Brookhaven National Laboratory

Summary: Quark Matter and High Energy Heavy Ion Collisions

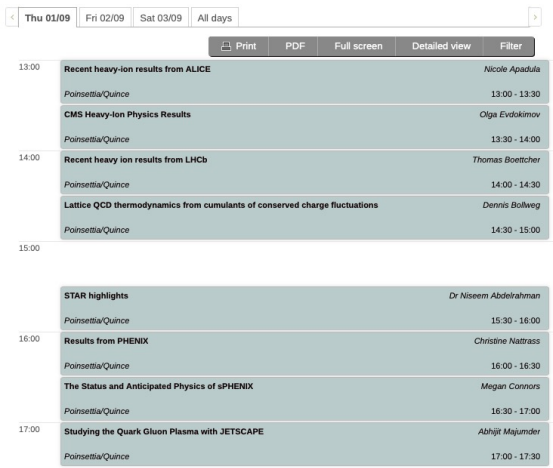
Rongrong Ma

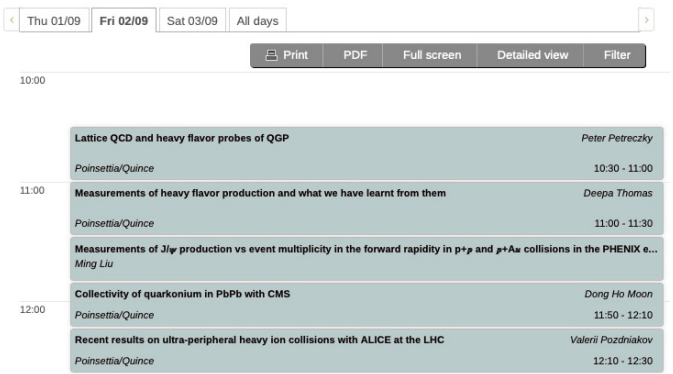
Brookhaven National Laboratory

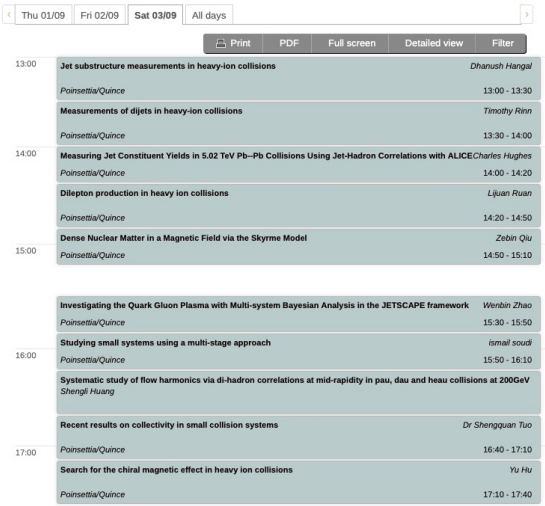
14th Conference on the Intersections of Particle and Nuclear Physics (CIPANP 2022)

Heavy-ion sessions

- Conveners:
  - Alexei Bazavov (MSU)
  - Anne Sickles (UIUC)
  - Rongrong Ma (BNL)



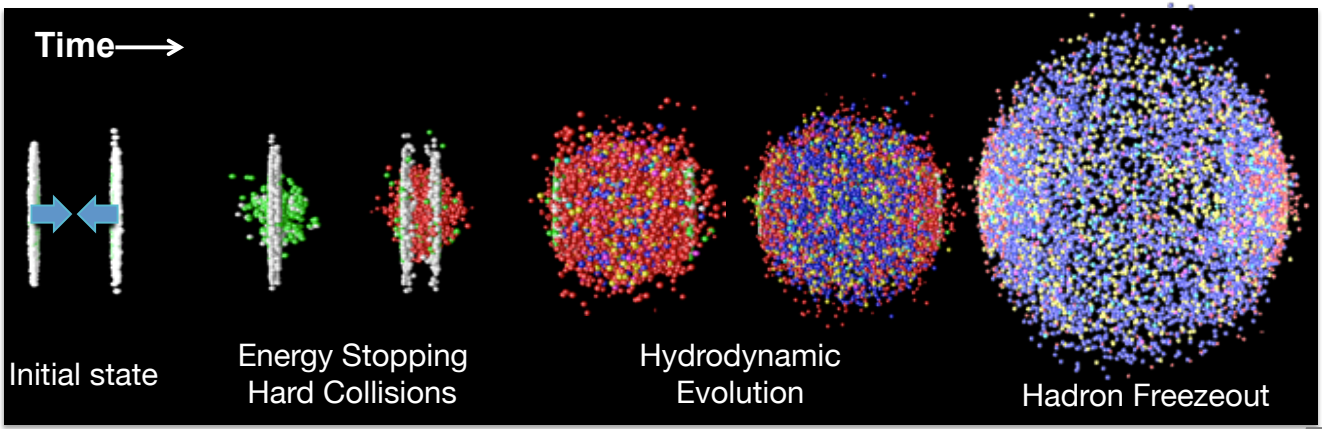




5 sessions, 22 talks

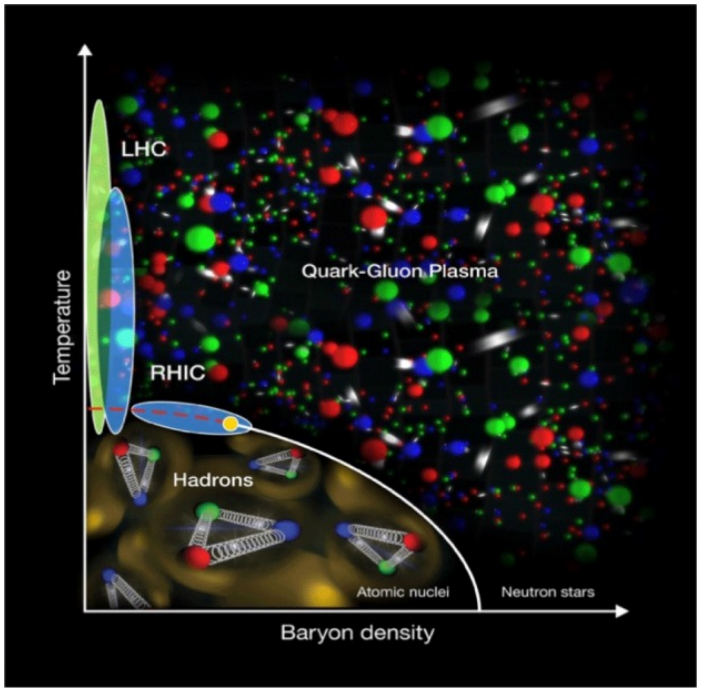
Heavy-ion collisions & QGP

- Quark gluon plasma (QGP): a state of matter consisting of deconfined quarks and gluons
  - Believed to have existed momentarily after the Big Bang
- Can be created in relativistic heavy-ion collisions.



T. Nayak, arXiv:1201.4264

Main goals of heavy-ion physics

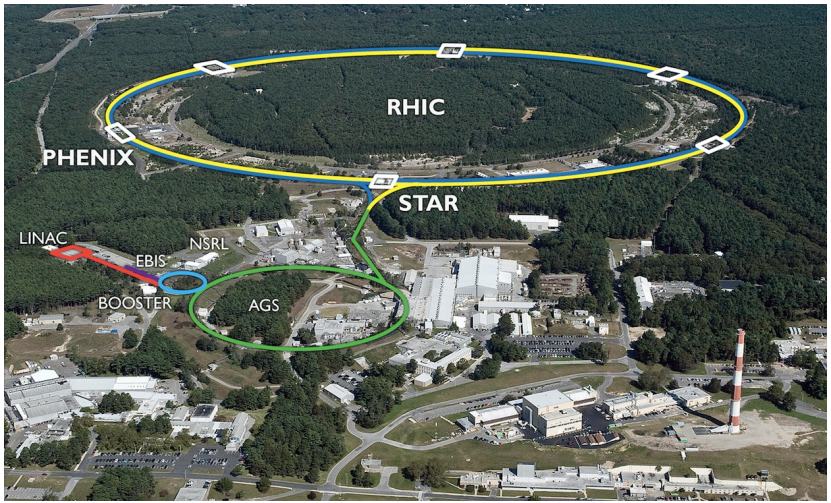


- Characterize and understand the properties of the QGP
  - How do they come about?
- Map out the phase diagram and search for the possible critical endpoint
- Multi-messenger approach

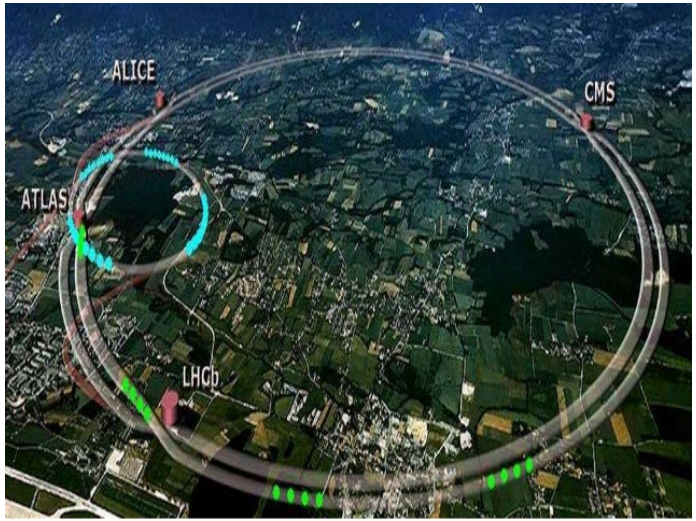
https://gdrqcd.in2p3.fr/working-group-2/

Major facilities

RHIC
(2000 -)



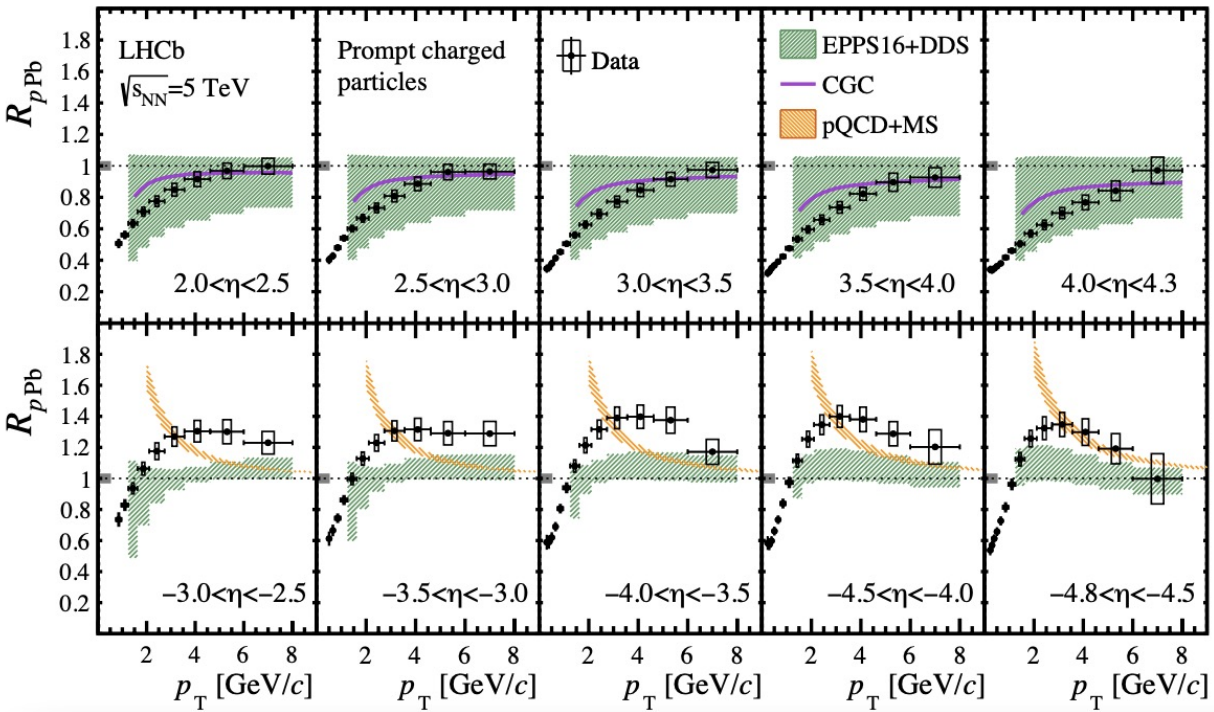
LHC
(2009 -)



**PHENIX completed operation in 2016*

Charged particle production in p+Pb

T. Boettcher (Thu. 14:00)



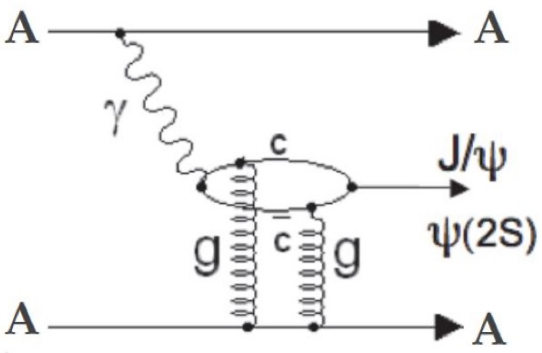
- x <~10^{-5}, Q^2 <~ 1 GeV^2
- Significant suppression at forward rapidity
- Enhancement at backward rapidity, not explained by nPDF
- Good precision to constrain nPDF

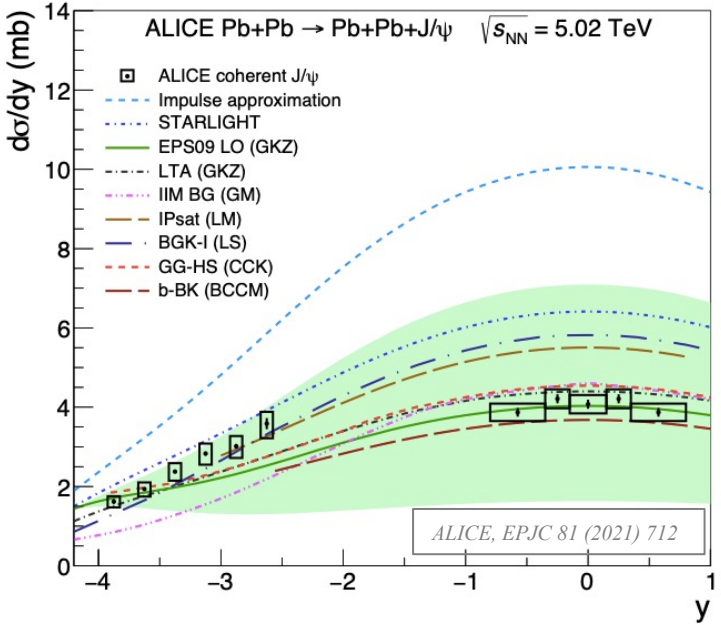
LHCb, PRL 128 (2022) 14

Coherent J/ψ production in UPC

V. Pozdnyakov (Fri. 12:10)

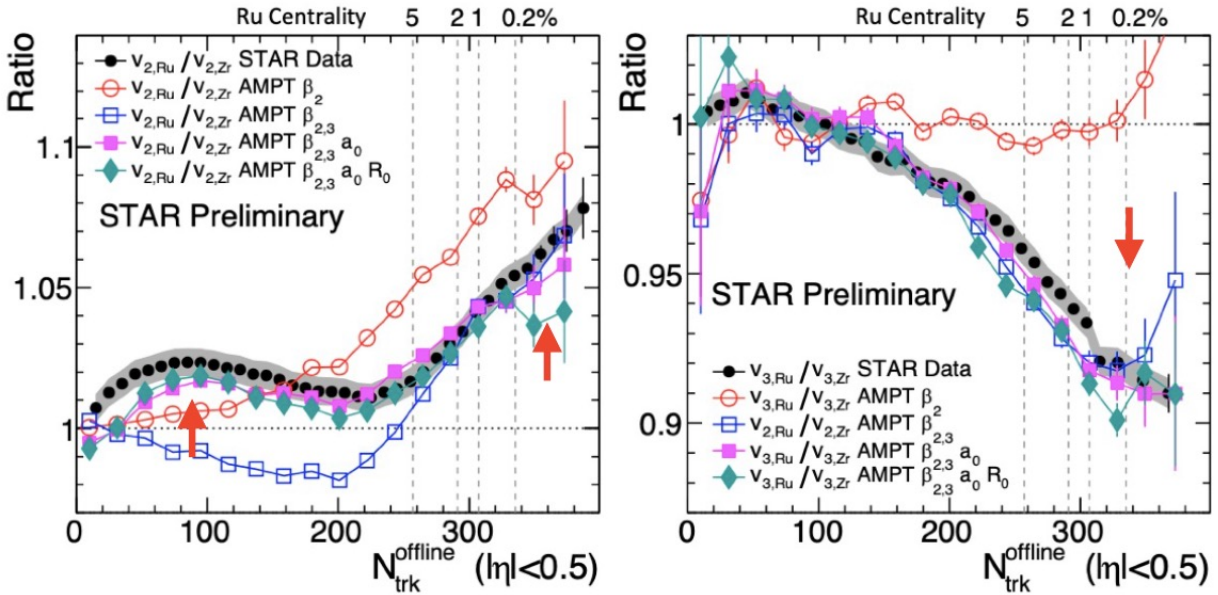
Ultra Peripheral Collisions
b > 2R

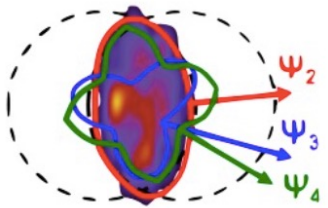




- The nuclear gluon shadowing factor is found to be ~ 0.65 at x values ~10^{-3}

Probe nuclear deformation at high energy

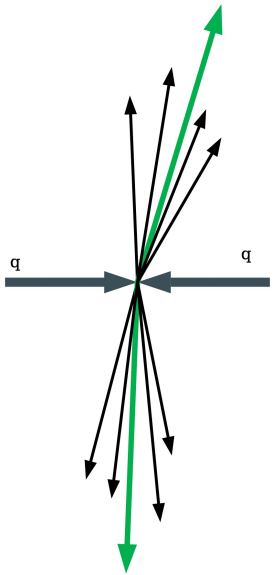




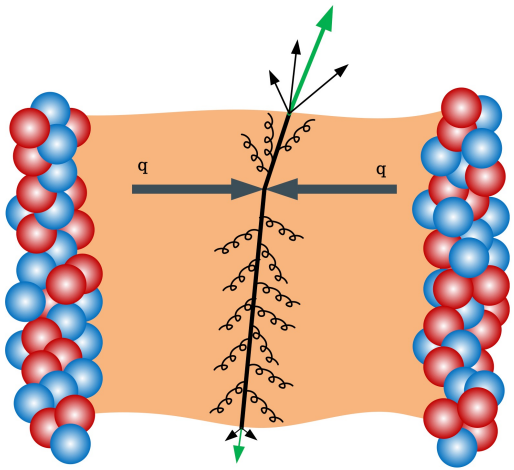
N. Abdelrahman (Thu. 15:30)

- Ratios show non-monotonic trends
- Based on AMPT model, one extract $\beta_{2,Ru} = 0.16 \pm 0.02$, $\beta_{3,Zr} = 0.20 \pm 0.02$

Jet quenching



p+p

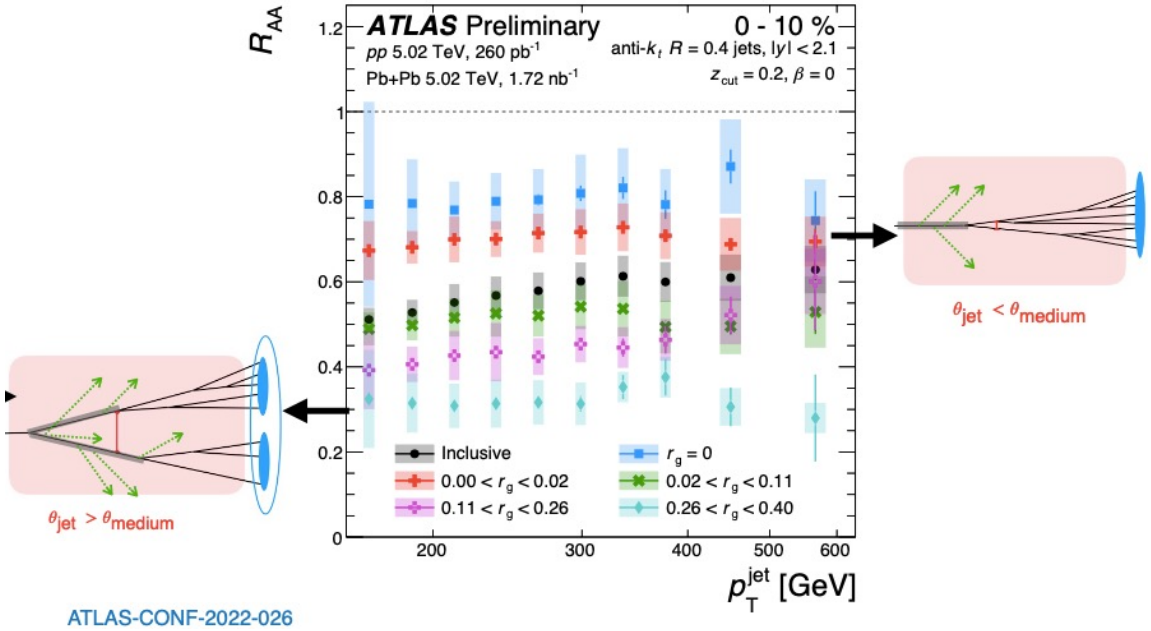


A+A

$$R_{AA} = \frac{1}{\langle N_{\mathrm{coll}} \rangle} \frac{\mathrm{d}N_{AA}/\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}N_{pp}/\mathrm{d}p_{\mathrm{T}}}$$

- ✓ $R_{AA} = 1$: no medium effect
- ✓ $R_{AA} < 1$: energy loss

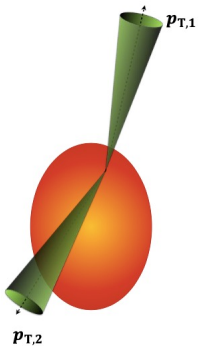
Coherence dependence of jet energy loss

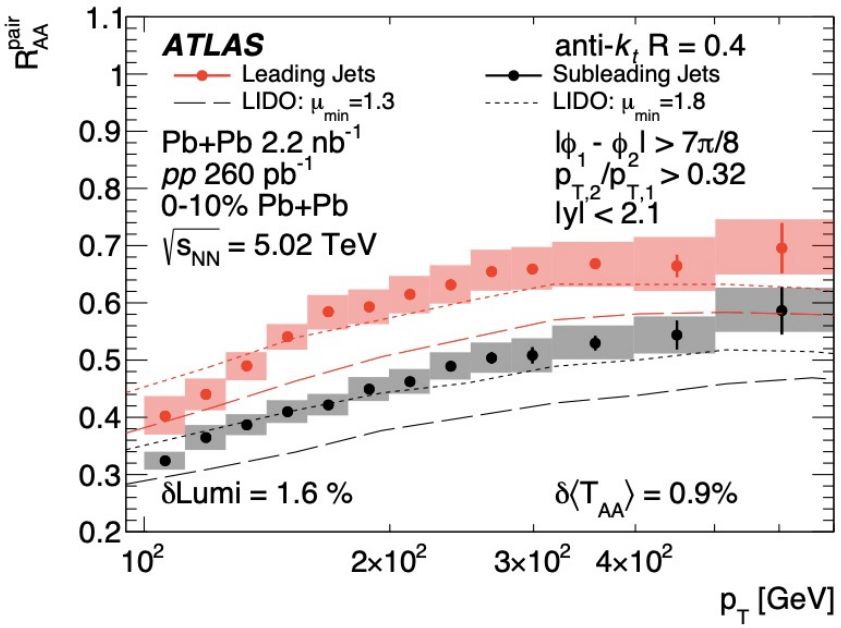


D. Hangal (Sat. 13:00)

- Jets that can be resolved by the QGP lose more energy

Pathlength dependence



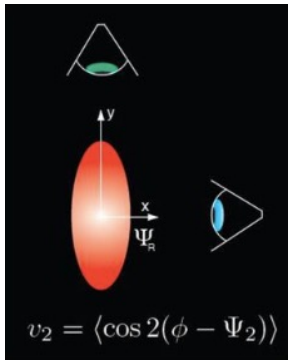


T. Rinn (Sat. 13:30)

- Jets traversing longer pathlength lose more energy

Prompt and non-prompt J/ψ v_2

D. Moon (Fri. 11:50)



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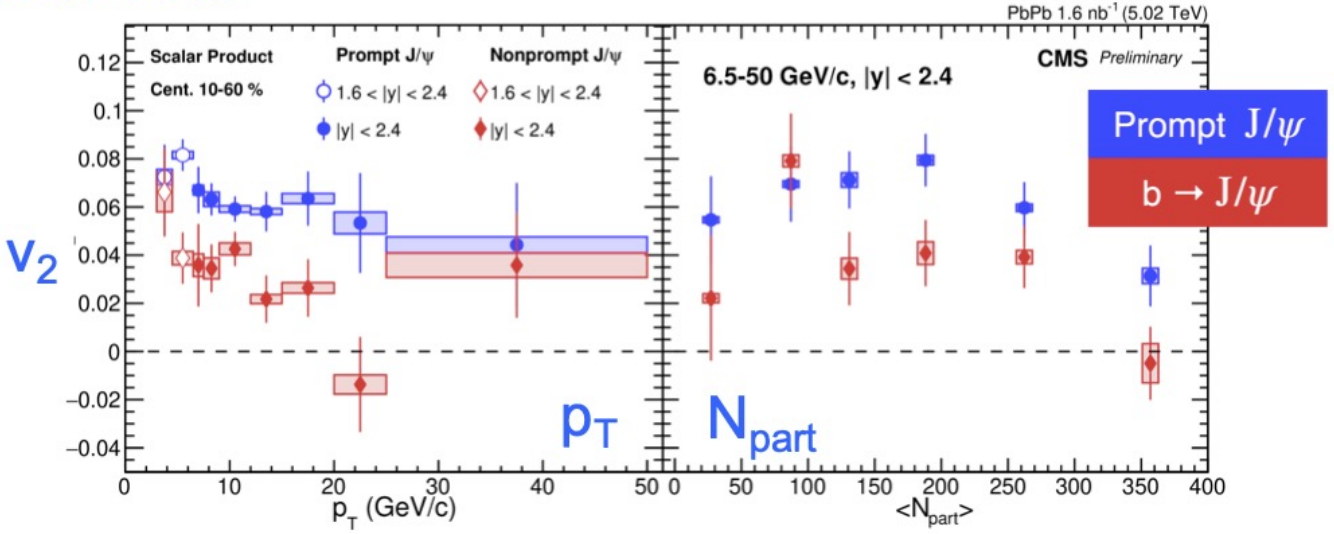
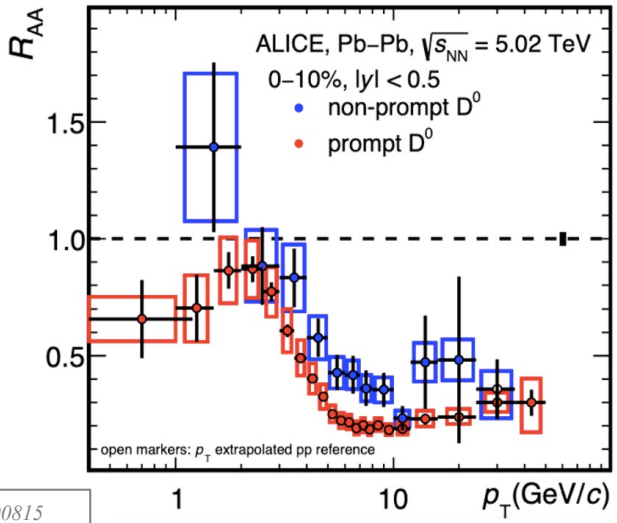


- Sizable v_2 up to 50 GeV/c, due to pathlength dependence of parton energy loss
- Large fraction of prompt J/ψ coming from gluon fragmentation, which loses energy before fragmenting

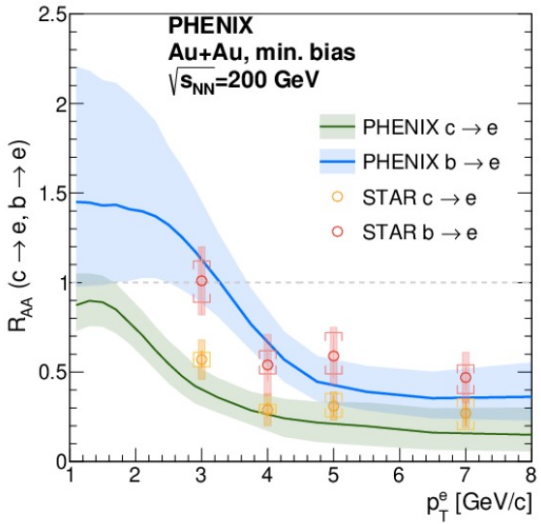
Mass dependent energy loss

- Expectation: $\Delta E_c > \Delta E_b$

N. Apadula (Thu. 13:00)



ALICE, arXiv:2202.00815



C. Nattrass (Thu. 16:00)

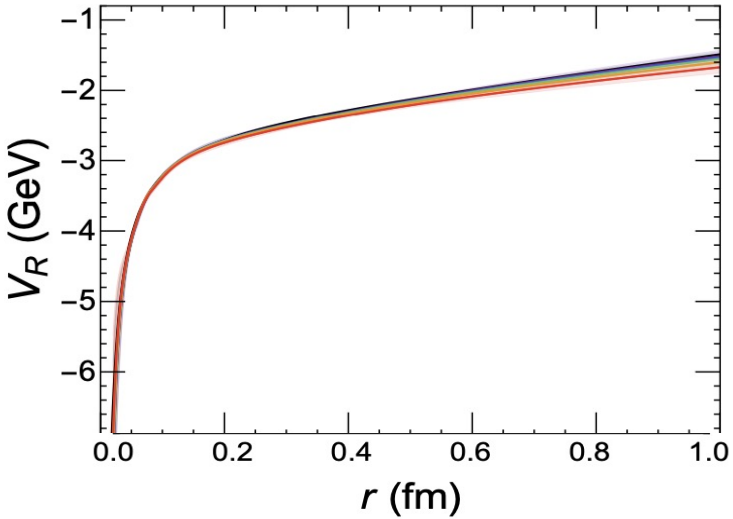
PHENIX, arXiv:2203.17058

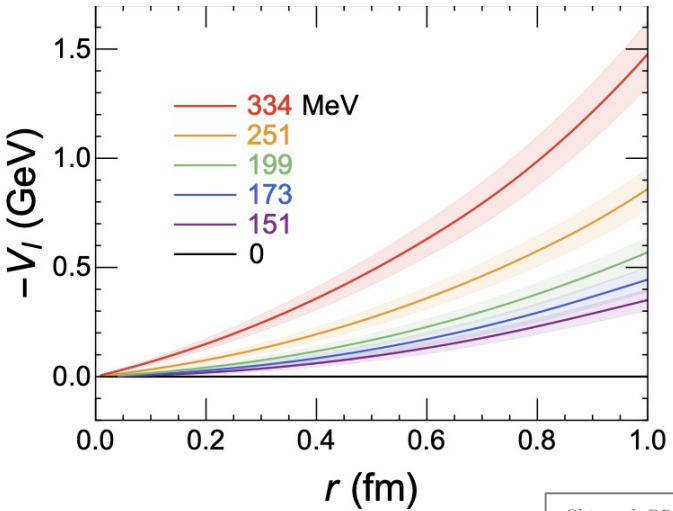
- Charm quarks lose more energy than bottom quarks

Quarkonia - QGP "thermometer"

- Quarkonia of different binding energies melt at different temperatures in the QGP

P. Petreczky (Fri. 10:30)

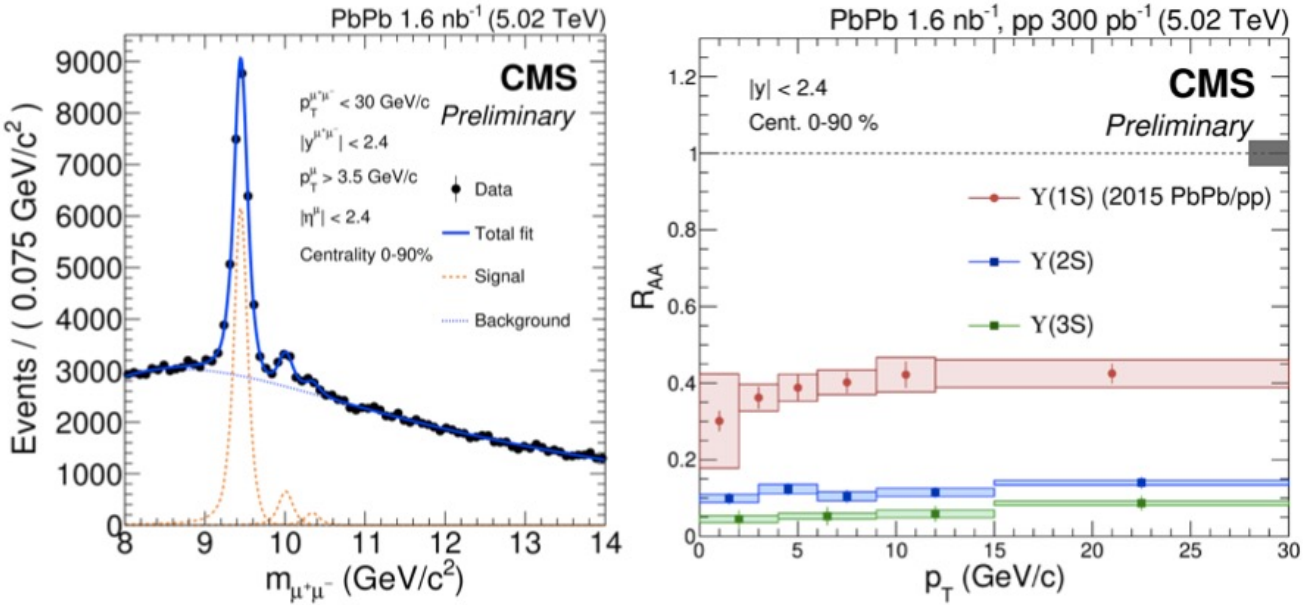




Shi et al, PRD 105 (2022) 014017

- Imaginary part of potential lead to melting
- $T_{\rm melt}(\Upsilon(1S)) > 500$ MeV, $T_{\rm melt}(\Upsilon(2S)) \sim 360$ MeV, $T_{\rm melt}(\Upsilon(3S)) \sim 220$ MeV

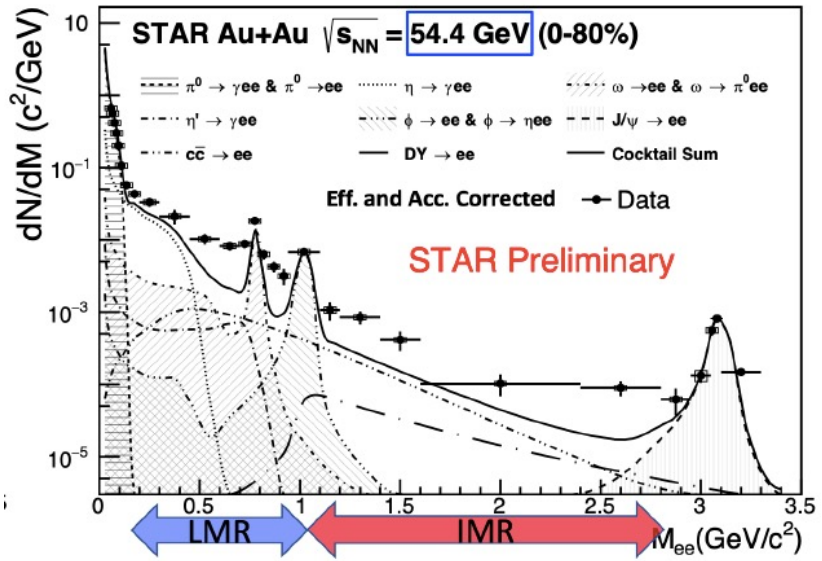
ϒ sequential melting

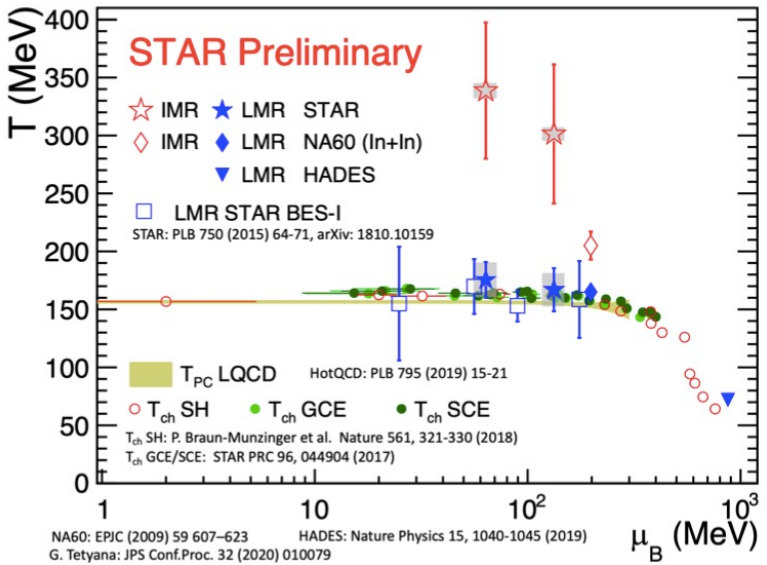


- First observation of ϒ(3S) in heavy-ion collisions
- More loosely bound states are more suppressed

O. Evdokimov (Thu. 13:30)

True thermometer: di-leptons



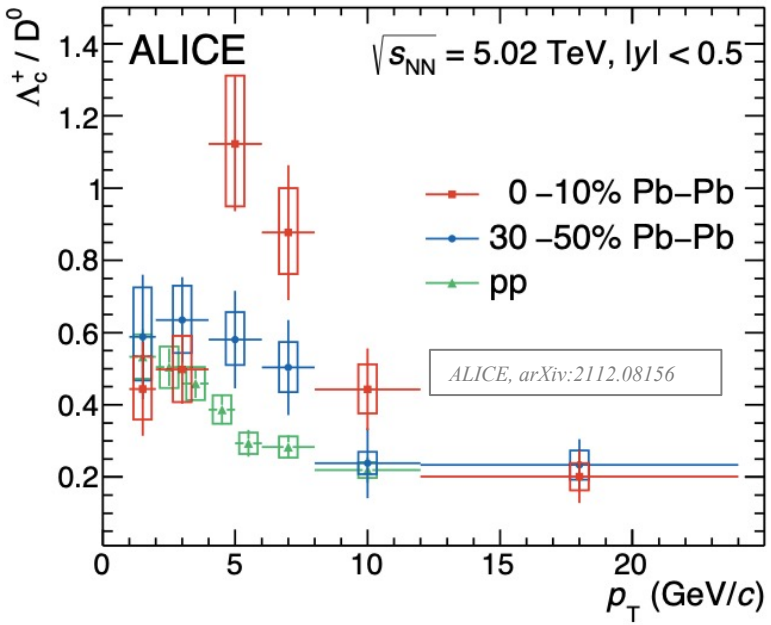


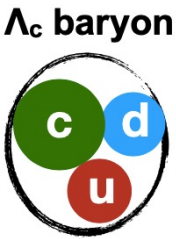
- QGP radiation within $1 < M < 2.8$ GeV/c^2
- Slope directly related to system temperature

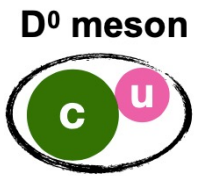
L. Ruan (Sat. 14:20)

Charm quark hadronization

D. Thomas (Fri. 11:00)







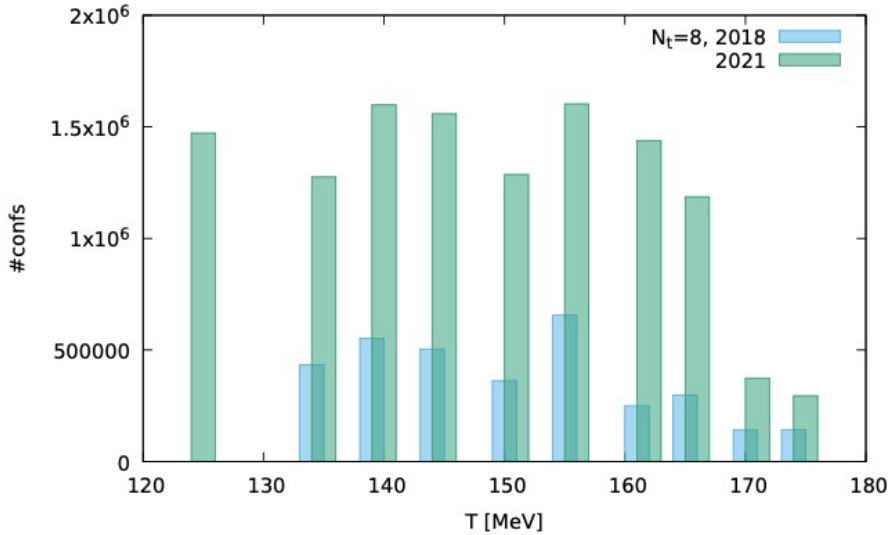
- Significant enhancement in Pb+Pb than p+p around 5 GeV/c
- Can be described by coalescence+fragmentation hadronization

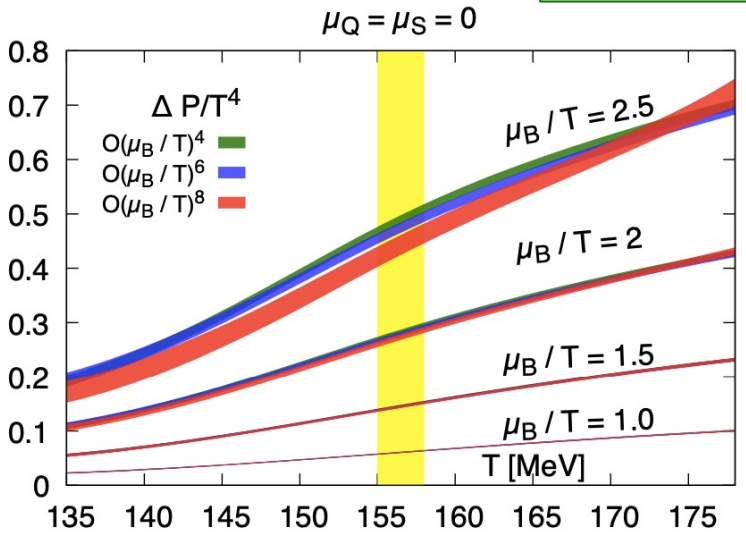
Theory collaborations

More lattice-QCD statistics

HotQCD, arXiv:2202.09184

D. Bollweg (Thu. 14:30)

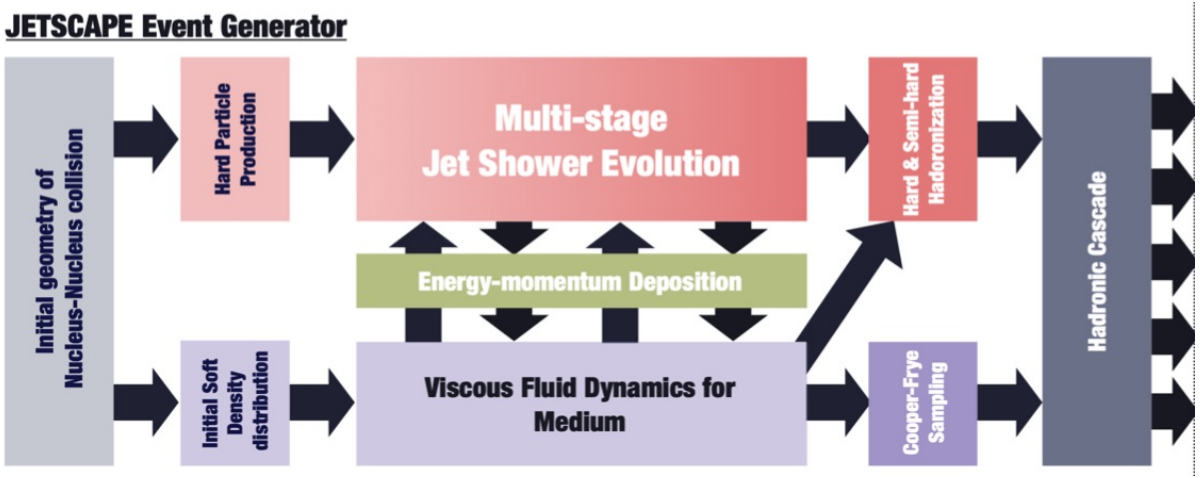




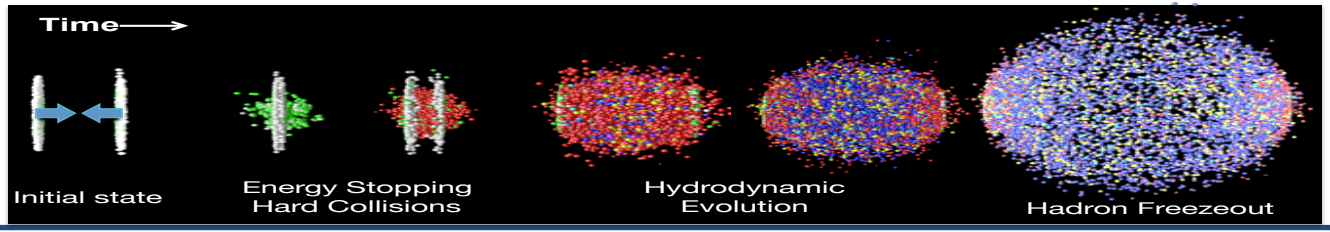
- Multi-year campaign generates large statistics
- Equation of state up to 8th order

JETSCAPE framework

- A modular framework one can swap out different components



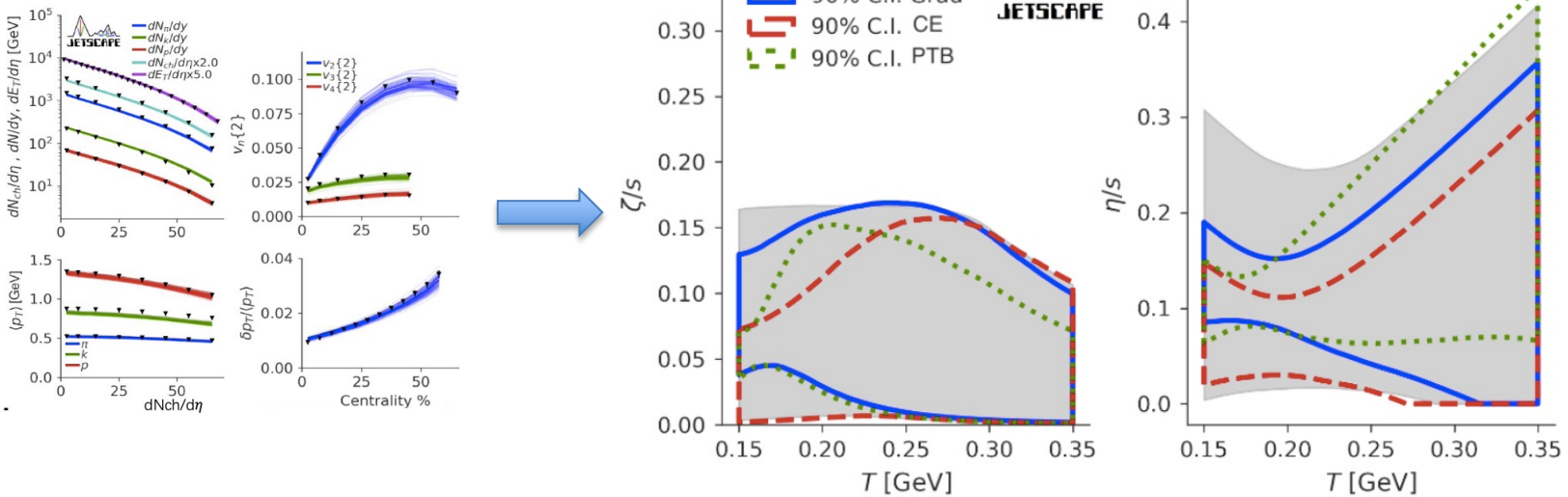
A. Majumder (Thu. 17:00)



Shear and bulk viscosities

W. Zhao (Sat. 15:30)

JETSCAPE, arXiv: 2022.01430, 2010.03928



- Bayesian analysis to extract medium viscosities

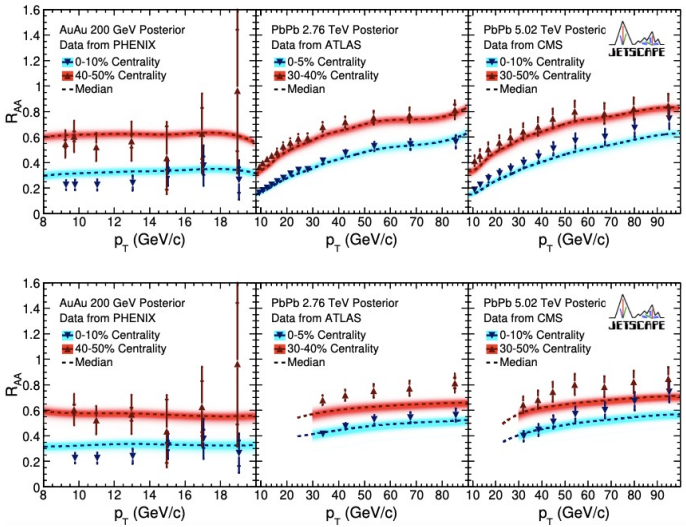
Constrain transport coefficient

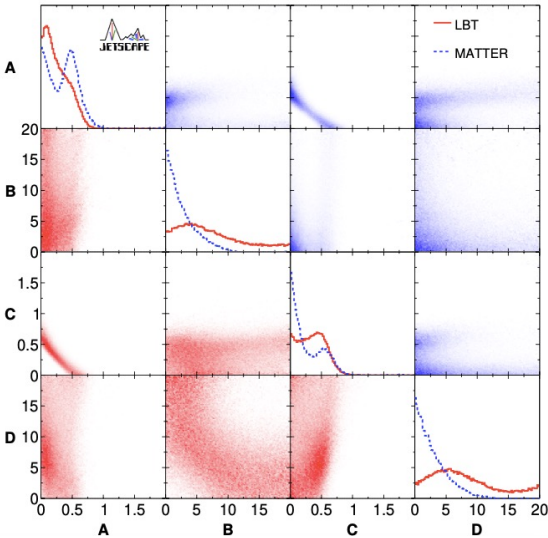
- We parametrize with

$$\frac{\hat{q}(E,T)|_{A,B,C,D}}{T^3} = 42 C_R \frac{\zeta(3)}{\pi}\left(\frac{4\pi}{9}\right)^2 \left\{ \frac{A\left[\ln\left(\frac{E}{\Lambda}\right) - \ln(B)\right]}{\left[\ln\left(\frac{E}{\Lambda}\right)\right]^2} + \frac{C\left[\ln\left(\frac{E}{T}\right) - \ln(D)\right]}{\left[\ln\left(\frac{ET}{\Lambda^2}\right)\right]^2} \right\}$$

A. Majumder (Thu. 17:00)

- Bayesian analysis to extract jet transport coefficient

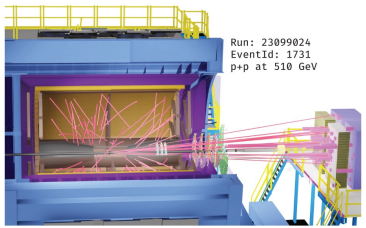


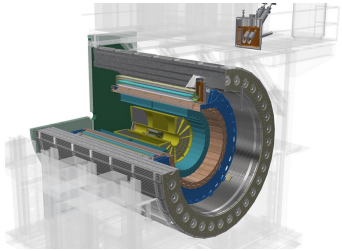


The future is bright

High-statistics data taking (Au+Au @ 200 GeV) through 2025

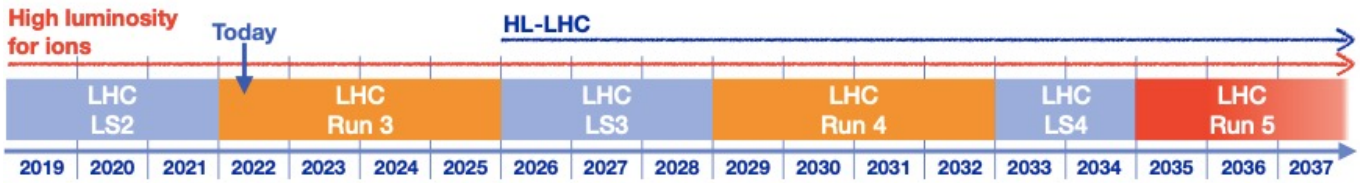
RHIC

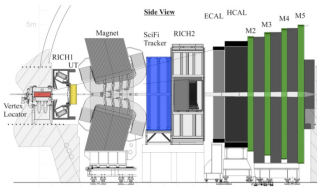


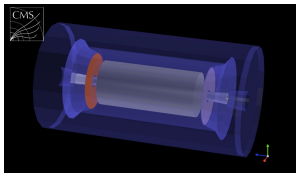


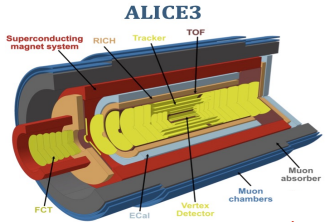
M. Connors (Thu. 16:30)

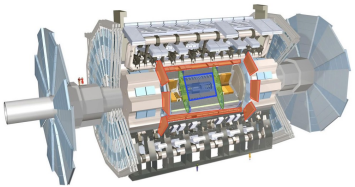
LHC









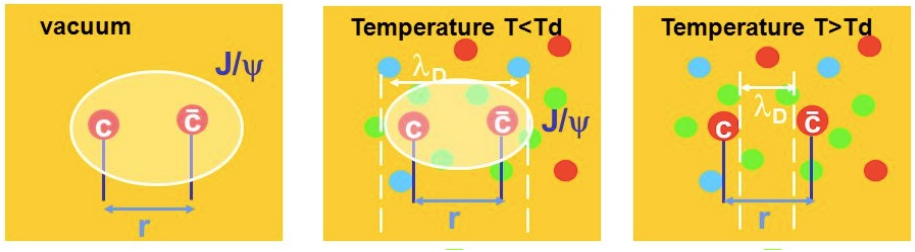


Backup

QGP "thermometer"

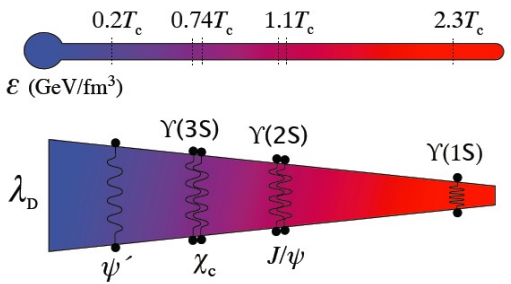
- Quark-antiquark potential color-screened by surrounding partons → *(static) dissociation*

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



$$r_{q\bar{q}} \sim 1/E_{binding} > r_D \sim 1/T$$

- **"Thermometer"**: different states dissociate at different temperatures → *sequential suppression*



	J/ψ	ψ(2S)	ϒ(1S)	ϒ(2S)	ϒ(3S)
E_b (MeV)	~ 640	~ 60	~ 1100	~ 500	~ 200

Charm quark diffusion coefficient

D. Thomas (Fri. 11:00)

ALICE, JHEP 01 (2022) 174