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U.S. DEPARTMENT OF ENERGY

Current research at BNL: J/ψ at RHIC

Rongrong Ma
Physics Department

Decades of Discovery at Brookhaven National Laboratory

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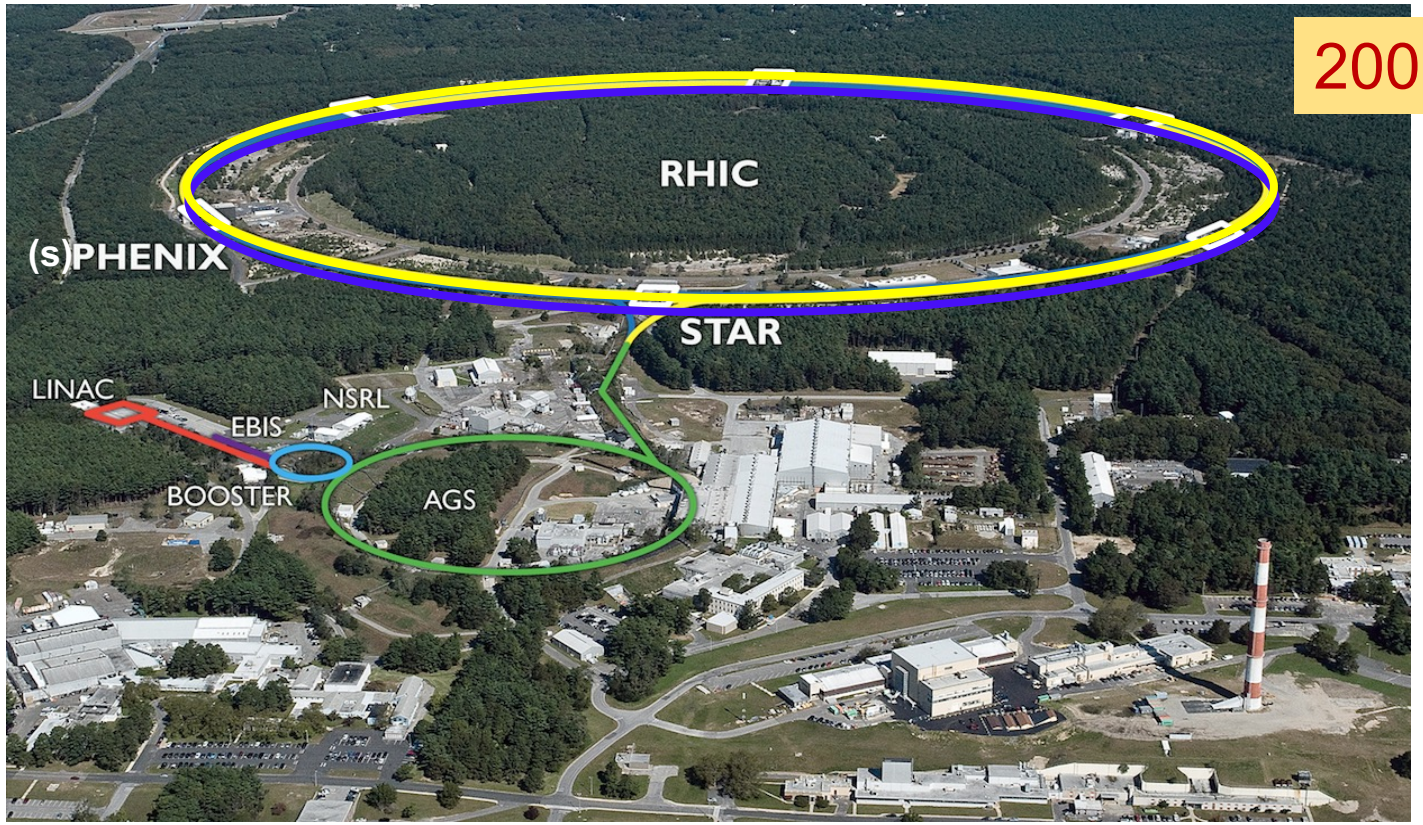
Relativistic Heavy Ion Collider (RHIC)



2000 - present

Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV
(99.995% of speed of light)

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Quark-Gluon Plasma (QGP)

- A novel state of matter made of deconfined quarks and gluons which are ordinarily confined within hadrons

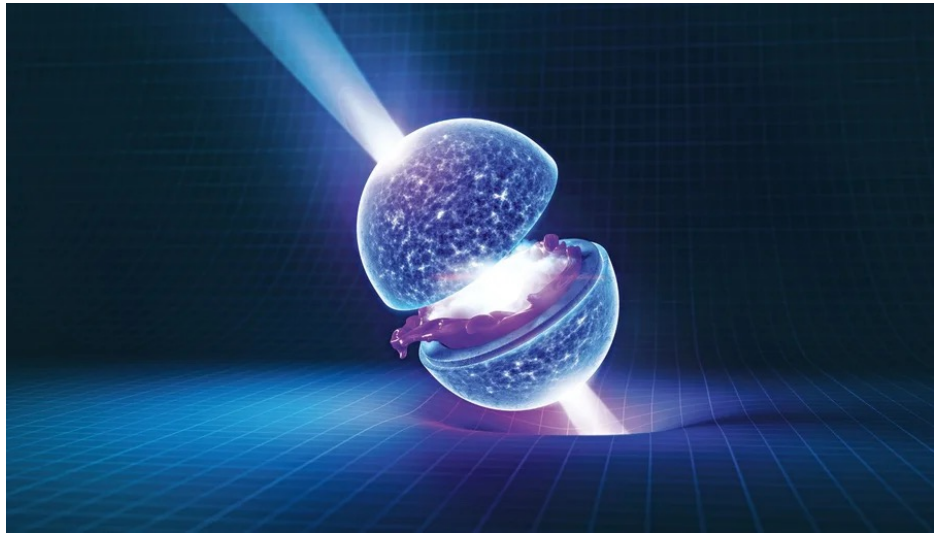
https://today.uic.edu/collider-reveals-sharp-change-from-quark-soup-to-atoms

Why study QGP?

- Understand properties of QCD matter under extreme conditions, such as high temperature or high density

Early Universe

Neutron star

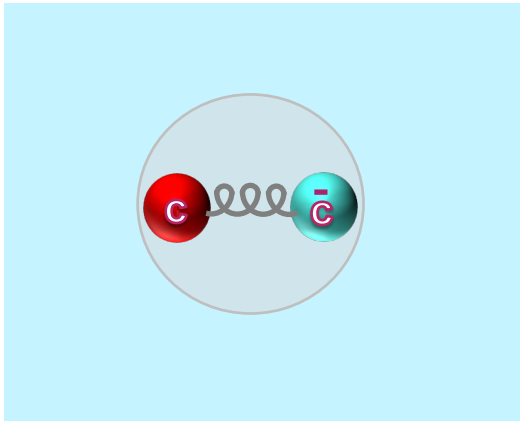


https://www.newscientist.com/article/mg22429991-000-how-to-think-about-the-big-bang
https://www.scientificamerican.com/article/neutron-stars-natures-weirdest-form-of-matter

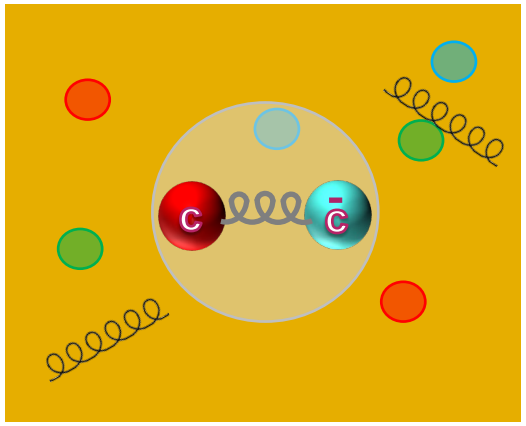
How to study QGP?

- **The J/ψ particle**
- Produced in Au+Au collisions before QGP is formed
- Can dissociate or "melt" in the QGP → Signature of QGP formation

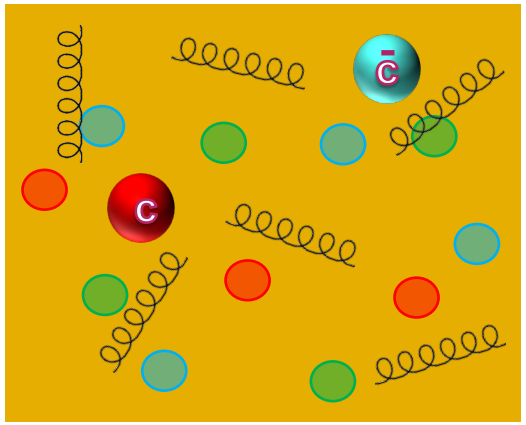
Vacuum



Low temperature
Low density



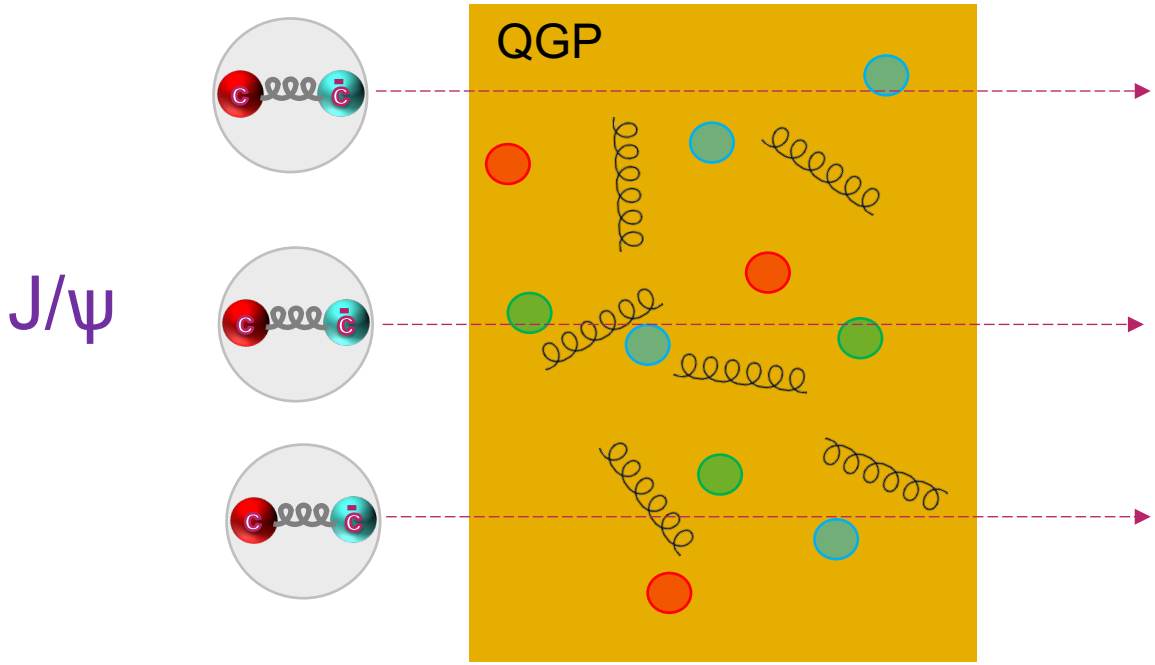
High temperature
High density



T. Matsui and H. Satz , PLB 178 (1986) 416

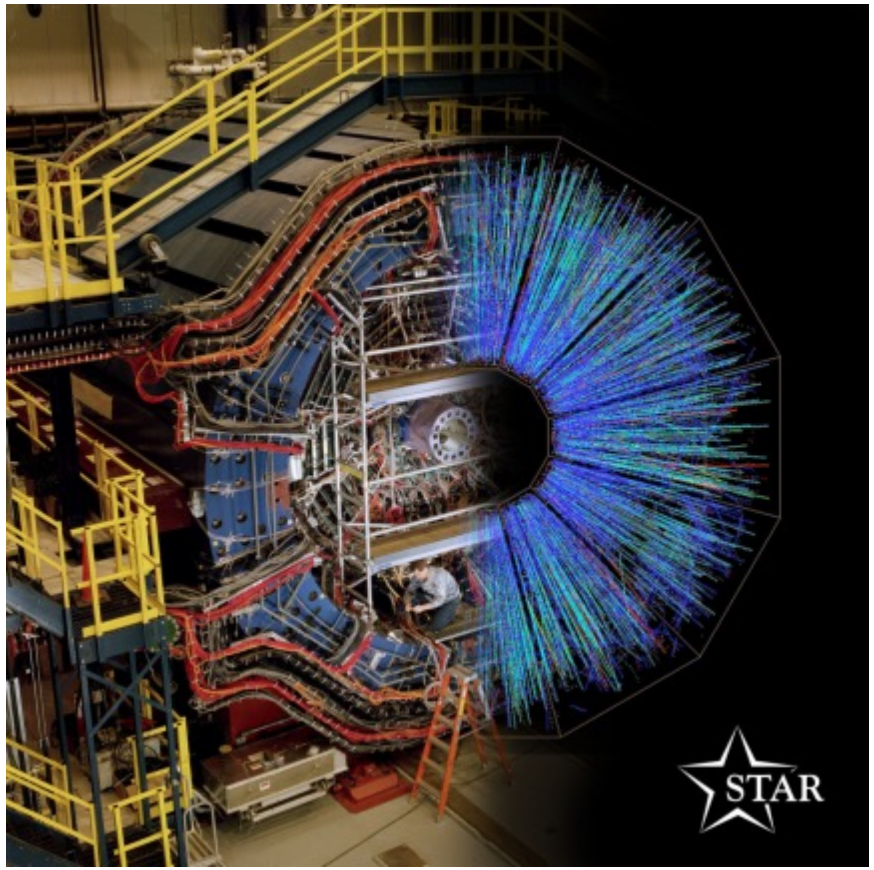
A counting experiment

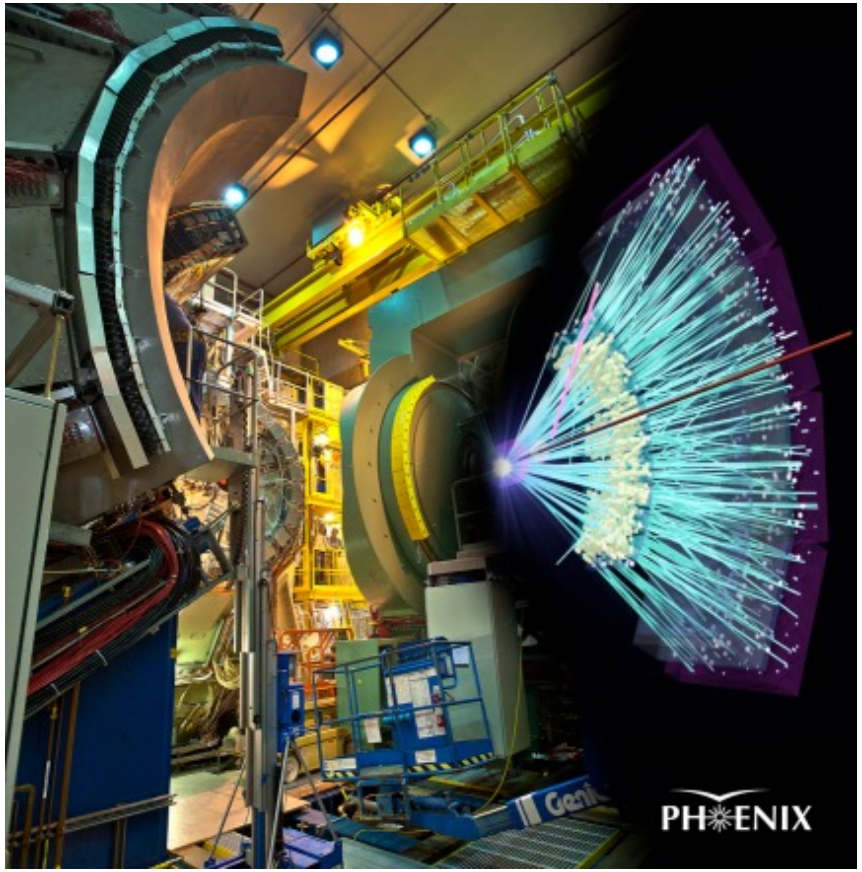
- Experimentally, one expects a reduced production yield



How many J/ψ's survive?

RHIC detectors





Nuclear Modification Factor (R_{AA})

- Quantify the level of J/ψ suppression in Au+Au collisions

$$R_{AA} = \frac{\text{J/ψ yield after going through QGP}}{\text{J/ψ yield before going through QGP}}$$

$$= \frac{\text{J/ψ yield in Au+Au collisions}}{\text{J/ψ yield in p+p collisions (scaled)}}$$

R_{AA} < 1: suppression

R_{AA} > 1: enhancement

Cold Nuclear Matter (CNM) effect

- Modifications to J/ψ production yield due to the presence of ions in the collisions, but not related to QGP formation
- Quantified via the ratio of p/d+Au to p+p

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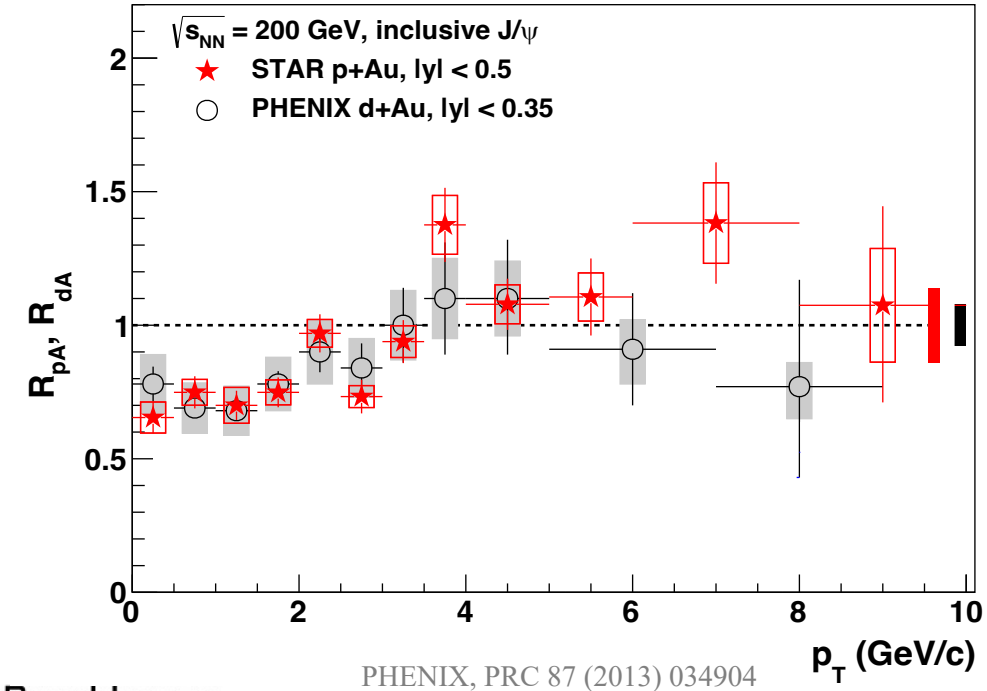

PHENIX, PRC 87 (2013) 034904
STAR, PLB 825 (2022) 136865

- ~30% suppression at low transverse momentum p_T
- Consistent with no suppression above ~ 3 GeV/c

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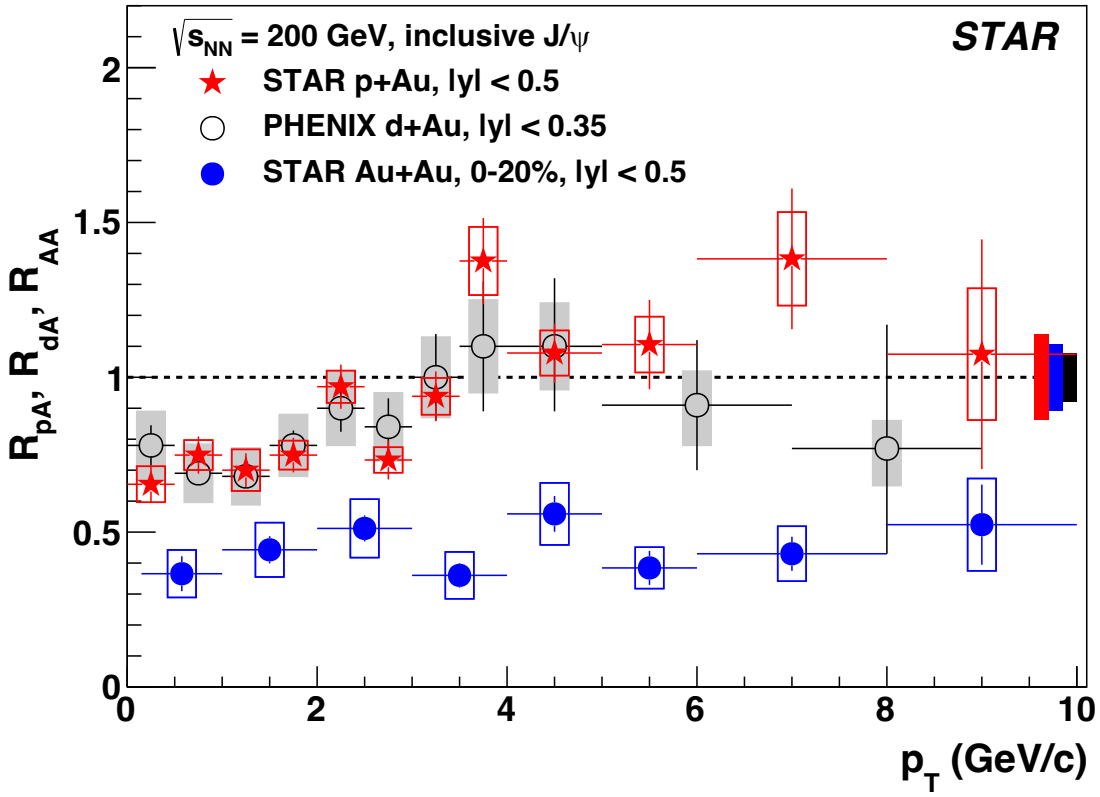
J/ψ dissociation



PHENIX, PRC 87 (2013) 034904
STAR, PLB 825 (2022) 136865
STAR, PLB 797 (2019) 134917

- Observed a factor 2-3 suppression of J/ψ production in heavy-ion collisions beyond CNM effects → evidence of QGP formation

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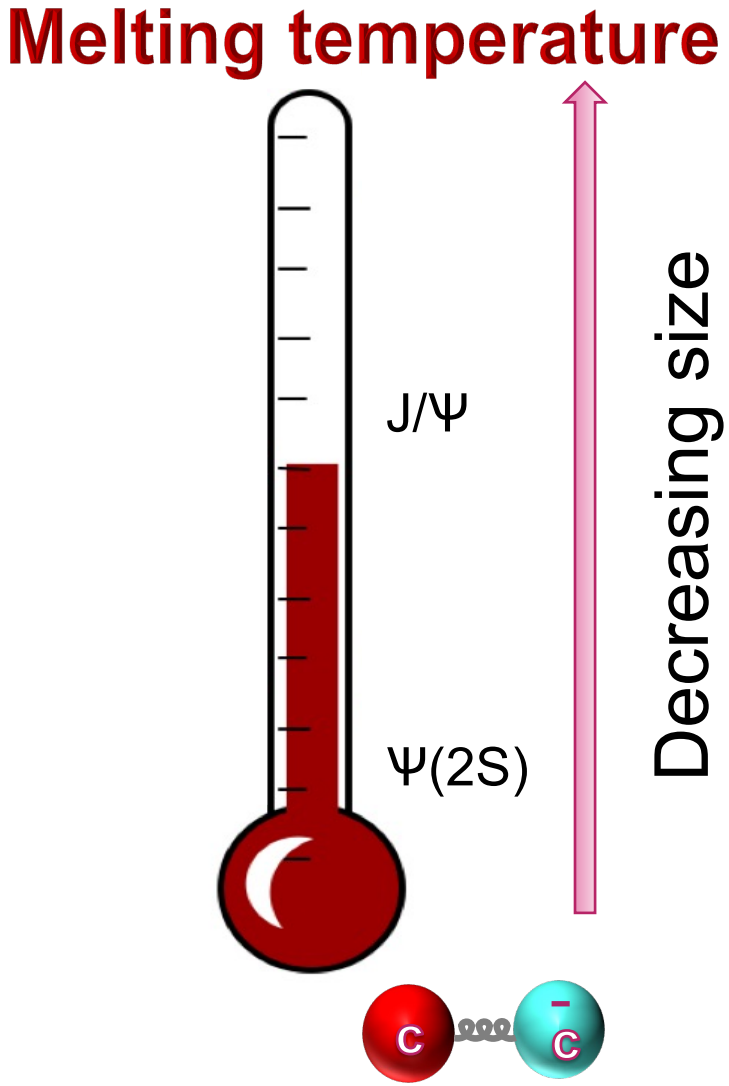
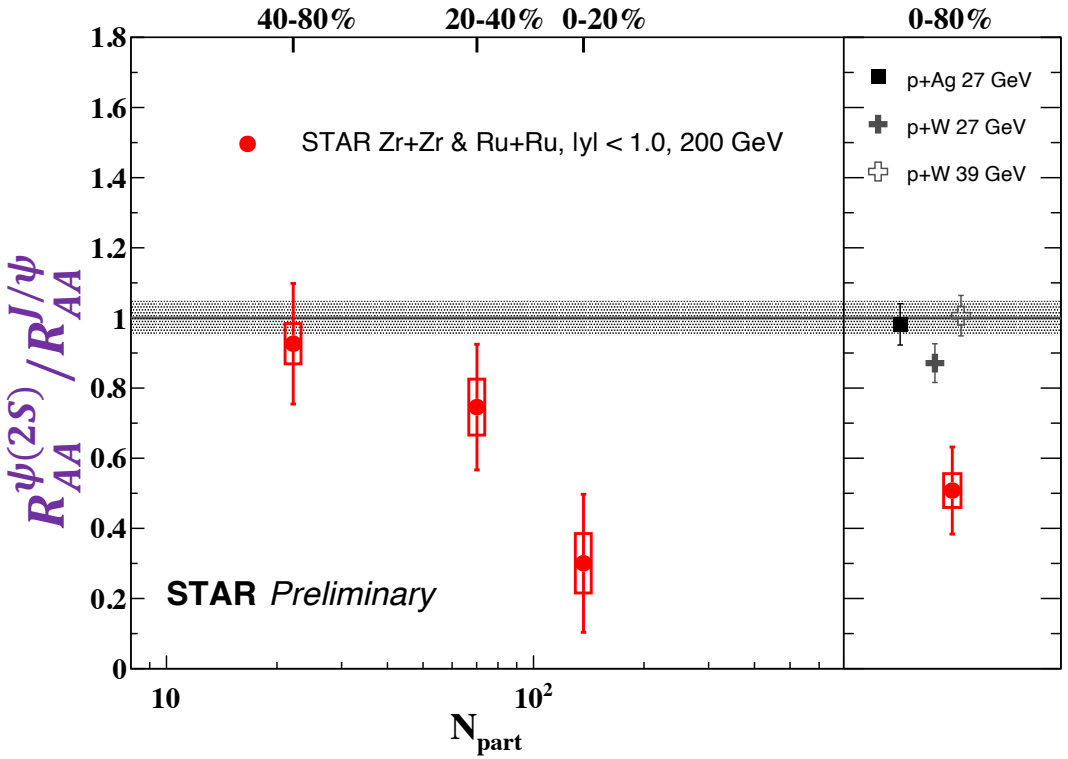
QGP “thermometer”

- For QGP of a given temperature profile, charmonia of larger sizes melt more easily



Charmonia sequential suppression

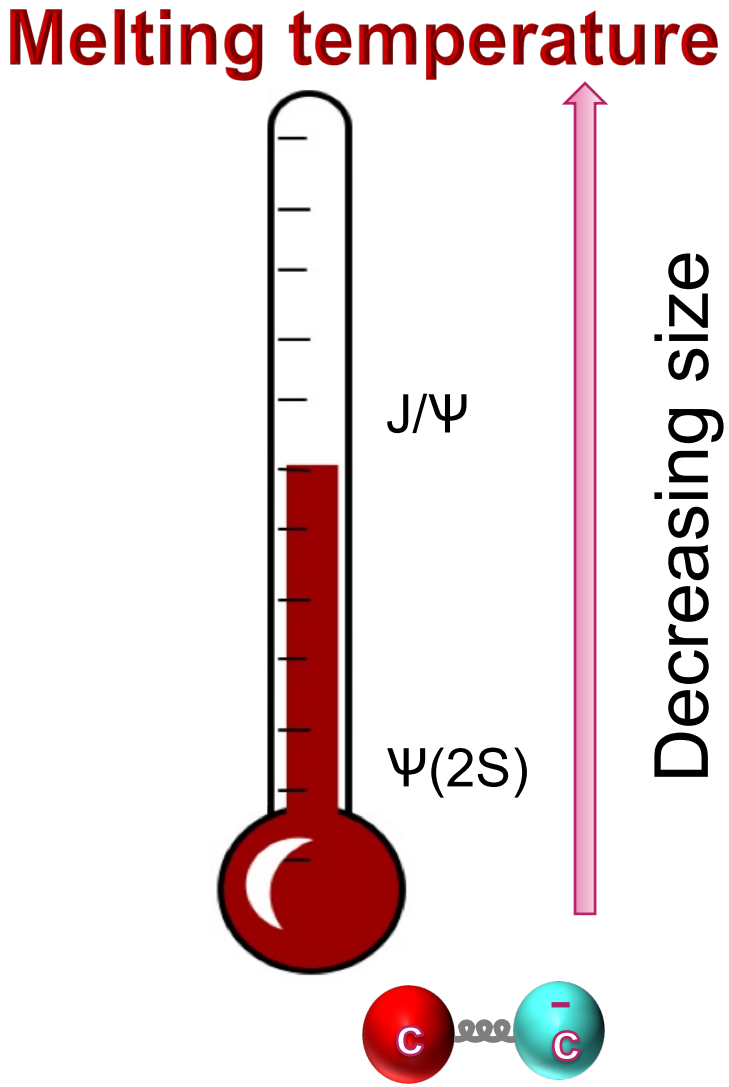


- The larger ψ(2S) is more suppressed than the smaller J/ψ

QGP “thermometer”

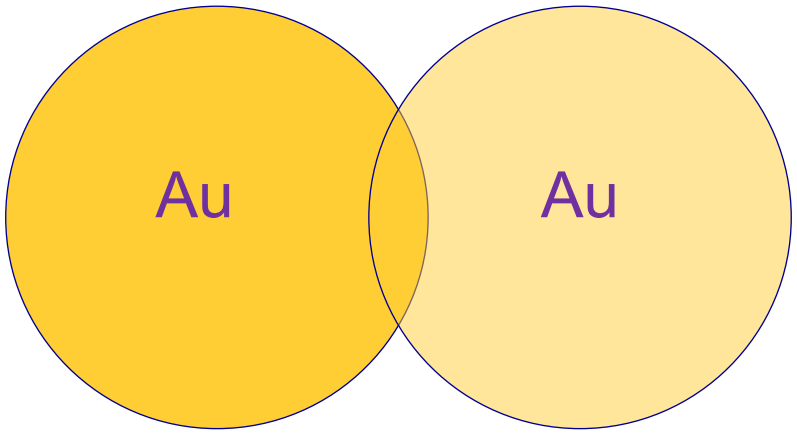
- For QGP of a given temperature profile, charmonia of larger sizes melt more easily

- For J/ψ, it melts more easily with increasing temperature

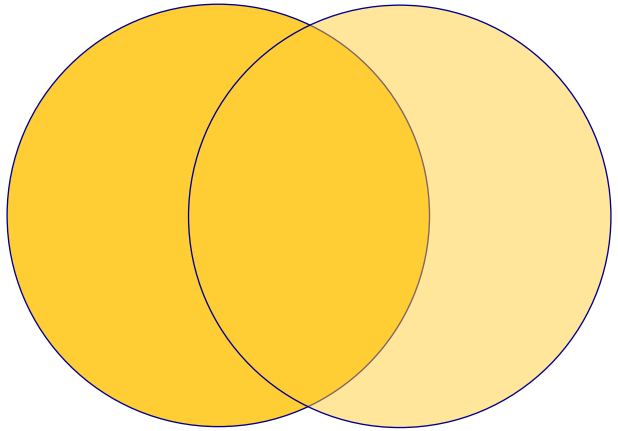


How to change QGP temperature?

Peripheral

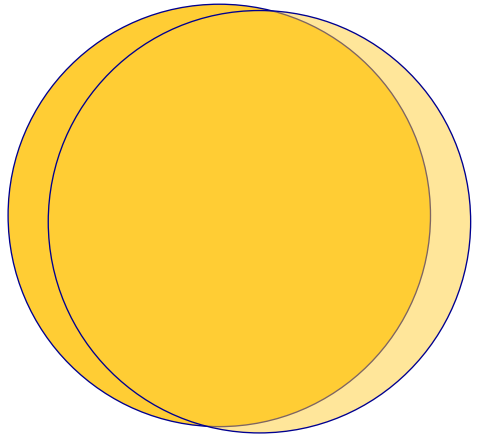


Low temperature



Mid temperature

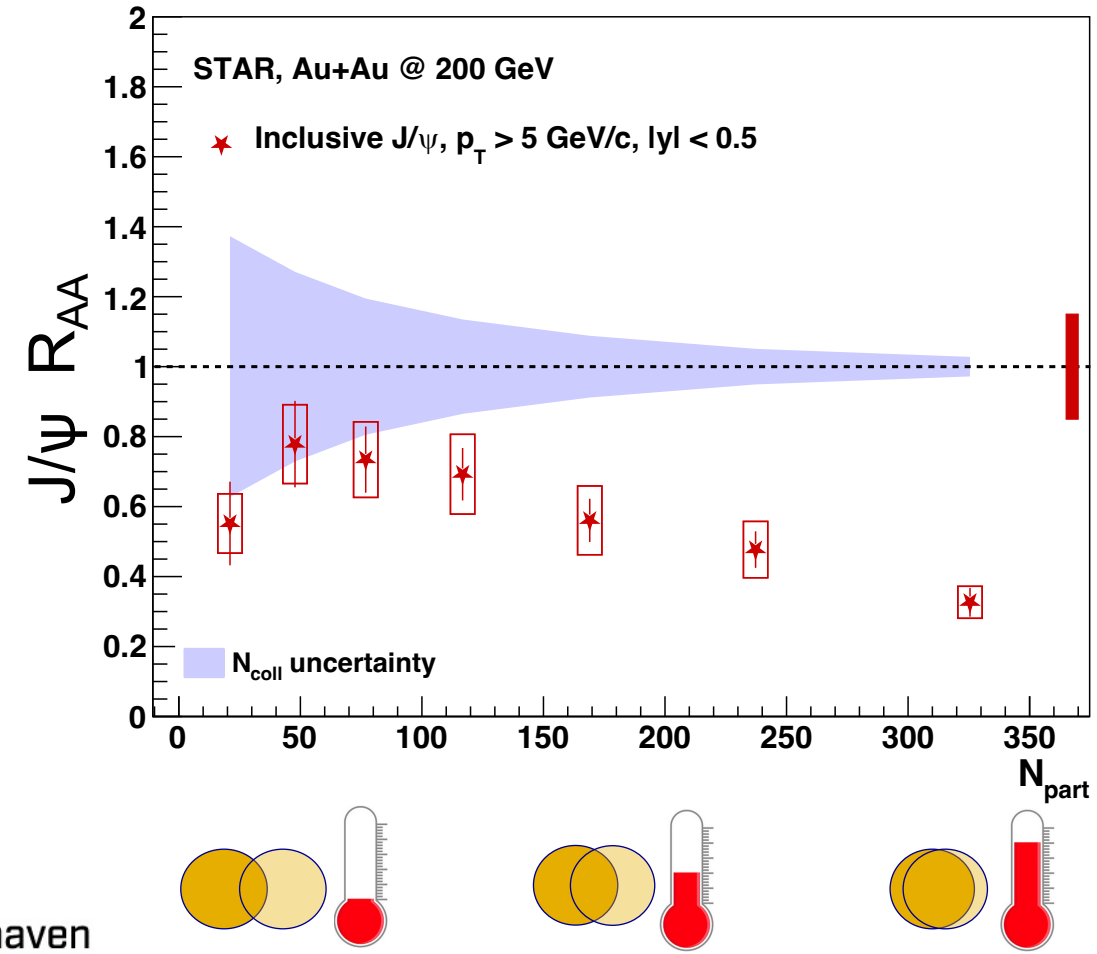
Head-on



High temperature

J/ψ suppression vs. “temperature”

STAR, PLB 797 (2019) 134917



✓ Higher temperature
→ larger suppression

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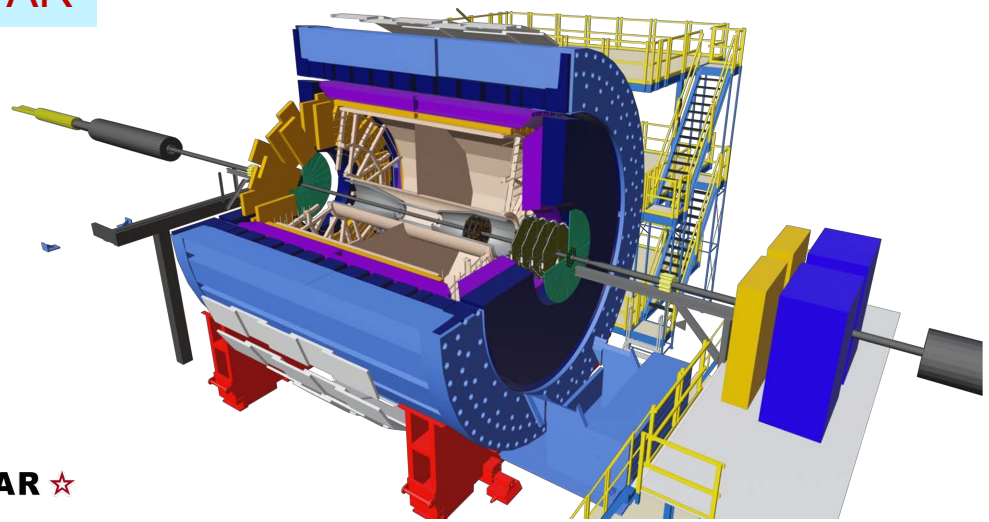
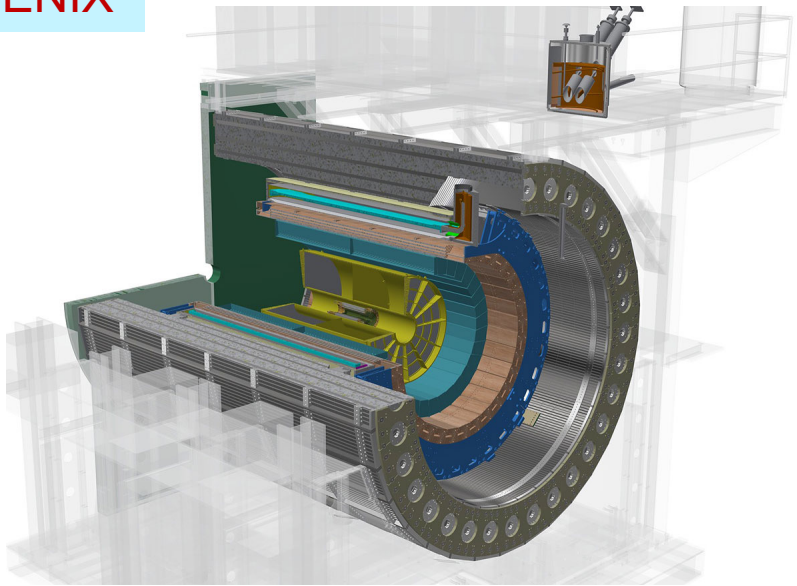
Near-future measurements

- Unprecedented statistics (Au+Au, p+p) to be collected at RHIC in 2023-2025 with new detector capabilities
  - J/ψ flow, spin alignment, etc.

STAR



sPHENIX



Summary

The J/ψ meson has played a pivotal role in RHIC's physics program since its inception

- ✓ J/ψ yield suppression → QGP formation
- ✓ Charmonia sequential suppression → QGP properties

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With anticipated statistics enhancement and new detector capability, J/ψ at RHIC will continue to shed new lights on our understanding of QCD under extreme conditions