Phenomenological modeling of quarkonium in QGP + scope of RRTF

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EMMI Rapid Reaction Task Force (RRTF)
Suppression and (re)generation of quarkonium in heavy-ion collisions at the LHC

December 16, 2019

Heavy Quarkonium Suppression

- In a high temperature quark-gluon plasma we expect **weaker color binding** (Debye screening + asymptotic freedom)

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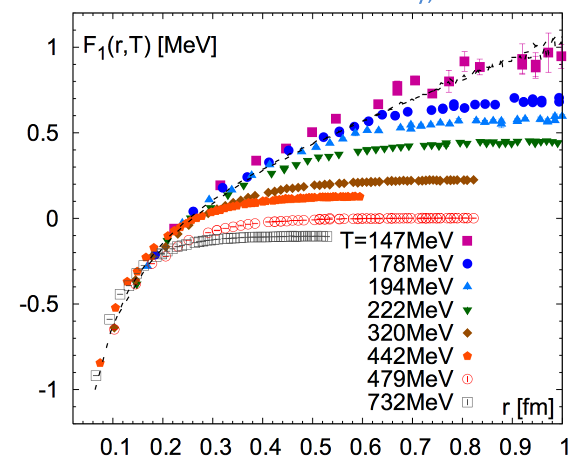
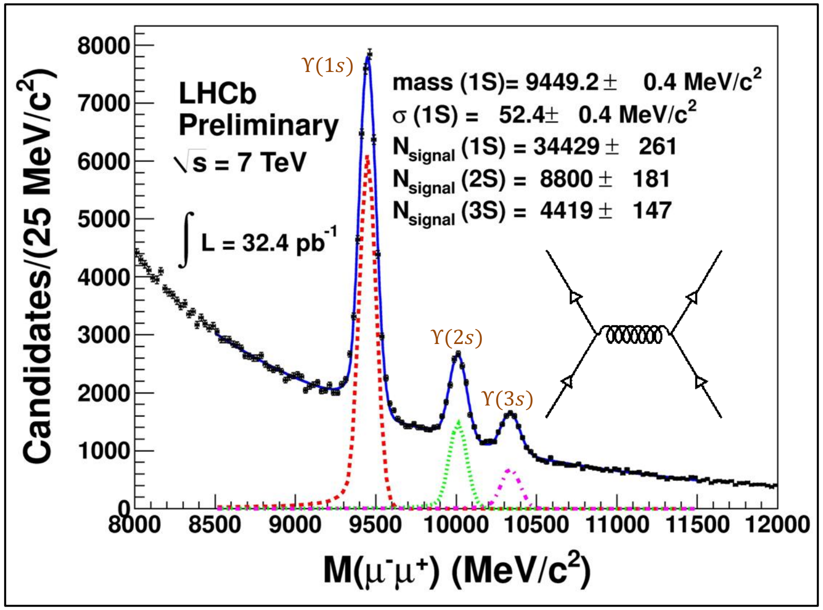
- Also, high energy plasma particles which slam into the bound states cause them to have shorter lifetimes → **larger spectral widths**

A. Bazavov and P. Petreczky, 1211.5638





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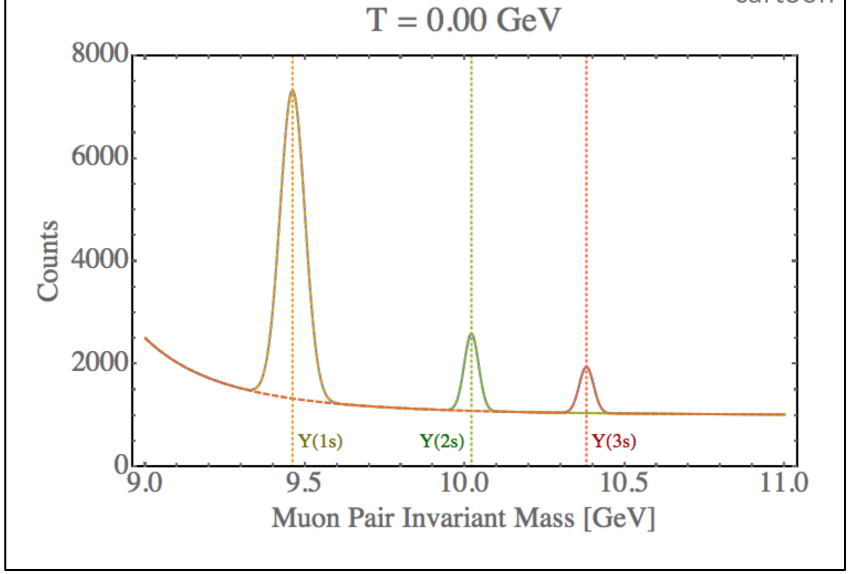

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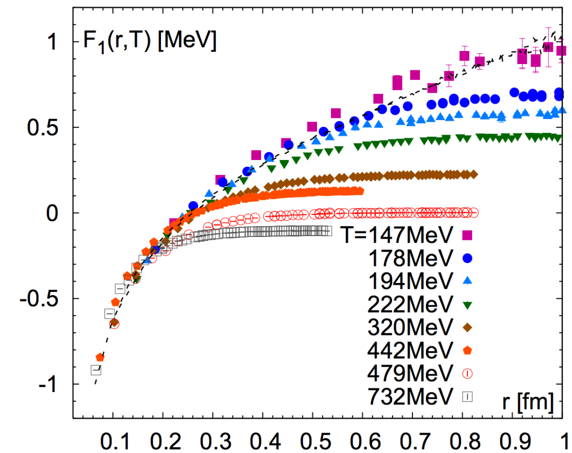

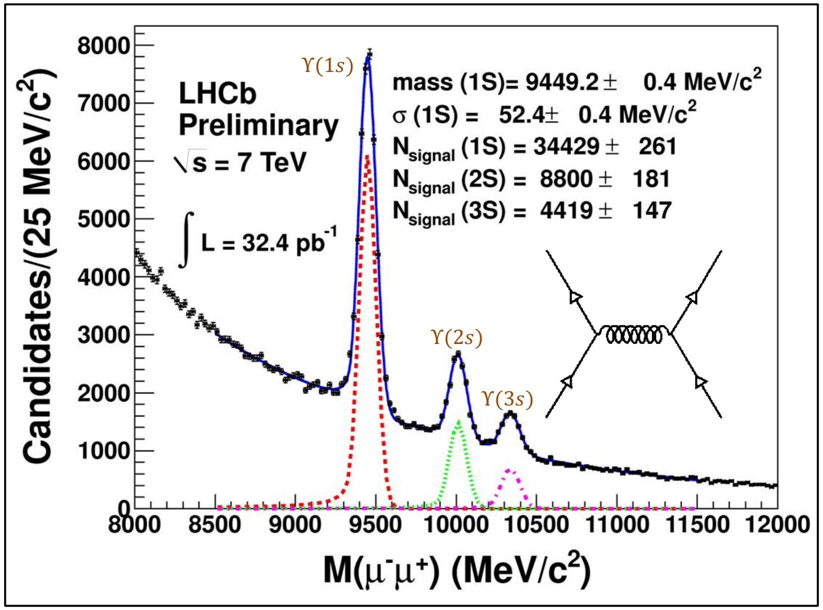

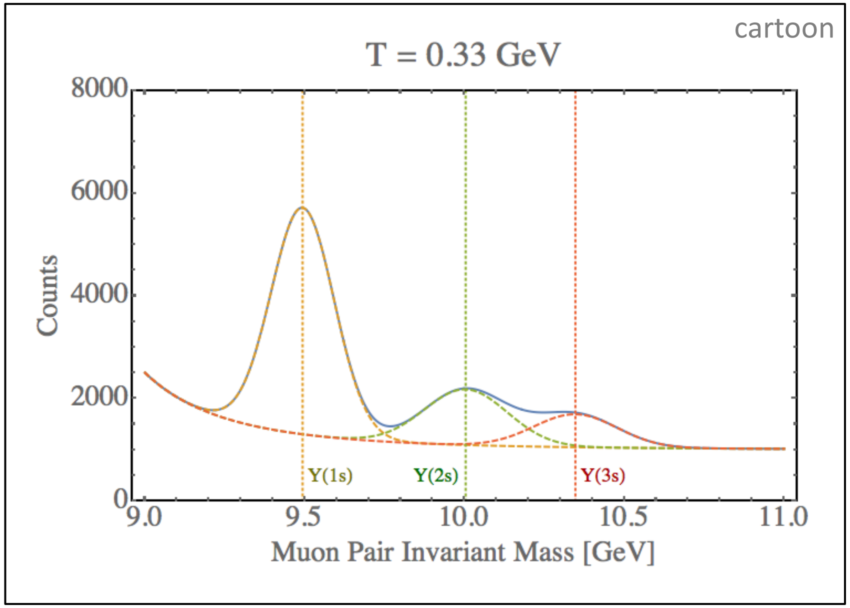

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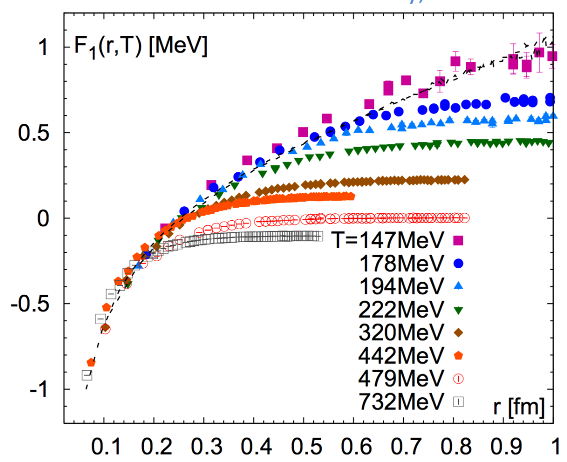

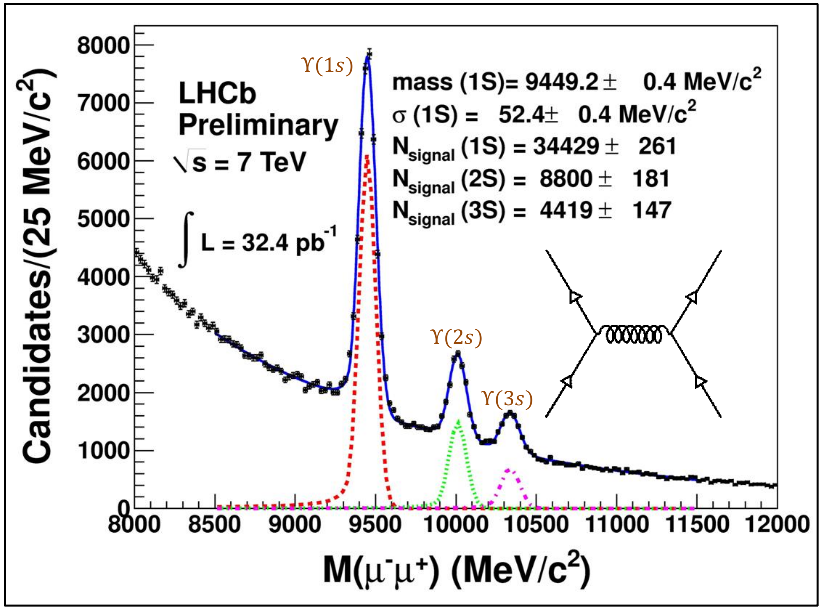

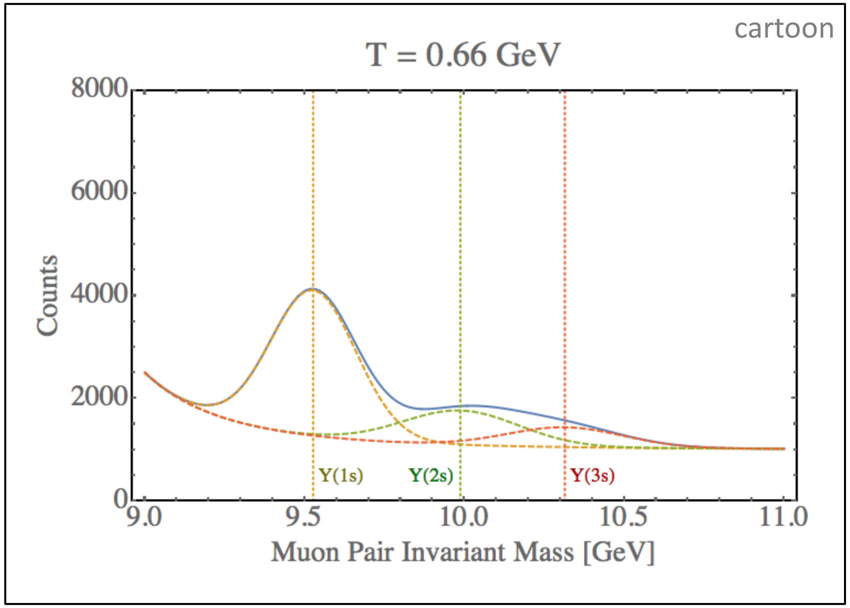

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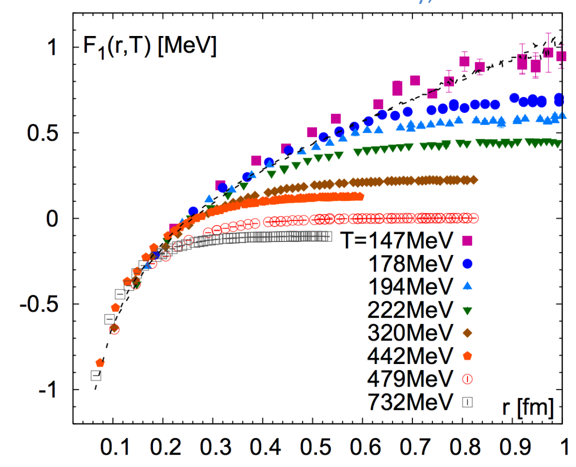

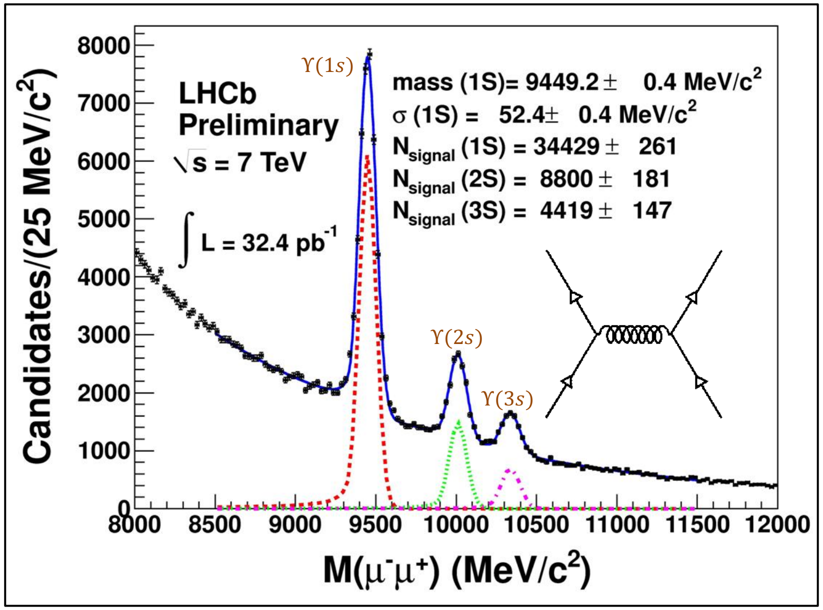

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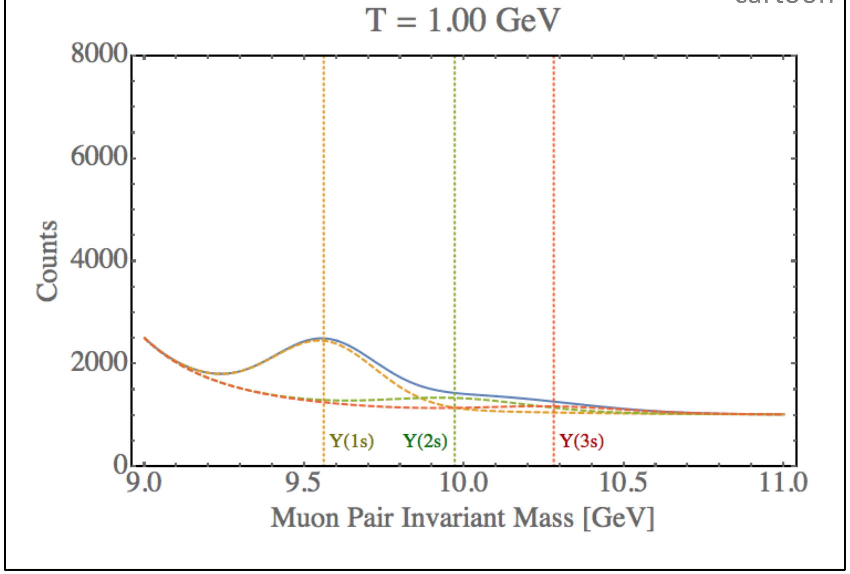

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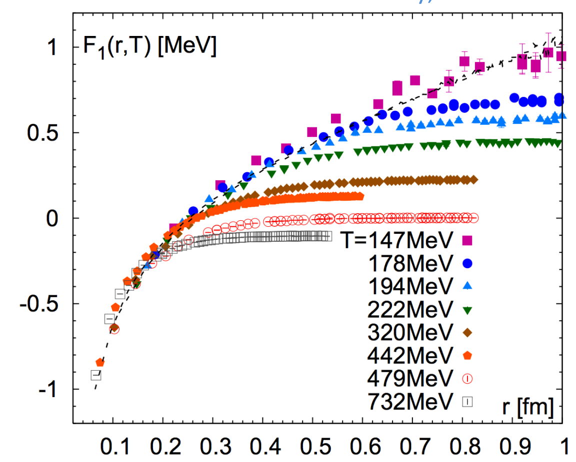
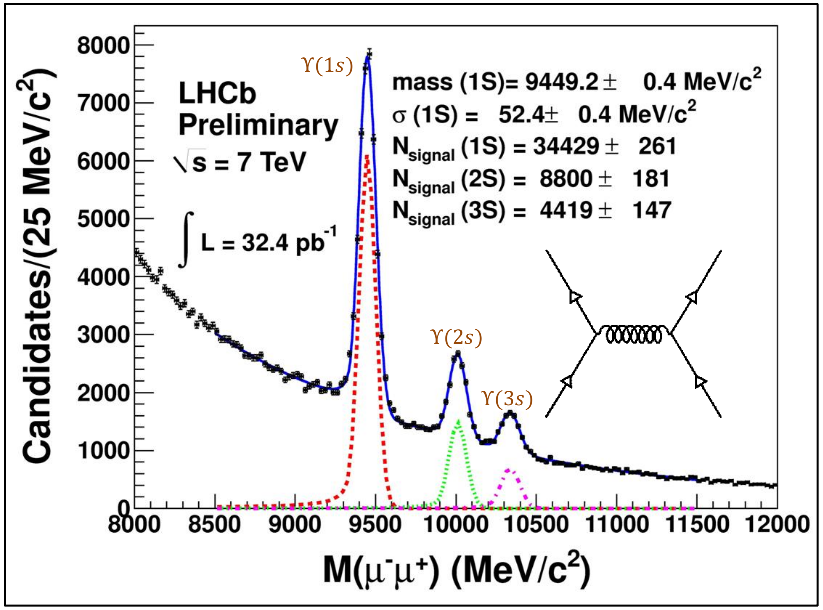
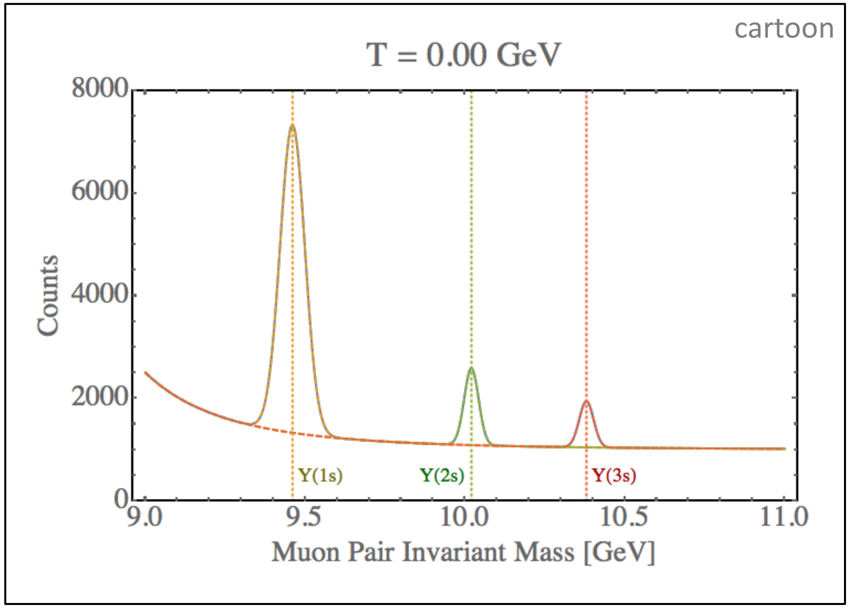
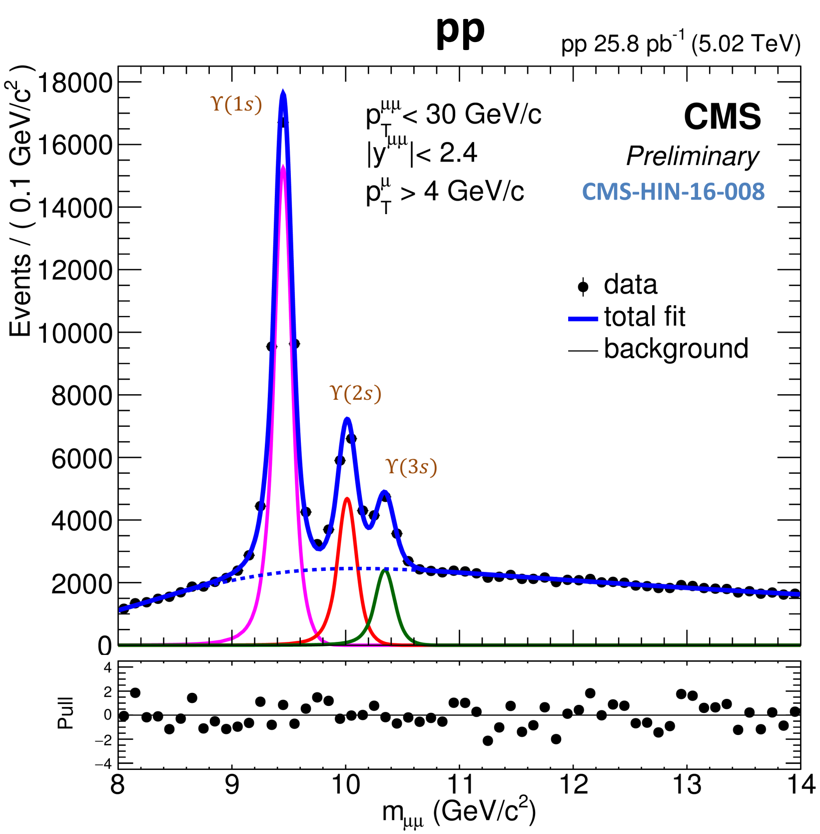


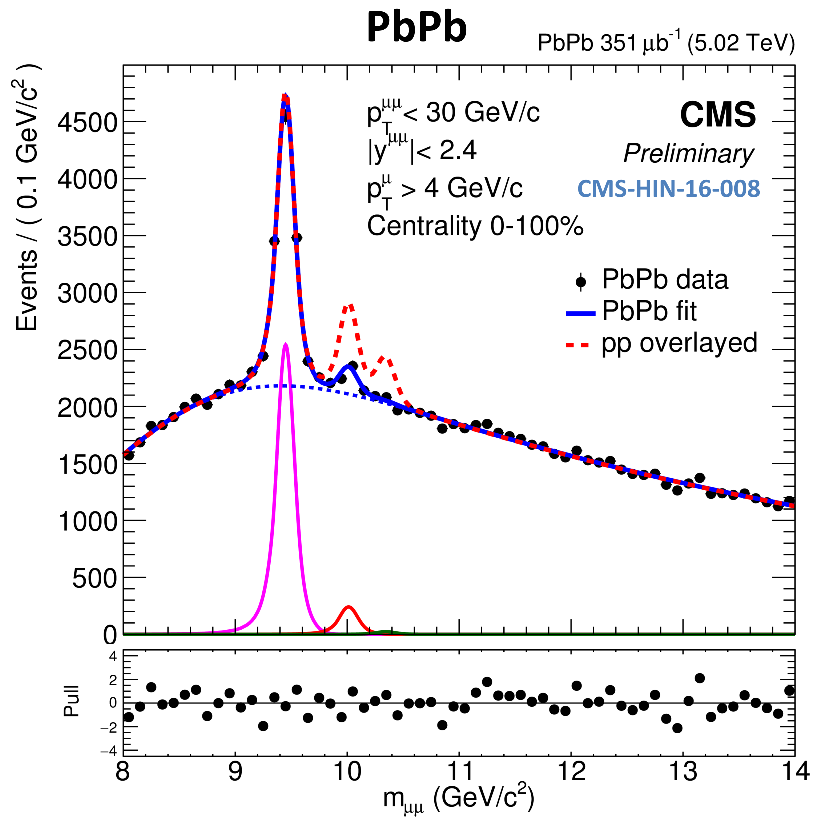




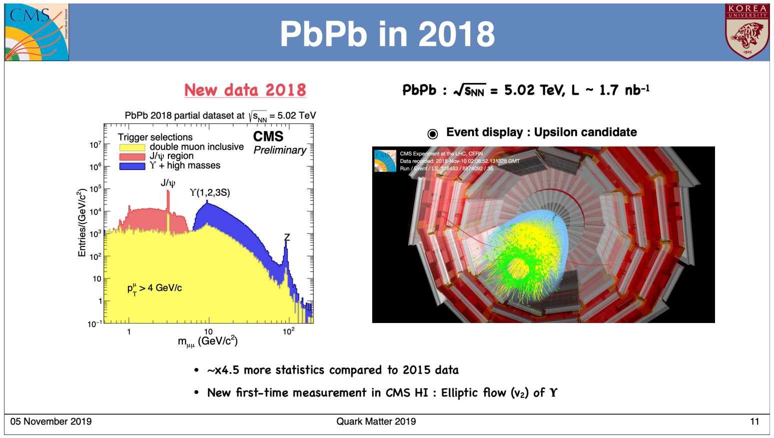
2016 CMS Data – 5.02 TeV Dimuon Spectra

The **CMS** (Compact Muon Solenoid) experiment has measured bottomonium spectra for both pp and Pb-Pb collisions. With this we can extract R_{AA} experimentally.

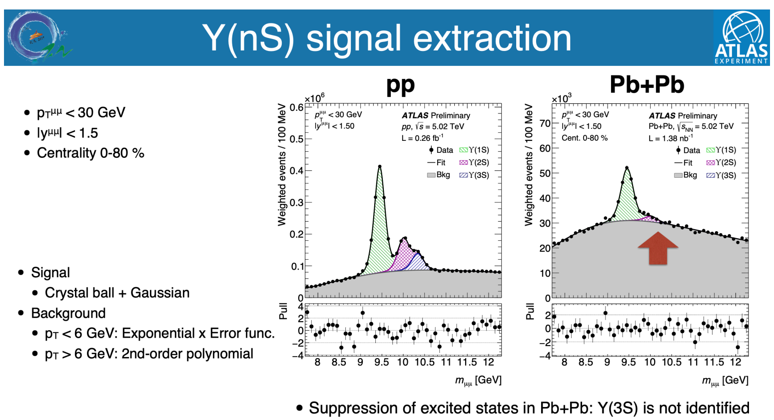


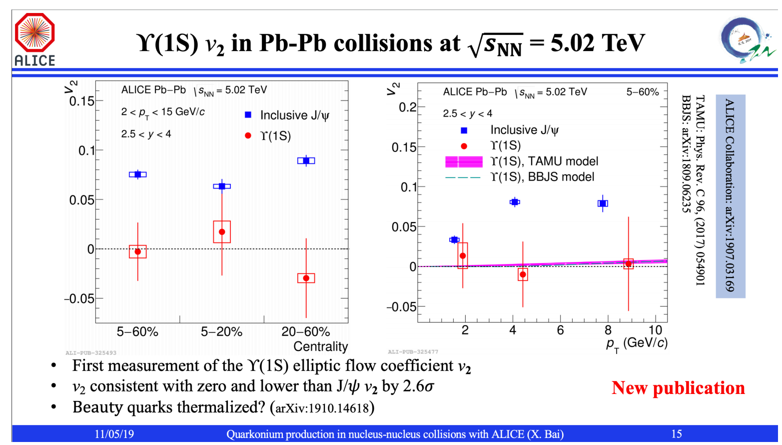


New data at QM19



- New data from CMS and ALICE
- Sufficient statistics to start extracting production anisotropies
- First data from ATLAS collaboration; data explained well by in-medium breakup model
- LHCb is joining the effort?

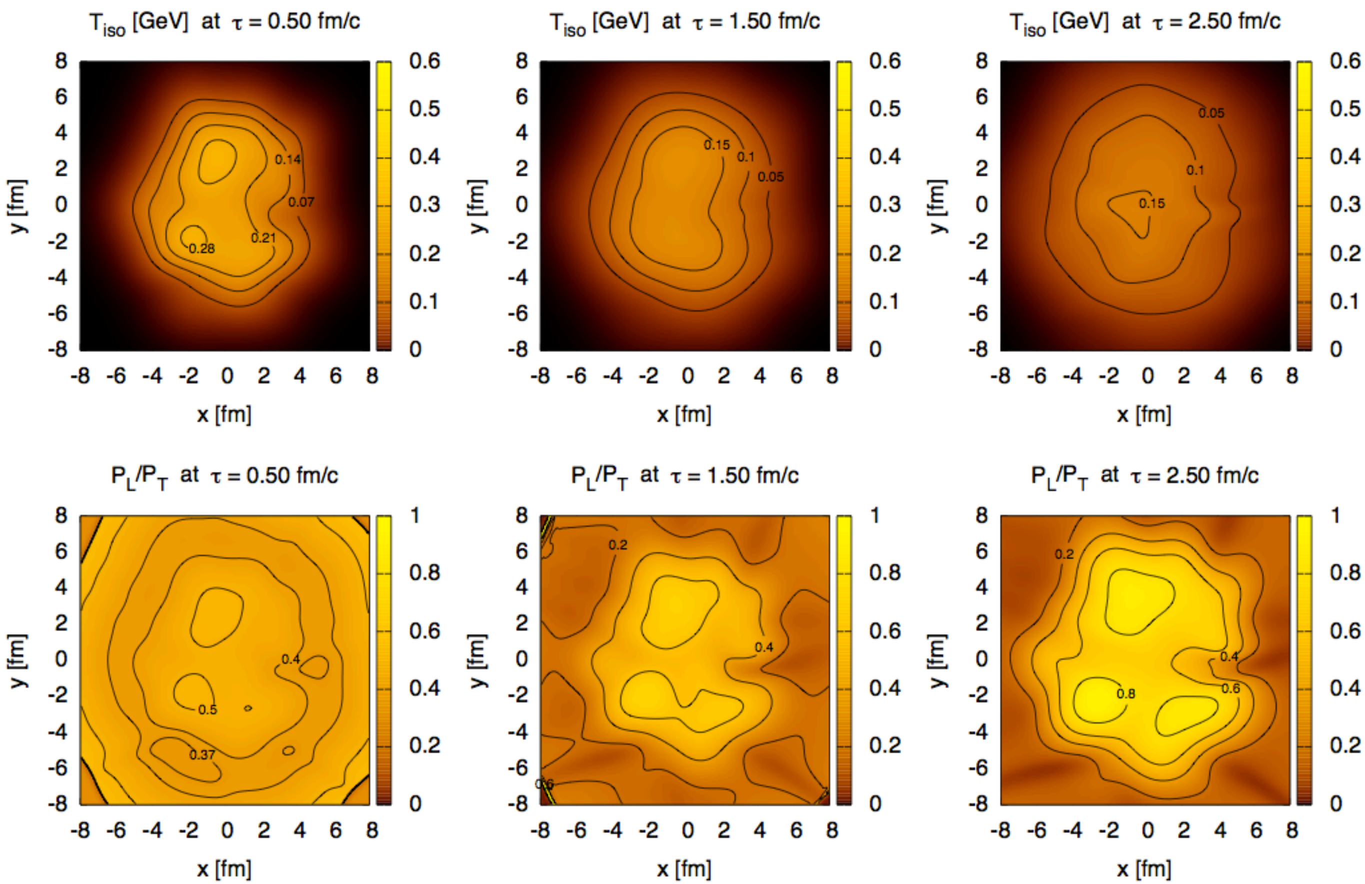




Phenomenology

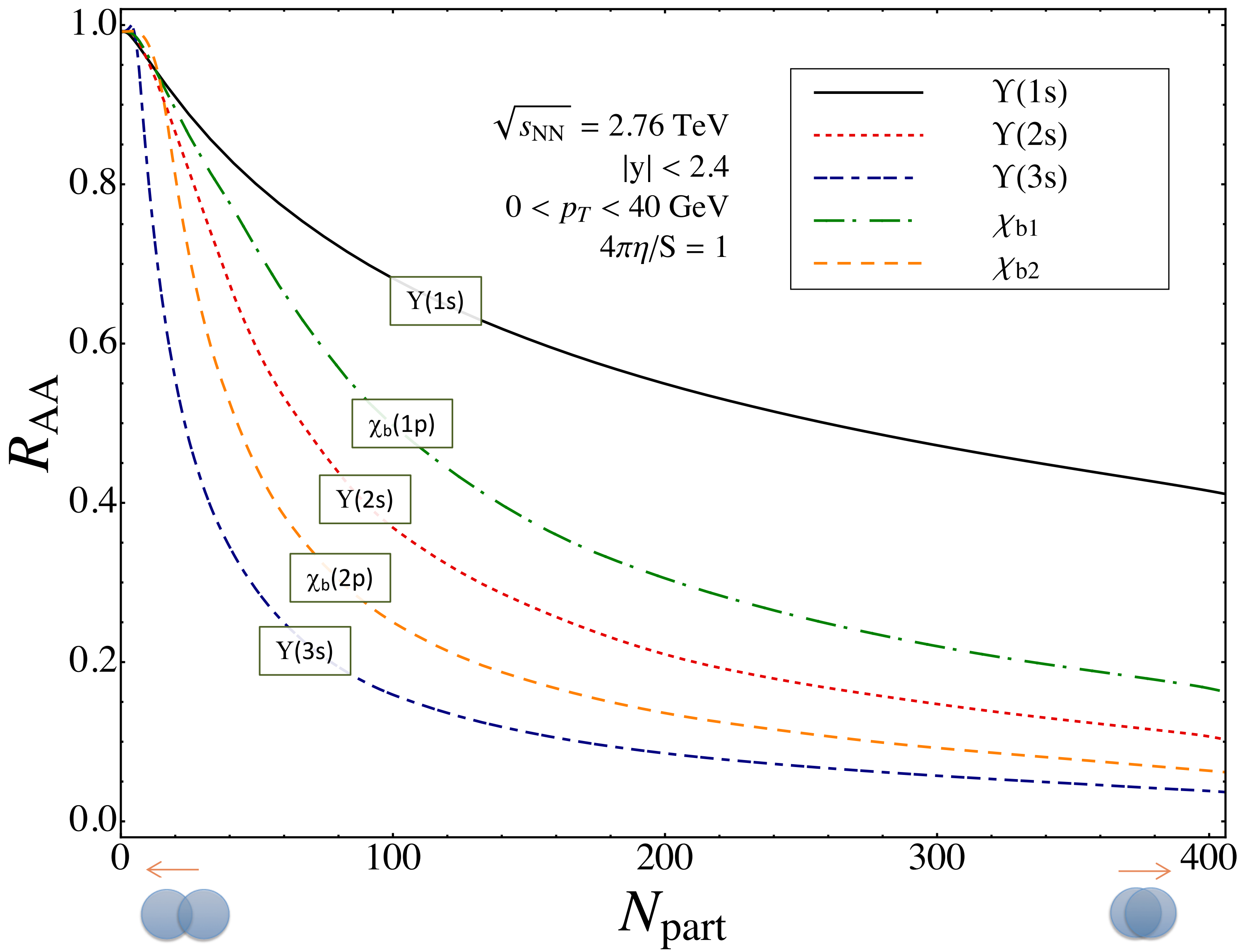
Conceptually simple calculation

For in-medium suppression, given the population of quarkonia states at some τ_0, we need to compute their survival probability as they propagate through the QGP.



Pb-Pb @ 2.76 TeV
T_0 = 600 MeV
τ_0 = 0.25 fm/c
b = 7 fm

State Suppression Factors, $R_{AA}{}^{i}$

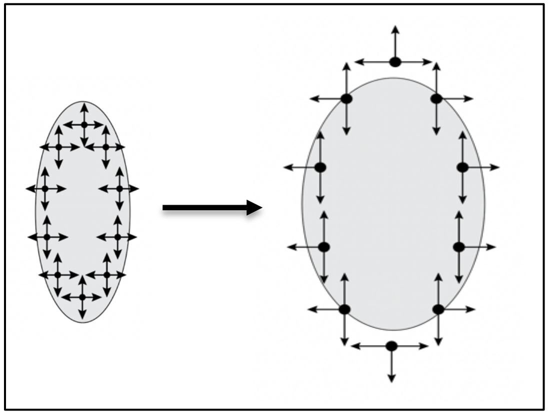


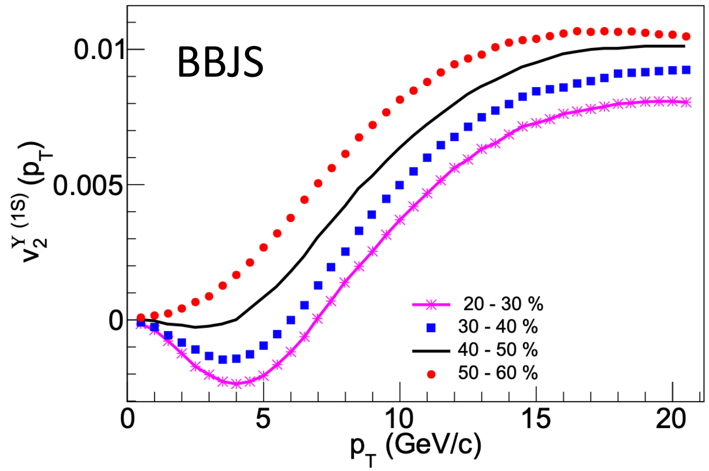
Υ(1S) Feed Down Fractions	
Υ(1S)	0.668
Υ(2S)	0.086
Υ(3S)	0.010
$\chi_b(1P)$	0.170
$\chi_b(2P)$	0.051
$\chi_b(3P)$	0.015

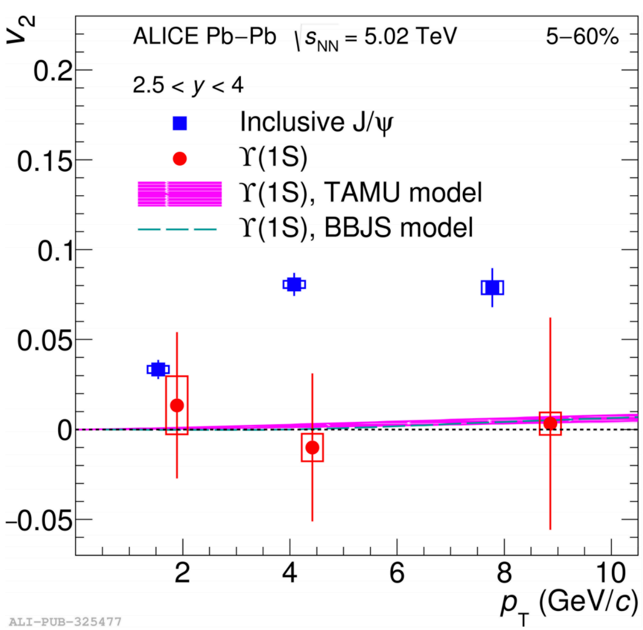
Υ(2S) Feed Down Fractions	
Υ(2S)	0.604
Υ(3S)	0.043
$\chi_b(2P)$	0.309
$\chi_b(3P)$	0.044

Bottomonium "flow" … or lack thereof

4d flow tomography



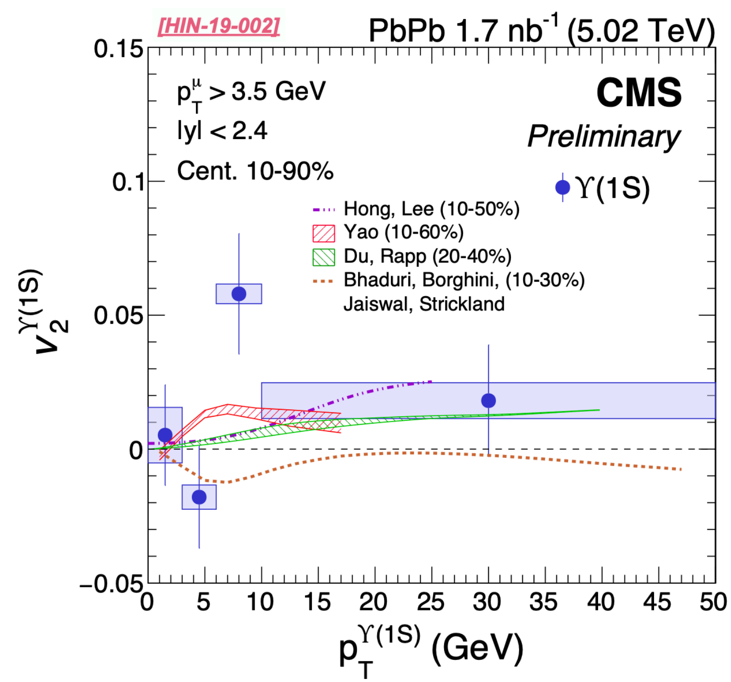




TAMU: Phys. Rev. C 96, (2017) 054901

BBJS: arXiv:1809.06235

ALICE Collaboration: arXiv:1907.03169



Other pieces of the puzzle

pp reference

Experimental measurements rely on R_{AA} which is **defined relative to the pp cross section**; therefore, we need reliable pp reference data and a firm theoretical understanding of open- and closed-charm production in pp collisions

Cold nuclear matter effects

Quarkonia production is also affected by **nuclear-modified PDFs, Cronin effect, and co-movers.** which can result in enhancement or suppression of quarkonia production depending on the kinematic window.

Regeneration

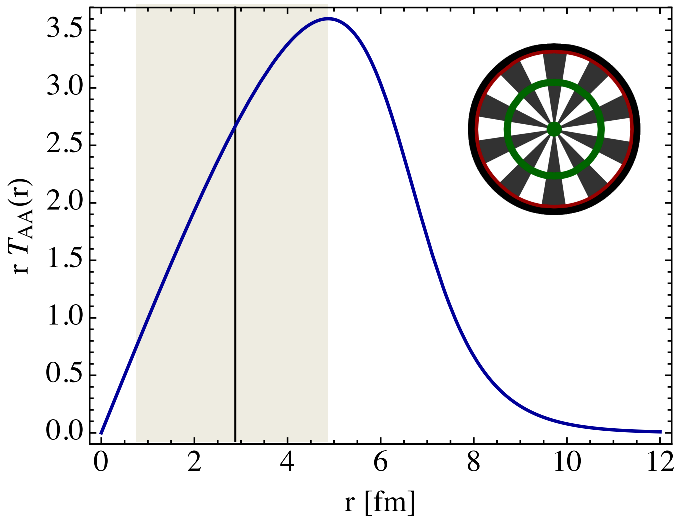
If the population of open- and closed-states is high, then it is possible for quarkonia to be regenerated through **recombination of open heavy flavor with a liberated heavy flavor**. There can also be local recombination of an individual bound state due to medium interactions.

Viscous QGP modeling

Quarkonia are sensitive to the full spatio-temporal evolution of the QGP. Need to compute dynamical processes including non-equilibrium corrections. **Should use codes that reproduce experimental data for bulk observables** such as particle spectra and azimuthal flow.

Good news and bad news

- Large binding energies → short formation times
- Formation time for Υ(1s), for example, is ≈ 0.2 fm/c
- This comes at a cost: **We need to reliably model the early-time dynamics since quarkonia are born into it.**
- In addition, production vertices can be anywhere in the transverse plane, not just the central hottest region.
- For example, for a central collision <r> ~ 3.2 fm and the most probable r is ~ 5 fm.
- **We need to reliably describe the dynamics in the full 3+1d volume.**



The models

Types of models

- **Thermal** – All states produced on freeze-out hypersurface. Treats heavy-flavor just like like light flavors up to some fugacity-related factors. Assumes all initial state information is lost.

- **Transport** – Treat states semi-classically; subject to transport equation with collision kernel etc. coming from underlying quantum theory; can include regeneration by guaranteeing approach to thermal equilibrium in collisional kernel.

- **Quantum** – Treat state admixtures quantum mechanically and solve real-time noisy Schrodinger and/or Linblad equation. Usually Schrodinger evolution only treats singlet states but can be extended beyond this. Linblad formalism can be used to track singlet and octet transitions.

This meeting

Main questions and objectives

1) Are the currently employed transport approaches (mostly carried out in semiclassical approximations) consistent in their treatment of quarkonium dissociation and regeneration?
2) How do the equilibrium limits of the transport approaches compare to the results of the statistical hadronization model?
3) What is the significance of the effects on quantum transport of the quarkonium wave packets, and what is needed to develop them into a realistic phenomenology?
4) How can the abundant information from lattice QCD (quarkonium correlation functions, heavy-quark free energies and susceptibilities, and the open heavy-flavor sector) be systematically implemented into transport and quantum approaches?
5) What are the ultimate model uncertainties and will those allow us to conclude on the fundamental question of the existence of hadronic correlations in a deconfined medium?

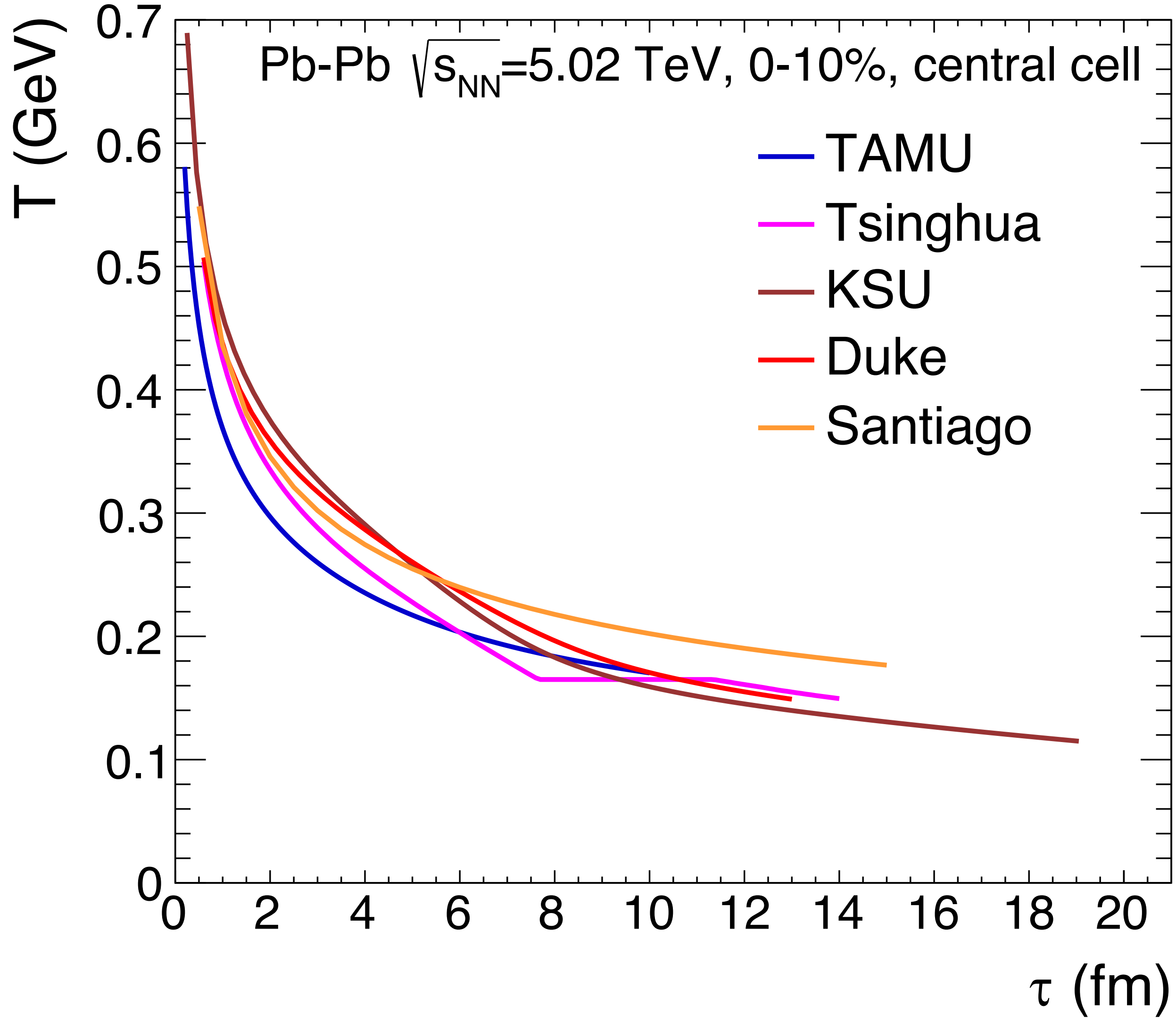
The homework

We assigned some homework to do before the meeting in order to have firm basis for our discussions this week.

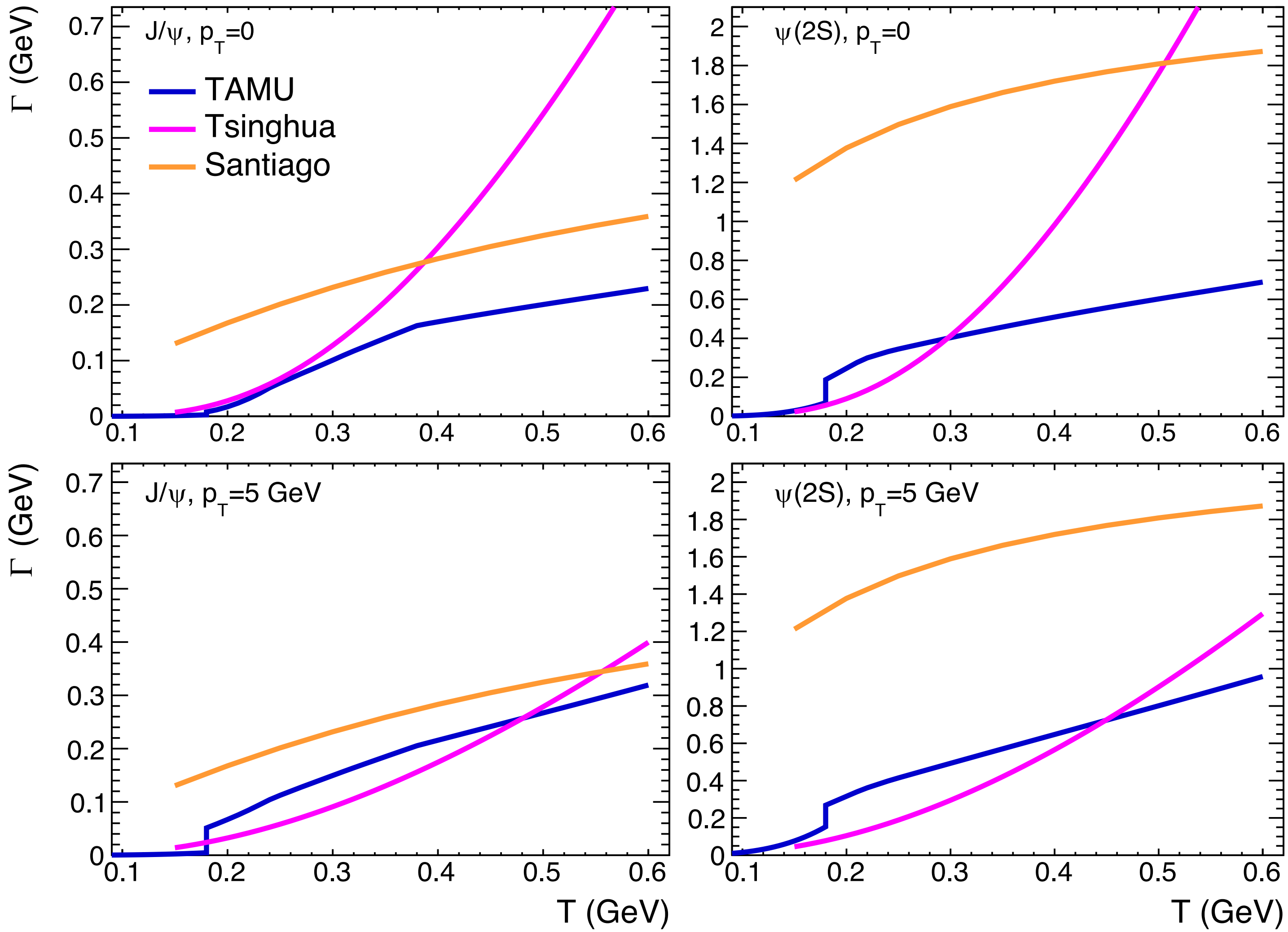
The submissions have been collected here: https://qgp.uni-muenster.de/~andronic/EMMI_RRTF_Q2019/

- Homework calculations:
  - SHM: : Npart dep. | pT dep., 0-10%: J/psi ; psi(2S) (ref.)
  - Transport model, TAMU (Rapp, Du): psi; Upsilon
  - Transport model, Tsinghua (Chen, Zhuang): psi; Upsilon
  - Hydro model, KSU (Strickland), Upsilon: Npart: Y(1S); Y(2S); Y(3S) | pT: Y(1S); Y(2S). Reaction rates: Y(1S); Y(2S); Y(3S) | Temperature | writeup
  - Comover model (Ferreiro): Npart dep.: psi; Upsilon | writeup
  - pNRQCD (Escobedo, Brambilla, Vairo) writeup
  - Density matrix (Escobedo, Blaizot) writeup (ref.)
  - Escape (Jaiswal, Bhaduri): File, Y(1S)
  - Coupled Boltzmann transport eq. (Yao, Duke): Npart: Y(1S); Y(2S) | pT: Y(1S); Y(2S). Reaction rates, Y: p=0; p=10 GeV | Temperature input pT spectra (PYTHIA*EPS09): Y(1S); Y(2S)
  - Shadowing, EPPS16 (Vogt): Data file
- Plots (homework):
  - T(tau), central cell
  - Reaction rates: psi | Upsilon
  - R_AA psi: Npart dep. | pT dep.
  - R_AA Upsilon: Npart dep. | pT dep.

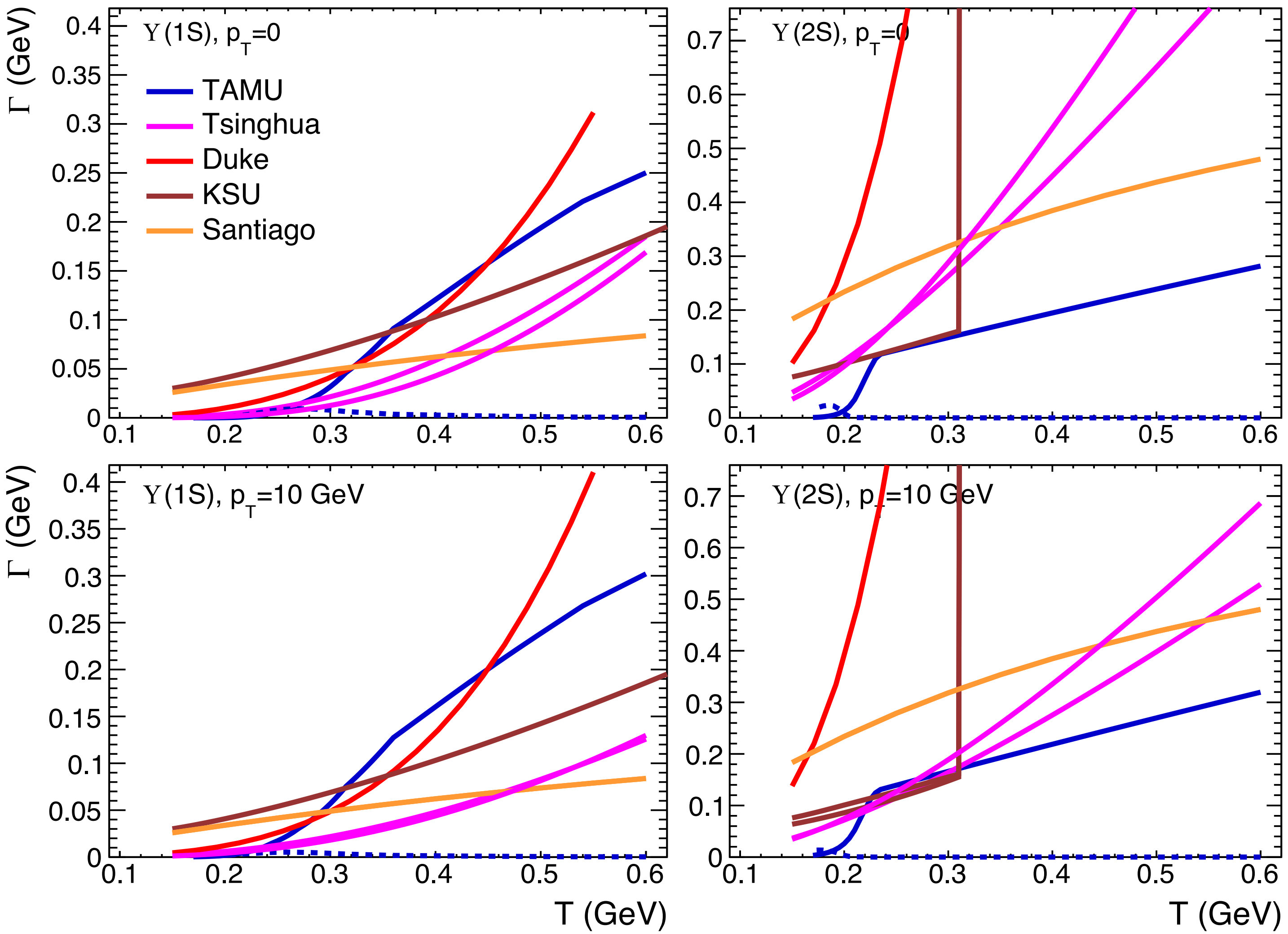
Temperature evolution (central cell)



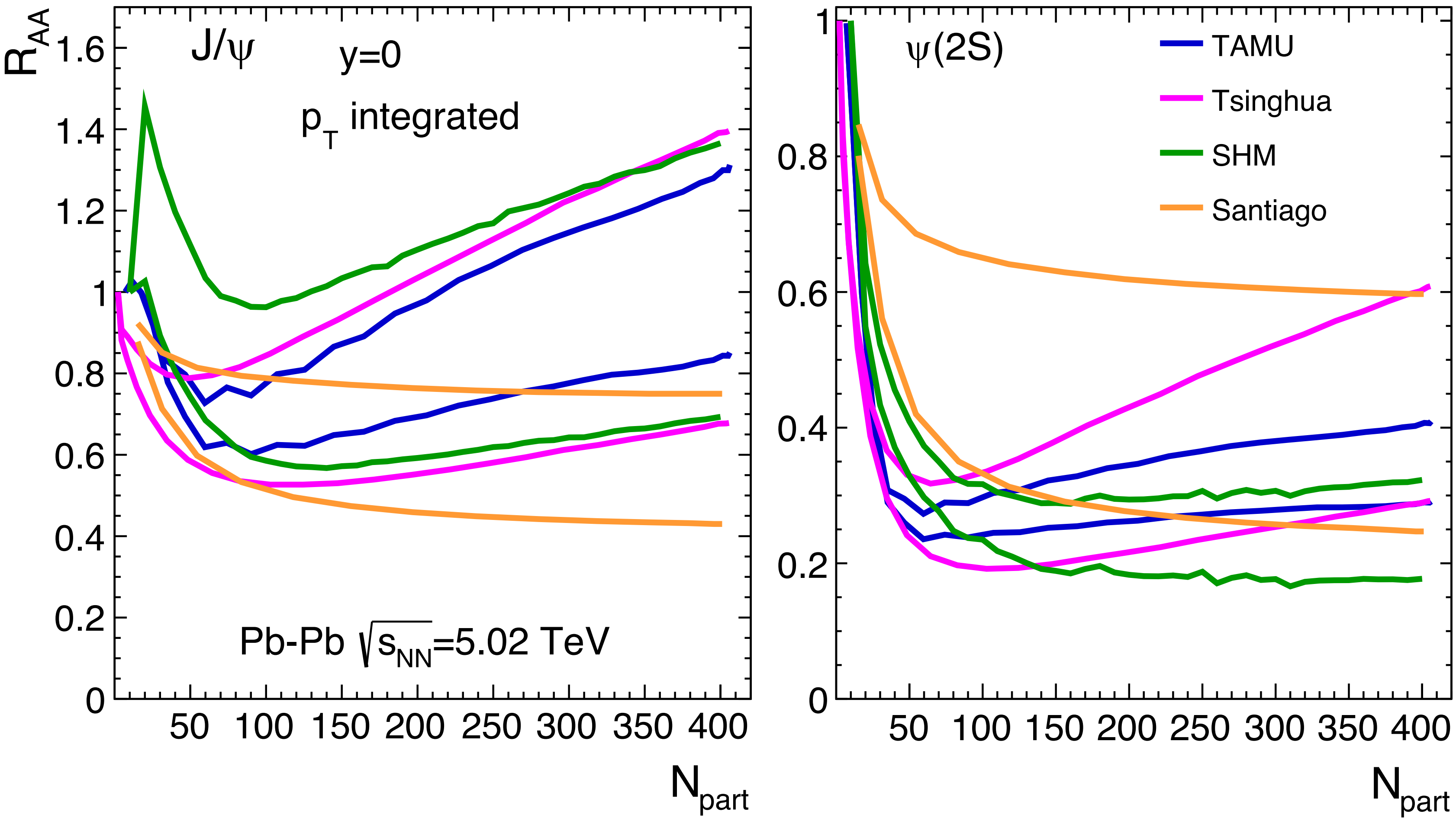
Breakup rates – J/Psi



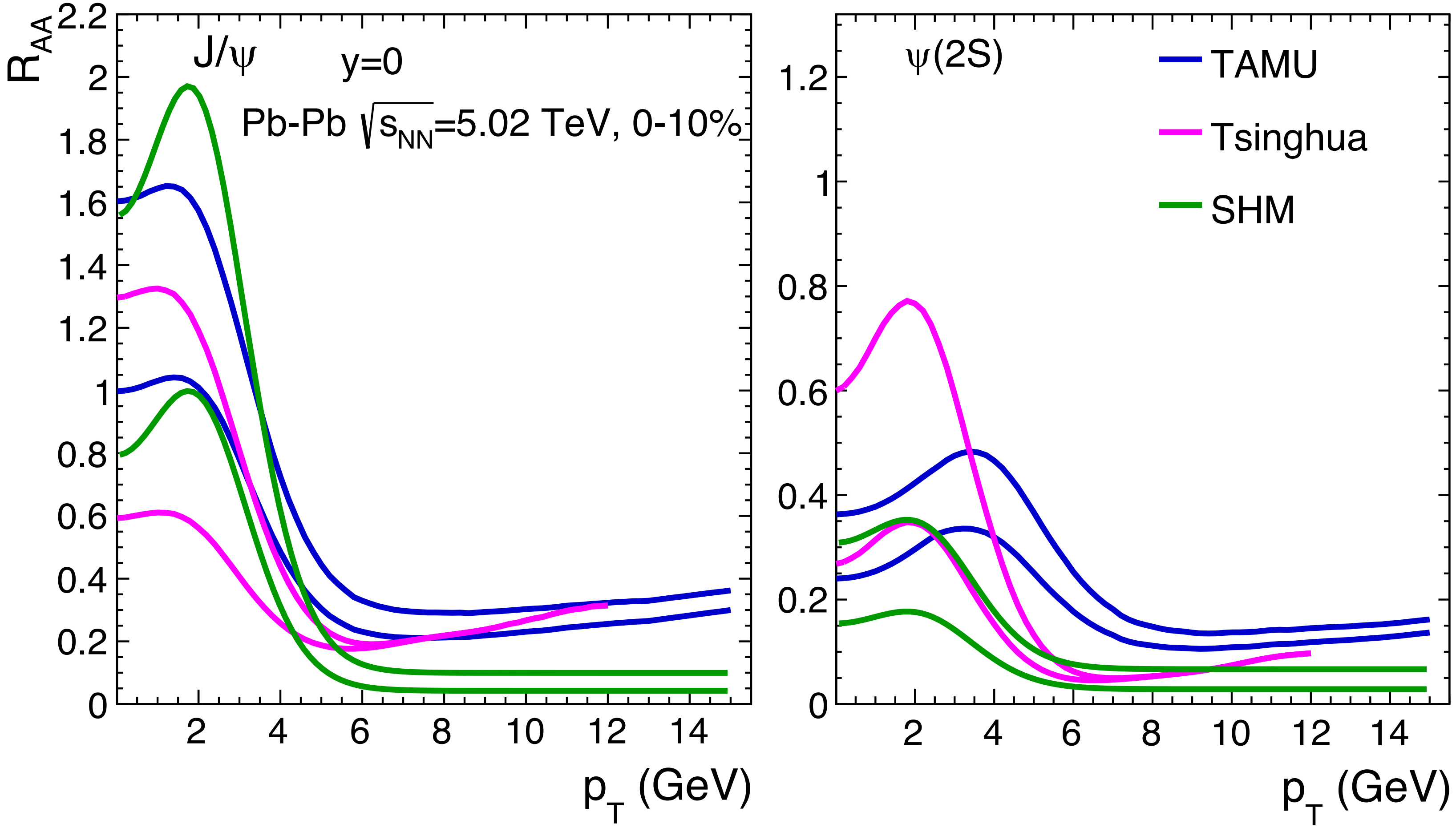
Breakup rates – Upilson



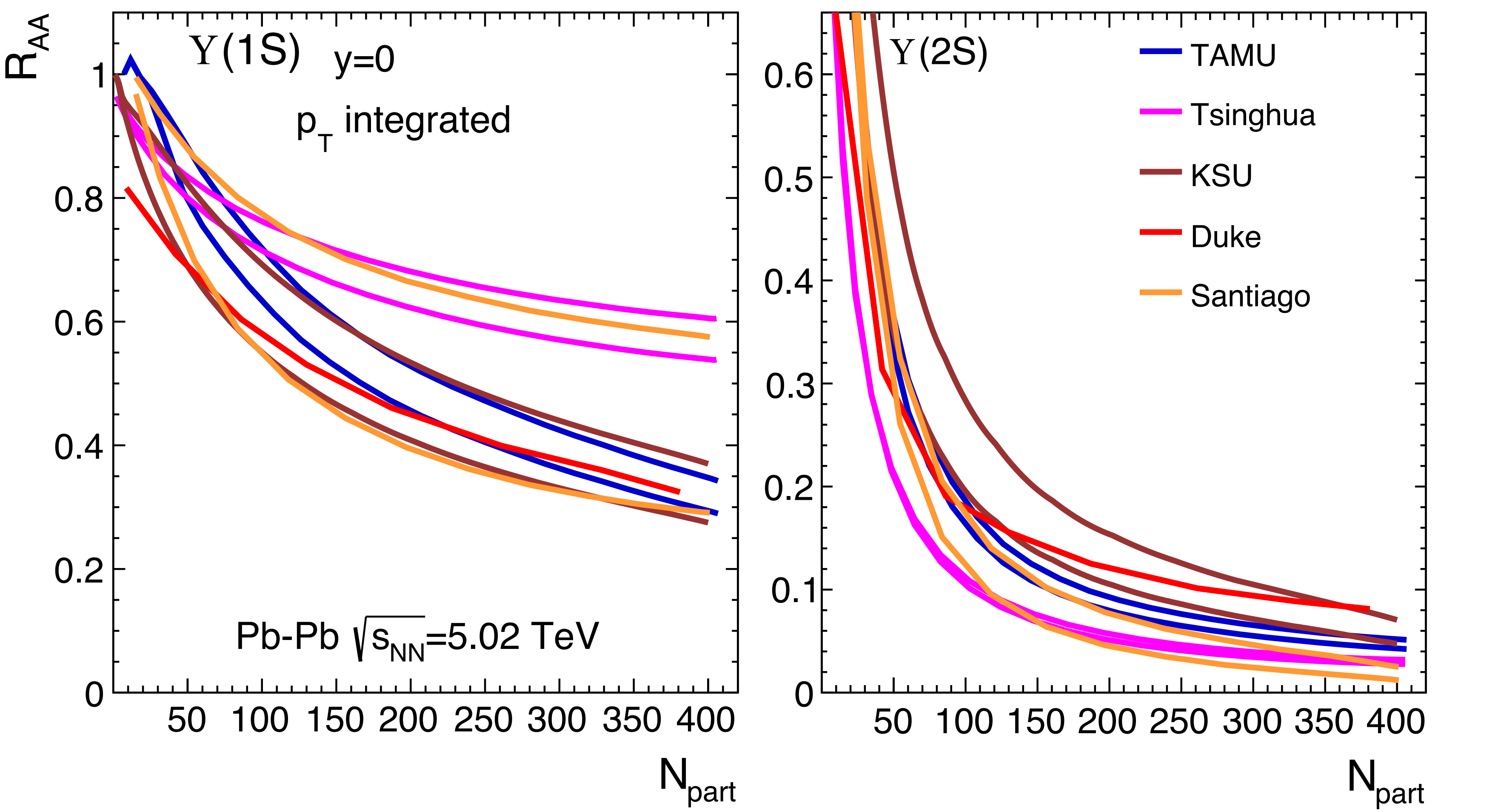
R_{AA} vs N_{part} – J/Psi



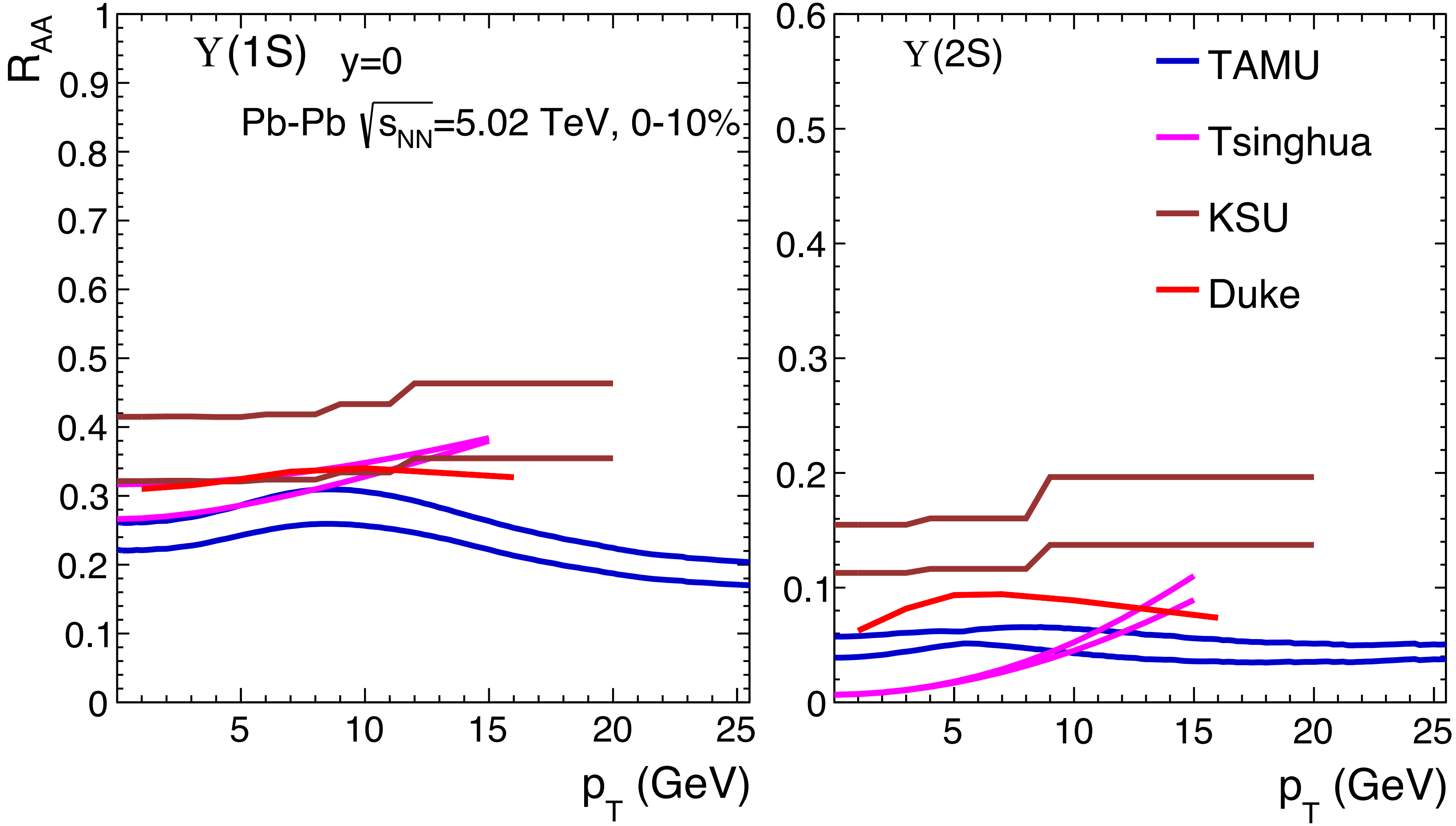
R_{AA} vs p_T – J/Psi



R_{AA} vs N_{part} – Upsilon



R_{AA} vs p_T – Upsilon



The organization

Today – Introductory symposium and discussions about the rest of the week in the afternoon

Tuesday – Focus is on inelastic breakup rates from all models including lattice; also some info from CNM calculations
(Convener: Ralf Rapp)

Wednesday – Focus is on quarkonium properties in hot equilibrium matter (aka "the equilibrium limit")
(Convener: Peter Petreczky)

Thursday – Focus is on off-equilibrium effects
(Convener: Pol-Bernard Gossiaux)

Friday – Discussions and planning for writeup

https://indico.gsi.de/event/9314/timetable/

Tomorrow

09:00	**Comover approach**	*Prof. Elena GONZALEZ FERREIRO*	*KBW lecture hall, GSI Helmholtzzentrum für Schwerionenforschung GmbH*	09:00 - 09:15
	Nantes approach	*Dr. Roland KATZ et al.*	*KBW lecture hall, GSI Helmholtzzentrum für Schwerionenforschung GmbH*	09:15 - 09:30
	Duke approach	*Dr. Xiaojun YAO*	*KBW lecture hall, GSI Helmholtzzentrum für Schwerionenforschung GmbH*	09:30 - 09:45
	Saclay approach	*Dr. Miguel Angel ESCOBEDO ESPINOSA et al.*	*KBW lecture hall, GSI Helmholtzzentrum für Schwerionenforschung GmbH*	09:45 - 10:00
10:00	**Munich approach**	*nora BRAMBILLA*	*KBW lecture hall, GSI Helmholtzzentrum für Schwerionenforschung GmbH*	10:00 - 10:15
	Stavanger/Osaka approach	*Dr. Alexander ROTHKOPF*	*KBW lecture hall, GSI Helmholtzzentrum für Schwerionenforschung GmbH*	10:15 - 10:30
	Coffee break		*KBW lecture hall, GSI Helmholtzzentrum für Schwerionenforschung GmbH*	10:30 - 11:00
11:00	**TAMU approach**	*Xiaojian DU et al.*	*KBW lecture hall, GSI Helmholtzzentrum für Schwerionenforschung GmbH*	11:00 - 11:15
	Kent State approach	*Mr. amaresh JAISWAL et al.*	*KBW lecture hall, GSI Helmholtzzentrum für Schwerionenforschung GmbH*	11:15 - 11:30
	PHSD approach	*Dr. Taesoo SONG*	*KBW lecture hall, GSI Helmholtzzentrum für Schwerionenforschung GmbH*	11:30 - 11:45
	CNM absorption	*Ramona Vogt VOGT*	*KBW lecture hall, GSI Helmholtzzentrum für Schwerionenforschung GmbH*	11:45 - 12:00
12:00	**Quarkonium Widths from Lattice QCD**	*Prof. Chris ALLTON et al.*	*KBW lecture hall, GSI Helmholtzzentrum für Schwerionenforschung GmbH*	12:00 - 12:20

https://indico.gsi.de/event/9314/timetable/

Conclusions

- None yet, let’s wait for Friday