The physics of sPHENIX (with emphasis on bottomonium)

GHP15, Baltimore, April 8 2015

Anthony D Frawley

sPHENIX motivation

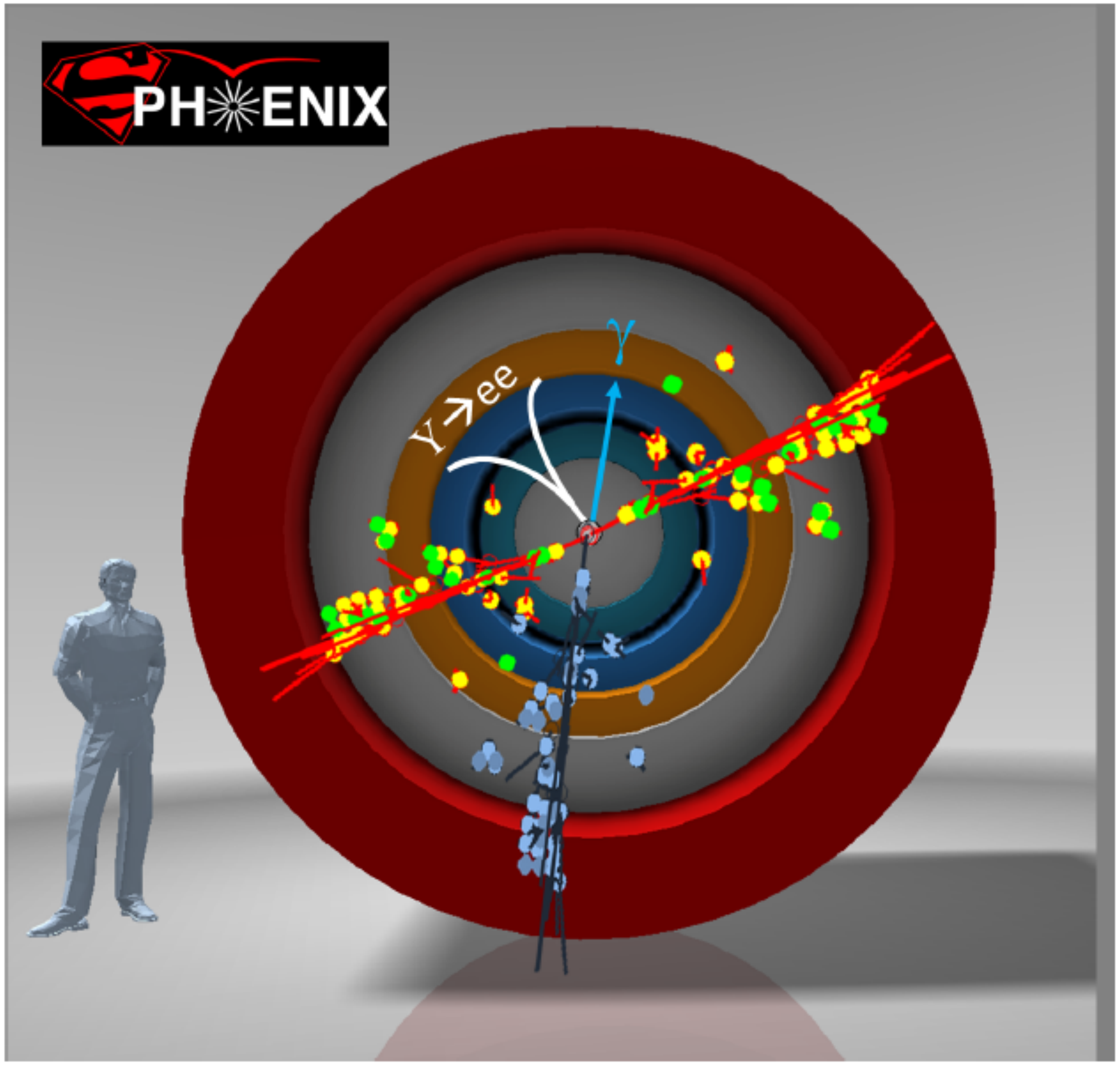
The sPHENIX detector at RHIC was proposed to provide the capability for:

- Unbiassed jet measurements
    - Including heavy quark tagged jets & photon tagged jets
- High precision bottomonium measurements

Physics focus:

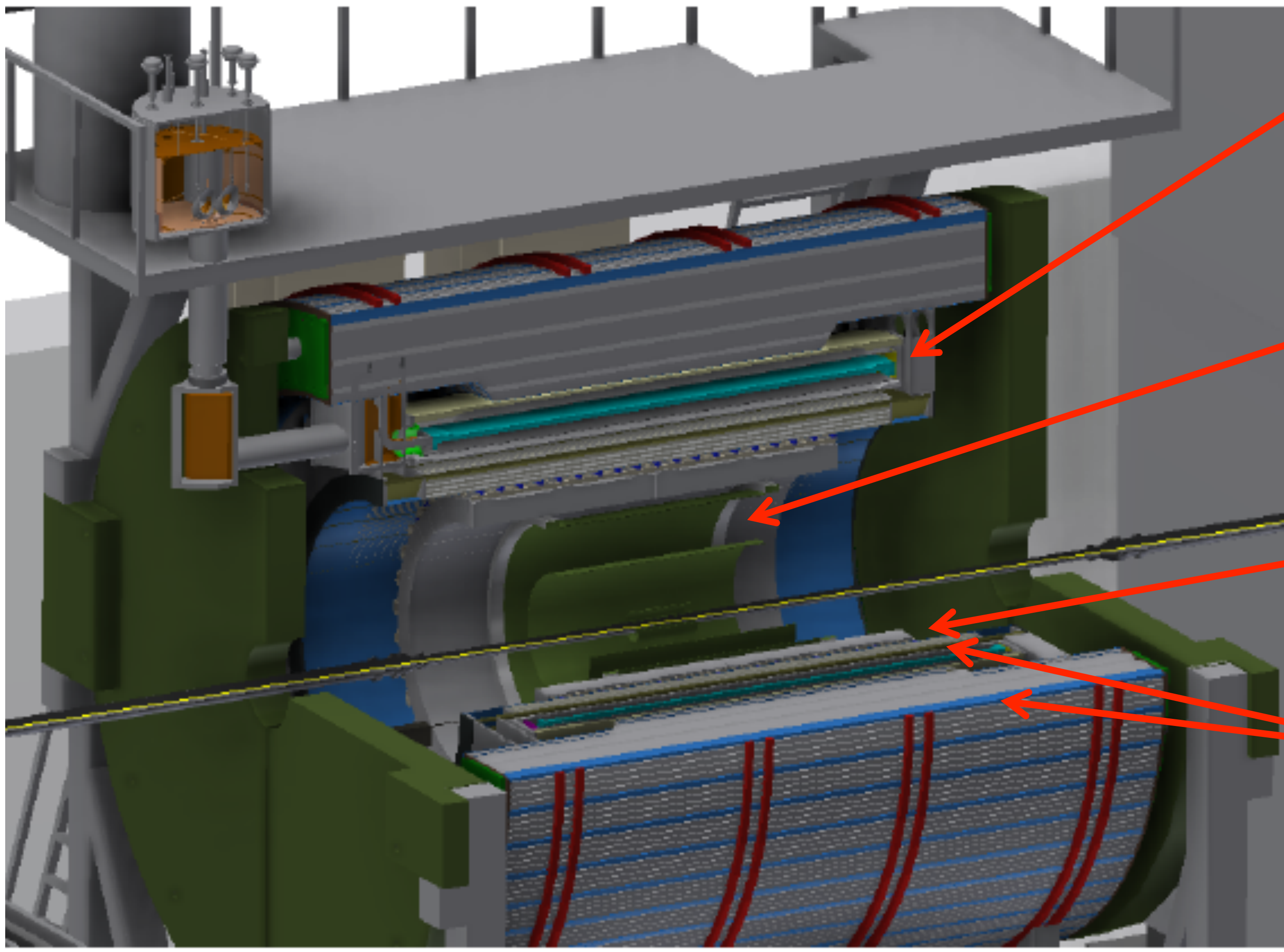
- Probing the QGP at a variety of length scales using hard scattered partons
- The temperature-sensitive coupling of bottomonium states to the medium.

The **goal** is to provide data sets at RHIC energies that will be complementary to the very precise jet and bottomonium data that will be available from the LHC by the end of Run 3 (2023).



sPHENIX

Compact detector built around a superconducting solenoid.



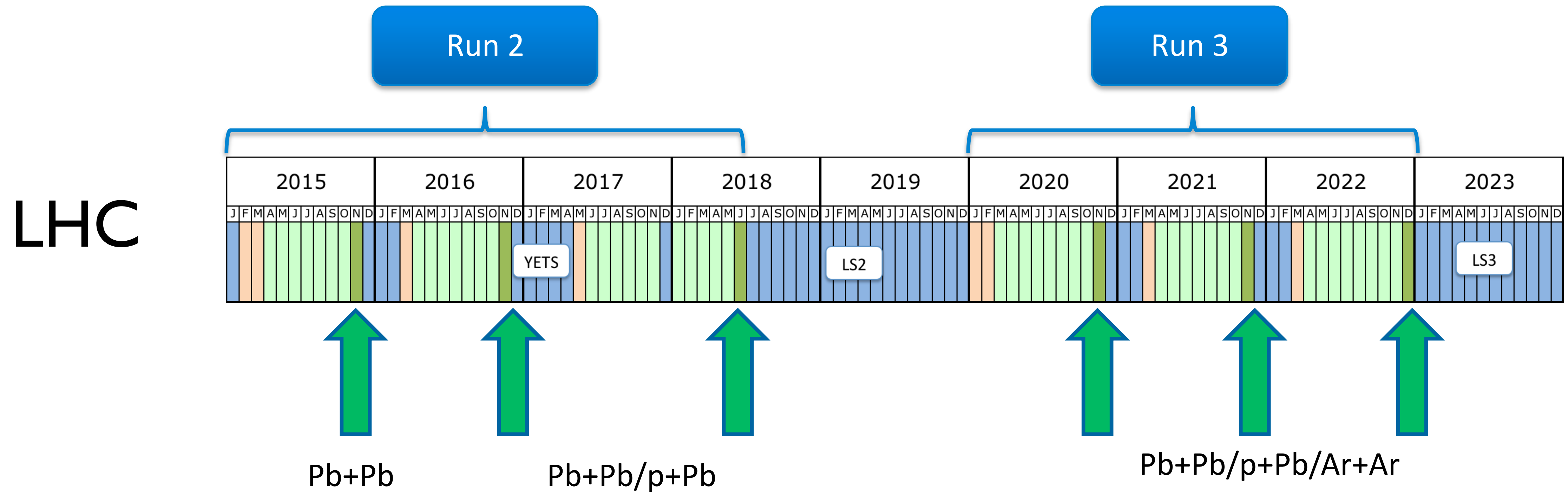
Hermetic coverage (required for good jet reconstruction).

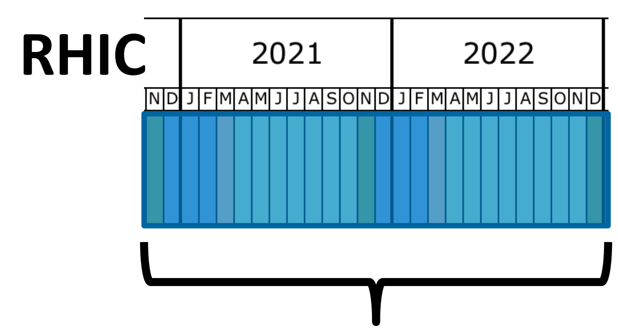
Upsilons will be measured using dielectrons

Brookhaven Lab proposed 10 year plan

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2014	15 GeV Au+Au 200 GeV Au+Au	Heavy flavor flow, energy loss, thermalization, etc. Quarkonium studies QCD critical point search	Electron lenses 56 MHz SRF STAR HFT STAR MTD
2015-16	p+p at 200 GeV p+Au, d+Au, ^{3}He+Au at 200 GeV High statistics Au+Au	Extract $\eta/s(T)$ + constrain initial quantum fluctuations More heavy flavor studies Sphaleron tests Transverse spin physics	PHENIX MPC-EX Coherent e-cooling test
2017	No Run	Remove PHENIX	Low energy e-cooling upgrade
2018-19	5-20 GeV Au+Au (BES-2)	Search for QCD critical point and onset of deconfinement	STAR ITPC upgrade Partial commissioning of sPHENIX (in 2019)
2020	No Run	Complete sPHENIX installation	Complete sPHENIX installation STAR forward upgrades
2021-22	Long 200 GeV Au+Au with upgraded detectors p+p, p/d+Au at 200 GeV	Jet, di-jet, γ-jet probes of parton transport and energy loss mechanism Color screening for different quarkonia	sPHENIX
2023-24	No Runs		Transition to eRHIC

sPHENIX timeline and LHC



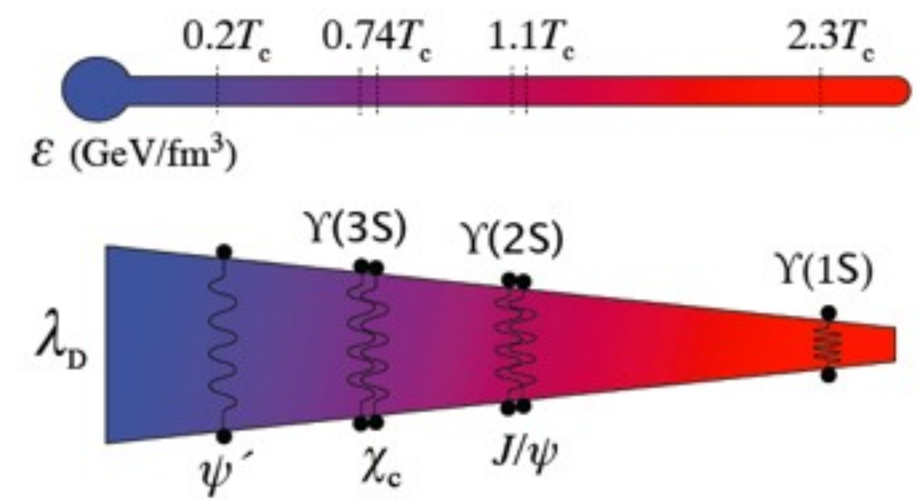


sPHENIX Schedule:
PHENIX shuts down after 2016 run
Central arm magnets and detectors removed
sPHENIX installed by 2020
Begins running in 2021

Will run for 2 (or 3) years.

Heavy quarkonia

Heavy quarkonia become unbound at different temperatures, depending on their radius - so they are sensitive to physics at different length scales (e.g. color screening).



However the modification of heavy quarkonia yields in nuclear collisions is caused by an interplay of:

- Energy density
- Coalescence
- Cold nuclear matter effects

All of these are significant contributors, and to study the effects of color screening on quarkonia bound states we need to understand the role played by all three of these effects.

Heavy quarkonia (cont.)

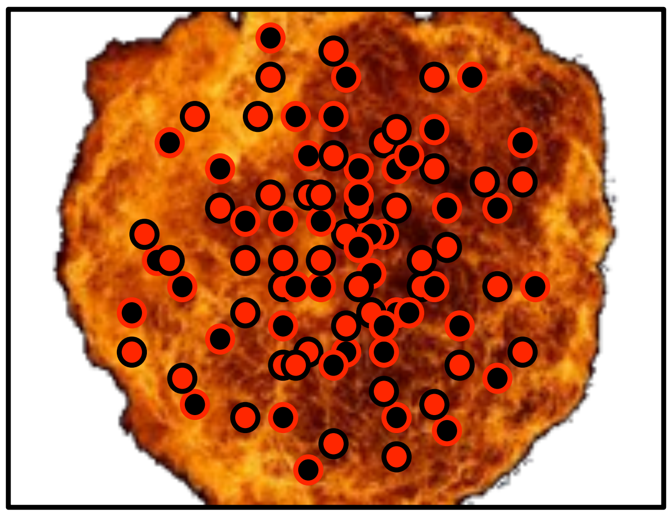
A comparison of as many heavy quarkonia systems as possible at multiple initial temperatures offers the best prospect for extracting the effects of color screening on quarkonia in the presence of the other competing effects.

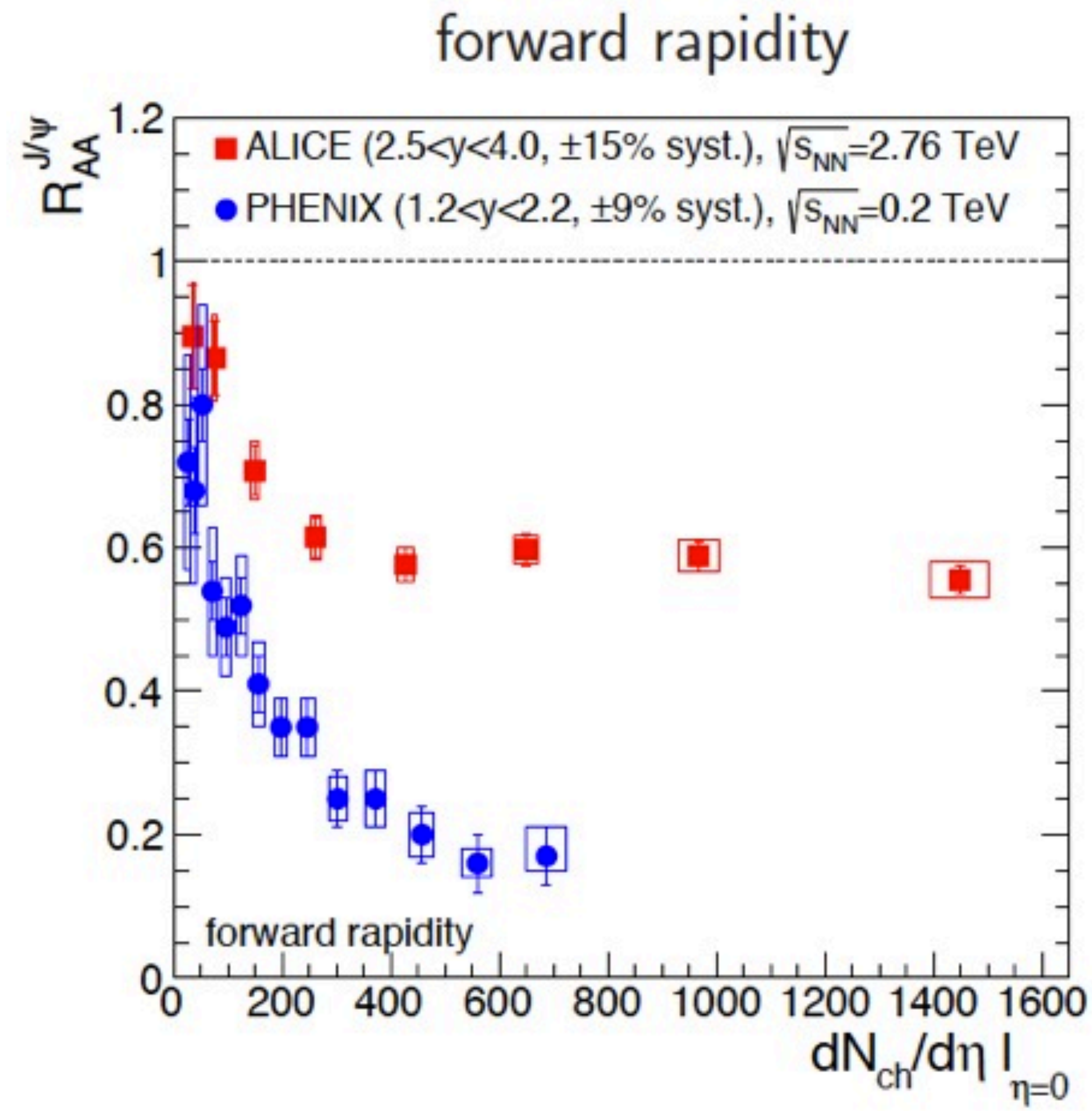
By comparing quarkonia yields in p+p, p(d)+A and A+A collisions at RHIC and LHC energies we:

- Change the initial temperature by ~ 30%
- Change the underlying heavy quark production cross section
- Change details of the cold nuclear matter modification

J/ψ at RHIC and LHC

The number of charm anti-charm pairs in a central HI collision at LHC energy is ~ 100, while at RHIC it is ~ 10.



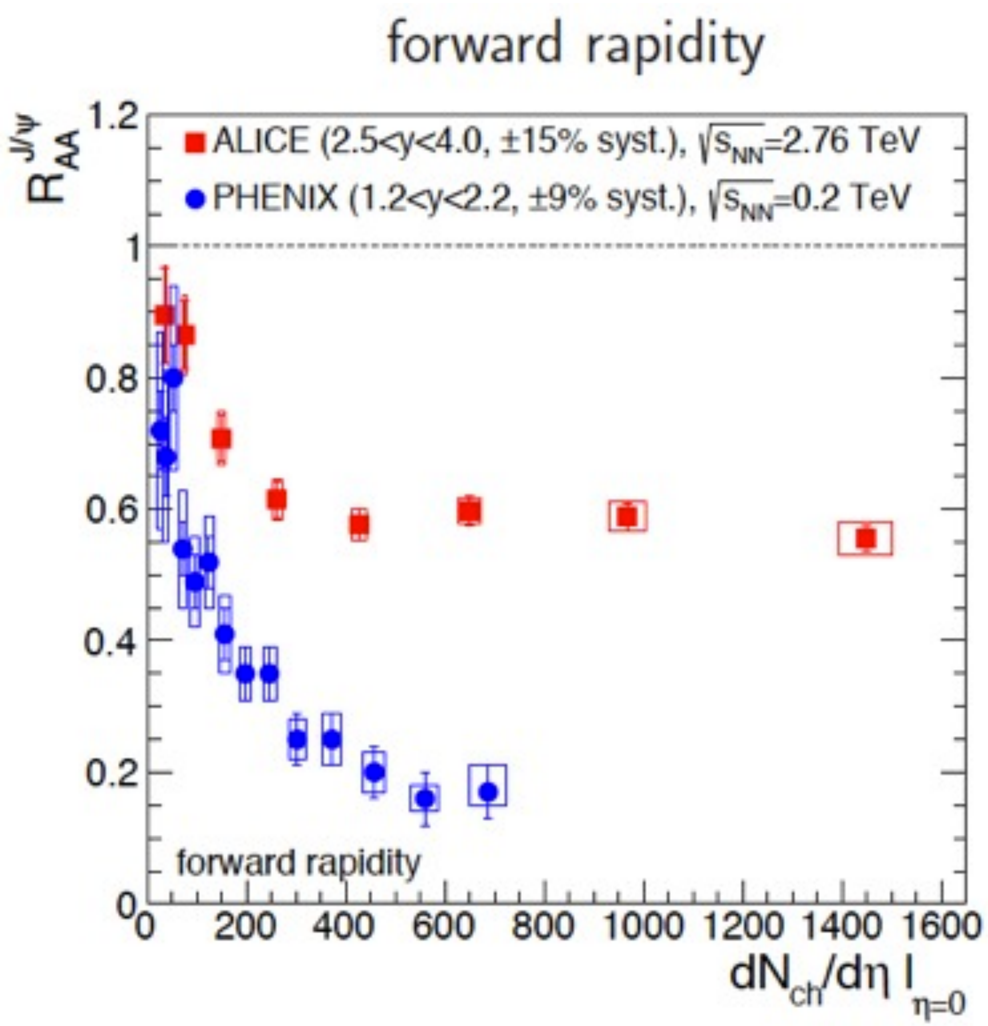


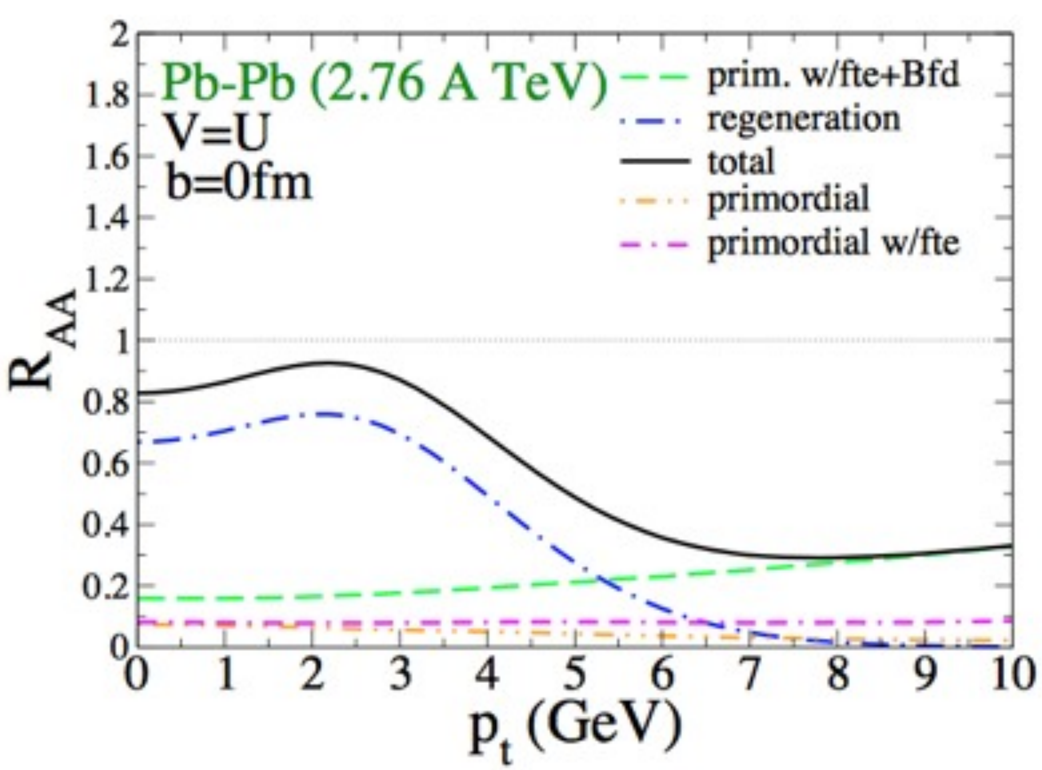
Comparison of ALICE and PHENIX data shows that at the same energy density the R_{AA} is much **smaller** at RHIC.

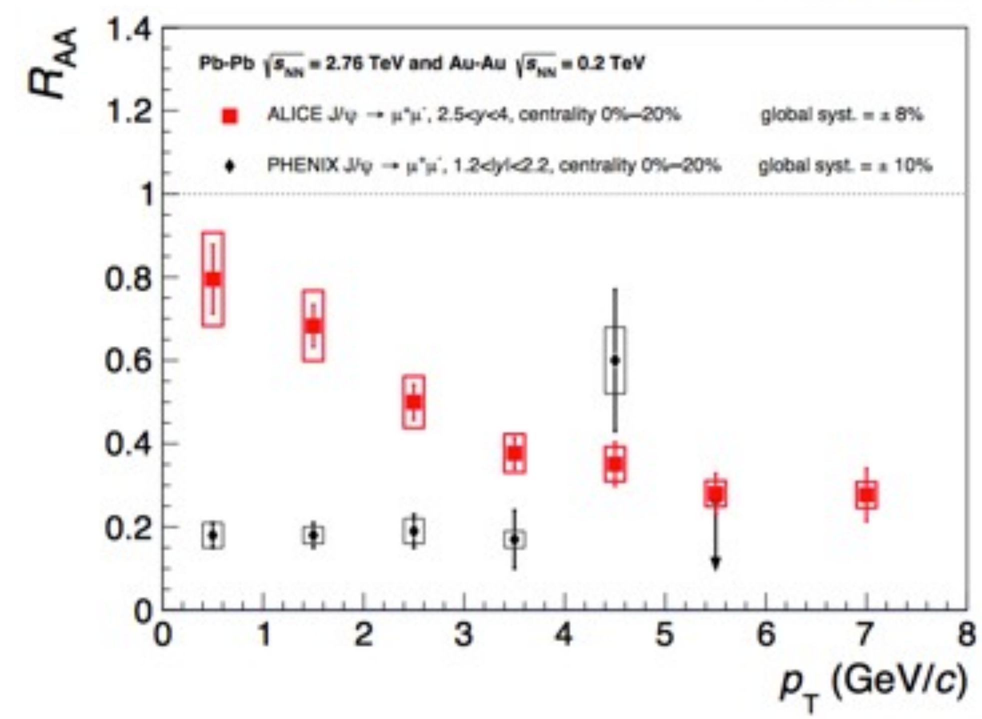
J/ψ at RHIC and LHC (cont.)

The much smaller R_{AA} at 200 GeV than at 2.76 TeV is consistent with predictions that **coalescence** of charm pairs will dominate at LHC energy

- Supported by v_2 of J/ψ at LHC
- Cool! But we do not get a direct comparison of screening effects at RHIC and LHC from the J/ψ







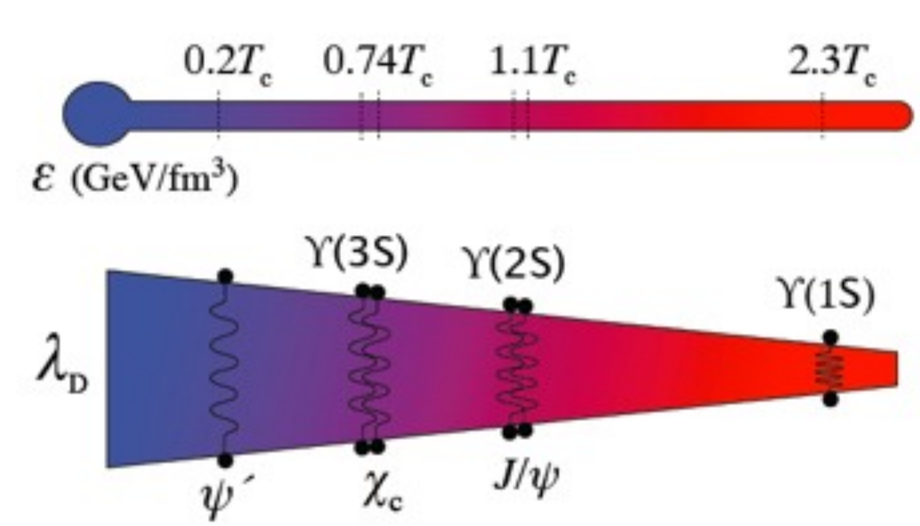
Upsilons

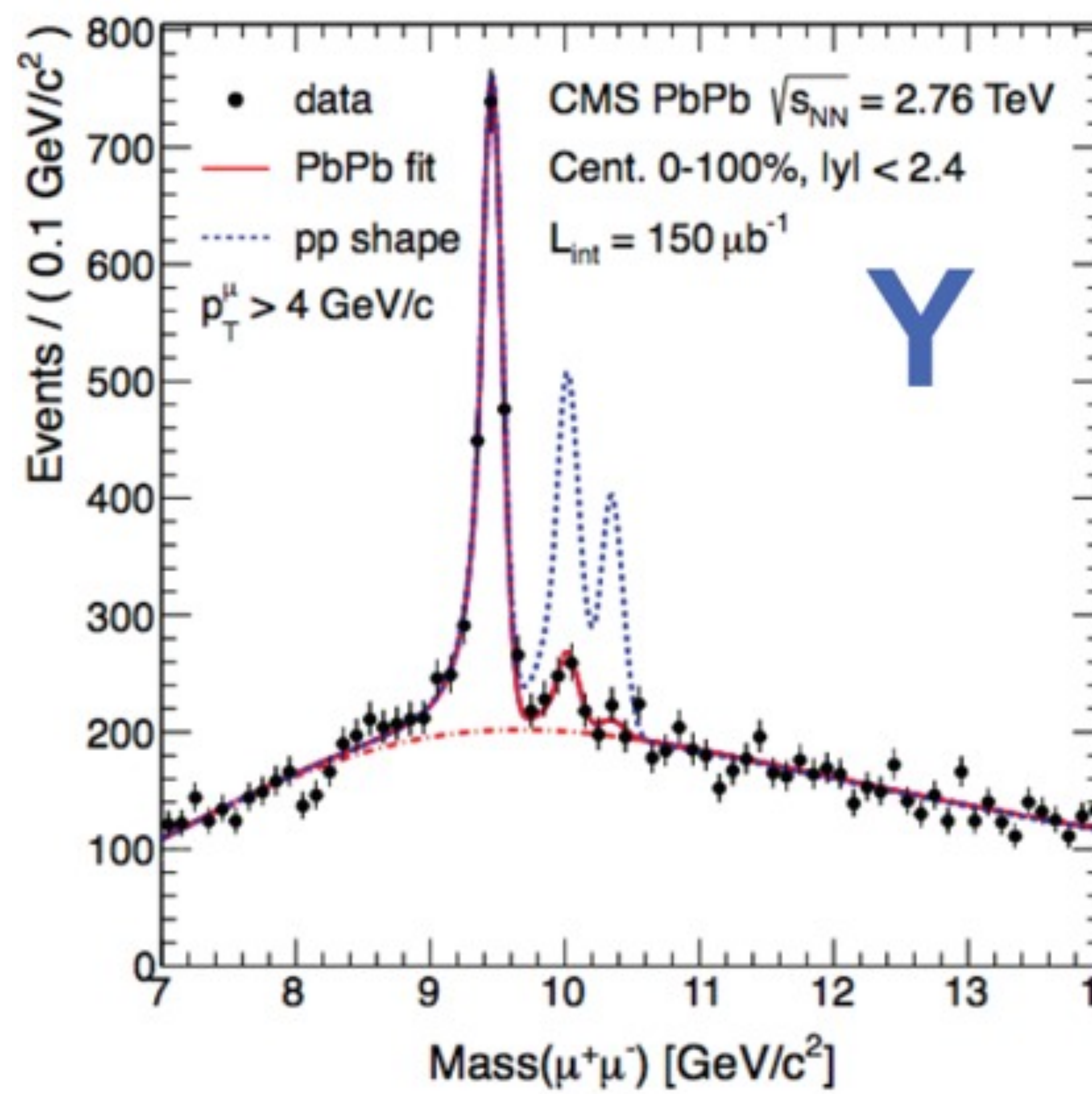
Upsilons have the advantages that:

- We measure all three states at the same time through their dielectron decays
- Bottom pairs per central collision: ~0.05 at RHIC, ~ 5 at LHC
  - Coalescence should not dominate at RHIC **or** LHC
- They span a large range of radii.

So we can directly compare melting at 200 GeV and 2.76 TeV on three states of very different size.

Beautiful Upsilon measurements by CMS show dramatic suppression of the 2S and 3S states in Pb+Pb collisions at 2.76 TeV.

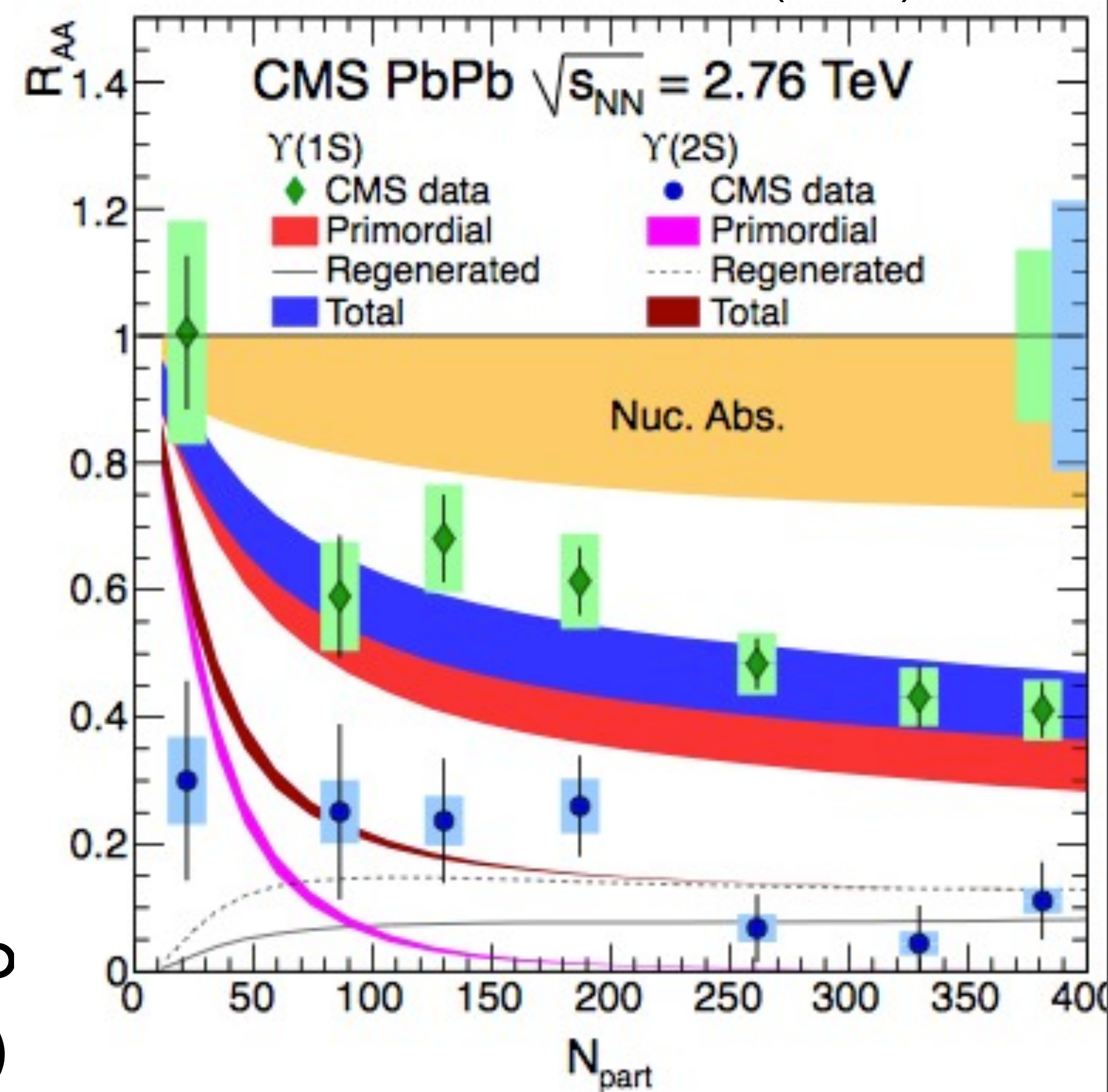




Upsilons (cont.)

A calculation from a transport model by Ralf Rapp's group showing the relative contributions of melting and coalescence to the Υ(1S) and Υ(2S) states compared with CMS data.

Zhao et al., NP A 904–905 (2013) 611c



This is a model in which a lattice guided potential is immersed in a hydrodynamically expanding medium. The properties of the medium modify the width and binding energy

The Υ(2S) yield is dominated by coalescence ("regenerated") only because the primordial population melts completely!

The Υ(1S) modification is mostly due to the loss of **feed down** from the Υ(2S) and Υ(3S) states. The Υ(1S) is not strongly suppressed.

Upsilons (cont.)

A different calculation in which the Upsilon is embedded in a hydrodynamically expanding medium.

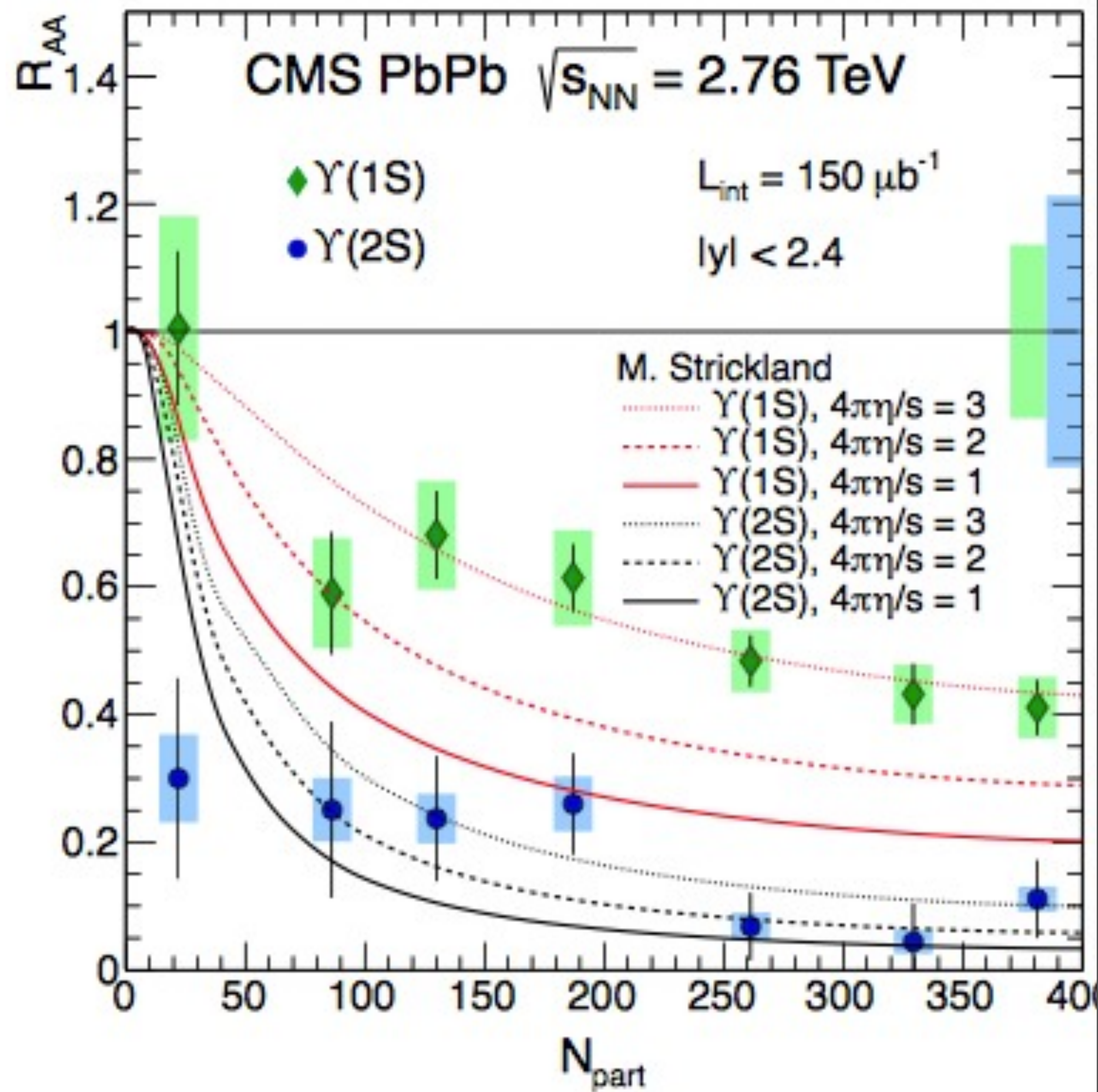
The model results depend strongly on the value used for **η/s** of the medium, since that strongly affects the time evolution of the QGP expansion.

The Υ(1S) R_{AA} measured by CMS already constrains the model parameters, favoring **$\eta/s \sim 0.24$**.

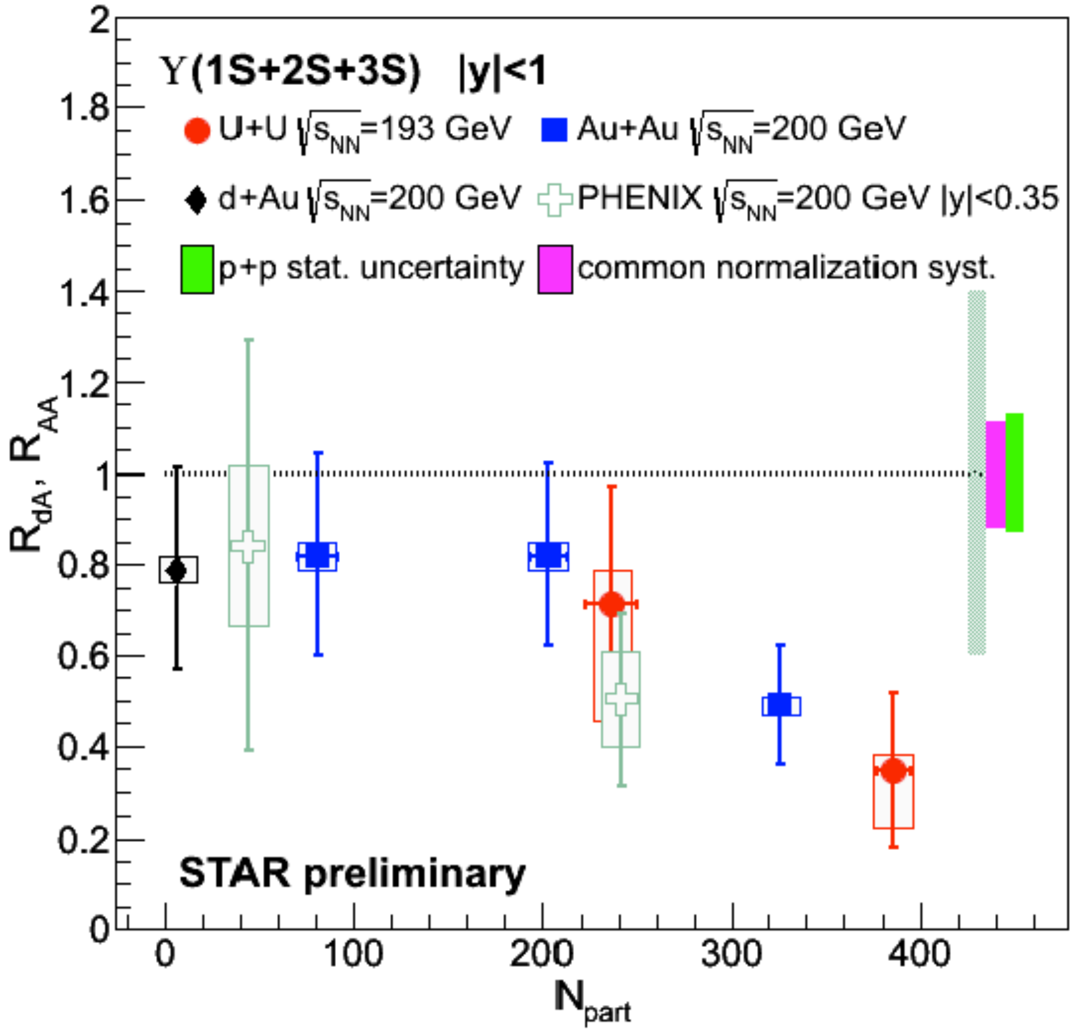
CMS will have ~ 30x this much data by 2023.

There are no measurements that can separate the Υ(2S) at RHIC yet.

Strickland and Bazow N.P. A879:25 2012



Upsilon measurements at RHIC



Existing RHIC Upsilon measurements are not comparable in quality with those at the LHC.

PHENIX measurements are limited to 30-40 counts with a mass resolution that does not separate the Upsilon states.

STAR measurements are better than those from PHENIX because of larger acceptance & better mass resolution. They will improve with the addition of the STAR **Muon Telescope Detector** upgrade. But this will still have less than optimum mass resolution, and the acceptance decreases (it will not be possible to measure a statistically adequate yield in p+p collisions).

sPHENIX will provide mass resolution good enough to separate all three Upsilon states (100 MeV) and about 7 x larger acceptance.

Key sPHENIX Features for Upsilon Measurements

DAQ bandwidth **15 kHz** with **Deadtimeless DAQ**

→ Au+Au: record **100B** minbias events

HCal:

- Helps reject background for Upsilon dielectron measurements

EMcal:

- Electromagnetic energy measurement.
- Electron ID via E/p cut and shower shape measurements.
  - x90 hadron rejection (with HCal) in central Au+Au at 70% single track efficiency.
- Upsilon dielectron **trigger** in p+p, p+Au.

Tracking requirements:

- Measure Upsilon mass via decay electron momentum with 100 MeV resolution.
- Provide good pattern recognition in central Au+Au events.

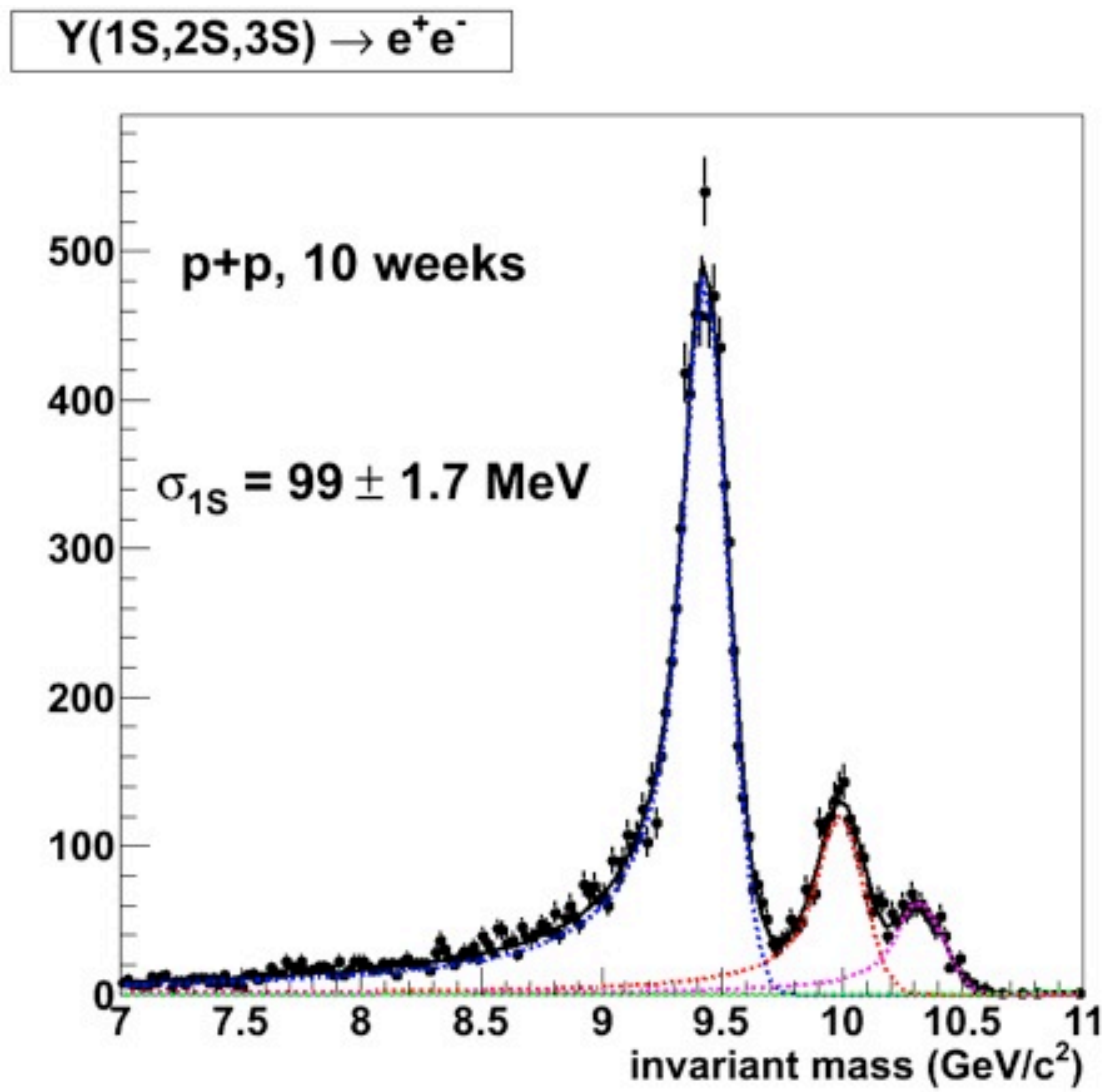
sPHENIX Upsilon performance

There are three major issues for the Upsilon measurement:

- Momentum resolution adequate for 100 MeV mass resolution.
- Low enough mass in the tracker to minimize Bremstrahlung tails on the mass peaks (a disadvantage of using electrons instead of muons).
- Good enough hadron rejection to keep background under the peaks small.

This plot shows the Upsilon mass spectrum for the signal only from a full GEANT 4 simulation for 10 weeks of p+p running

The mass width is from a crystal ball fit.



Upsilon performance - central Au+Au

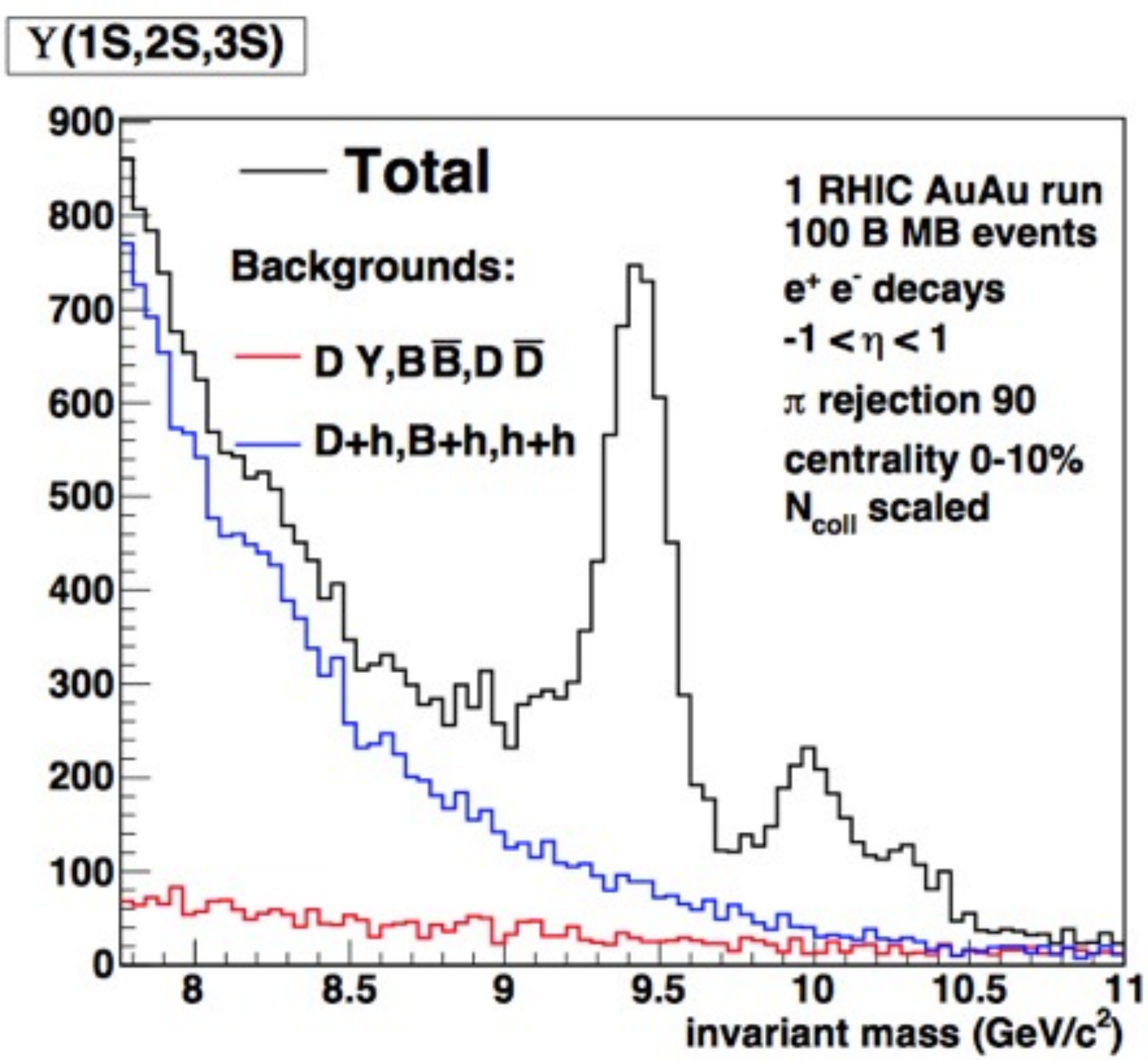
Signal+correlated background after subtraction of combinatoric background.

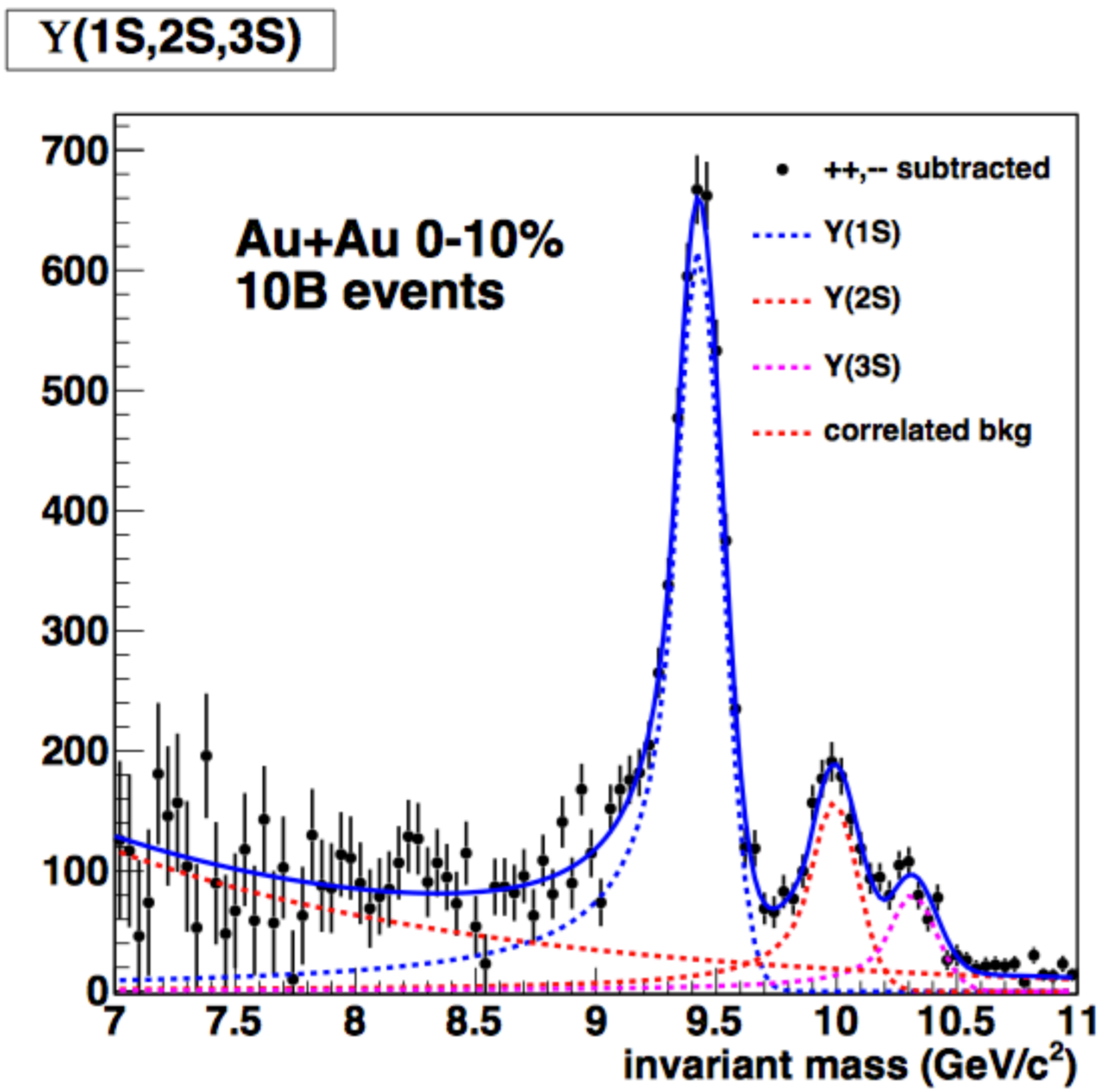
- Background: fast simulation based on measured yields in central Au+Au.

Background estimates assume a **hadron rejection of 90** using EMCal E/p, shower shape cuts and a HCal veto - rejection from GEANT 4 simulations.

Correlated background:

- Drell-Yan, correlated charm & bottom





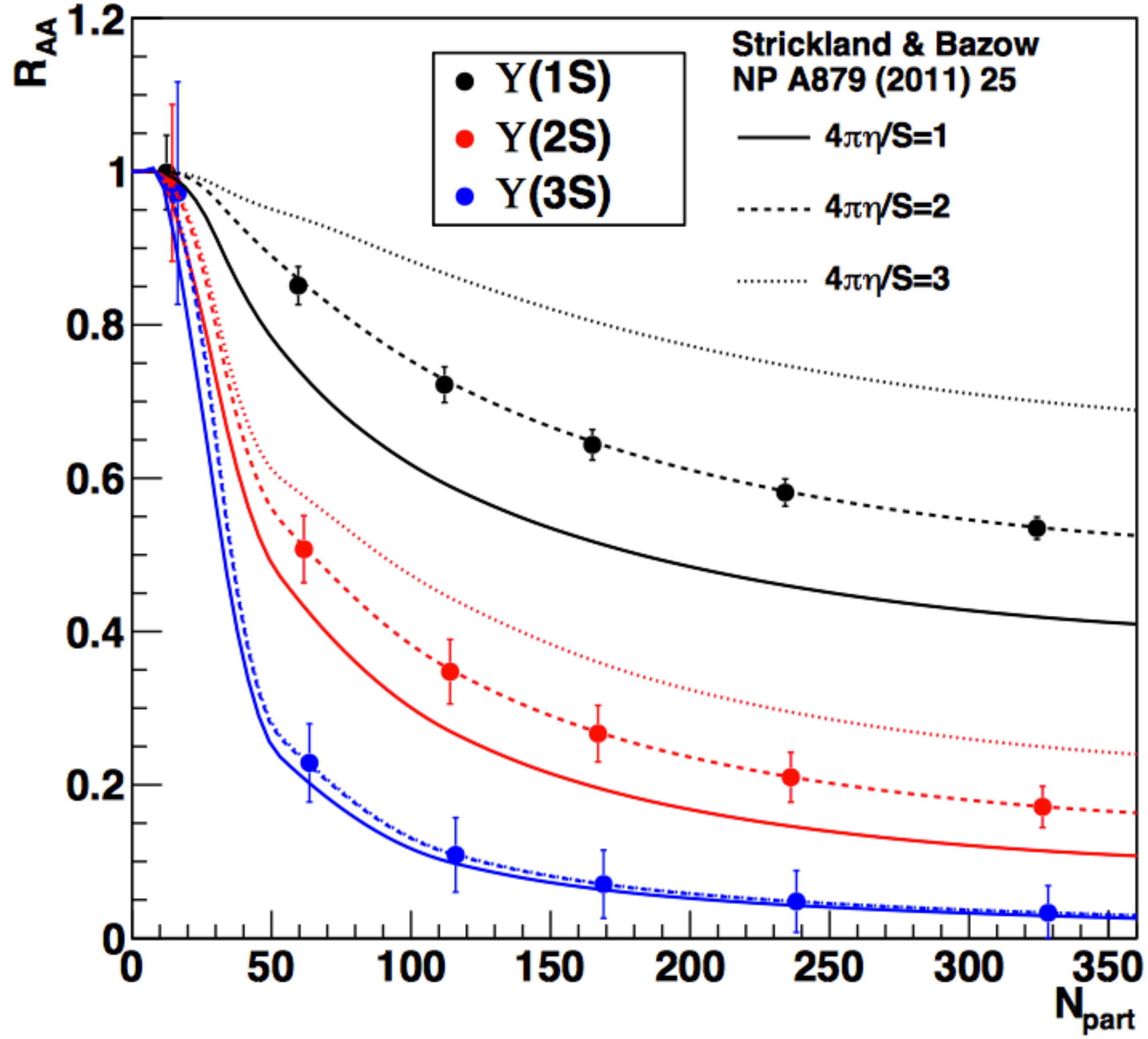
Upsilon performance - 0-10% central Au+Au

Expected statistical precision for the three Upsilon states measured with sPHENIX.

The statistical precision includes the effects of the estimated signal to background ratio.

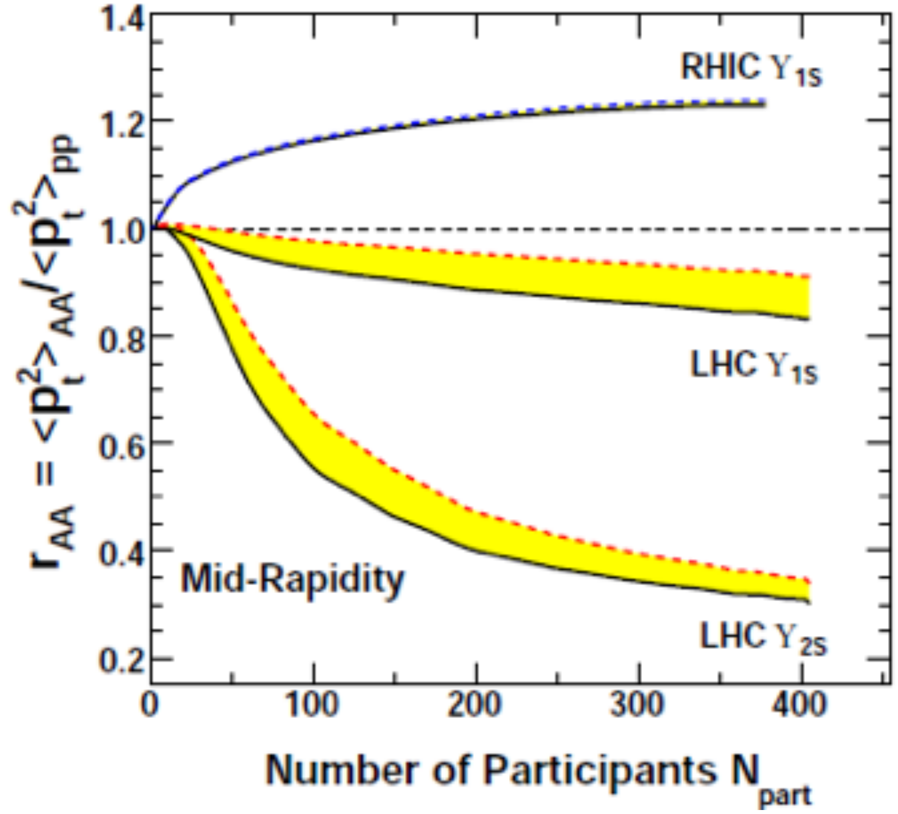
Would provide tight constraints on theoretical descriptions of RHIC energy data to complement those provided by CMS for data at LHC energy.

Strickland and Bazow N.P. A879:25 2012
(and private communication)



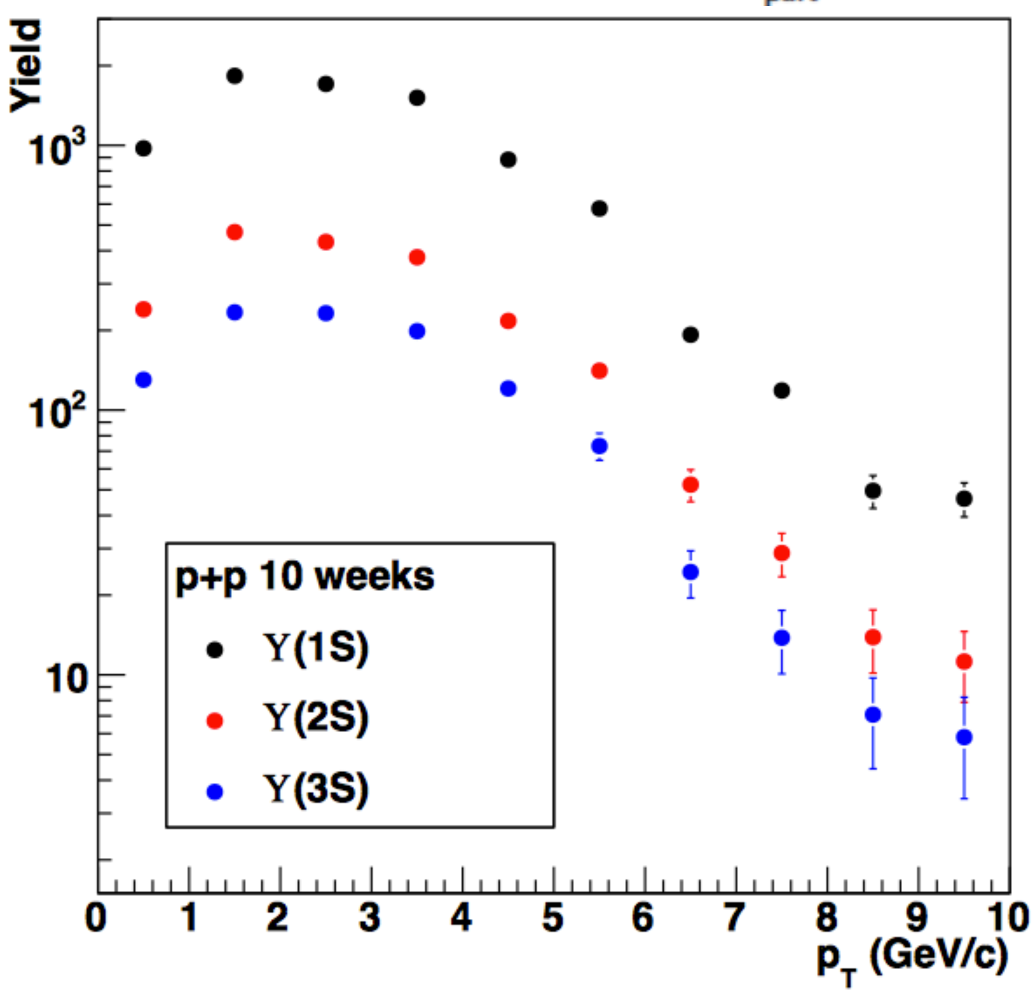
Au+Au Upsilon p_T dependence

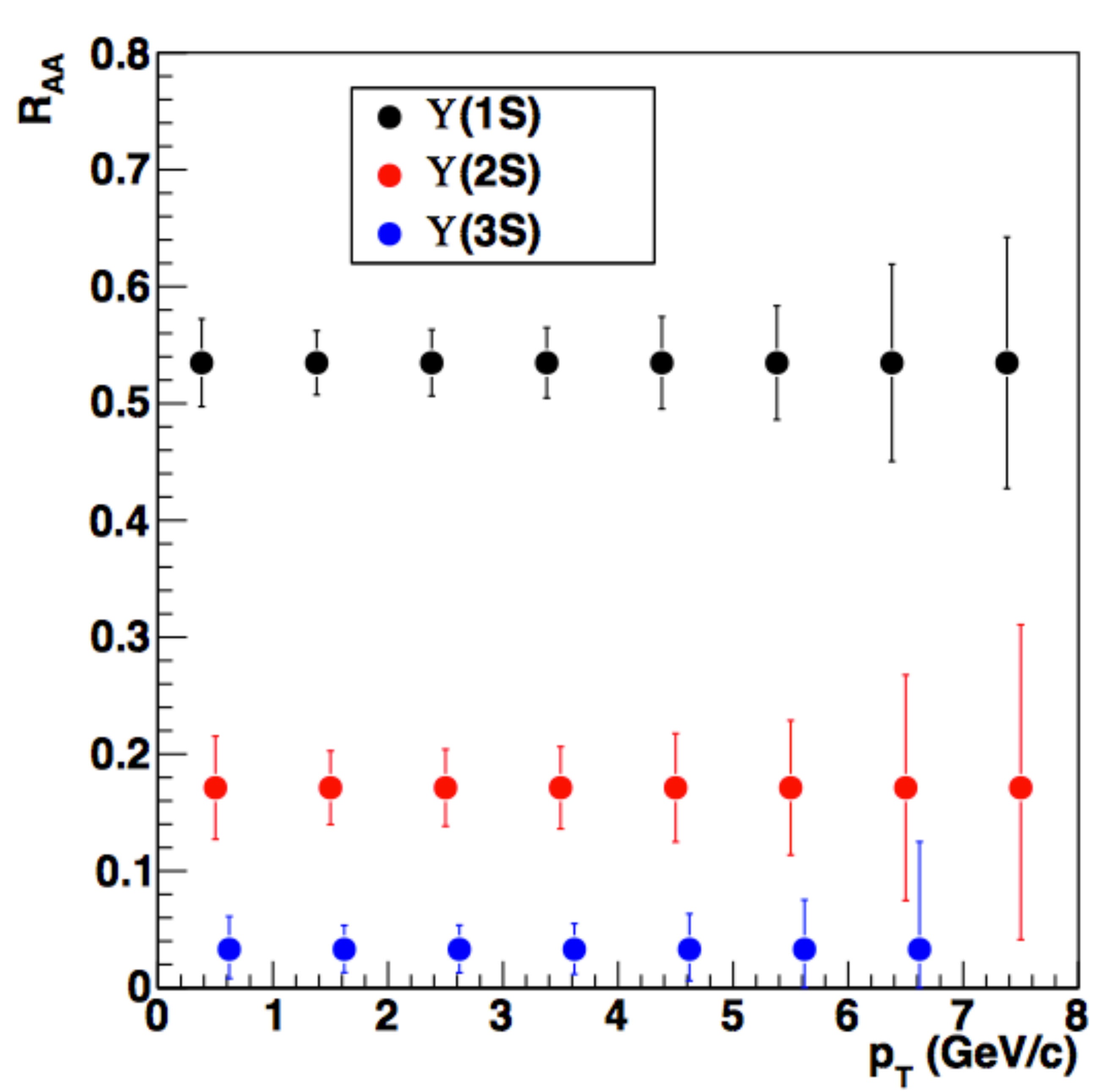
Zhou, Xu, Zhuang arXiv:1309.7520



Strong differences in p_T dependence predicted between RHIC & LHC, and between different Υ states.

Want the maximum possible p_T reach for testing models.

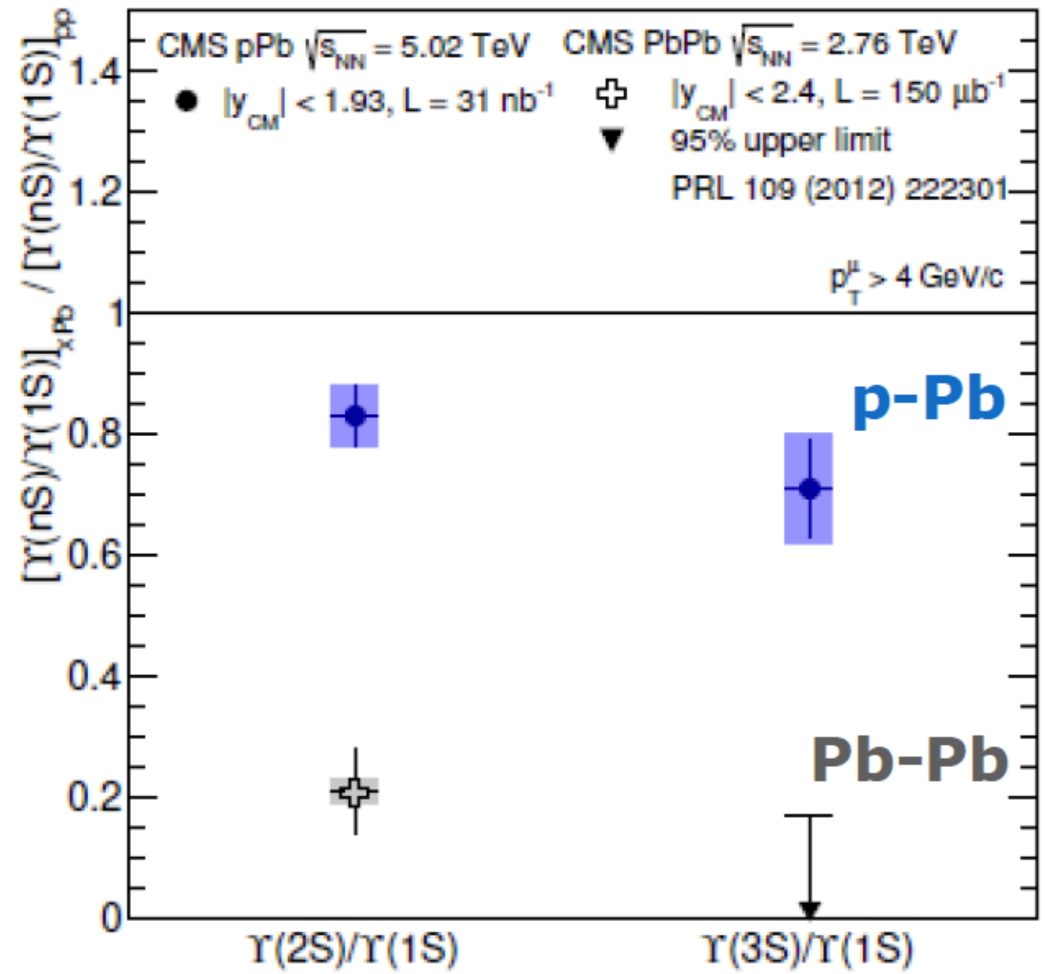




Upsilons in p+A

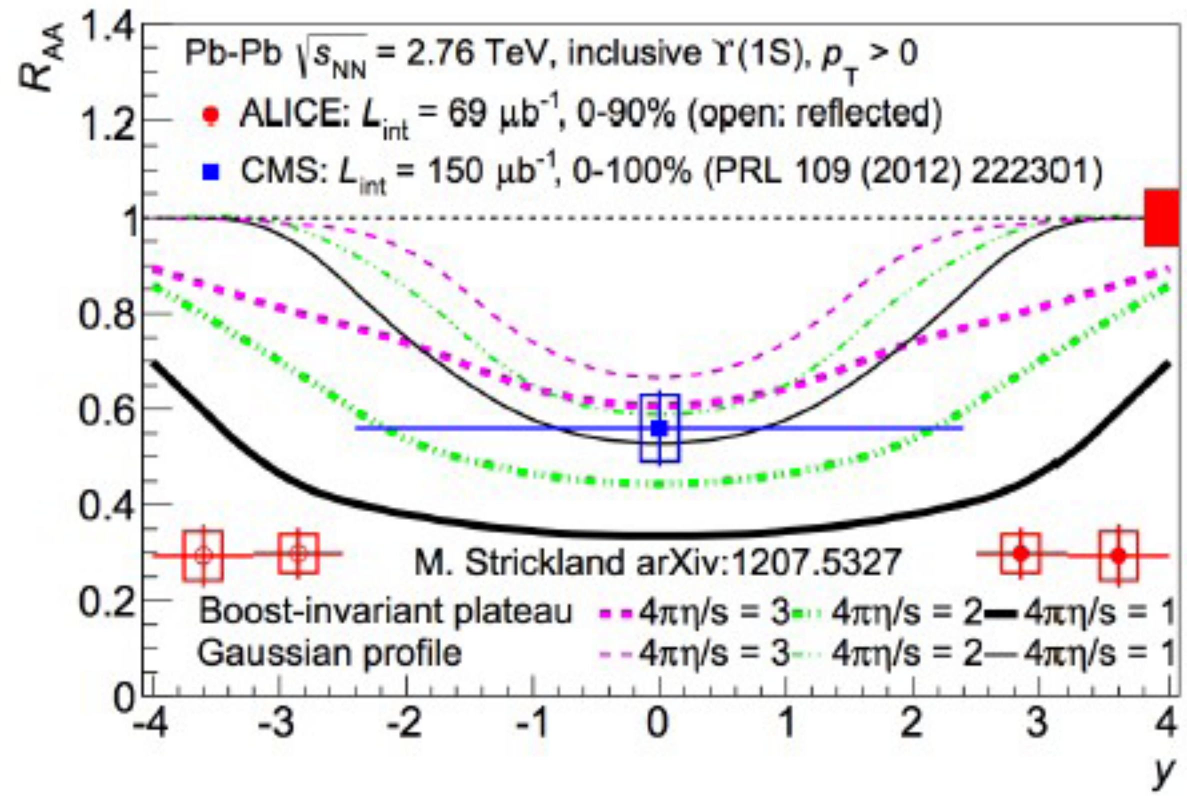
p+Au data is of interest for two reasons:

- The modification in p+A collisions is a necessary input when trying to understand the modification in A +A collisions.
- The physics of quarkonia modification in p+A collisions is interesting in its own right.



Existing pPb Upsilon data from LHC:

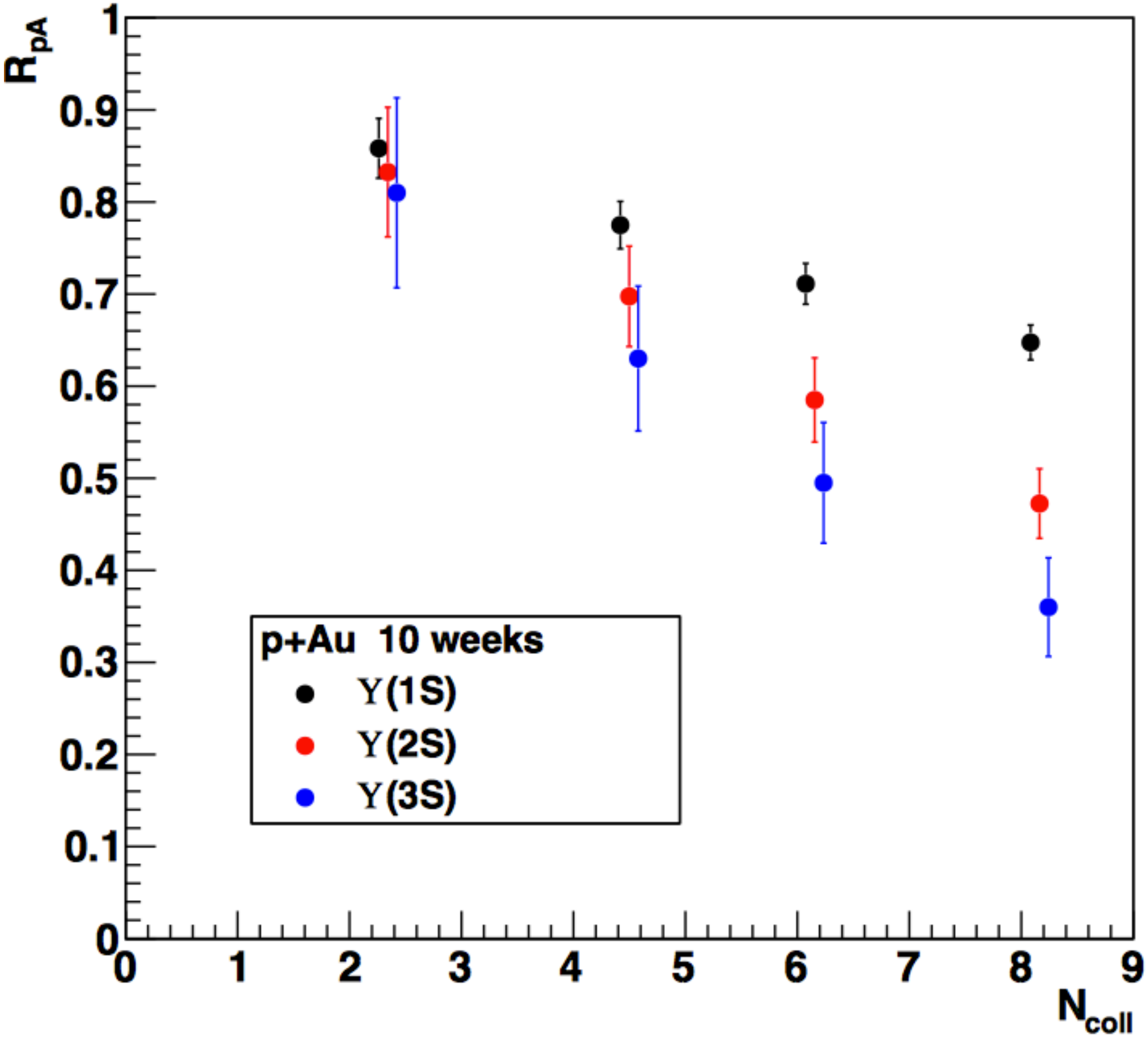
- strong suppression of ϒ(1S)
- differential suppression of ϒ(2S) & ϒ(3S) relative to ϒ(1S)



Should have excellent pPb ϒ data by the end of Run 3 from CMS at midrapidity, and ALICE at forward/ backward rapidity.

Upsilon performance - p+Au

Estimates of the R_{pAu} precision vs N_{coll} from a 10 week p+Au run with sPHENIX.



Summary

The sPHENIX detector will provide a comprehensive set of Upsilon measurements at RHIC by about the end of LHC Run 3.

- Improvements in RHIC luminosity for **p+p** collisions will provide an excellent baseline measurement for all three Υ states in 10 weeks.
- A MB data set of 100 B events is expected from 22 weeks of **Au+Au** collisions, enabling high precision R_{AA} measurements for all three Υ states.
- A 10 week **p+Au** run will provide a high precision cold nuclear matter baseline for the AuAu data.

This high precision Υ data set at 200 GeV/A collision energy will, when combined with the very precise data set from the LHC, strongly constrain theoretical models of the interaction between the Υ states and the medium.

Backups

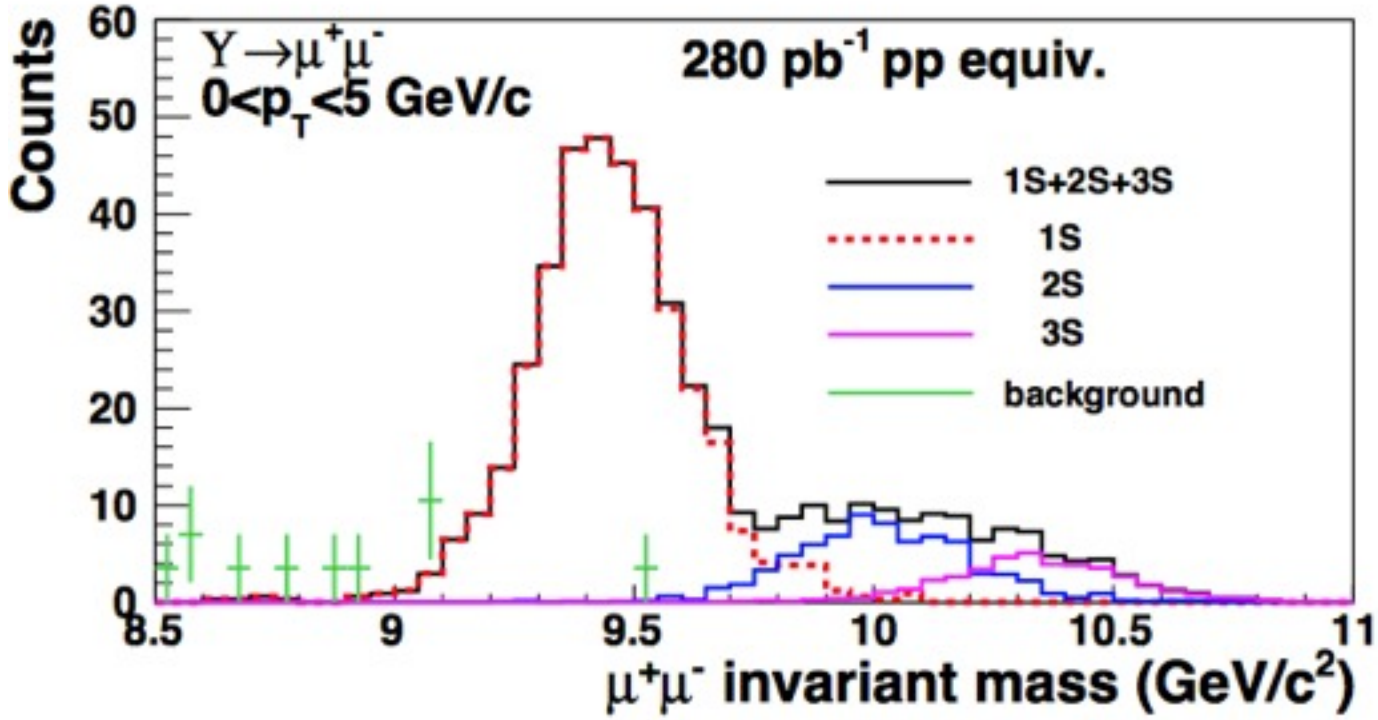
sPHENIX Tracking configuration

Layer	radius (cm)	sensor pitch (μm)	sensor length (mm)	sensor depth (μm)	total thickness % X_0	area m^2
1	2.7	50	0.425	200	1.3	0.034
2	4.6	50	0.425	200	1.3	0.059
3	9.5	60	8	320	1.35	0.152
4	10.5	240	2	320	1.35	0.185
5	44.5	60	8	320	1	3.3
6	45.5	240	2	320	1	3.5
7	80.0	60	8	320	2	10.8

Upsilon yield estimates

Species	weeks	Lum. sampled or recorded	eID efficiency	Trigger efficiency	Υ(1S)	Υ(2S)	Υ(3S)
p+p	10	175 pb^{-1}	0.9	0.98	8770	2205	1155
Au+Au 0-10%	22	100 B MB events	0.49	1.0	5625	1415	740
p+Au 0-20%	10	1200 nb^{-1}	0.8	0.9	2950	740	388

STAR MTD performance



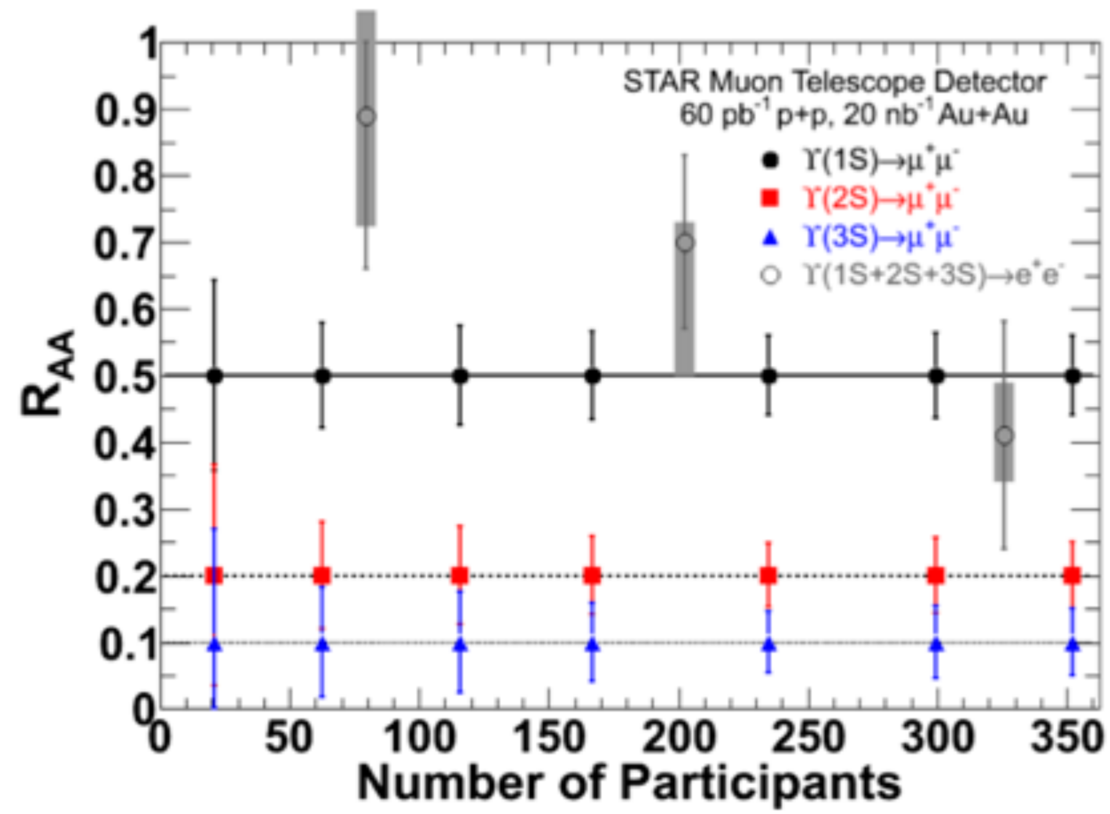


Table 2. The Υ statistics estimation for different collision systems at RHIC-II era. Deli. Lumi.: delivered luminosity in 12 weeks in 2013. Samp. Lumi.: sampled luminosity in 12 weeks in 2013. According to the efficiency of STAR, we use 70% as the estimation. Min. Lumi.: required sampled luminosity with 10% precision on $\Upsilon(3S)$ state. Min. Lumi.II: required sampled luminosity with 10% precision on $\Upsilon(2S+3S)$ measurement.

collision system	Deli. Lumi.	Samp. Lumi.	Υ counts	Min. Lumi.	Min. Lumi.II
200 GeV p+p	480 pb^{-1}	336 pb^{-1}	930	420 pb^{-1}	150 pb^{-1}
200 GeV p+p	200 pb^{-1}	140 pb^{-1}	390		
500 GeV p+p	1200 pb^{-1}	840 pb^{-1}	6970	140 pb^{-1}	50 pb^{-1}
200 GeV Au+Au	22 nb^{-1}	16 nb^{-1}	1770	10 nb^{-1}	3.8 nb^{-1}