown; (early) Thews



Transport theory assuming spatial homogeneous $f_i(p)$. ☺ diff spectra. ☹ misses surface effects, x-p correl, Q are not uniformly distributed. Thews and Mangano

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Transport theory. ☺ solves the caviats of other approaches. ☹ may obscure the physics. Zhang (AMPT); Bratkovskaya (HSD); Gossiaux;…

… does not mean a hierarchy of answers (hopefully)!

Common ingredients in (most of the) state of the art *dynamical* models

Early decoupling btwn various states in the initial stage (as in H. Satz)

Mean field (screening)

- Vetoing at the time of production if $T>T_{dissoc}$
- Evaluation of the wave functions ψ_n at finite T

Fluctuations (dissociation)

- Evaluate dissociation cross sections using transition operators + ψ_n

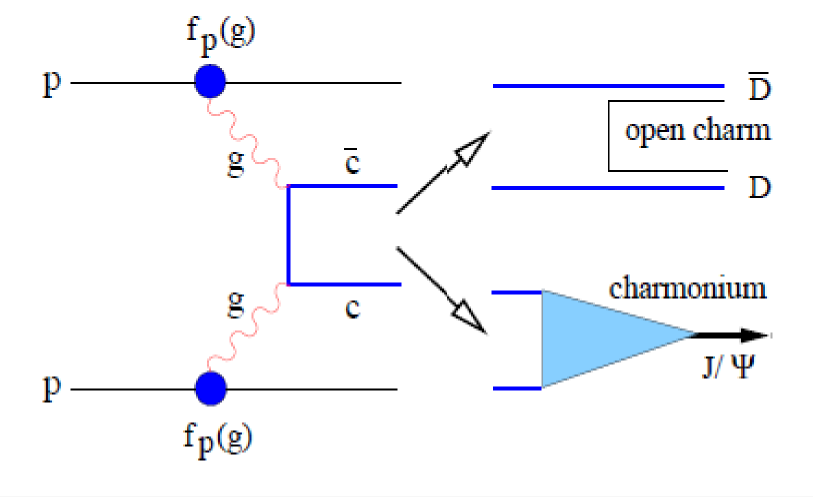
or

- Evaluation of the width Γ using some imaginary potential => survival a $\exp(-\Gamma t)$

+ recombination (using detailed balance of)

Back to the concepts

Picture

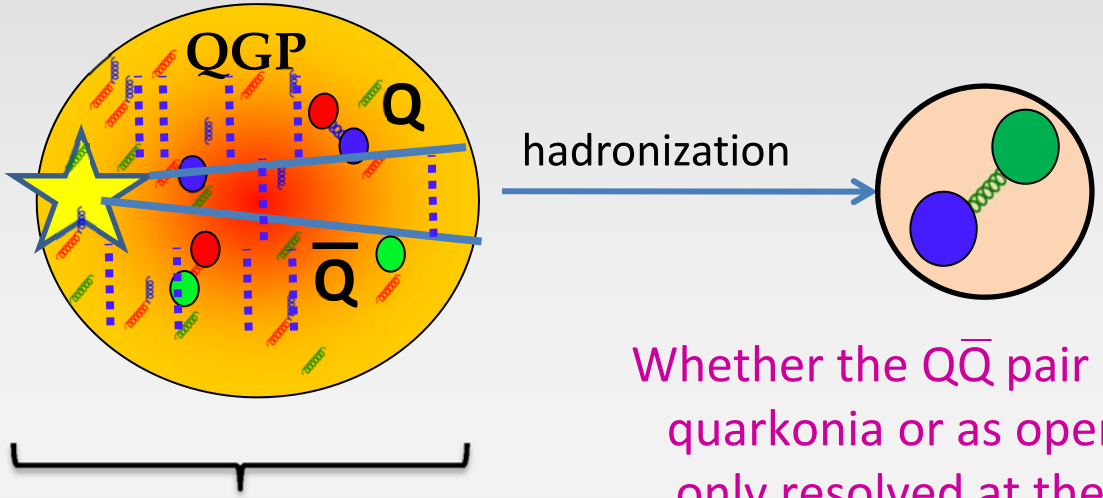


Early decoupling

between various

states

Motivation: Quarkonium formation and Q-Qbar evolution in URHIC is a deeply quantum and dynamical problem:



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

Whether the $Q\bar{Q}$ pair emerges as a quarkonia or as open mesons is <u>only resolved at the end of the evolution</u>

No independent Y(1S), Y(2S),.. evolution during QGP history

Beware of quantum coherence during the evolution !

Need for full quantum treatment

Dating back to Blaizot & Ollitrault, Thews, Cugnon and Gossiaux; early 90's

Motivation

Quarkonium formation and Q-Qbar evolution in URHIC is a deeply quantum and dynamical problem requiring

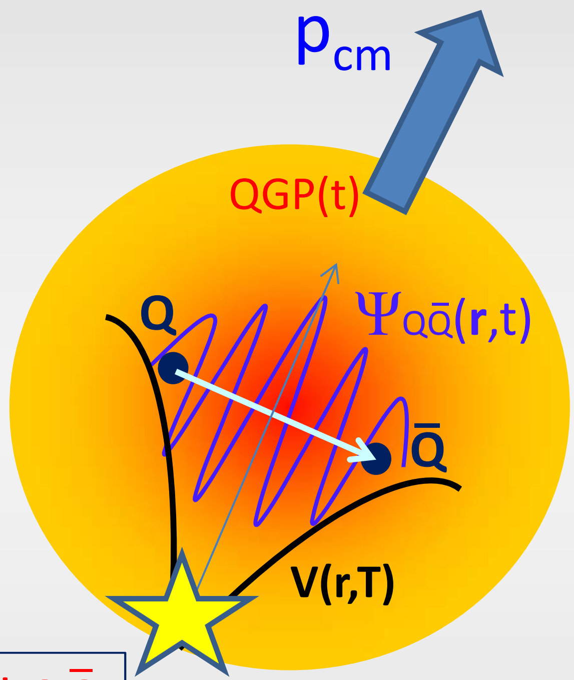
- ✓ **QGP genuine time-dependent scenario**
- ✓ **quantum description of the $Q\bar{Q}$**
- ✓ **interaction between the 2 systems (screening, « thermalisation »)**

A priori: Nothing is instantaneous,nothing is adiabatic, nothing is stationnary and nothing is *decoupled*

Ingredients of our model

QGP temperature scenarios T(t,x)

Cooling QGP



Initial $Q\bar{Q}$ state

Mean field: color screened binding potential V(r,T)

polarization due to color charges

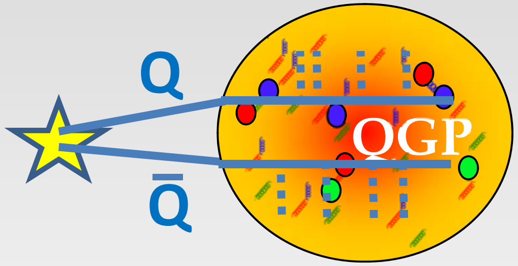
+

Thermalisation and diffusion

Direct interactions with the thermal bath

+ Dynamical scheme
(Schroedinger Langevin equation)

Dynamical scheme ?



Partonic approac ✖

Very complicated QFT lem !

NOT EFFECTIVE$^{(1)}$

The com approach ✖

- **Idea:** density m + bath} => bath integrated out

  ⇒ non u tion + decoherence effects

  Akamatsu* -> complex potential
  Borghini** -> a master equation

- **But** defining the bath is complicated and the calculation entangled…

* Y. Akamatsu Phys.Rev. D87 (2013) 045016 ; ** N. Borghini et al., Eur. Phys. J. C 72 (2012) 2000

(**1) See however Jean-Paul Blaizot et al: http://arxiv.org/abs/1503.03857**

Dynamical scheme ?

Effective: Langevin-like approaches ✓

Quarkonia are Brownian particles ($M_{Q\bar{Q}} >> T$)

+ Drag A(T) => need for a Langevin-like eq.

(A(T) from single heavy quark observables or lQCD calculations)

- **Idea:** Effective equations to unravel/mock the open quantum approach

Young and Shuryak * -> semi-classical Langevin

Akamatsu and Rothkopf ** -> stochastic and complex potential

Semi-classical
See our SQM 2013
proceeding ***

Schrödinger-Langevin
equation

Others
Failed at
low/medium
temperatures

Effective thermalisation from fluctuation/dissipation

* C. Young and Shuryak E 2009 Phys. Rev. C 79: 034907 ; ** Y. Akamatsu and A. Rothkopf. Phys. Rev. D 85, 105011 (2012) ;

*** R. Katz and P.B. Gossaiux J.Phys.Conf.Ser. 509 (2014) 012095

Schrödinger-Langevin (SL) equation

Derived from the Heisenberg-Langevin equation*, in Bohmian mechanics** …

$$i\hbar\frac{\partial\Psi_{Q\bar{Q}}(\mathbf{r},t)}{\partial t} = \left(\widehat{H}_{\mathrm{MF}}(\mathbf{r}) - \mathbf{F}_{\mathbf{R}}(t).\mathbf{r} + A\big(S(\mathbf{r},t) - \langle S(\mathbf{r},t)\rangle_{\mathbf{r}}\big)\right)\Psi_{Q\bar{Q}}(\mathbf{r},t)$$

$\mathbf{r} = b - \bar{b}$ relative position

Hamiltonian
includes the
Mean Field
(color binding potential)

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* Kostin The J. of Chem. Phys. 57(9):3589–3590, (1972)

** Garashchuk et al. J. of Chem. Phys. 138, 054107 (2013)

Schrödinger-Langevin (SL) equation

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Dissipation

✓ non-linearly dependent on $\Psi_{\mathrm{Q\bar{Q}}}$

$$S(\mathbf{r},t) = \arg\big(\Psi_{Q\bar{Q}}(\mathbf{r},t)\big)$$

✓ real and ohmic

✓ ***A*** = drag *coefficient* (inverse relaxation time)

✓ Brings the system to the lowest state

Schrödinger-Langevin (SL) equation

$$i\hbar\frac{\partial\Psi_{Q\bar{Q}}(\mathbf{r},t)}{\partial t}=\left(\widehat{H}(\mathbf{r})-\mathbf{F}(t).\mathbf{r}+\boxed{A\big(S(\mathbf{r},t)-\langle S(\mathbf{r},t)\rangle_{\mathbf{r}}\big)}\right)\Psi_{Q\bar{Q}}(\mathbf{r},t)$$

dissipative non-linear potential
(wavefunction dependent

where $S(\mathbf{r},t)=\arg\big(\Psi_{Q\bar{Q}}(\mathbf{r},t)\big)$

- ✓ Brings the QQ to the lowest state (0 node)
- ✓ Friction (assumed to be local in time)

- ➢ Solution for V=0 (free wave packet): $\psi(\vec{x},t)\propto e^{i\vec{p}_{\mathrm{cl}}(t)\cdot\vec{r}+i\alpha(t)(\vec{r}-\vec{r}_{\mathrm{cl}}(t))^2-i\varphi(t)}$

where $\vec{p}_{\mathrm{cl}}(t)$ and $\vec{x}_{\mathrm{cl}}(t)$ satisfy the classical laws of motion

- ➢ $\vec{p}_{\mathrm{cl}}(t)=\vec{p}_{\mathrm{cl}}(0)e^{-At}\Rightarrow$ A is the drag coefficient (inverse relaxation time)

A can be fixed through the modelling of single heavy quarks observables and comparison with the data OR using lattice QCD calculations

Schrödinger-Langevin (SL) equation

$$i\hbar\frac{\partial\Psi_{Q\bar{Q}}(\mathbf{r},t)}{\partial t} = \left(\widehat{H}(\mathbf{r}) - \mathbf{F}(t).\mathbf{r} + \boxed{A\big(S(\mathbf{r},t) - \langle S(\mathbf{r},t)\rangle_{\mathbf{r}}\big)}\right)\Psi_{Q\bar{Q}}(\mathbf{r},t)$$

dissipative non-linear potential
(wavefunction dependent

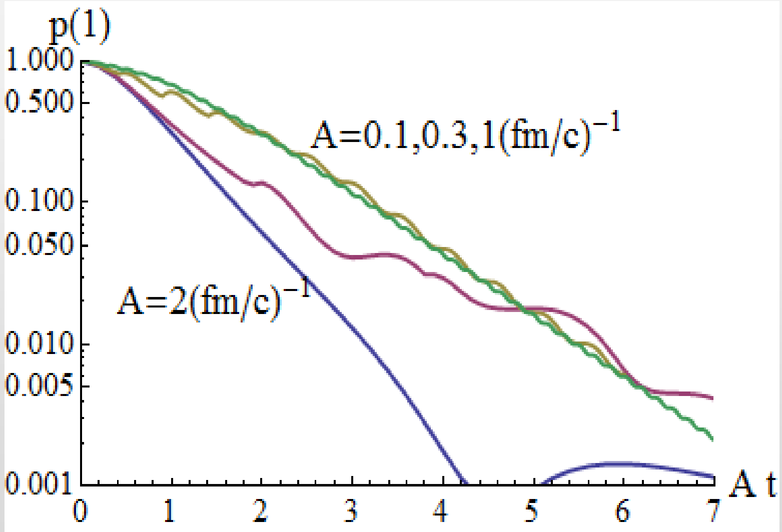
where $S(\mathbf{r},t) = \arg\big(\Psi_{Q\bar{Q}}(\mathbf{r},t)\big)$

- ✓ Brings the QQ to the lowest state (0 node)
- ✓ Friction (assumed to be local in time)

- ➢ Solution for harmonic potential as well: $\psi(\vec{x},t) \propto e^{i\vec{p}_{\rm cl}(t)\cdot\vec{r}+i\alpha(t)(\vec{r}-\vec{r}_{\rm cl})^2-i\varphi(t)}$

Illustration: probability of finding the first excited state in a 1D-harmonic potential, as function of time, for various values of A …

Scaling relation found for A<ω



Schrödinger-Langevin (SL) equation

$$i\hbar\frac{\partial\Psi_{Q\bar{Q}}(\mathbf{r},t)}{\partial t} = \left(\widehat{H}(\mathbf{r}) - \boxed{\mathbf{F}(t).\mathbf{r}} + \underline{A\big(S(\mathbf{r},t) - \langle S(\mathbf{r},t)\rangle_{\mathbf{r}}\big)}\right)\Psi_{Q\bar{Q}}(\mathbf{r},t)$$

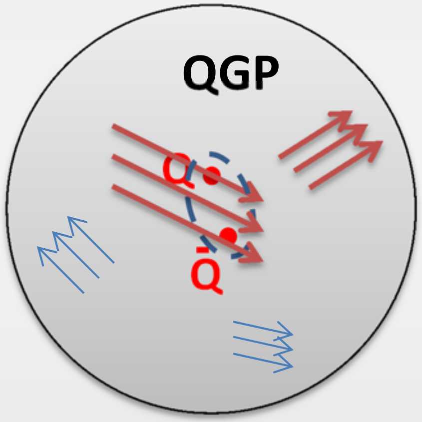
Stochastic operator; "warming"

$\langle\mathbf{F}(t)\rangle = 0\,,\ \langle\mathbf{F}(t)\mathbf{F}(t')\rangle = \Gamma(t,t')$?

Brownian hierarchy: $m \gg T \ \Rightarrow\ \sigma \ll \tau_{\text{relax}}$

- ✓ σ = autocorrelation time of the gluonic fields
- ✓ τ_{relax} = quarkonia relaxation time

$\Gamma(t,t')$: gaussian correlation of parameter σ and norm B



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3 parameters: *A* (the drag coef), *B* (the diffusion coef) and σ (autocorrelation time)

Schrödinger-Langevin (SL) equation

Derived from the Heisenberg-Langevin equation, in Bohmian mechanics …

$$i\hbar\frac{\partial \Psi_{Q\bar{Q}}(\mathbf{r},t)}{\partial t} = \left(\widehat{H}_{\mathrm{MF}}(\mathbf{r}) - \mathbf{F}_{\mathbf{R}}(t).\mathbf{r} + A\big(S(\mathbf{r},t) - \langle S(\mathbf{r},t)\rangle_{\mathbf{r}}\big)\right)\Psi_{Q\bar{Q}}(\mathbf{r},t)$$

Fluctuations

taken as a « classical » stochastic force

White quantum noise *

$$\langle F_R(t)F_R(t+\tau)\rangle = 2mA\,E_0\left[\coth\left(\frac{E_0}{kT_{\mathrm{bath}}}\right) - 1\right]\delta(\tau)$$

Color quantum noise **

$$\langle N[F_R(t)F_R(t+\tau)]\rangle = \frac{2mA}{\pi}\int_0^{\infty}\frac{\hbar\omega}{\exp(\hbar\omega/kT_{\mathrm{bath}}) - 1}\cos(\omega\tau)\,d\omega.$$

* I. R. Senitzky, Phys. Rev. 119, 670 (1960); 124}, 642 (1961).

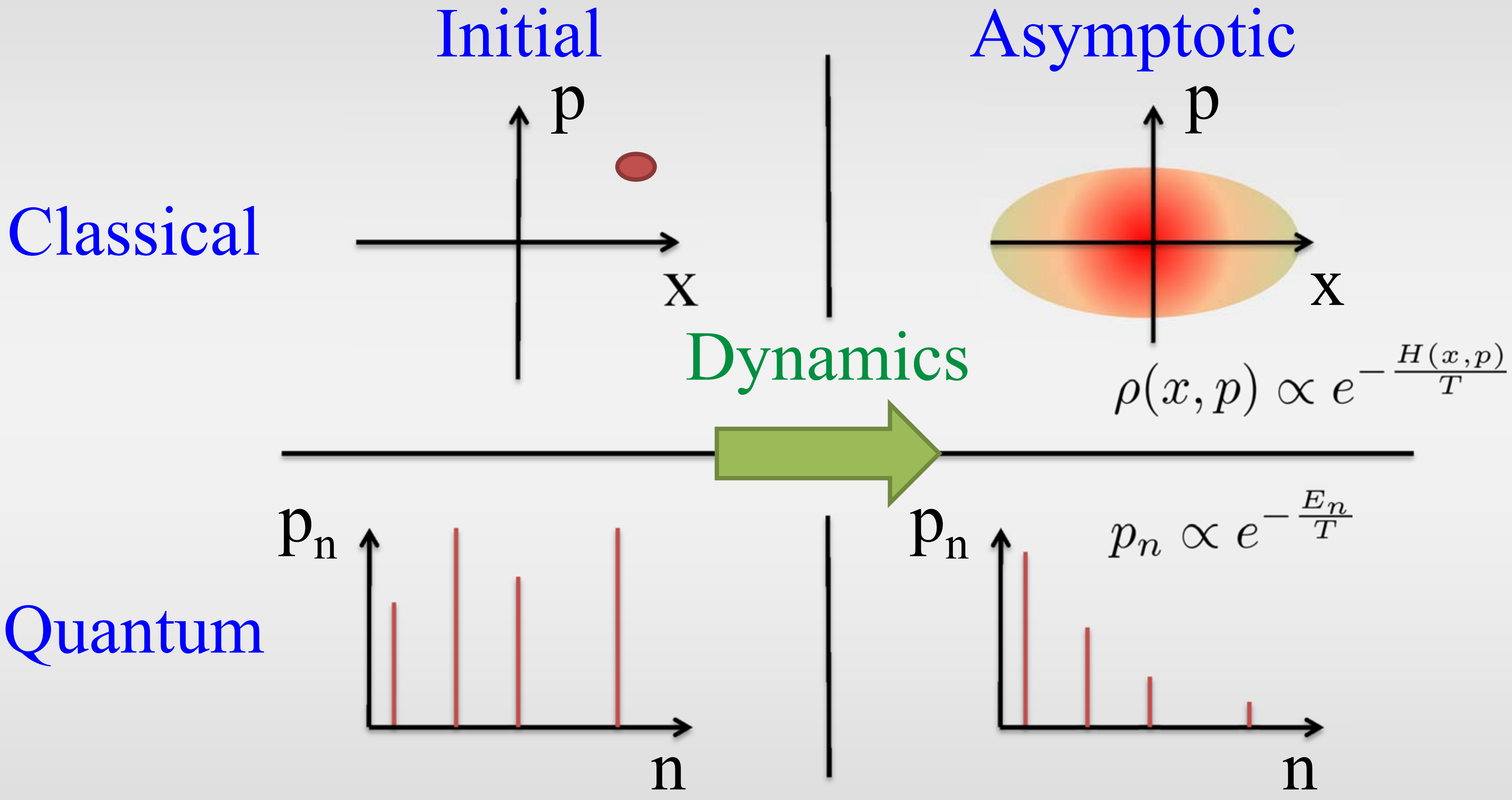
** G. W. Ford, M. Kac, and P. Mazur, J. Math. Phys. 6, 504 (1965).

Properties of the SL equation

- **2 parameters: A (Drag) and T (temperature)**
- Unitarity (no decay of the norm as with imaginary potentials)
- Heisenberg principle satisfied at any T
- Non linear => Violation of the superposition principle
  (=> decoherence)
- Gradual evolution from pure to mixed states (large statistics)
- **Mixed state observables:** $$\left\langle \langle\psi(t)|\hat{O}|\psi(t)\rangle \right\rangle_{\text{stat}} = \lim_{n_{\text{stat}}\to\infty} \frac{1}{n_{\text{stat}}} \sum_{r=1}^{n_{\text{stat}}} \langle\psi^{(r)}(t)|\hat{O}|\psi^{(r)}(t)\rangle$$
- Easy to implement numerically (especially in EBE MC generators)
- **Leads to (approximate) thermalization of the subsystem**

See R. Katz and P. B. Gossiaux, Annals of Physics (2016), pp. 267-295, arXiv:1504.08087 [quant-ph]

Important feature of Langevin Dynamics



Initial

Asymptotic

Classical

Quantum

Dynamics

$\rho(x,p) \propto e^{-\frac{H(x,p)}{T}}$

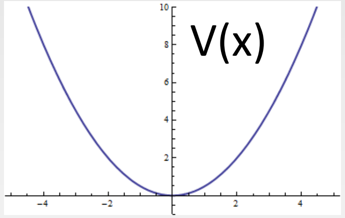
$p_n \propto e^{-\frac{E_n}{T}}$

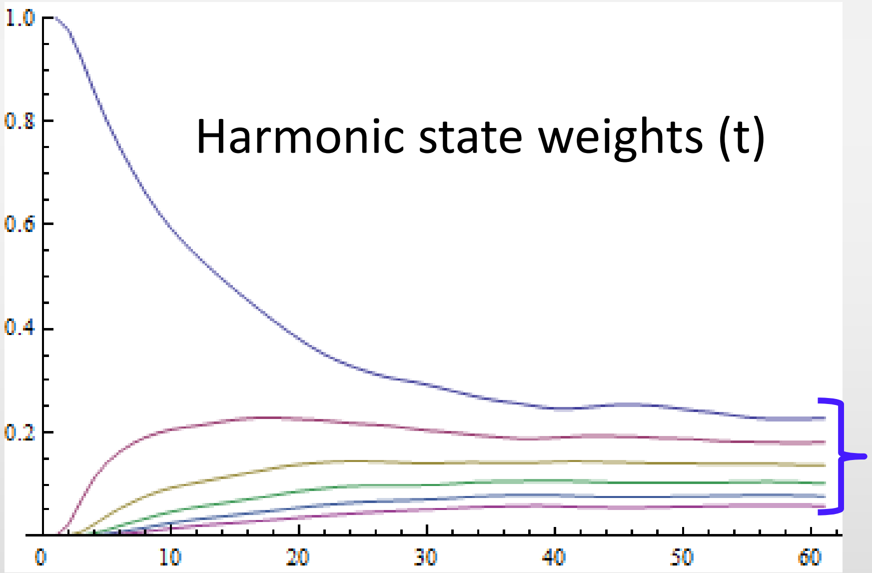
Need for Einstein relation aka fluctuation-dissipation theorem: challenge for effective approaches

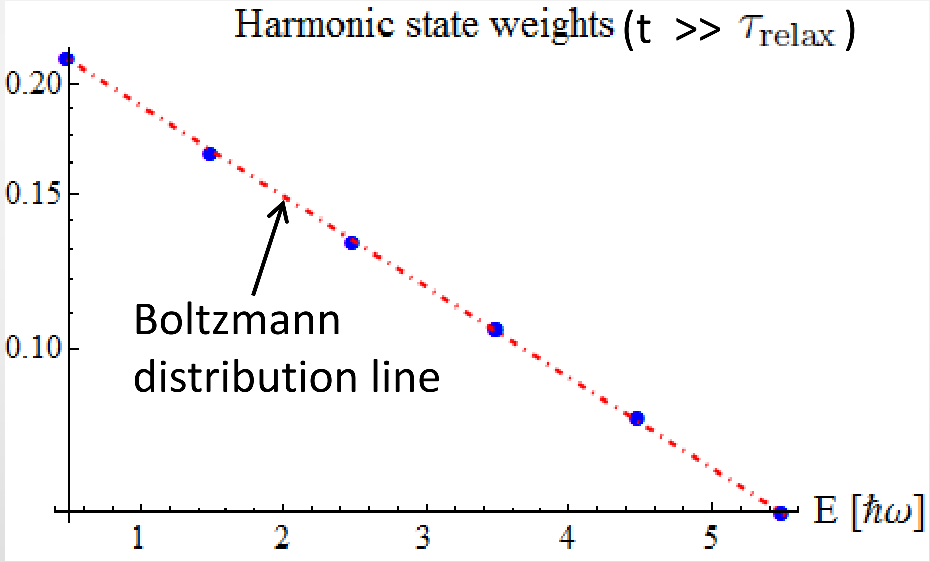
SL: numerical test of thermalisation

Harmonic potential

Asymptotic Boltzmann distributions ? YES
for any (A,B,σ) and from any initial state

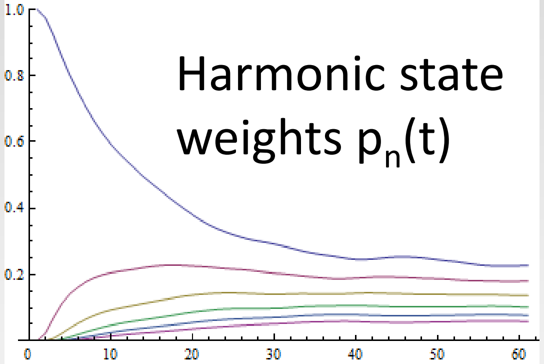



Harmonic state weights (t)

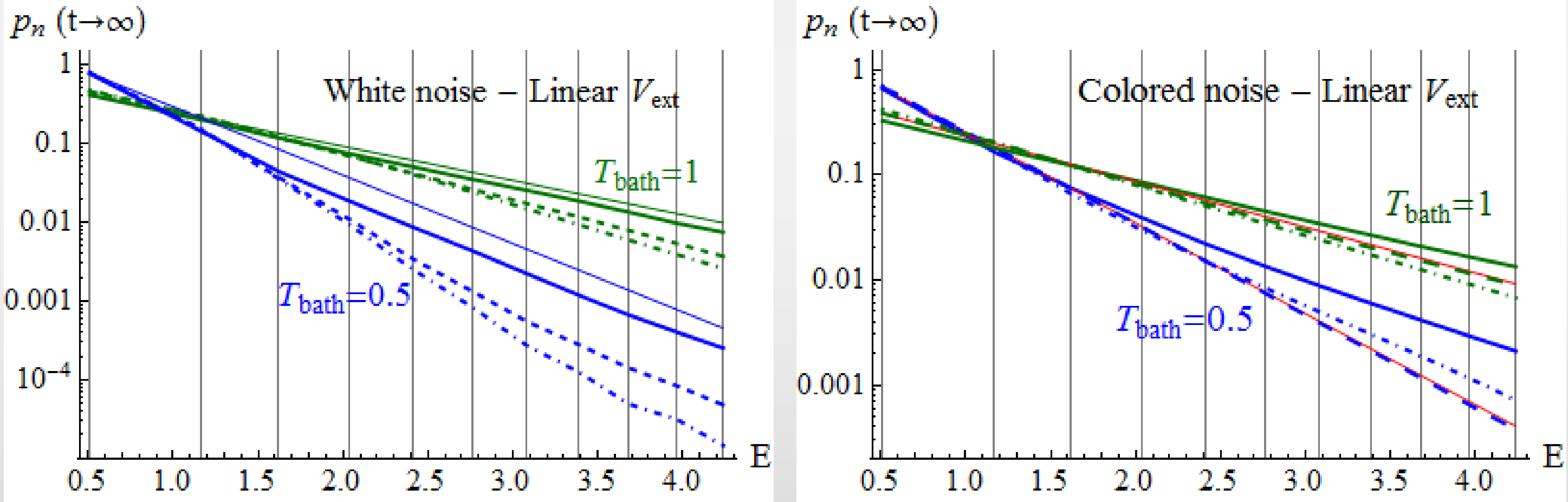

Harmonic state weights (t >> τ_{relax})

Boltzmann distribution line

Equilibration with SL equation



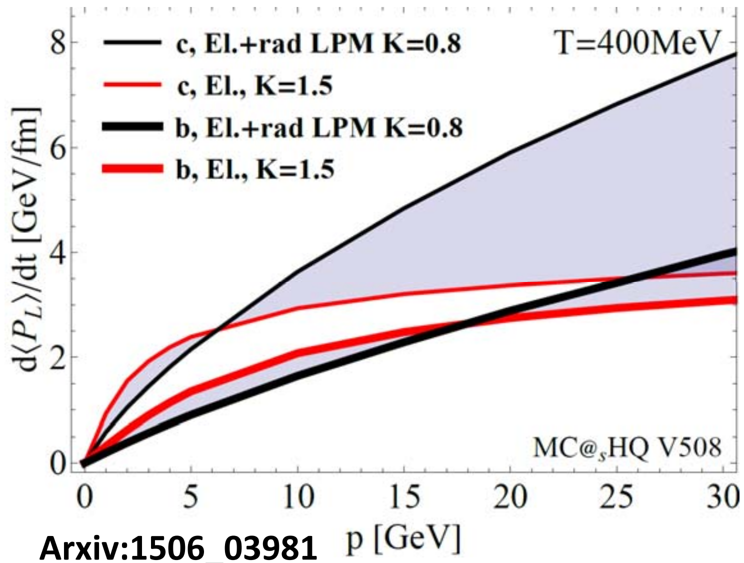
Leads the subsystem to thermal equilibrium (Boltzmann distributions) for at least the low lying states



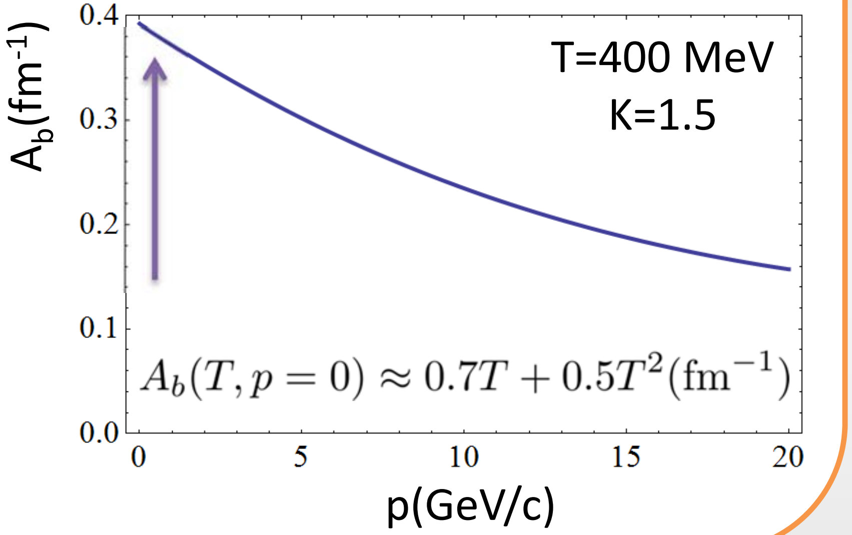
See R. Katz and P. B. Gossiaux, Annals of Physics (2016), pp. 267-295, arXiv:1504.08087 [quant-ph]

Drag coefficient A_b

- Obtained within our running α_s approach*



Arxiv:1506_03981



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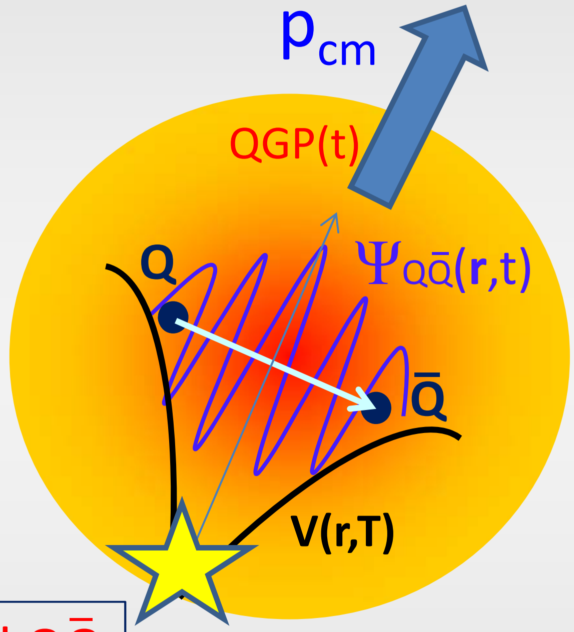
* P.B. Gossiaux and J. Aichelin 2008 Phys. Rev. C 78 014904

Ingredients for a dynamical model based on Schroedinger-Langevin Equation

QGP temperature scenarios T(t,x)

Cooling QGP



Initial $Q\bar{Q}$ state

Mean field: color screened binding potential V(r,T)

polarization due to color charges

+

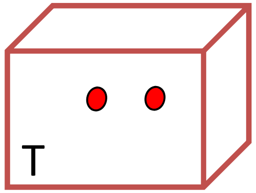
Thermalisation and diffusion: √

Direct interactions with the thermal bath

Understanding the physics in a stationary medium

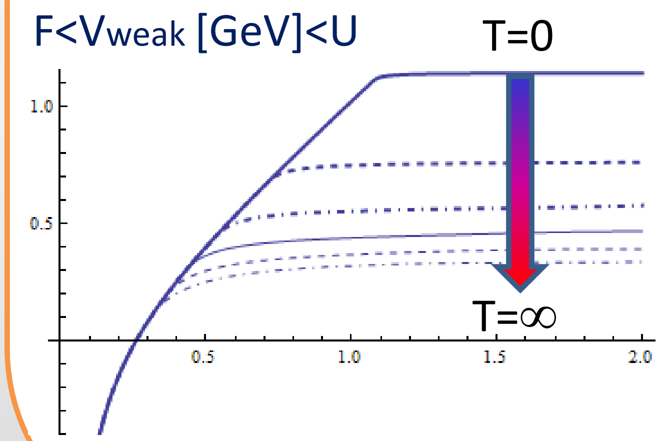
Mean color field : screened V(T_{red}, r) binding the $Q\bar{Q}$

Static lQCD calculations (maximum heat exchange with the medium):

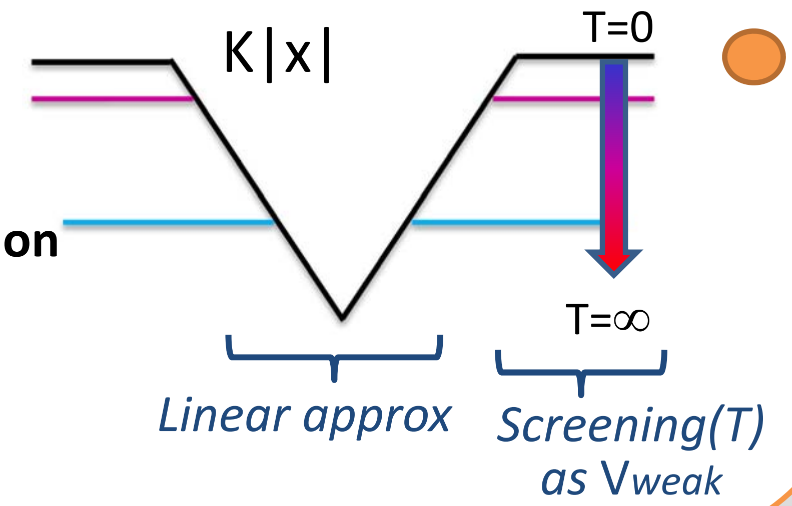


→ { F : free energy
S : entropy } → U=F+TS : internal energy
(no heat exchange)

- “Weak potential” F<Vweak<U * => some heat exchange
- “Strong potential” V=U ** => adiabatic evolution



1D → **simplification**



* Mócsy & Petreczky Phys.Rev.D77:014501,2008
** Kaczmarek & Zantow arXiv:hep-lat/0512031v1

In vacuum: $V(T_{red}=0, r)$

Parameters chosen to reproduce Upsilon spectrum + BBbar threshold

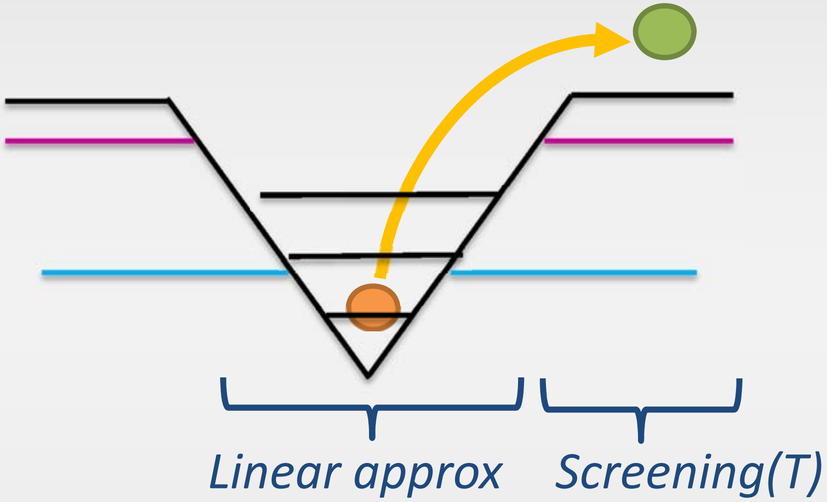
state	Mass calc	Mass exp	Diff exp-calc
1S	9.46	9.460	0.
1P	9,77	9,86	0.09
2S	9,99	10.023	0.01
2P	10.18	10.255	0.075
3S	10.35	10.355	0.0
3P	10.51	10.51	0.0

mb=4.61, K_l=2.491 GeV/fm & Vmax=1.338 GeV

Dynamics of Q$\bar{\text{Q}}$ with SL equation

Evolutions at constant T: understanding the model

- Simplified Potential but contains the essential physics



Stochastic forces => feed up of higher states and continuum => Leakage of bound component

- Observables: **Weight** $W_i(t) = \left\langle \left|\langle\psi_i(T=0)|\psi_{Q\bar{Q}}(t)\rangle\right|^2 \right\rangle_{\mathrm{stat}}$

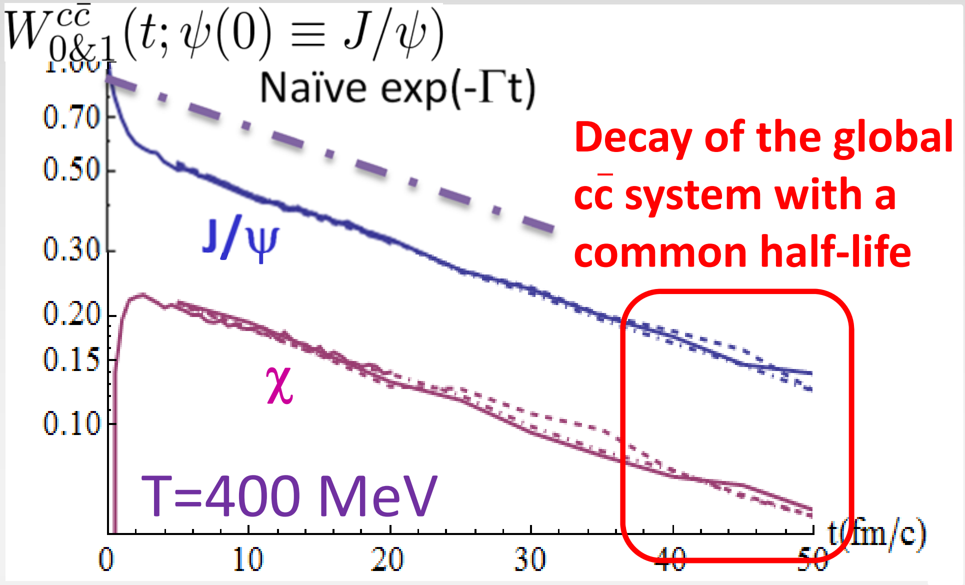
Initial Q$\bar{\text{Q}}$ wavefunction

- Produced at the very beginning : $\tau_f^{Q\bar{Q}} \sim \hbar/(2m_Q\,c^2) < 0.1\ \mathrm{fm/c}$

Evolution with V(T=0) + Fstocha

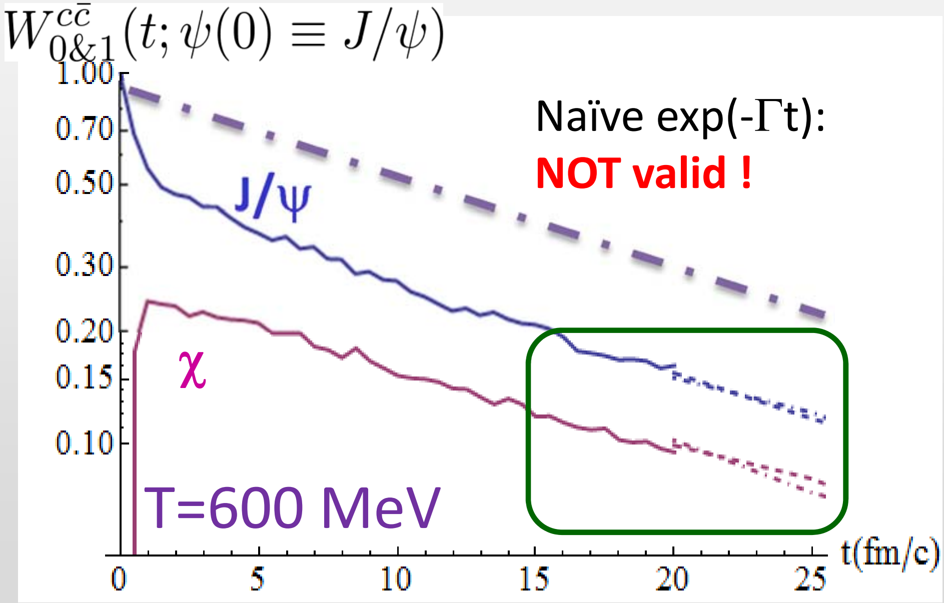
V(T=0) => NO Debye screening

Results for charmonia
(equivalent behaviour for
bottomonia)



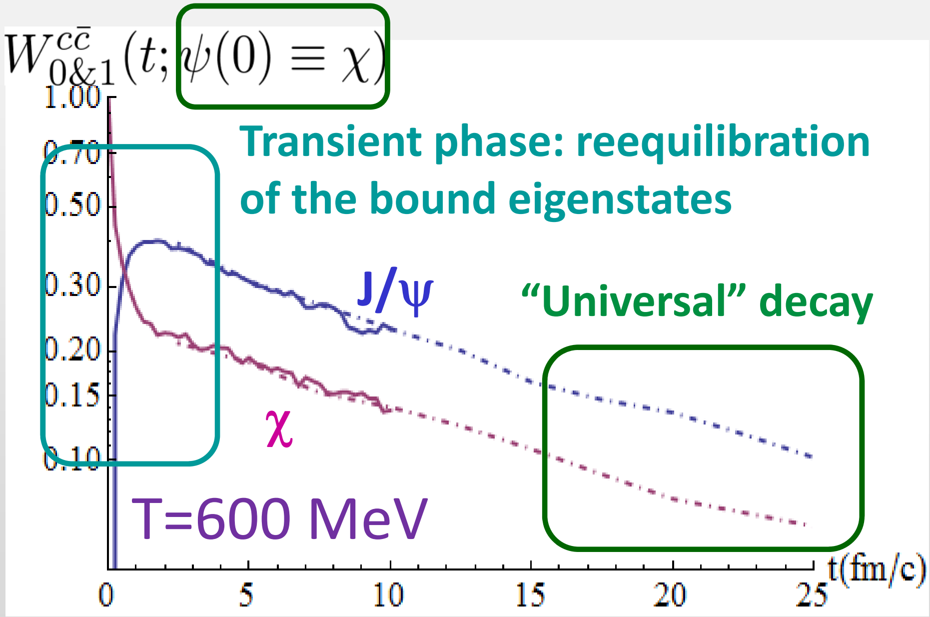
$W^{c\bar{c}}_{0\&1}(t;\psi(0)\equiv J/\psi)$

Decay of the global $c\bar{c}$ system with a common half-life



$W^{c\bar{c}}_{0\&1}(t;\psi(0)\equiv J/\psi)$

Naïve exp(-Γt): **NOT valid !**

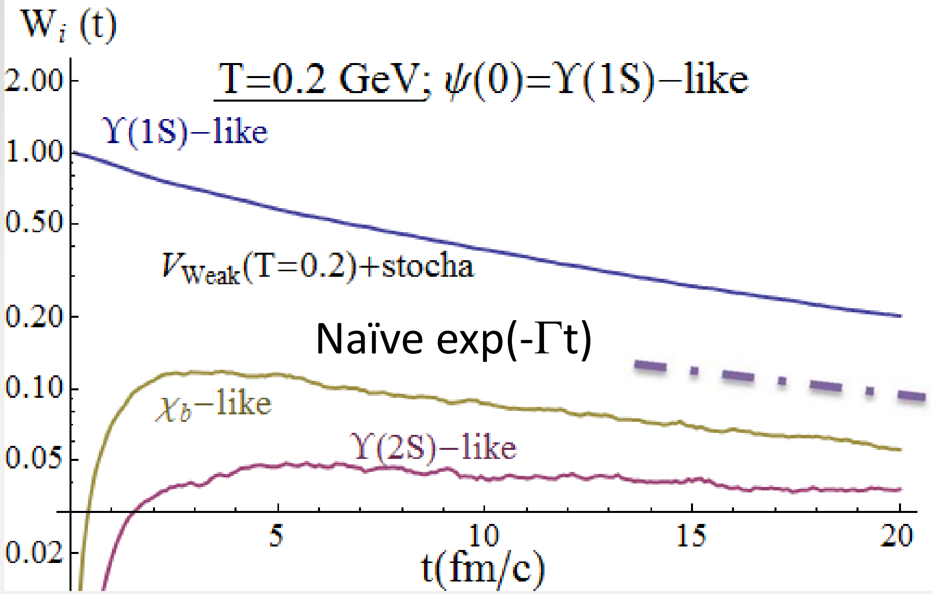


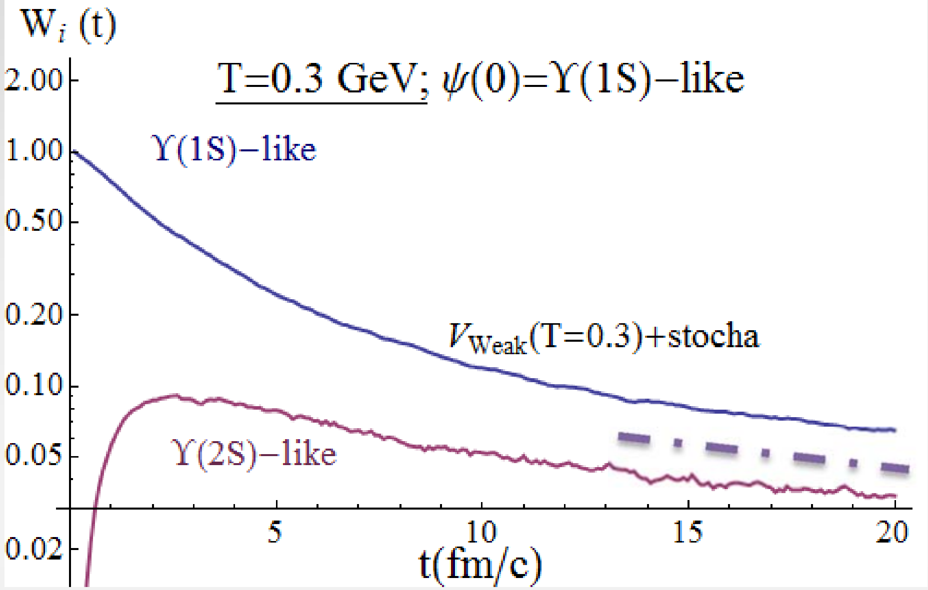
$W^{c\bar{c}}_{0\&1}(t;\psi(0)\equiv \chi)$

Transient phase: reequilibration of the bound eigenstates

"Universal" decay

Evolutions with V(T=cst) + Fstocha

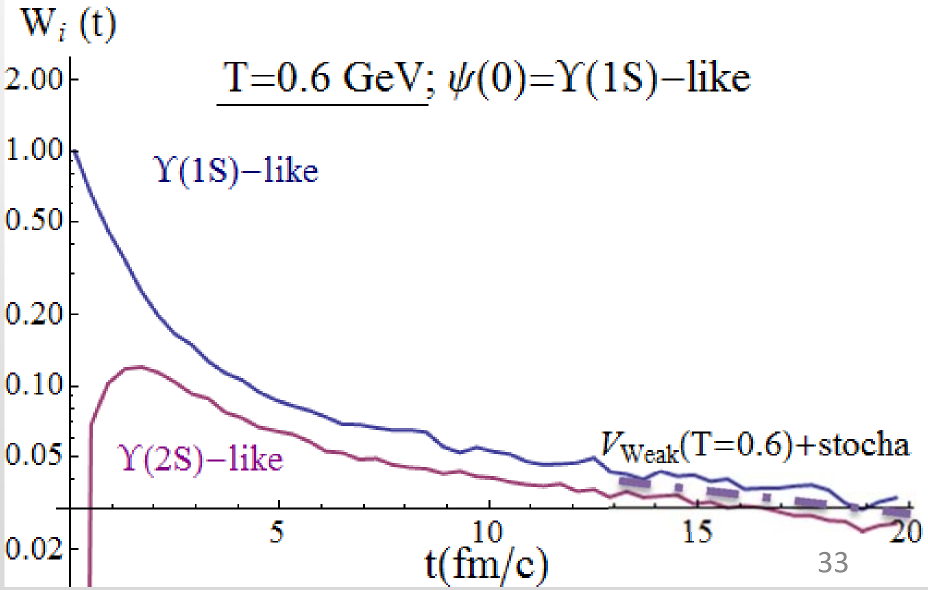




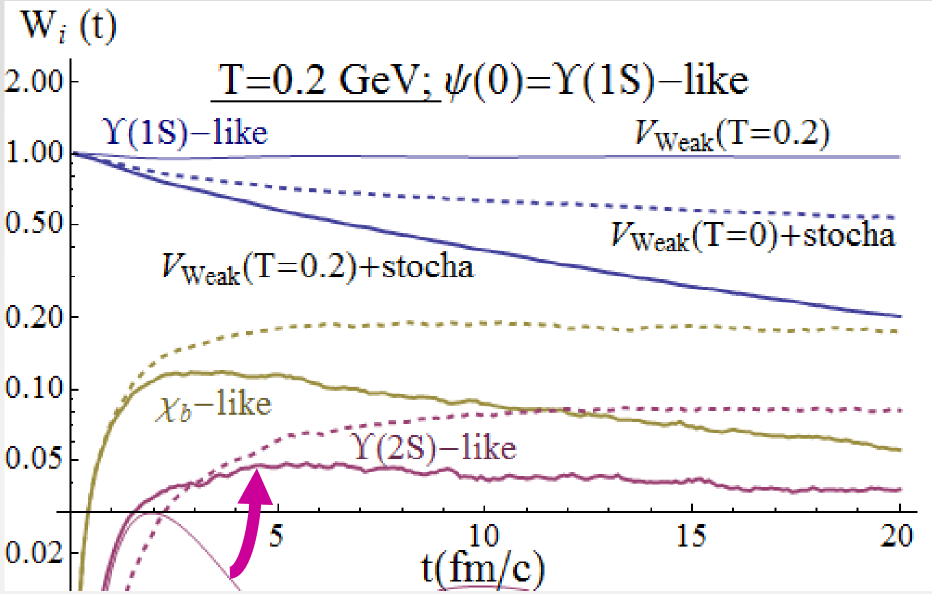
✓ Common decay law at large t (leakage+internal equilibration)

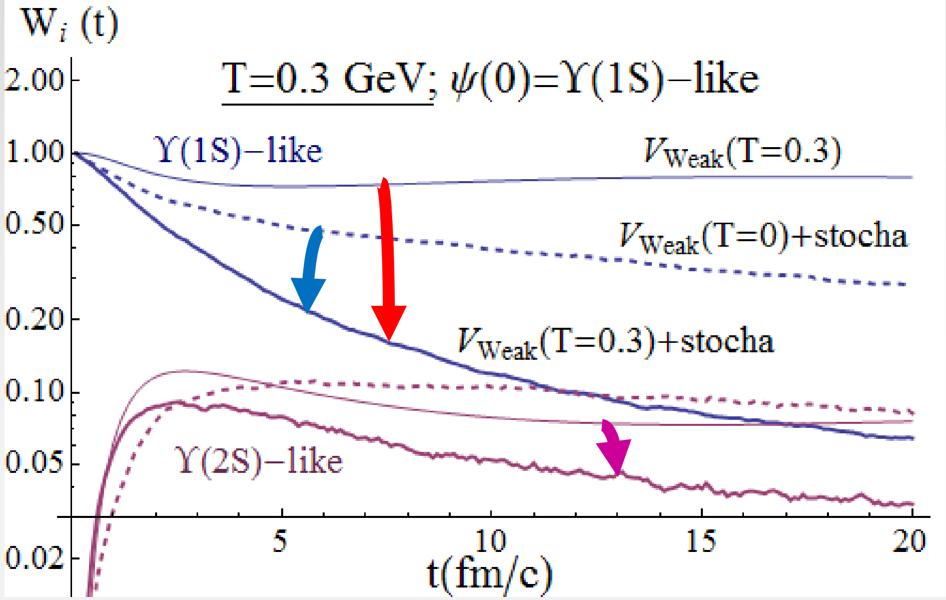
✓ Γ increases with T

✓ Starting from Υ(1S), higher states are asymptotically more populated at large T.

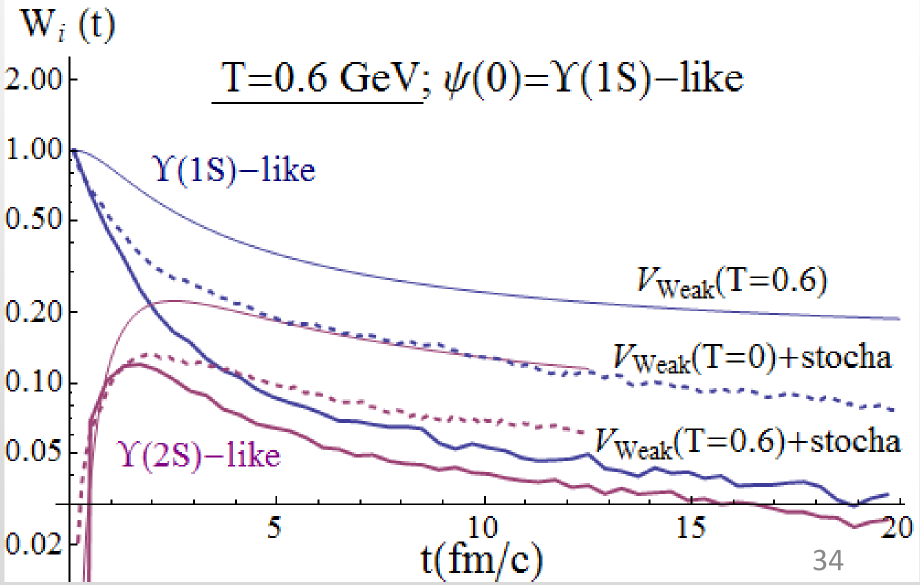


Evolutions with V(T=cst) + Fstocha

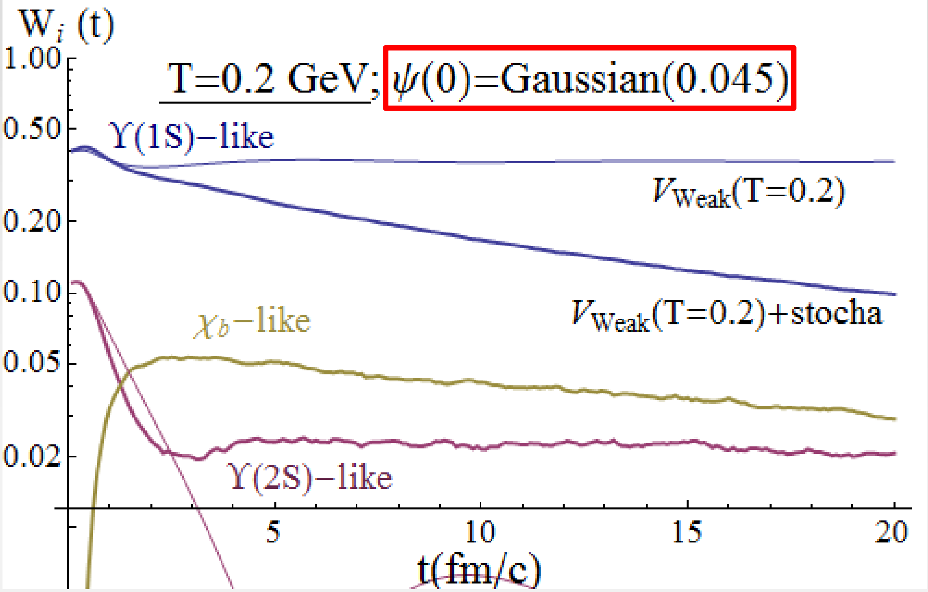


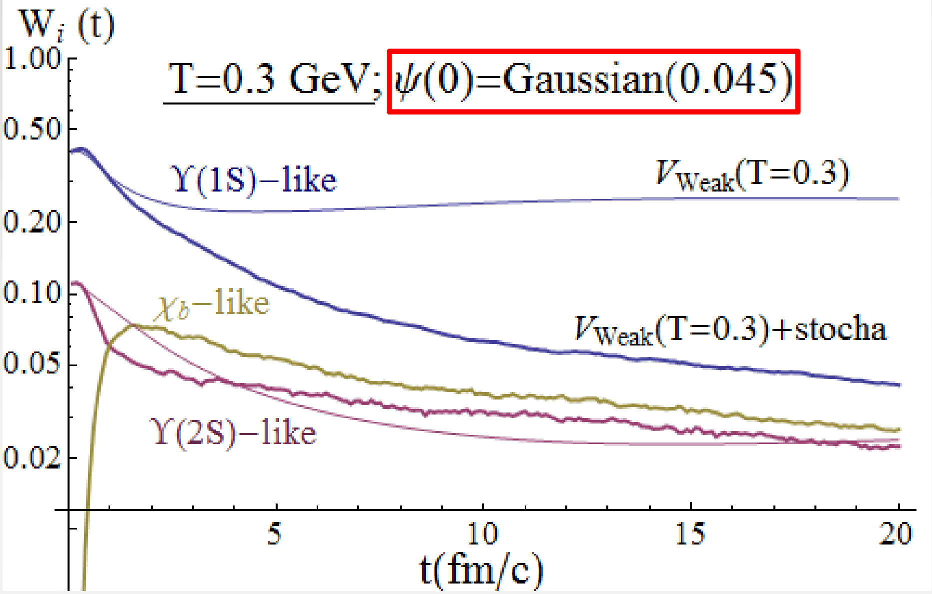


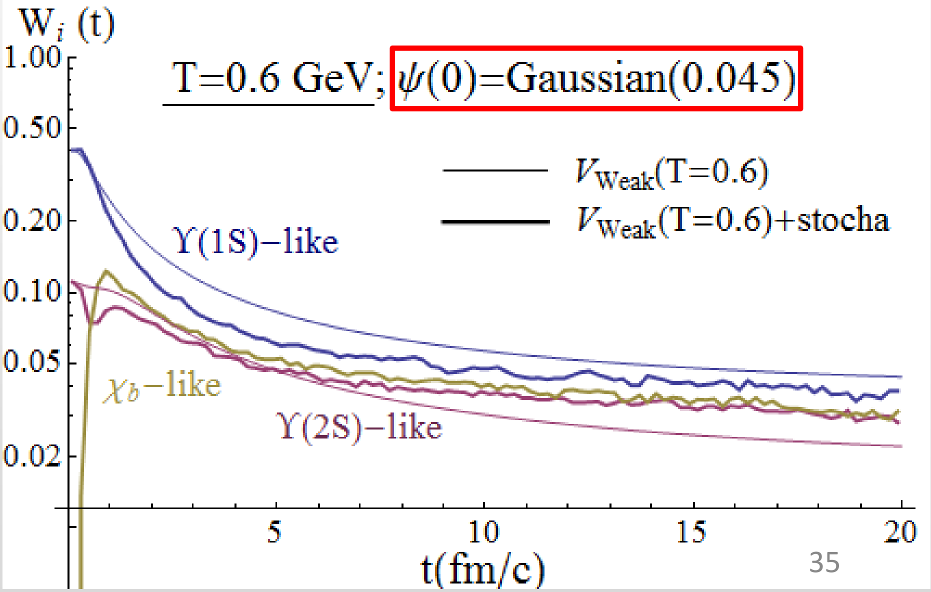
- ✓ Υ(1S): The stochastic forces leads to larger suppressions
- ✓ Υ(2S): ……… for T≥0.3 only
- ✓ The screening also leads to larger suppression



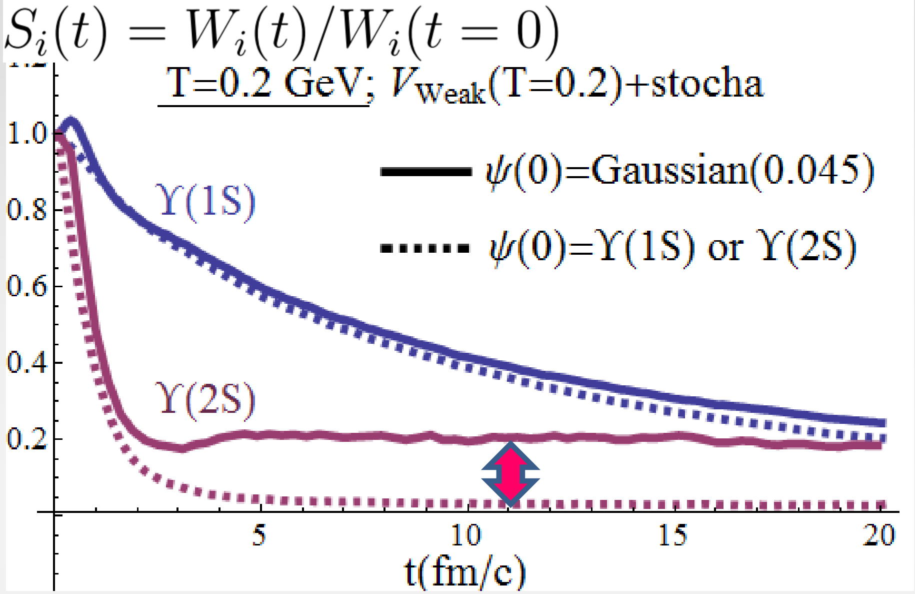
Evolution with V(T=cst) and initial Gaussian

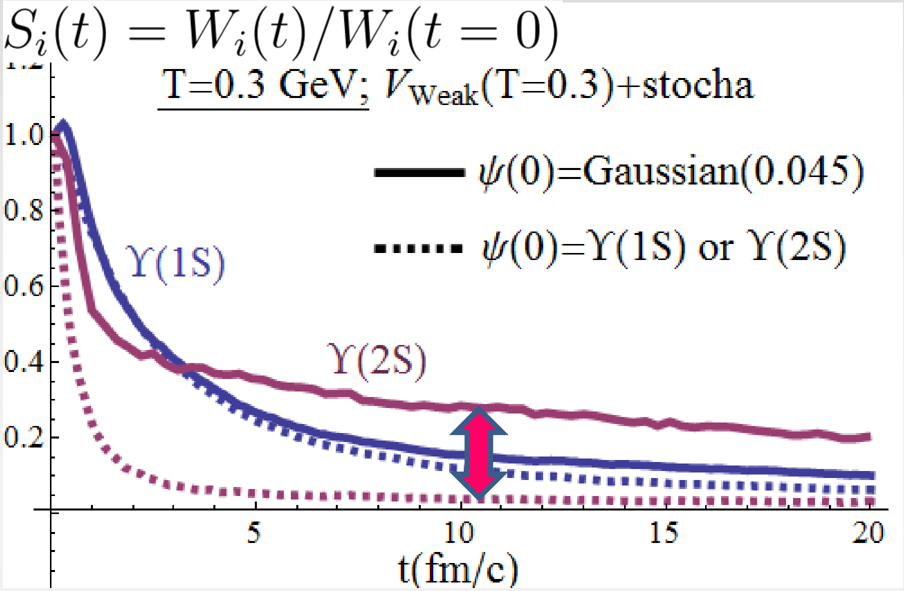


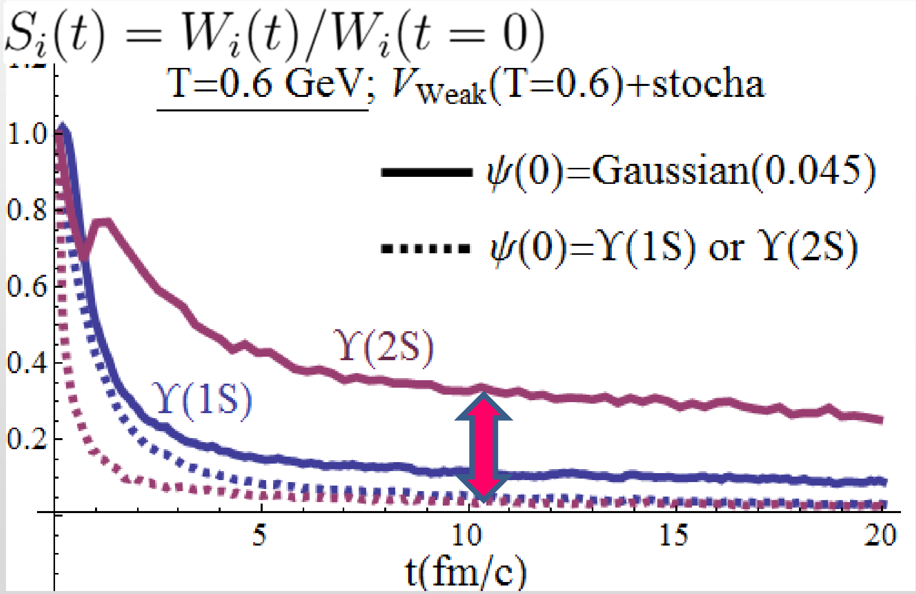




Evolutions with V(T=cst) + Fstocha







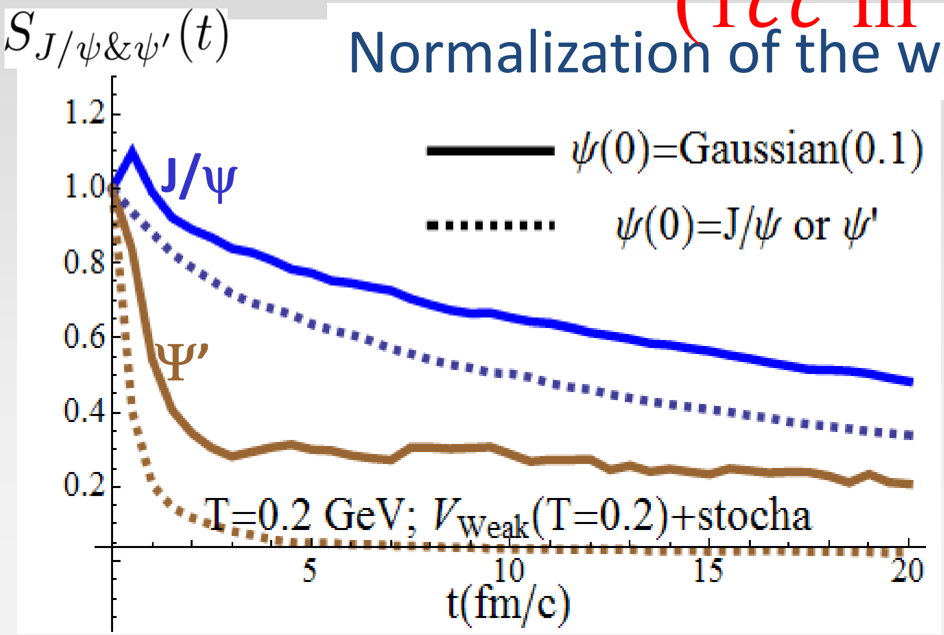
✓ S quite depends on the initial quantum state !

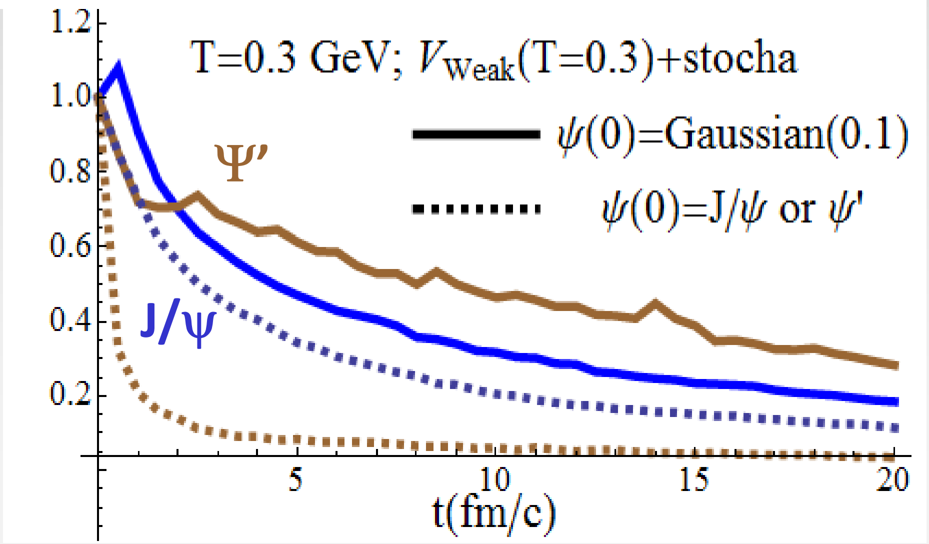
=> Kills the assumption of quantum decoherence at t=0

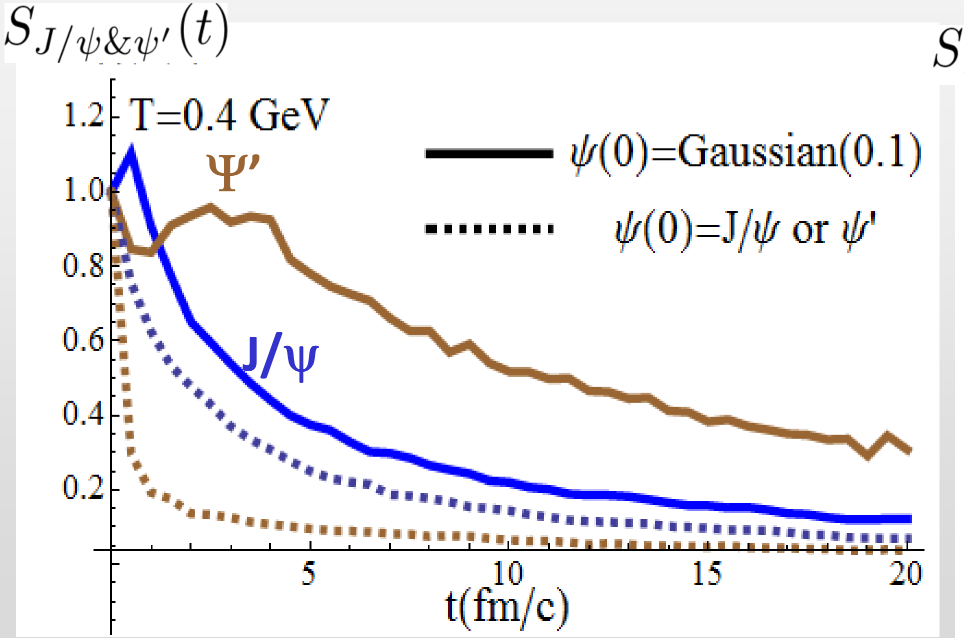
Suppression of states as a function of time

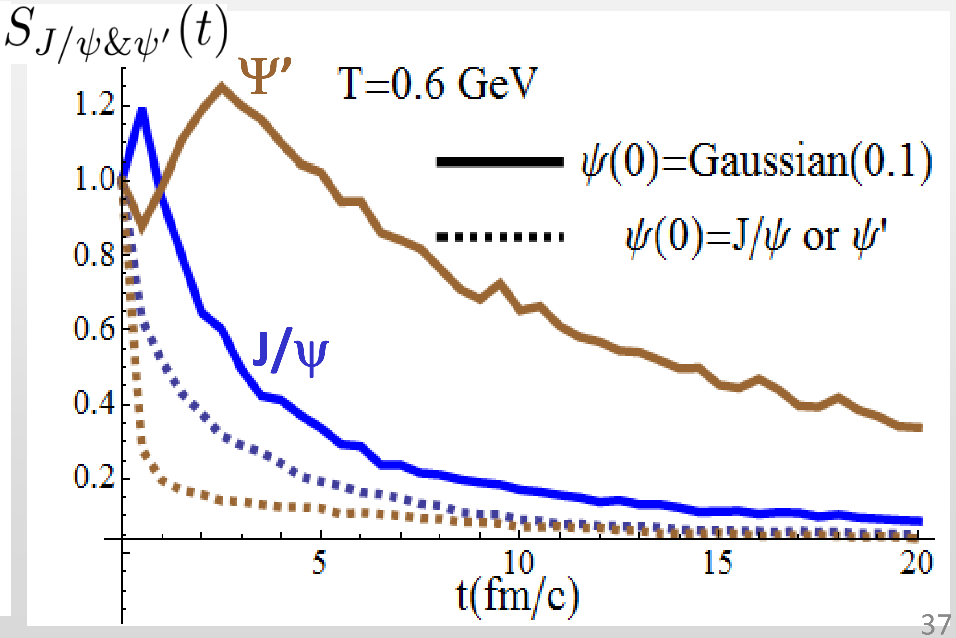
$(1c\bar{c}$ in the HB$)$

Normalization of the weights by their t=0 values





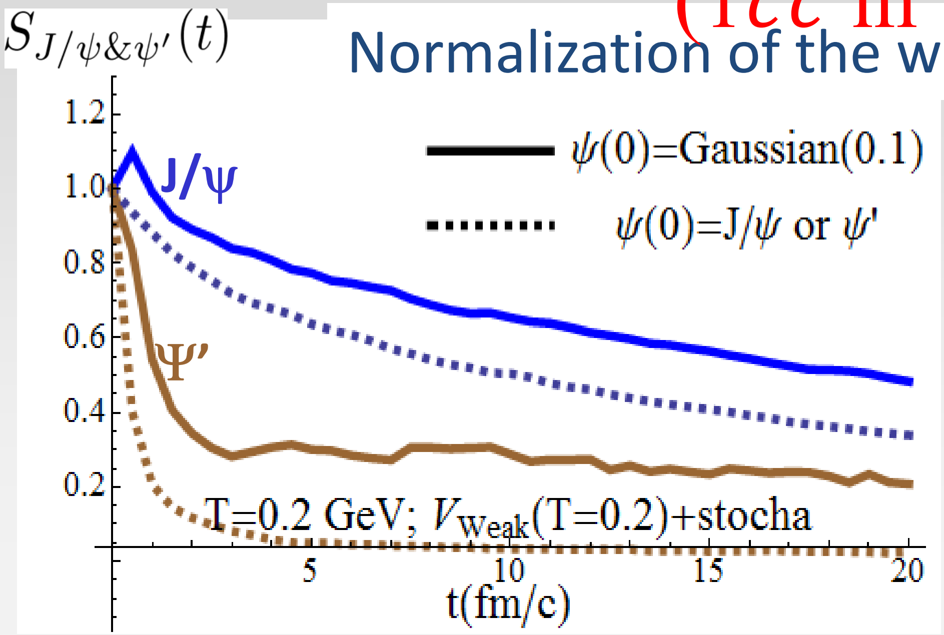


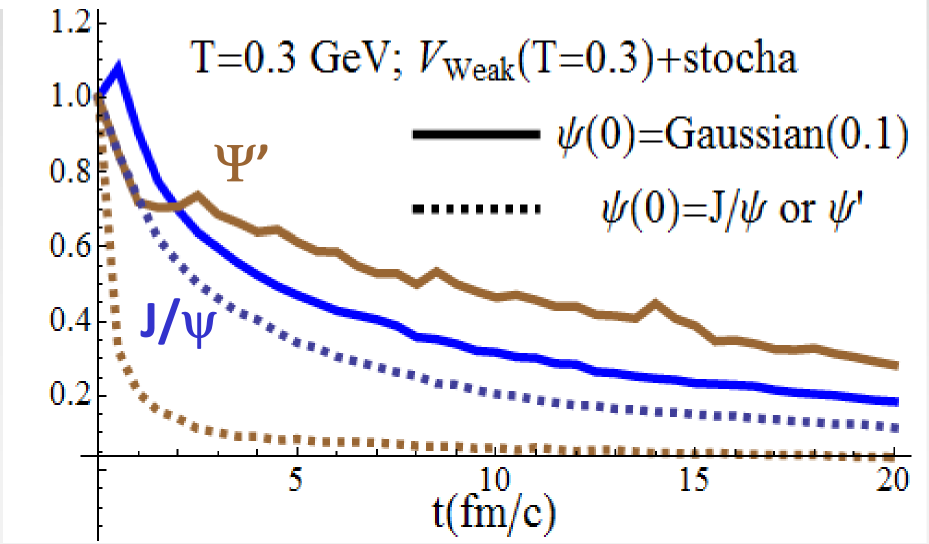


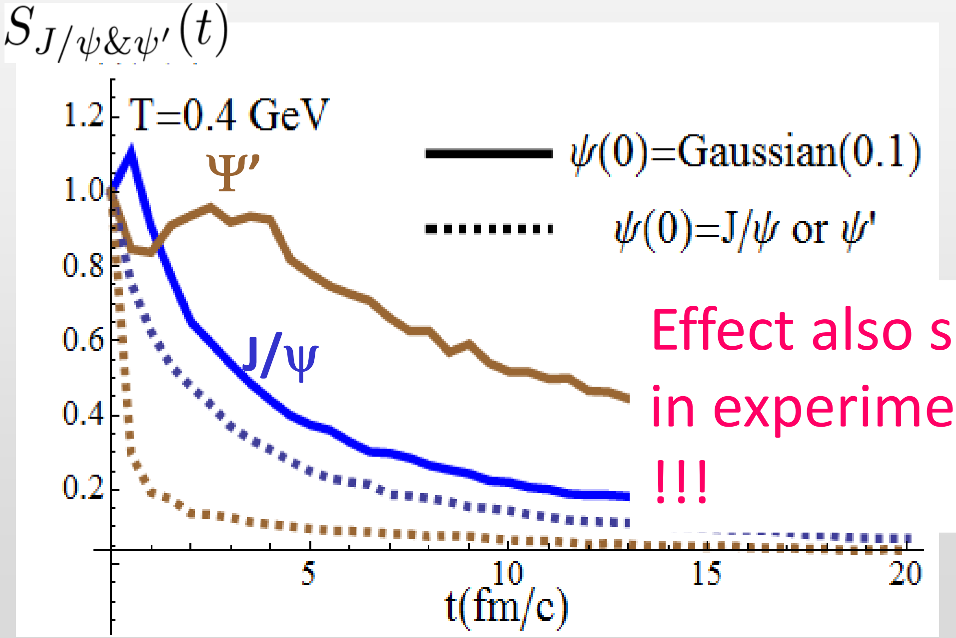
Suppression of states as a function of time

$(1 c\bar{c}$ in the HB)

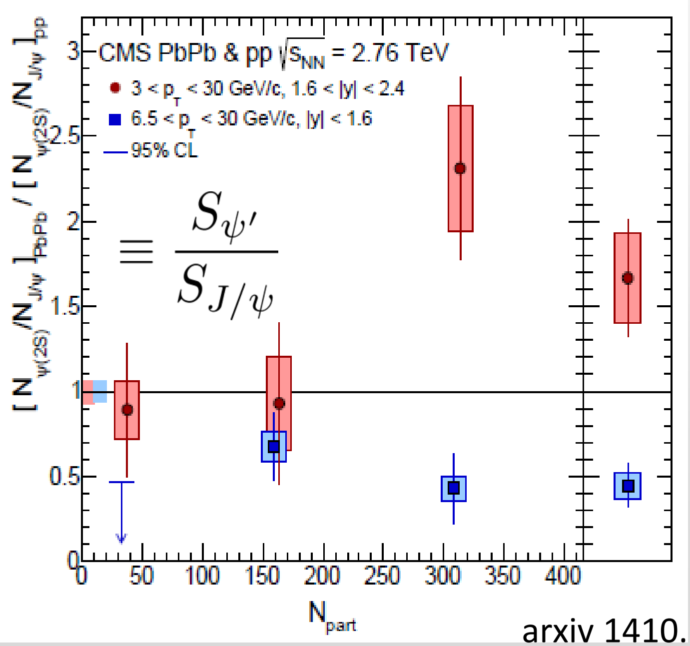
Normalization of the weights by their t=0 values







Effect also seen in experiment !!!

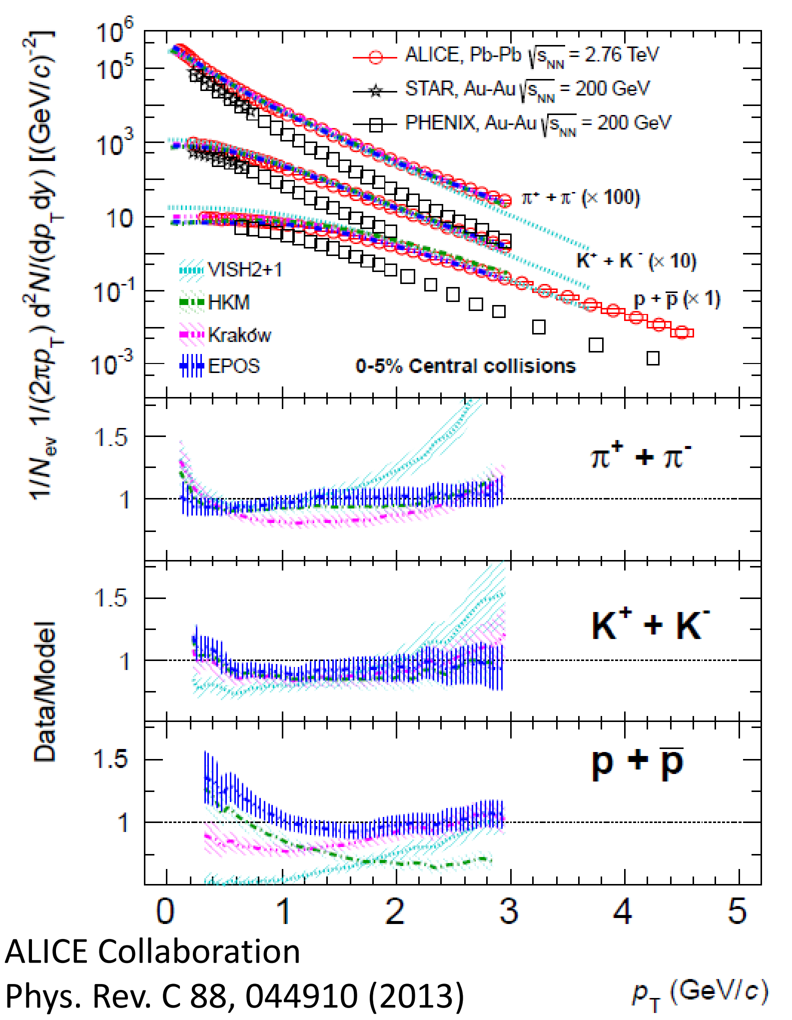


$$\equiv \frac{S_{\psi'}}{S_{J/\psi}}$$

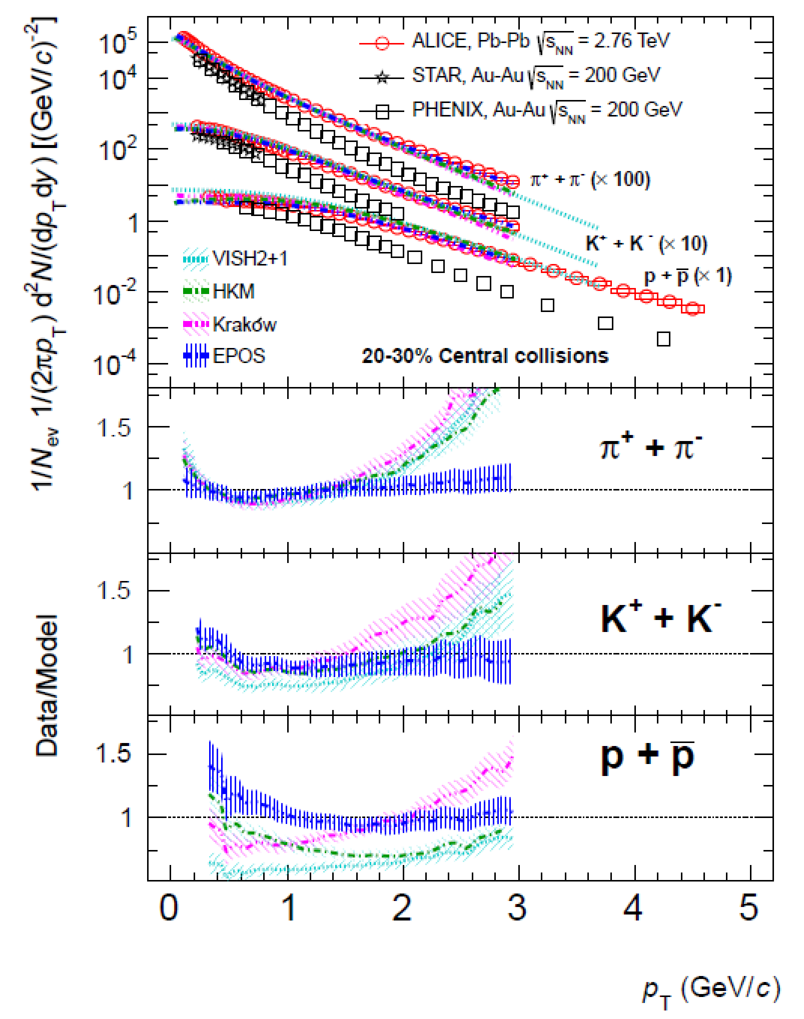
arxiv 1410.1804

Going realistic

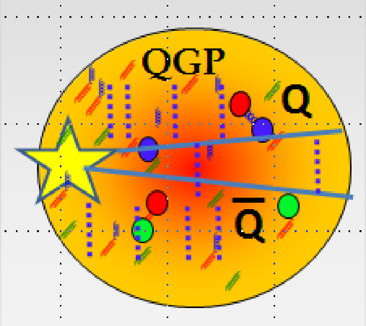
- **Evolution in EPOS2 background (very good model for AA*)**



ALICE Collaboration
Phys. Rev. C 88, 044910 (2013)



* K. Werner, I. Karpenko, T. Pierog, M. Bleicher and K. Mikhailov, Phys. Rev. C 82 (2010) 044904. K. Werner, I. Karpenko, M. Bleicher, T. Pierog and S. Porteboeuf-Houssais, Phys. Rev. C 85 (2012) 064907



Interlude

How much of the quantum coherence should we keep / do we know in the initial state ?

- None (decoupled): $\psi_{Q\bar{Q}}(t=0) = \psi_i(T=0)$ (eigenstate)

Practical advantage:

$$d\sigma^{AA}_{\text{direct}}(\Phi_i) = W_i \times d\sigma^{pp}_{\text{direct}}(\Phi_i)$$

From your favorite model (CEM,…) or from data fitting

$$d\sigma^{AA}_{\text{prompt}}(\Phi_i) = \sum_j B_{ij} \times d\sigma^{AA}_{\text{direct}}(\Phi_j)$$

- Only in a given harmonics ? Then, often $\psi_{Q\bar{Q};l=0}(t=0) = \text{Gaussian}$

  Practical advantage for radial potential: no mixing

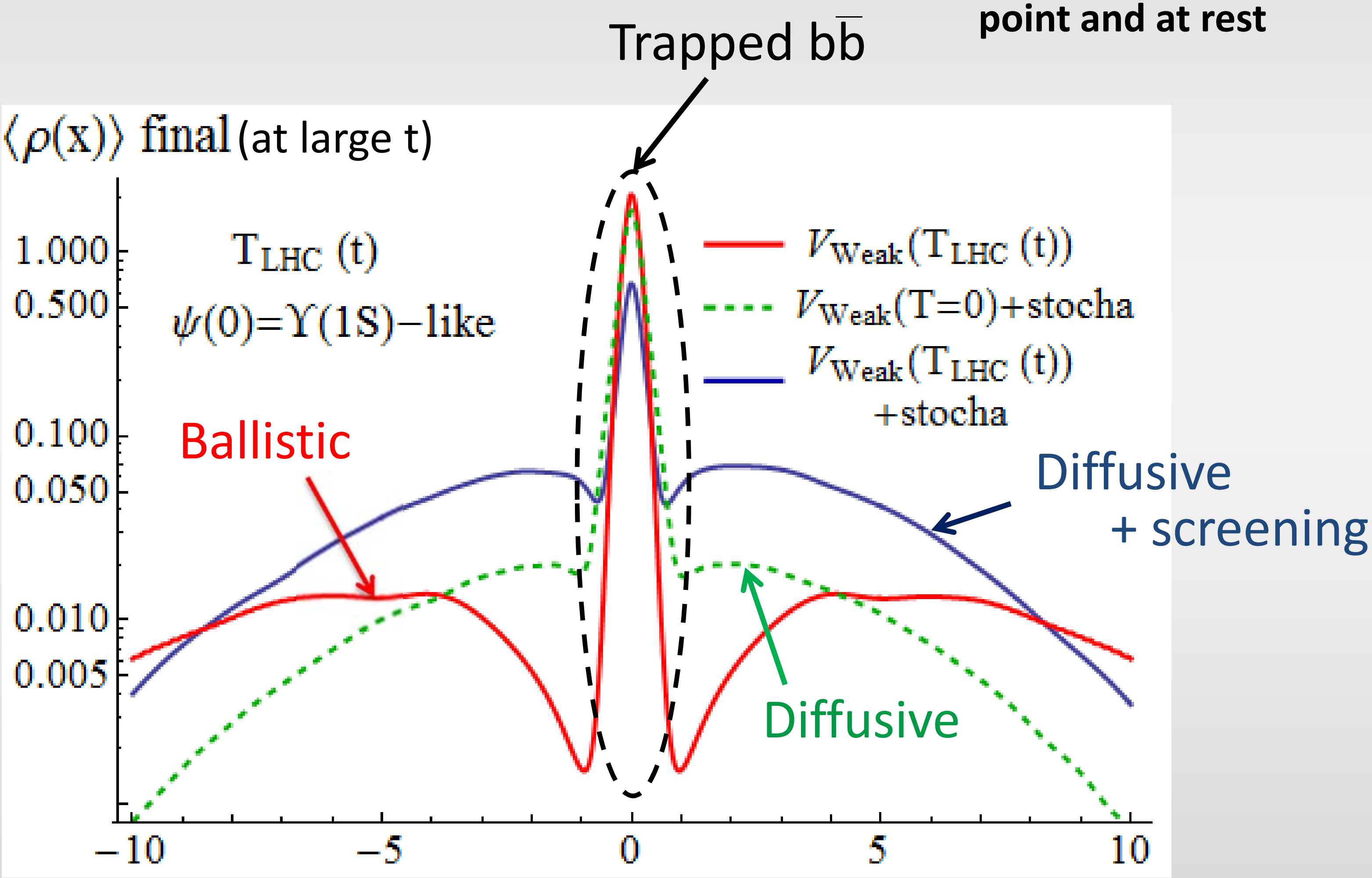
  Need to find a width that accomodates measured ratios (in this harmonics)

- Only in a given color representation ?

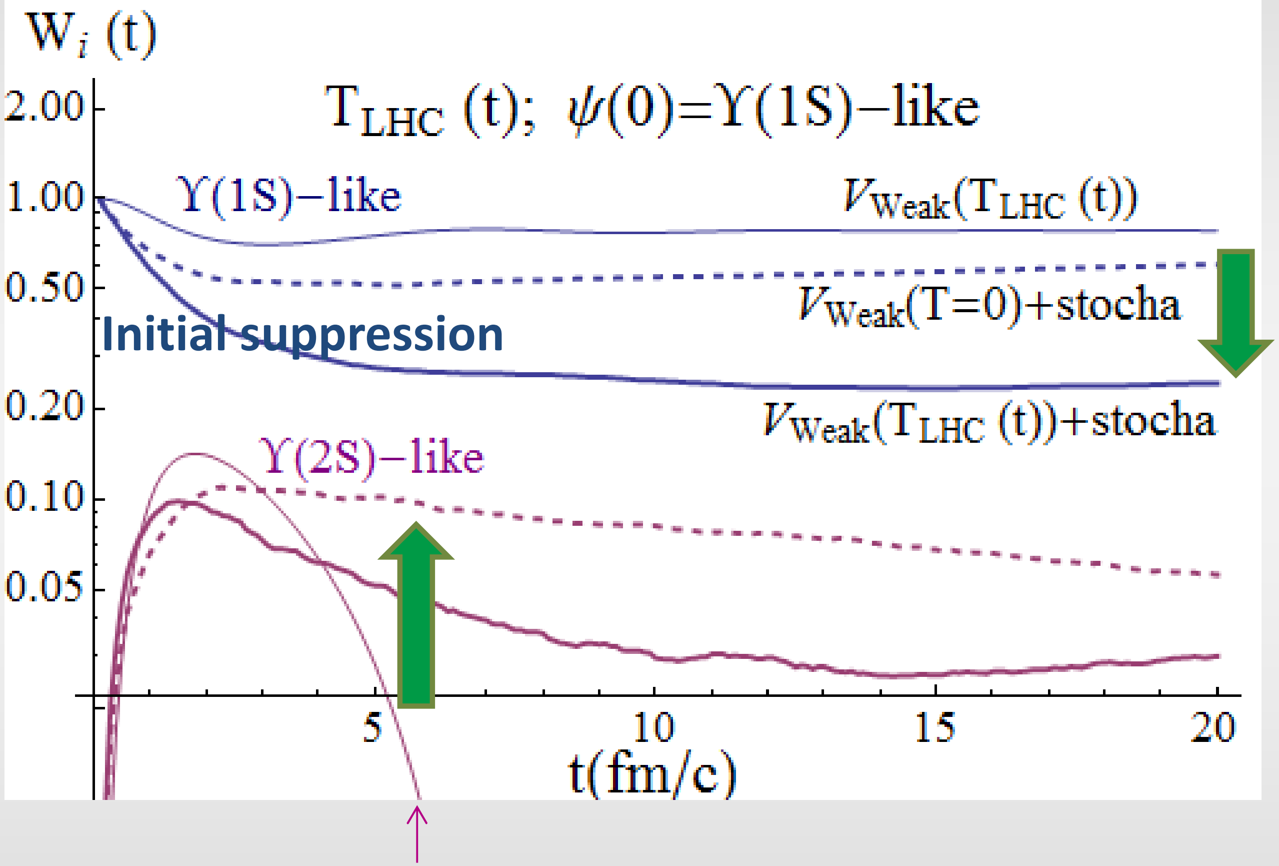
Understanding the physics in a uniform medium with T(t)

Density with V(T_LHC(t,0)) and initial Υ(1S)

Case of bbar at hottest QGP point and at rest



Evolutions with V(TLHC(t,0)) and initial Y(1S)

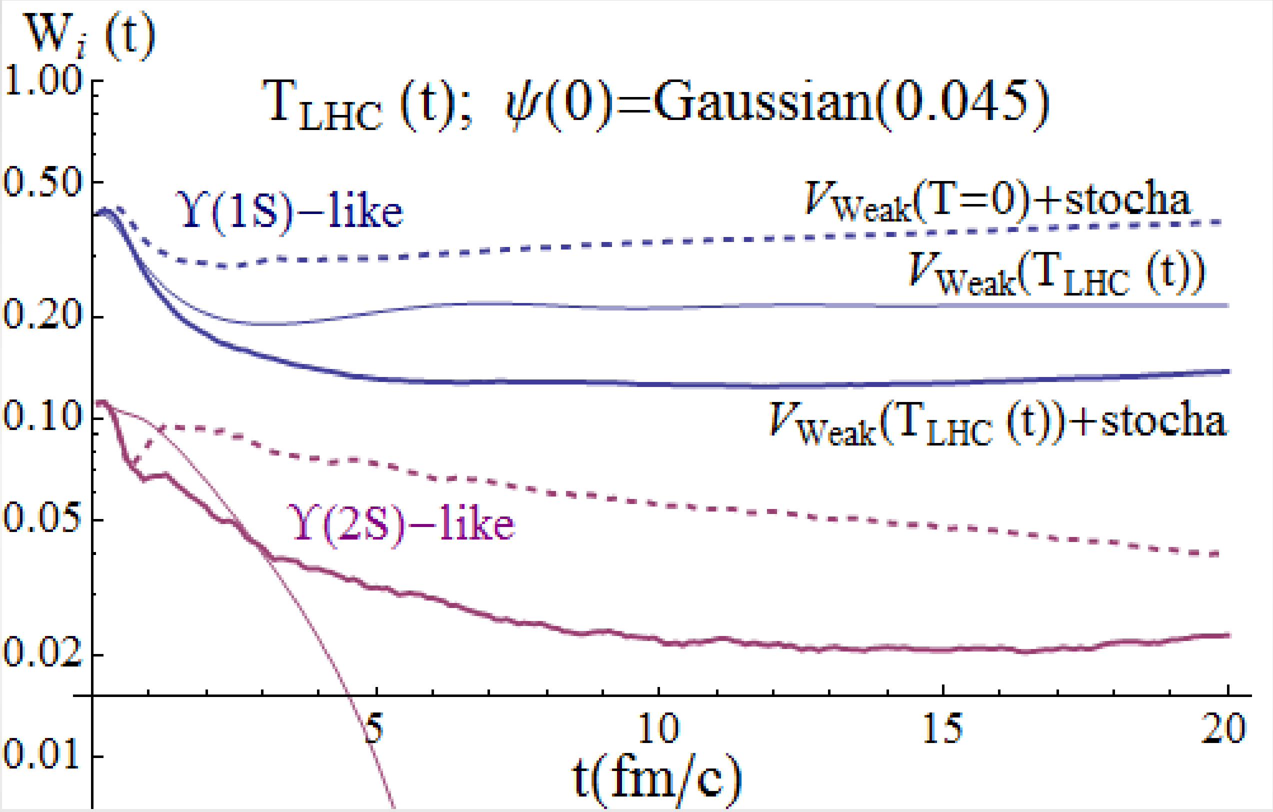


Continuous depopulation from stochastic forces

Continuous *repopulation* from stochastic forces

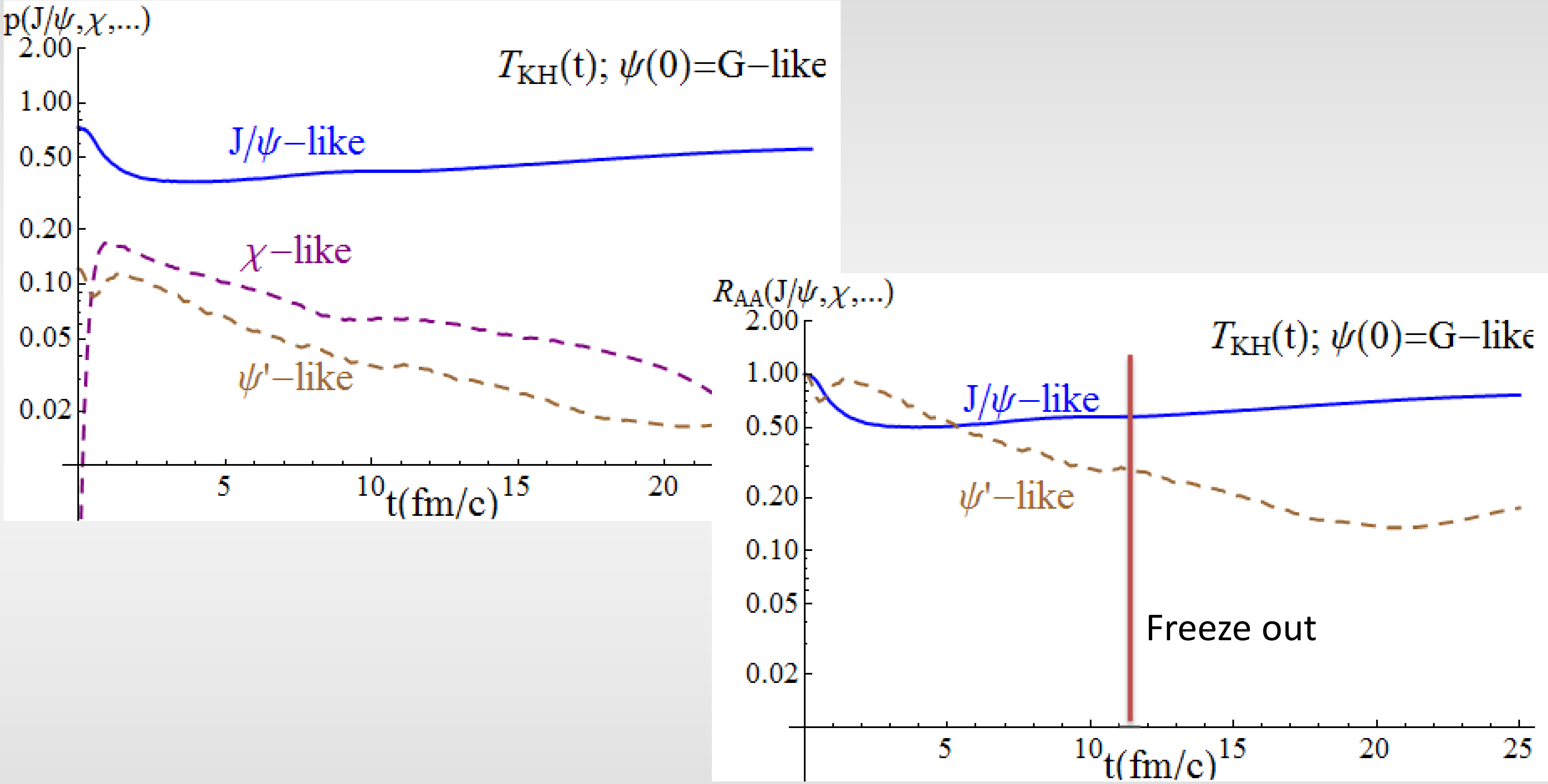
Fast suppression in MF only

Evolutions with V(TLHC(t,0)) and initial Gaussian



✓ Initial weights have no big influence on large time weights

Evolutions with V(TLHC(t,0)) and initial Gaussian



✓ Psi’ more suppressed in a dynamical plasma !

Going realistic

Realistic initial state

Initial QQ wavefunction

- Can we cope with the p-p data at LHC, including the various feed-down ?

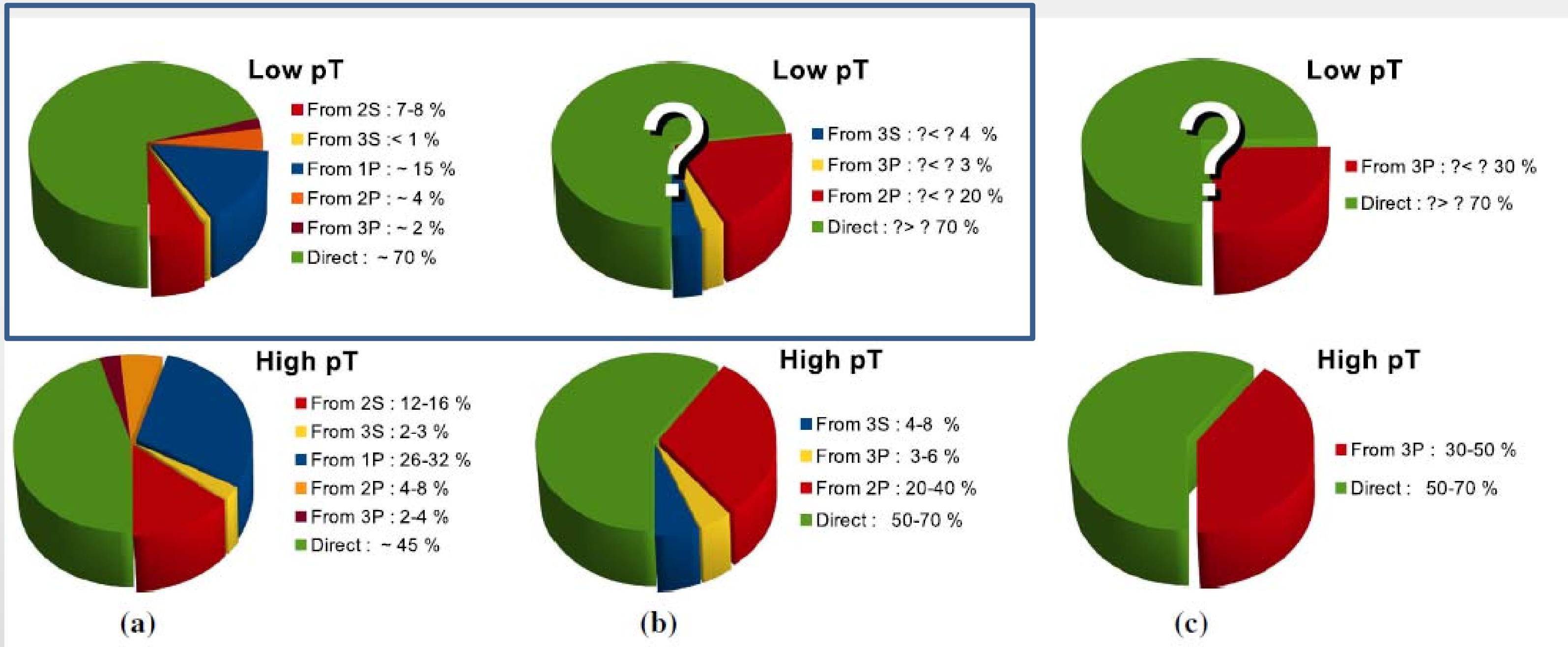


Fig. 14 Typical sources of $\Upsilon(nS)$ at low and high p_T. These numbers are mostly derived from LHC measurements [197–199, 203–208] assuming an absence of a significant rapidity dependence. **a** $\Upsilon(1S)$; **b** $\Upsilon(2S)$; **c** $\Upsilon(3S)$

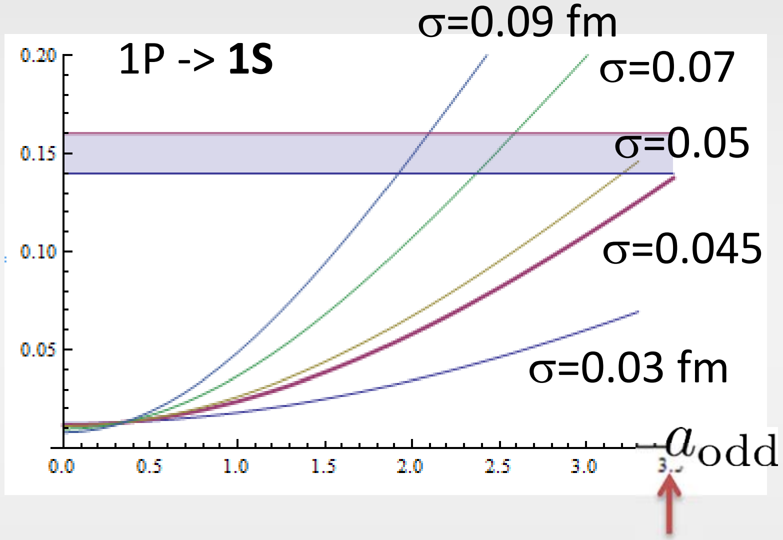
Initial State has S-like and P-like components

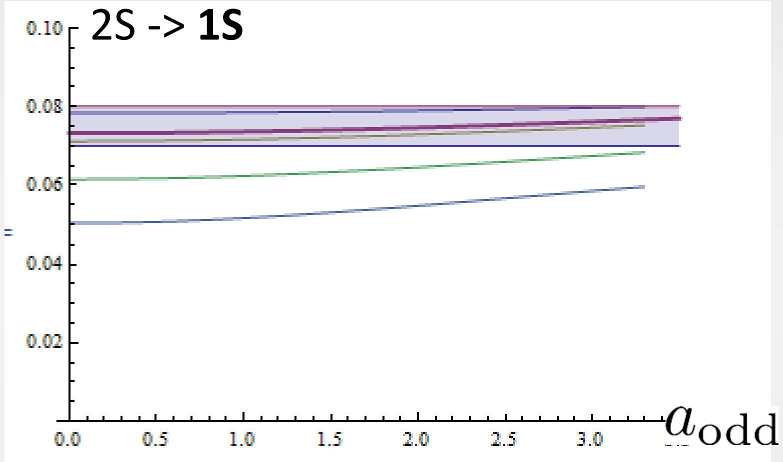
Trial S+P initial state:

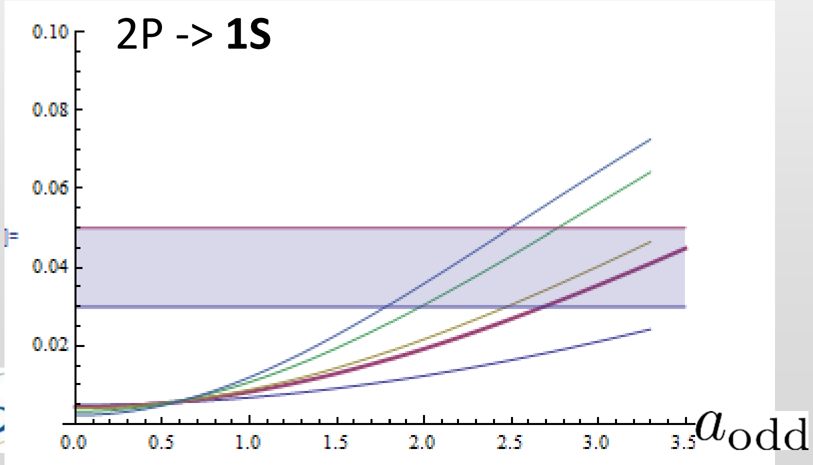
$$\psi_{b\bar{b}}(t=0,x) \propto e^{-\frac{x^2}{2\sigma^2}} \left(1 + a_{\mathrm{odd}}\, \frac{x}{\sigma}\right)$$

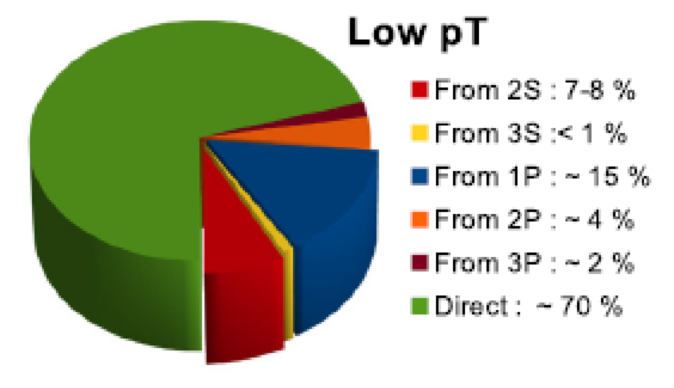
Looking at integrated production as a proxy for **low p_T:**

$$\sigma = 0.045\ \mathrm{fm}\quad a_{\mathrm{odd}} = 3.5$$









7-8%
1 %
14%
4 %
0 %

Trial S+P initial state:

$$\psi_{b\bar{b}}(t=0,x) \propto e^{-\frac{x^2}{2\sigma^2}} \left(1 + a_{\mathrm{odd}} \frac{x}{\sigma}\right)$$

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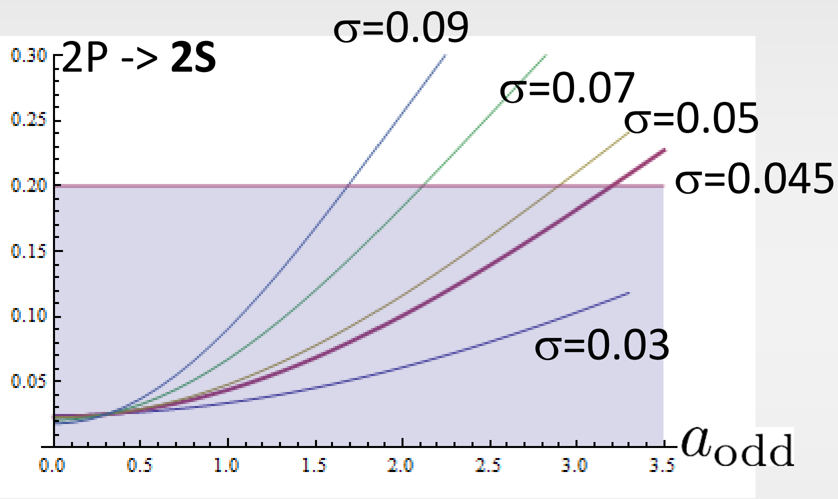
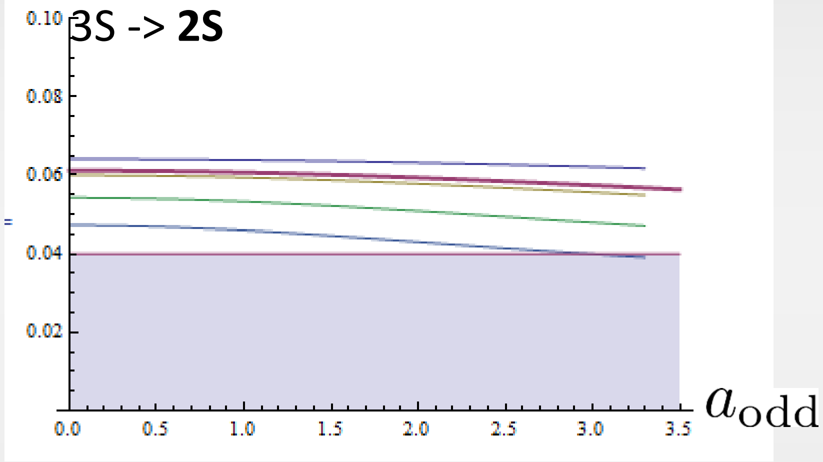
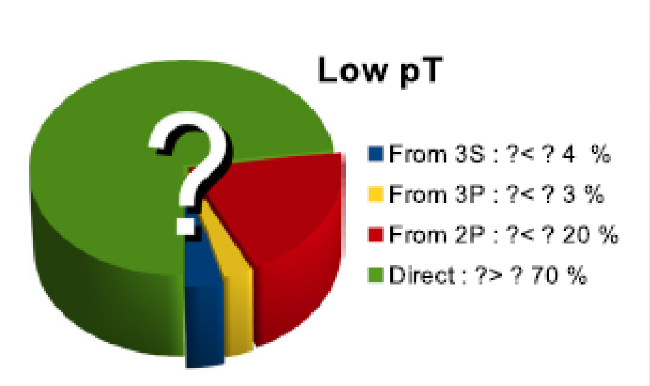






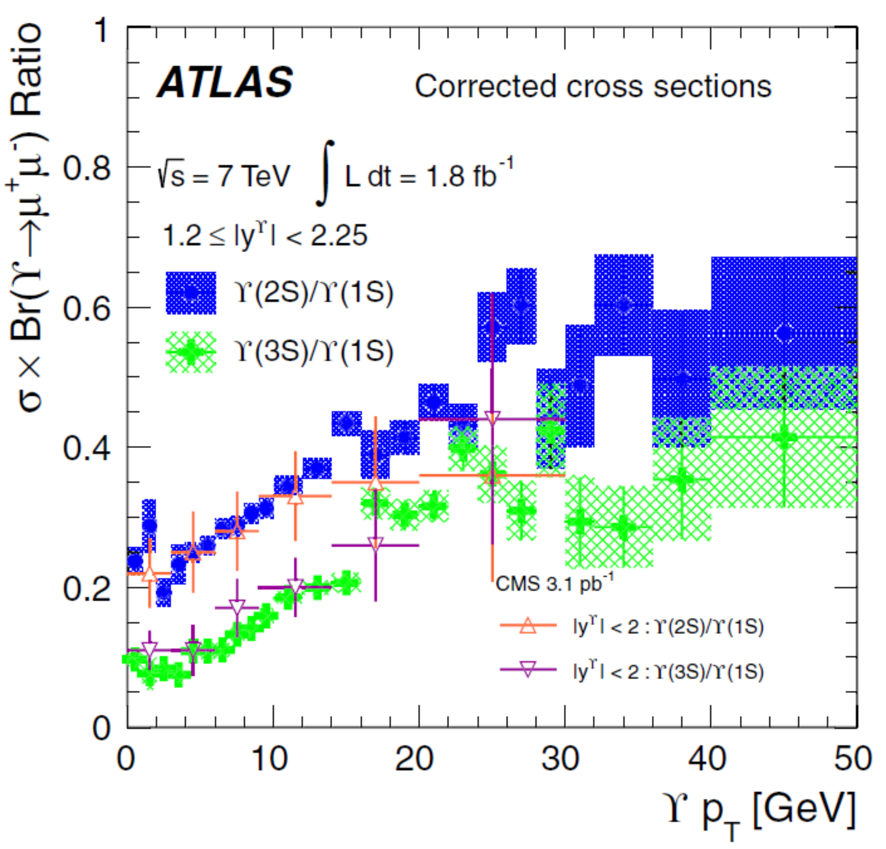
6%
0 %
22 %

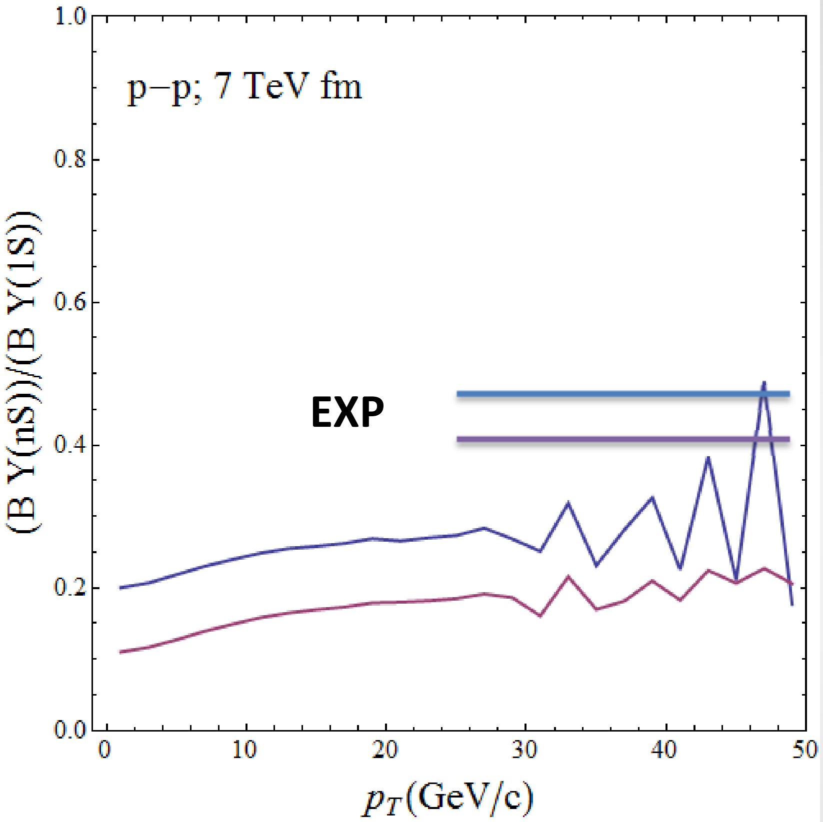
Good « fit » at low p_T

Enables us to deal with feed down

… But other possibilities exist

Going high p_T:





Mild increase vs p_T but saturates too low

Need for a better understanding of quarkonium production at high p_T. If mere gluon splitting + Eloss, our model doesn't apply anyhow

Going realistic

- **Evolution in EPOS2 background (very good model for AA*)**
- Glauber model for initial position of the b-bar pairs, No CNM effects
- b-bars assumed to be color singlets and then moving straight line with no Energy loss
- Initial internal b-bar state chosen as a gaussian (l=0+l=1)
- Observables:
  - **Weight :** $W_i(t) = \left\langle |\langle \psi_i(T=0)|\psi_{b\bar{b}}(t)\rangle|^2 \right\rangle_{\rm stat}$
  - **Survivance :** $S_i(t) = W_i(t)/W_i(t=0)$

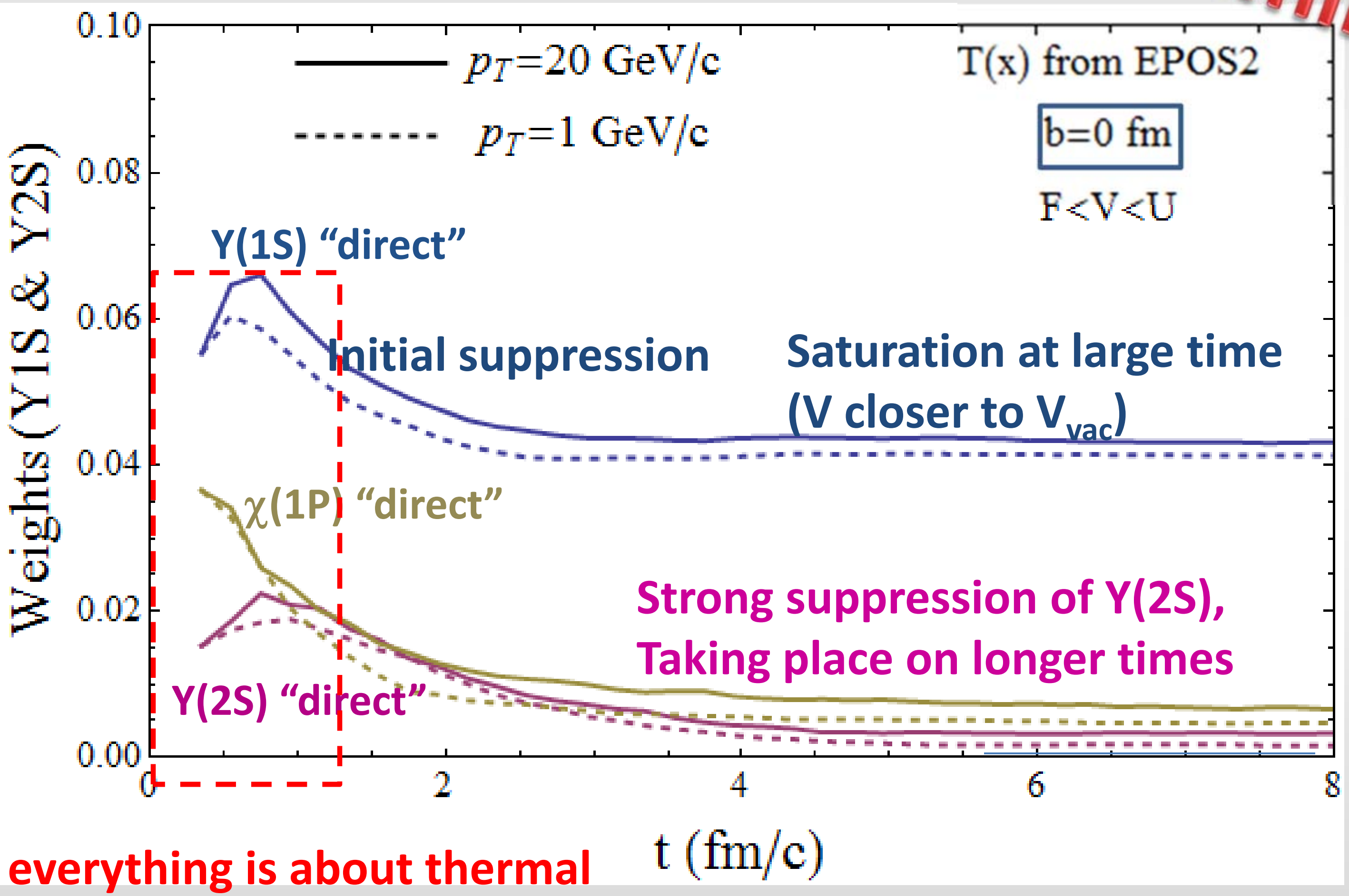
Convoluted with p_T-y spectra => R_{AA}

- STILL NOT AIMED to reproduce exp. data (just grasp the global trends): **proof of principle**

* K. Werner, I. Karpenko, T. Pierog, M. Bleicher and K. Mikhailov, Phys. Rev. C 82 (2010) 044904. K. Werner, I. Karpenko, M. Bleicher, T. Pierog and S. Porteboeuf-Houssais, Phys. Rev. C 85 (2012) 064907

Full EPOS2 evolutions

Preliminary



Y(1S) “direct”

Initial suppression

Saturation at large time (V closer to V_{vac})

χ(1P) “direct”

Strong suppression of Y(2S), Taking place on longer times

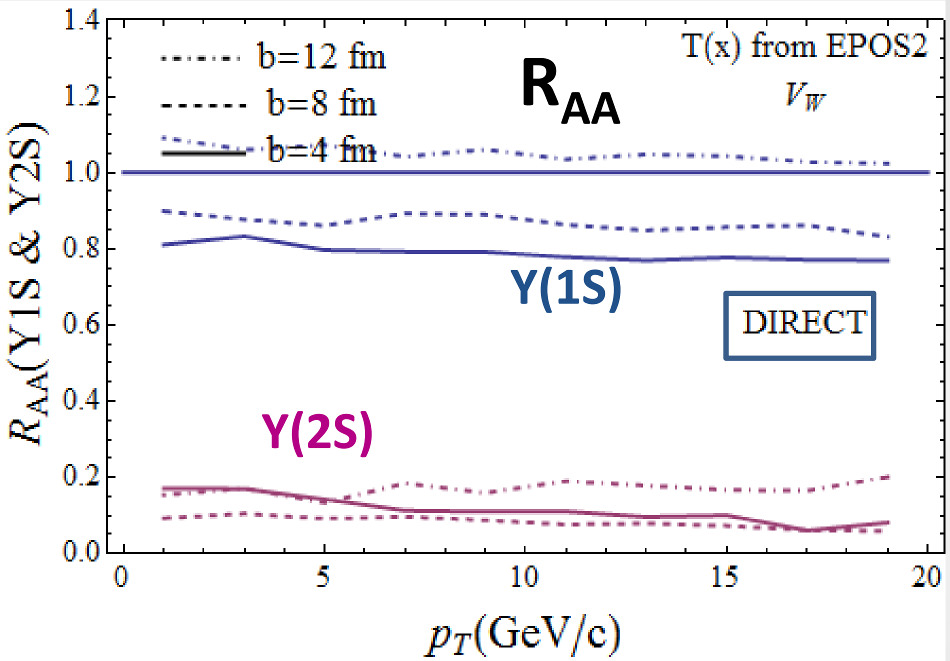
Y(2S) “direct”

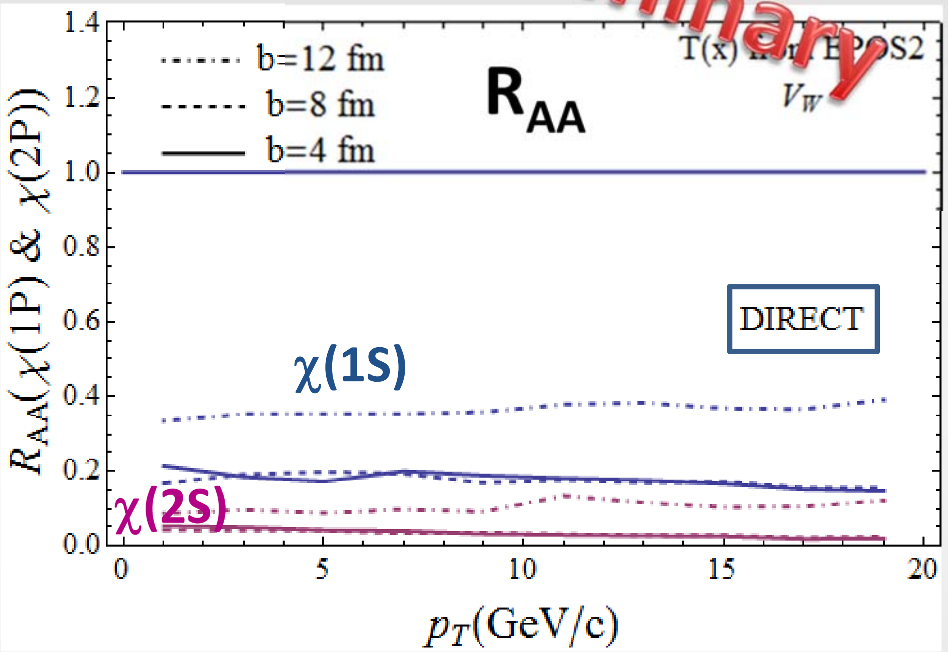
Not everything is about thermal decay widths !!!

NO STRONG p_T DEPENDENCE

Final suppression (1): vs p_T

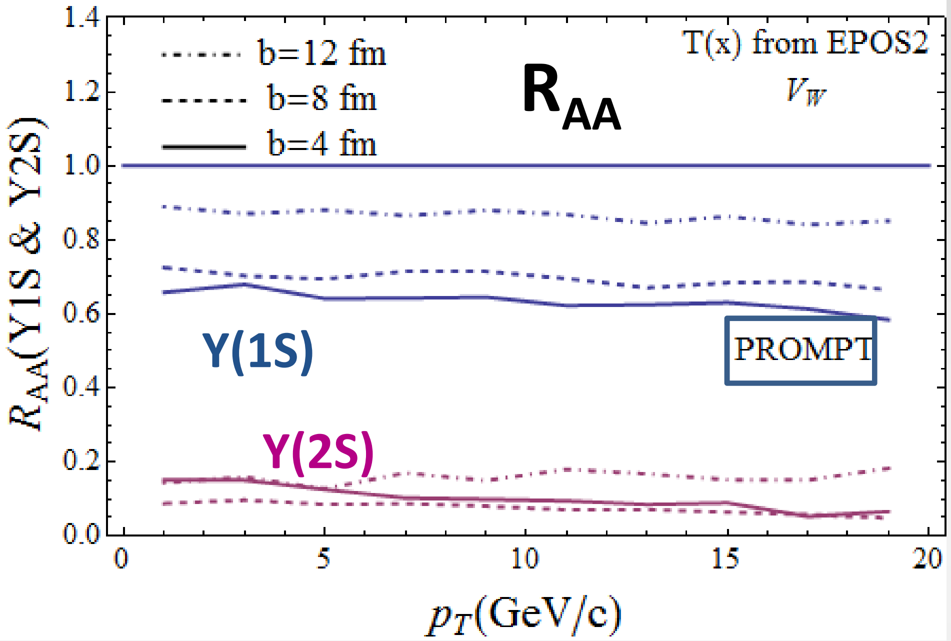
Preliminary

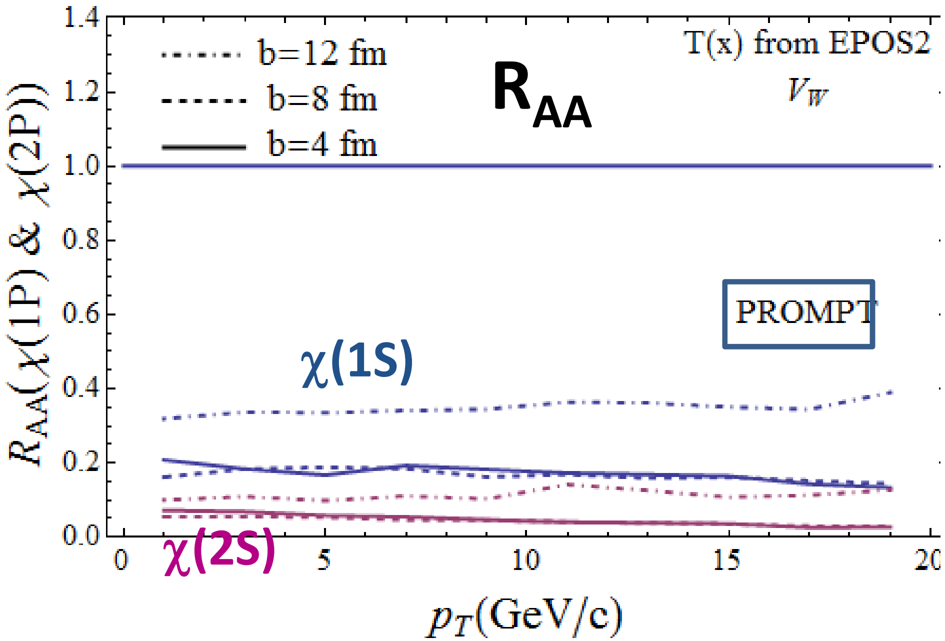




Flatish $R_{AA}(p_T)$ for all Bottomonium states

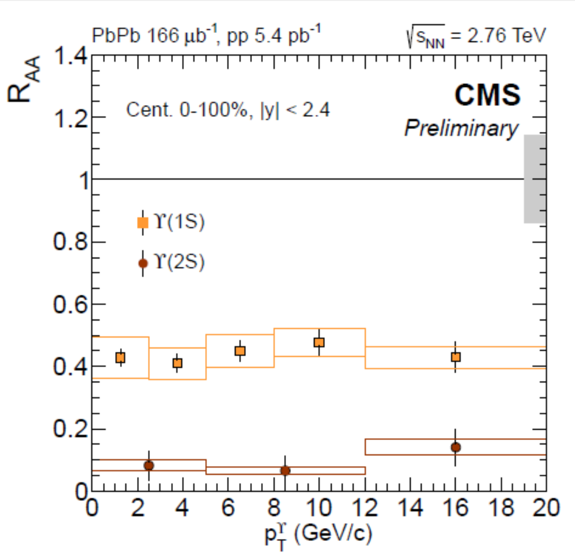
Final suppression (2): vs p_T





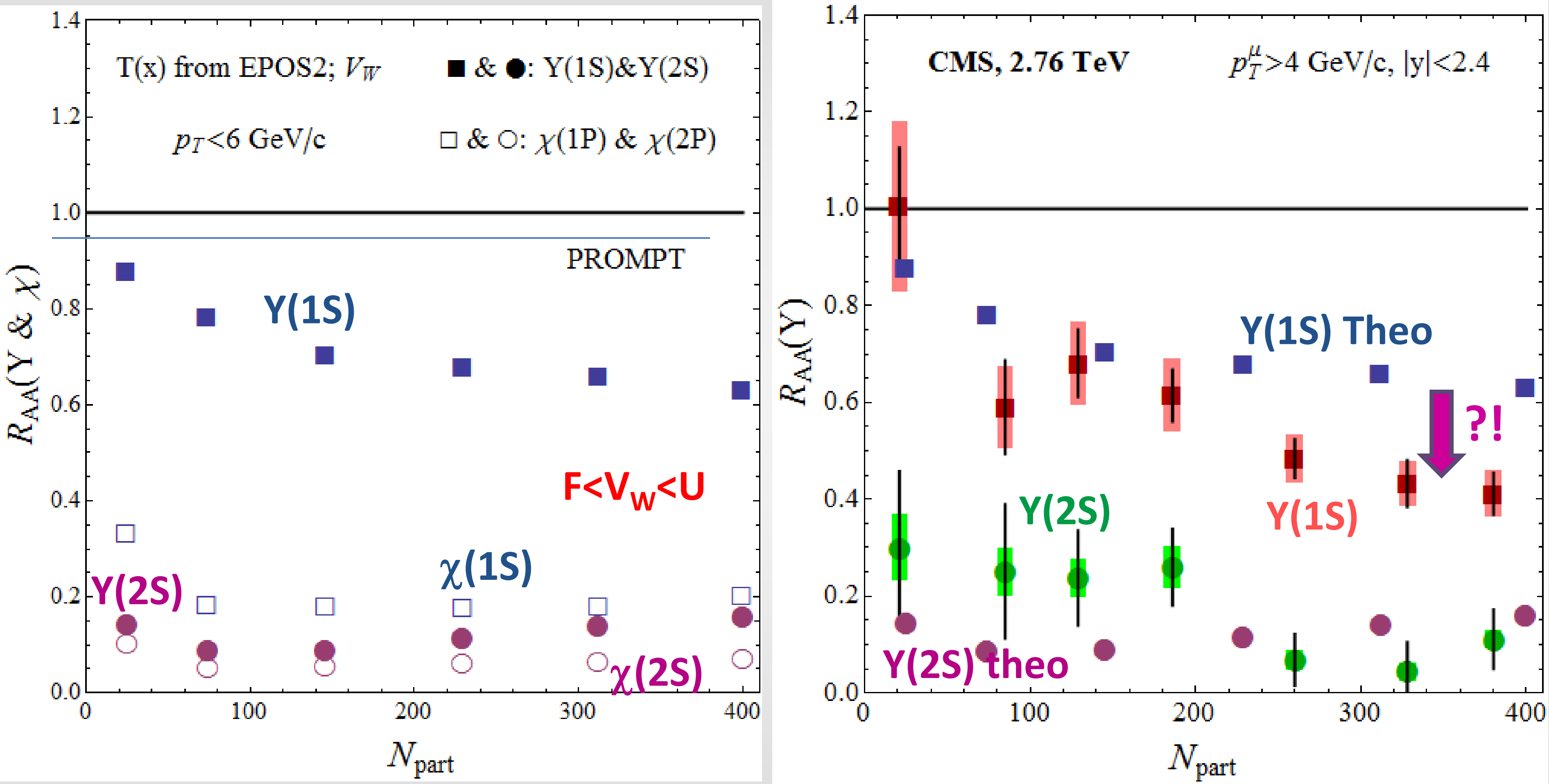
Simple rule for Upsilon decay:

$$\mathbf{p}_{\text{daughter}} = \frac{M_{\text{daughter}}}{M_{\text{mother}}}\mathbf{p}_{\text{mother}}$$



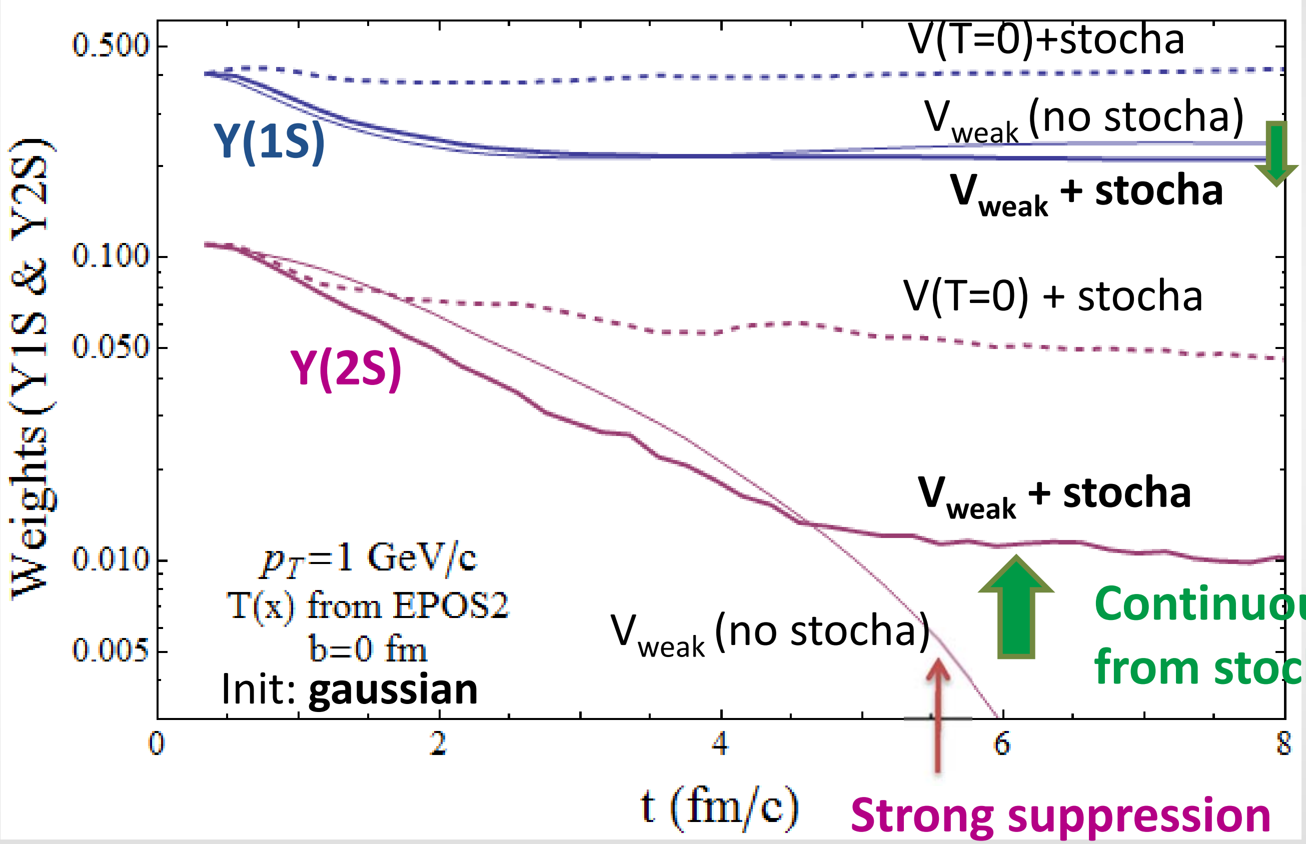
Trends well reproduced but absolute values too high (lack of suppression)

Final suppression (3): vs N_{part}



We miss a some suppression in most central events (under investigation; CNM ?)

Refined analysis: Role of the various contributions in the SLE

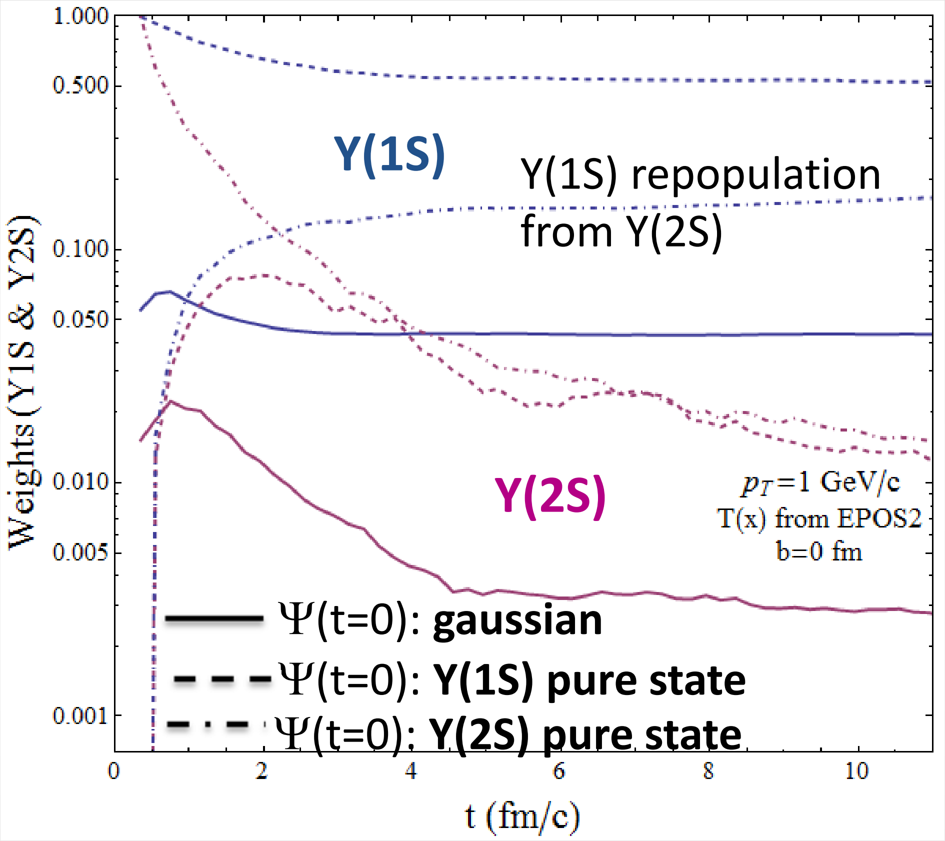


Slight depopulation from stochastic forces

Continuous repopulation from stochastic forces

Strong suppression in Mean Field only

Refined analysis: Role of initial bbar state

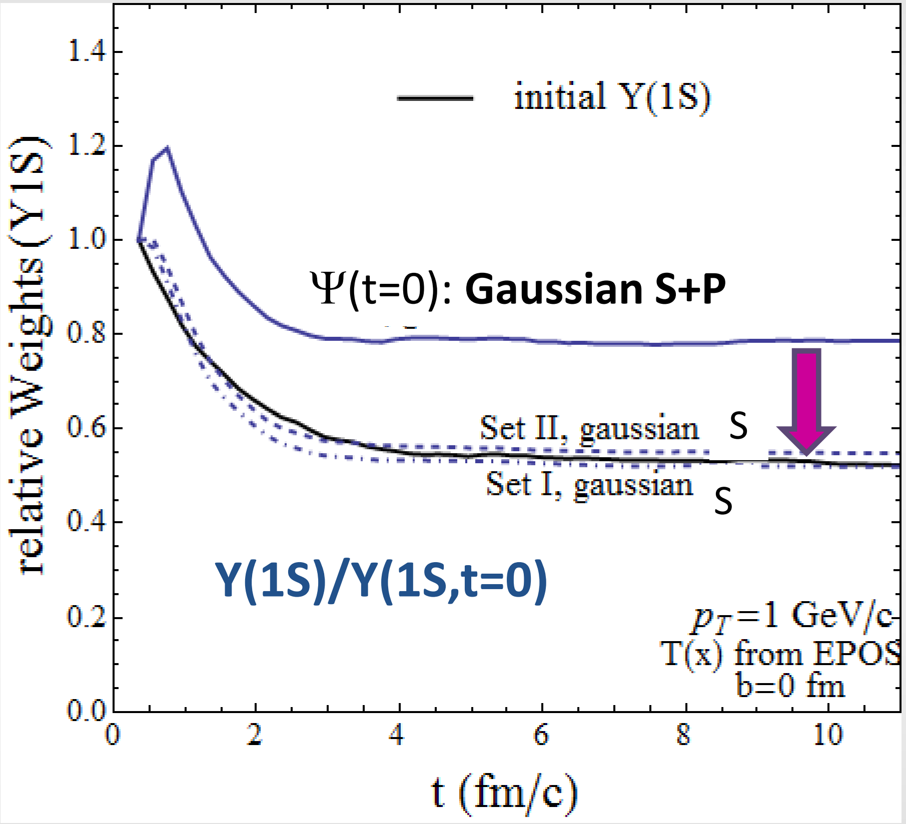


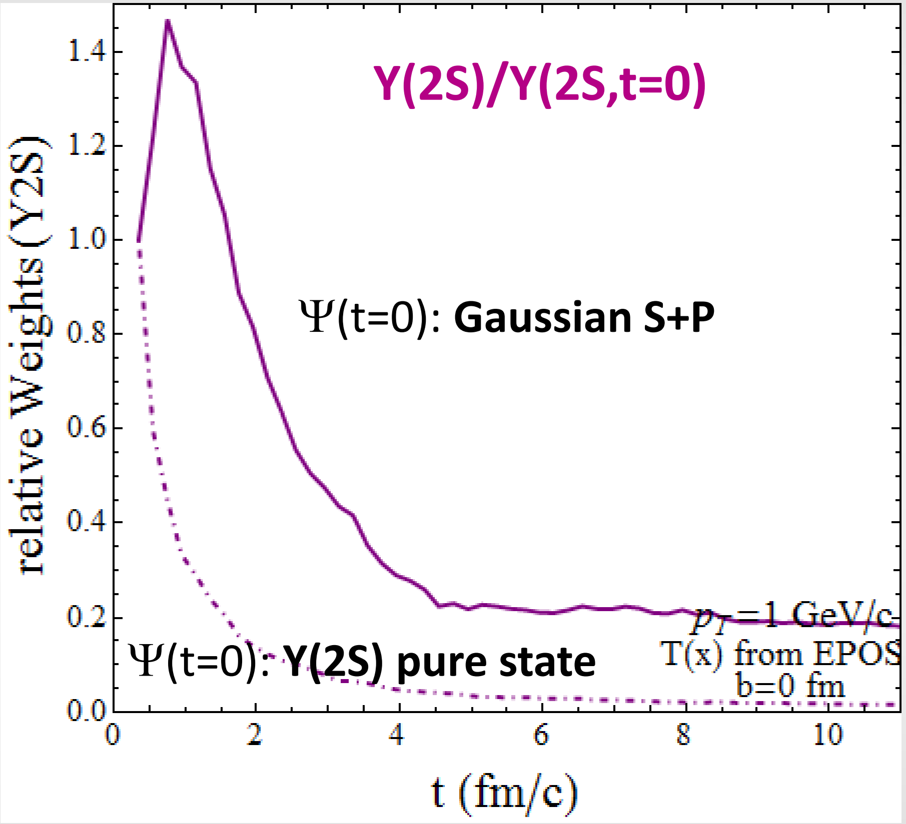
Original Y(2S) would survive with a probability less then 2%

In actual life $\psi_{init}\approx$ Gaussian =>

Y(2S) found at the end of QGP evolution are mostly the ones regenerated from the Y(1S)

Refined analysis: Role of cross channel evolution (exemple from LHC)





L=1 component feeds the Y(1S) at small times

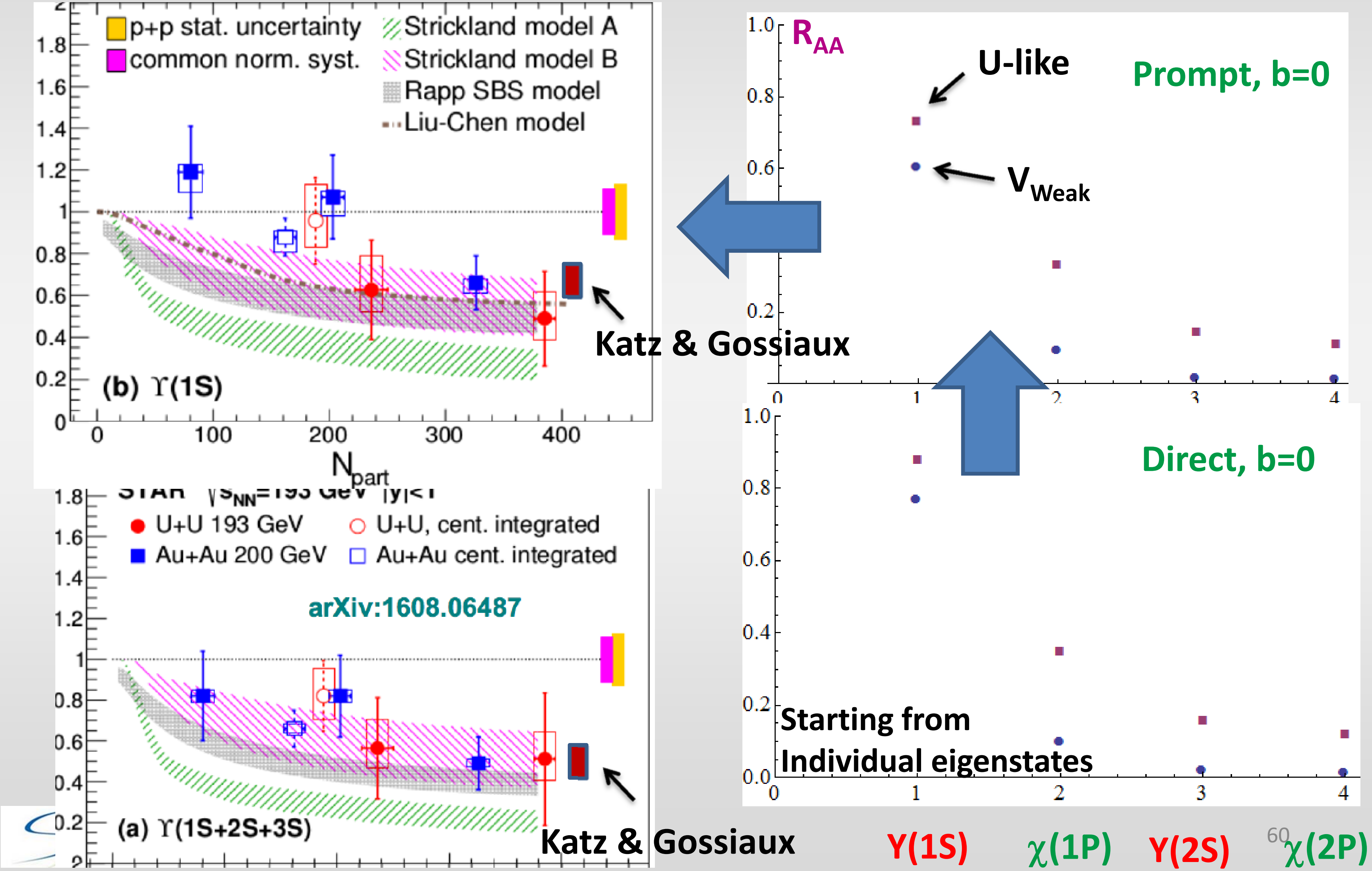
Y(2S) found at the end of QGP evolution are mostly the ones regenerated from the 1S & 1P

Going RHIC

- EPOS3 still needs validation for RHIC. Back to Kolb-Heinz (which at least offers some consistency ./. our previous predictions on open HF)

- **Particular focus on the role of the initial state**

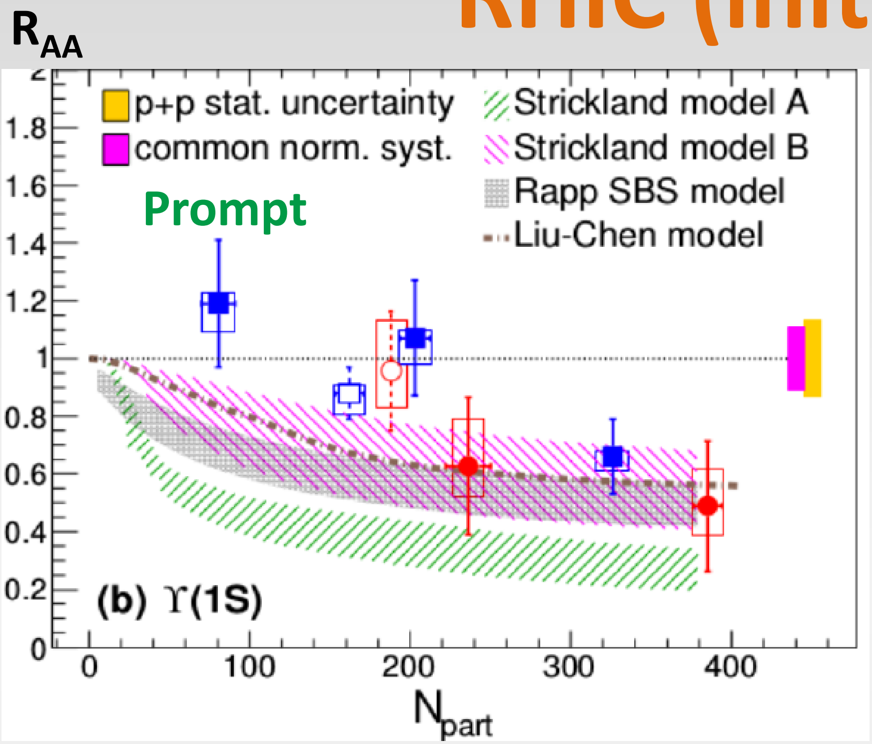
RHIC (init decoupled)

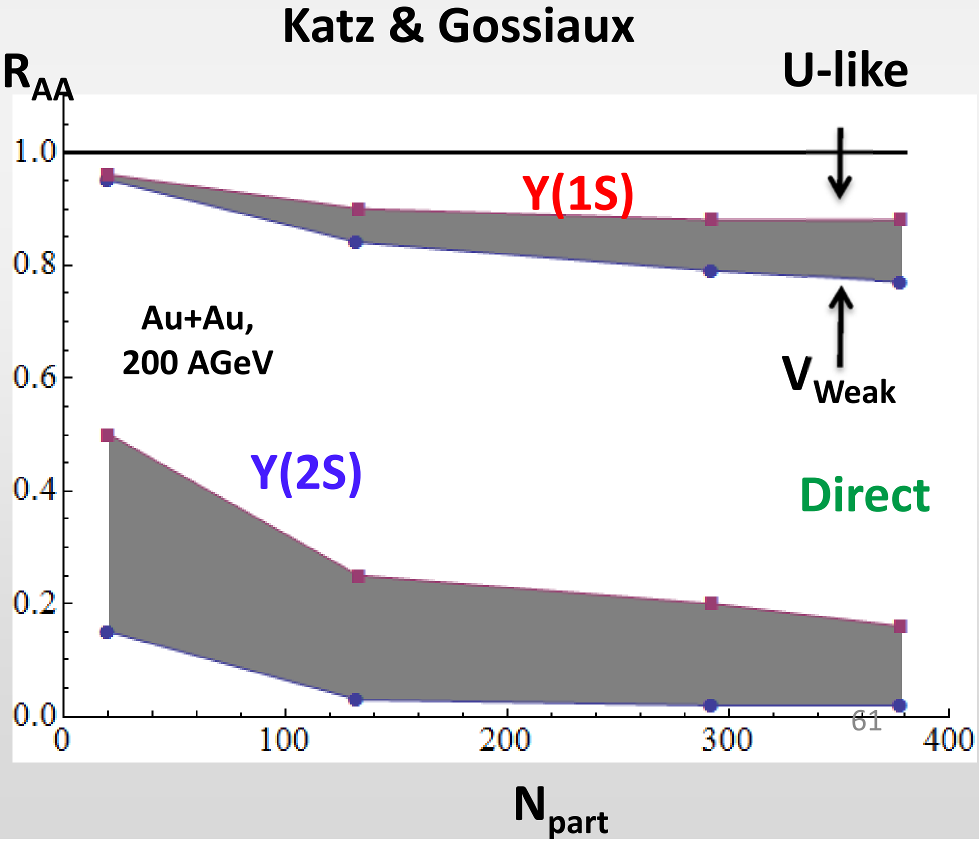


arXiv:1608.06487

Starting from
Individual eigenstates

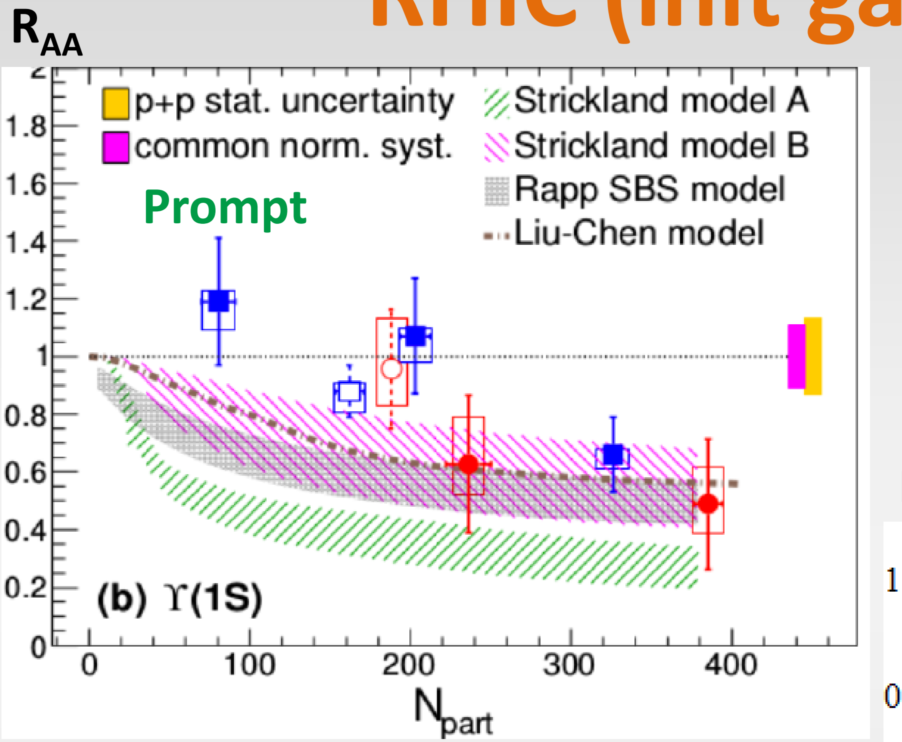
RHIC (init decoupled)

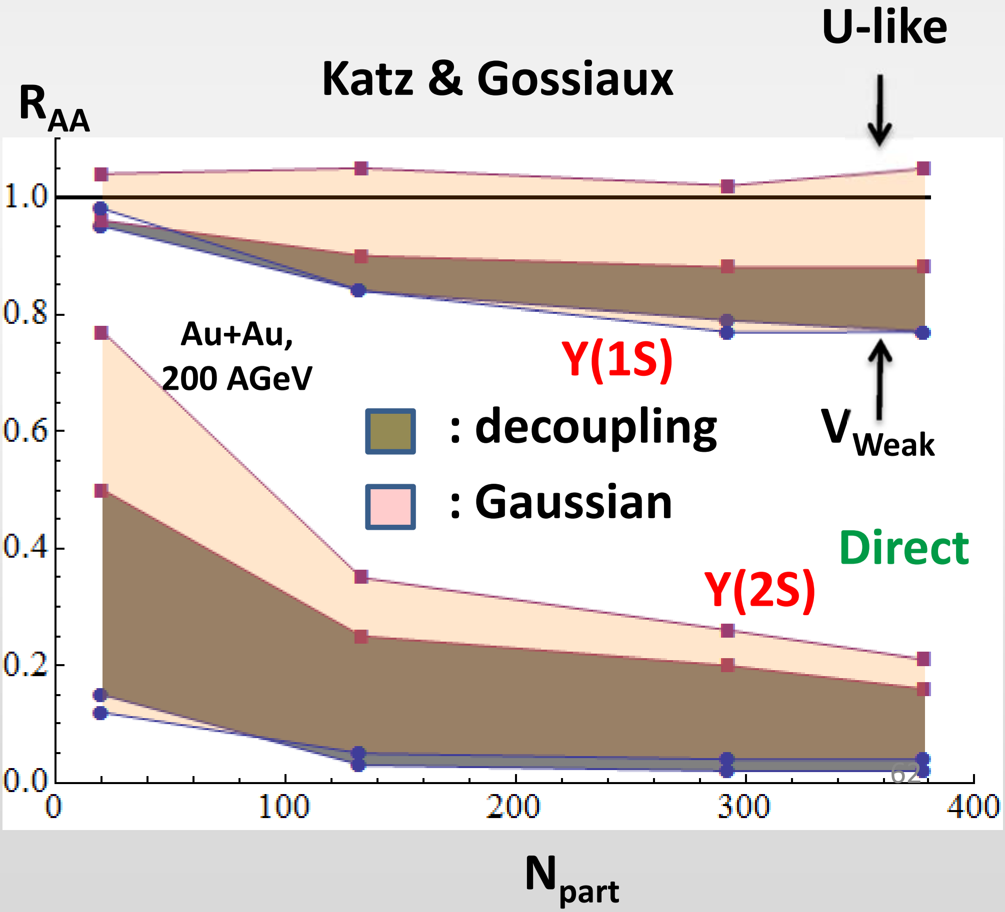




Both models seem compatible with the data. Y(2S) measurement would help

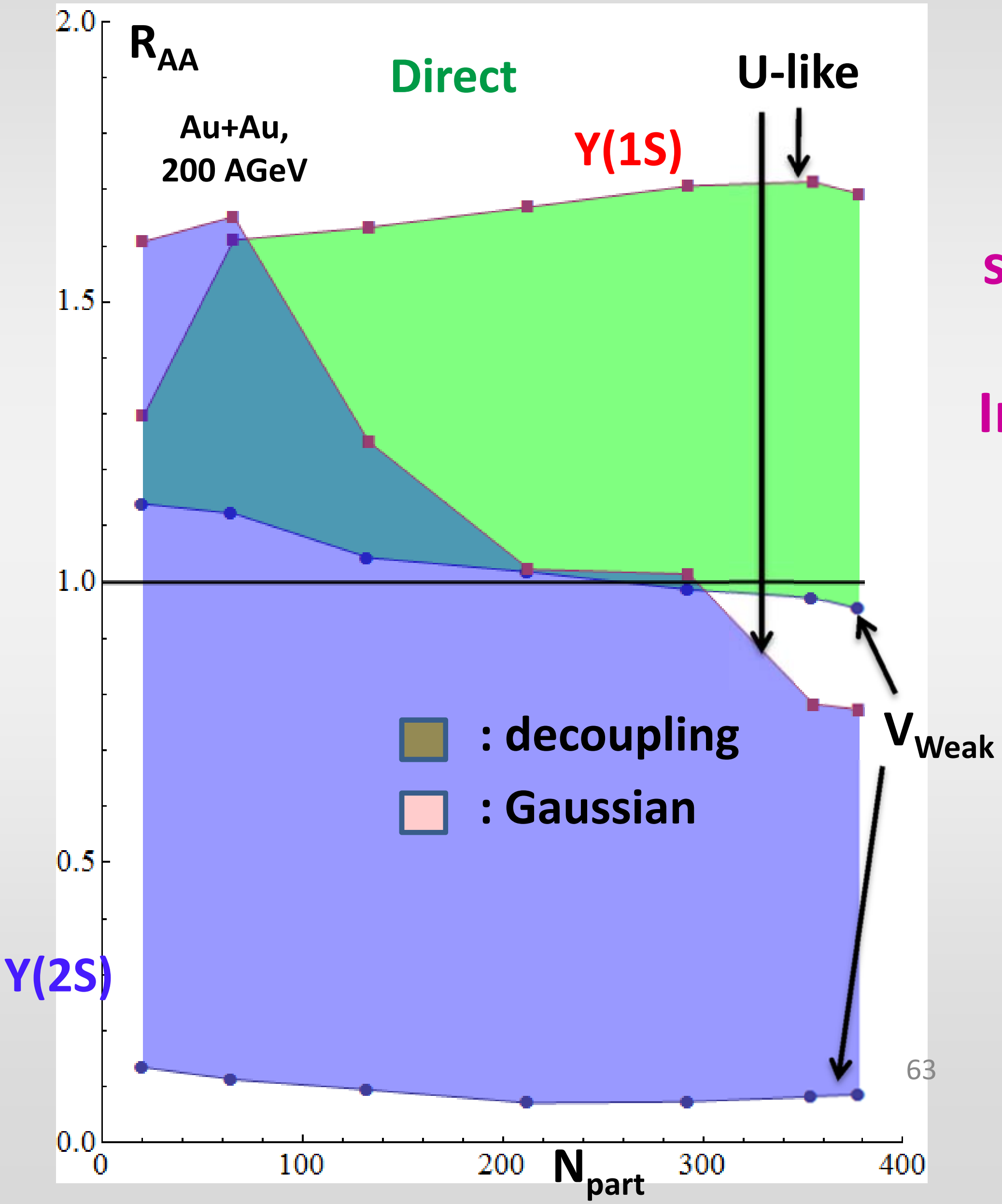
RHIC (init gaussian S-like)





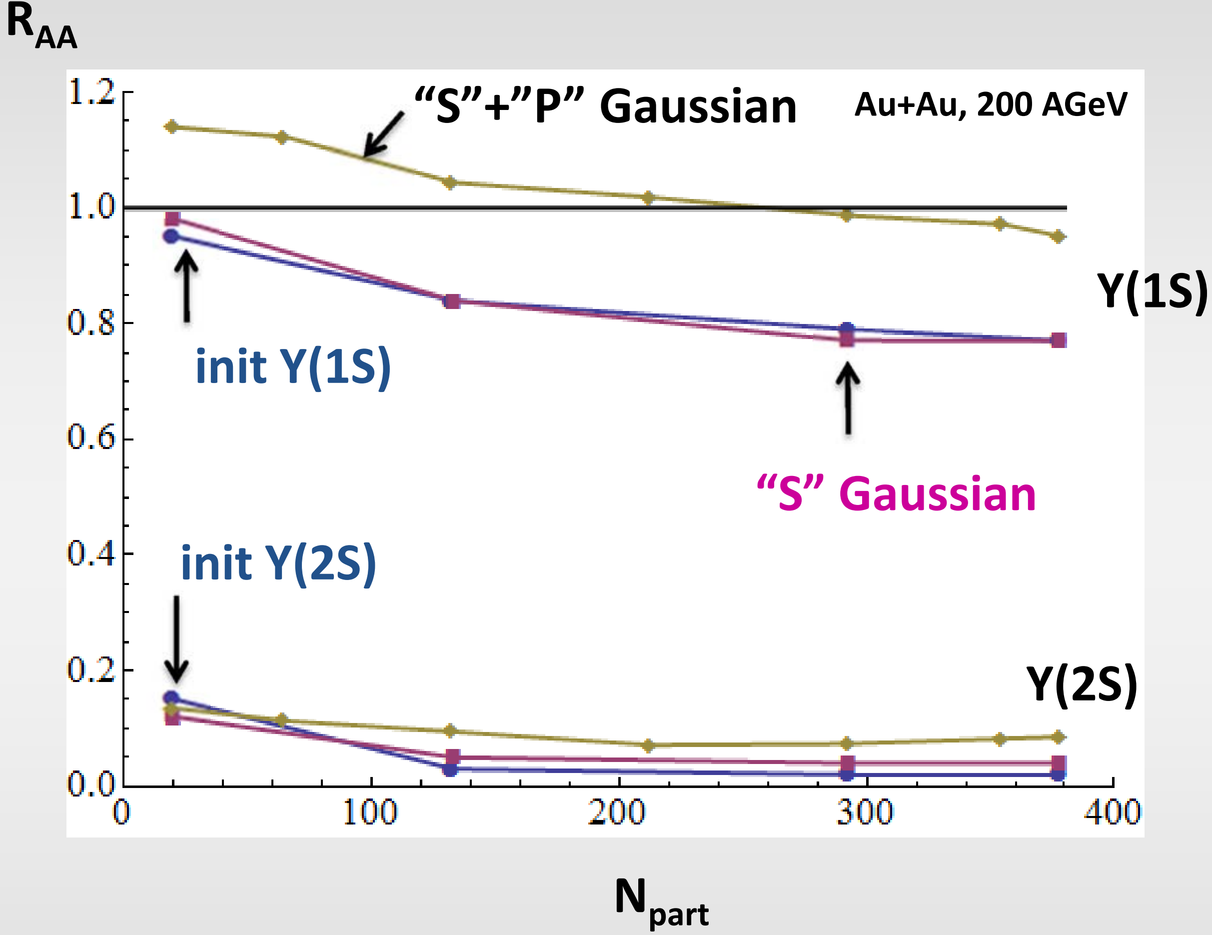
U-type potential more sensitive to the initial state

RHIC (init gaussian S-like + P-like)

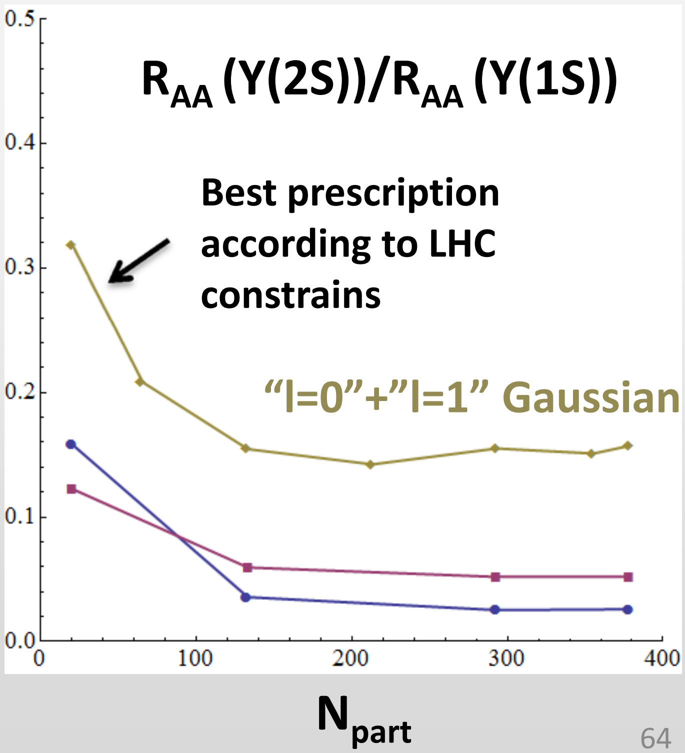


Transition from dipolar stochastic forces increase the RAA of "l=0" states !
In particular, U-type potential leads to values much > 1 !!!

RHIC : summary for V_{weak}



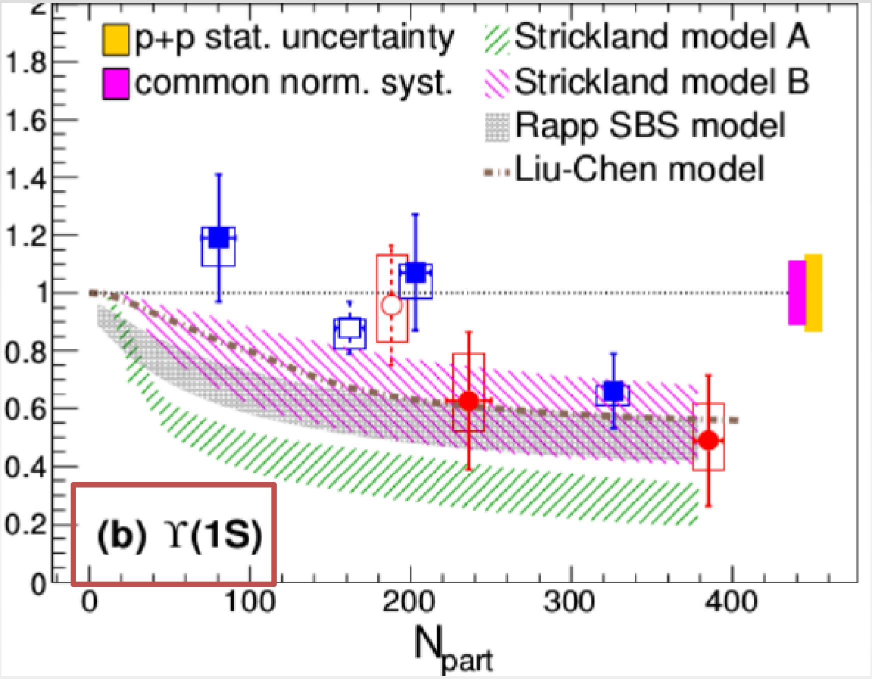
Direct production

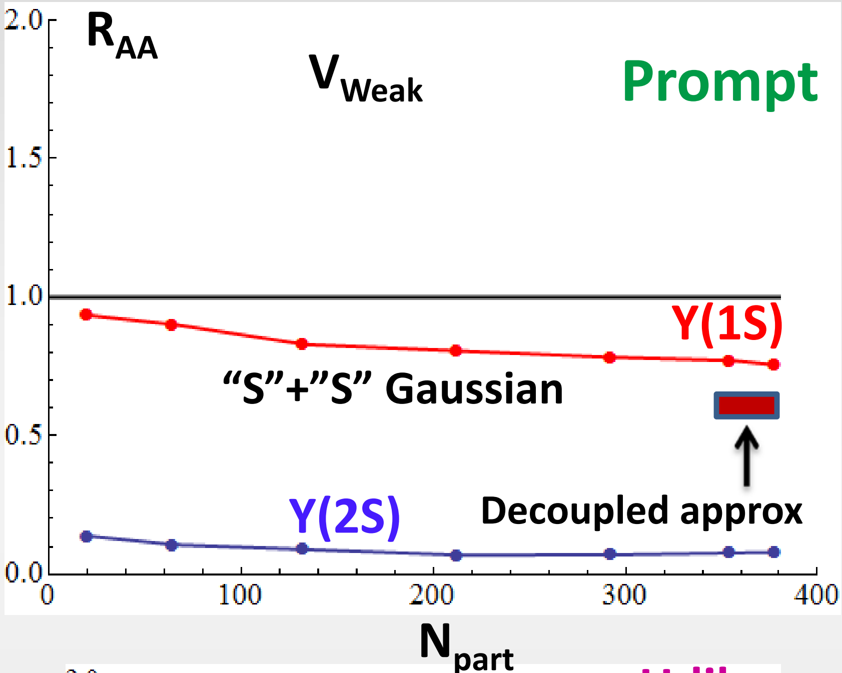


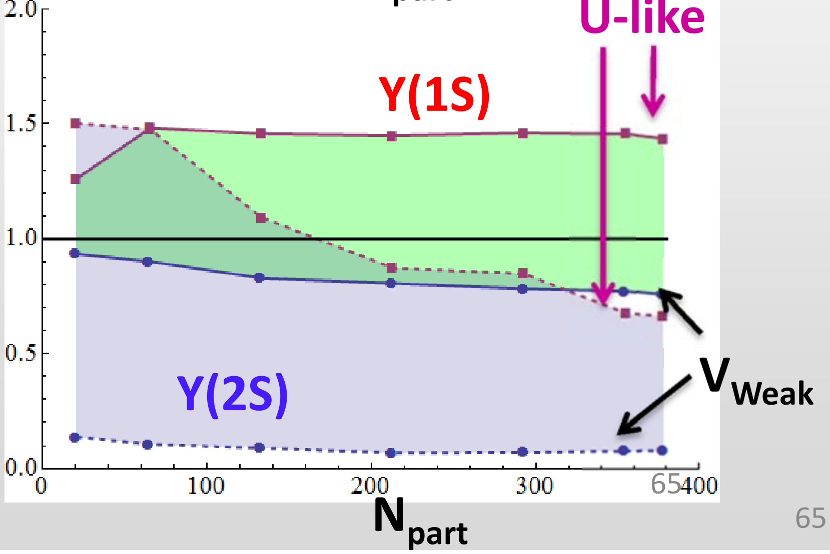
Large effects of the initial state on the RAA Υ(2S)/ RAA Υ(1S) ratio

RHIC Summary

Including decays



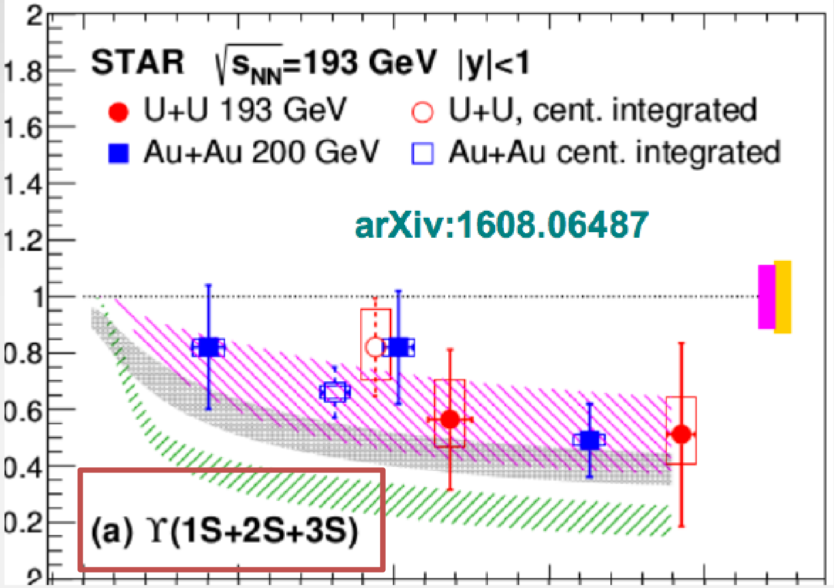


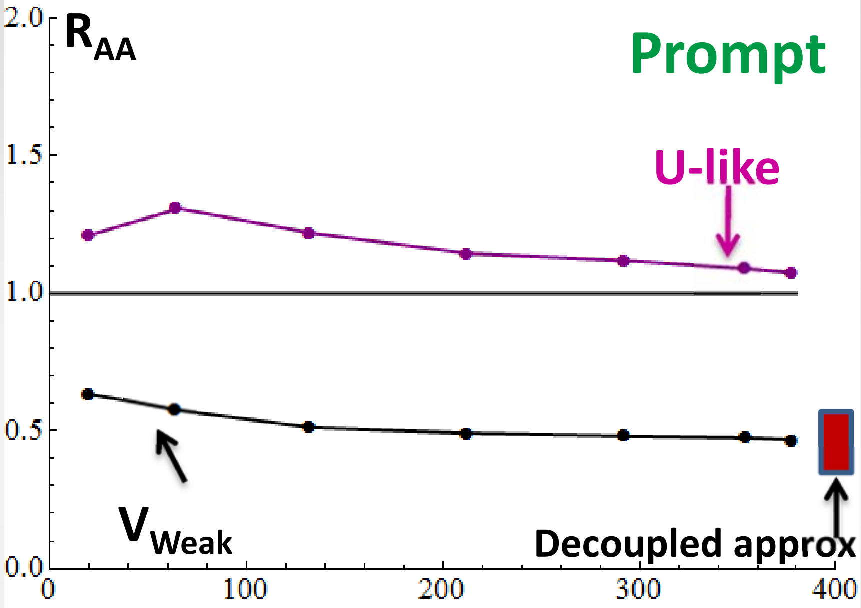


- Roughly good agreement with the data (story ends not so bad for V_{weak})
- A bit too high RAA for largest centrality
- With U-like: results strongly depend on the initial state considered !

RHIC Summary

Including decays





Summary

- First prediction of our formalism for upsilon suppression at RHIC in "not so state of the art background" (KH) with feed downs, reproduces experimental trends provided $F<V_{weak}<U$ potential is chosen
- Initial state may have LARGE effects ? Theory inputs from our pp colleagues ?
- Some lack of suppression in most central events