XXV DAE-BRNS HEP Symposium
IISER Mohali
DEC 12TH - DEC 16TH

Physics at RHIC and FAIR

QCD matter at large μ_B

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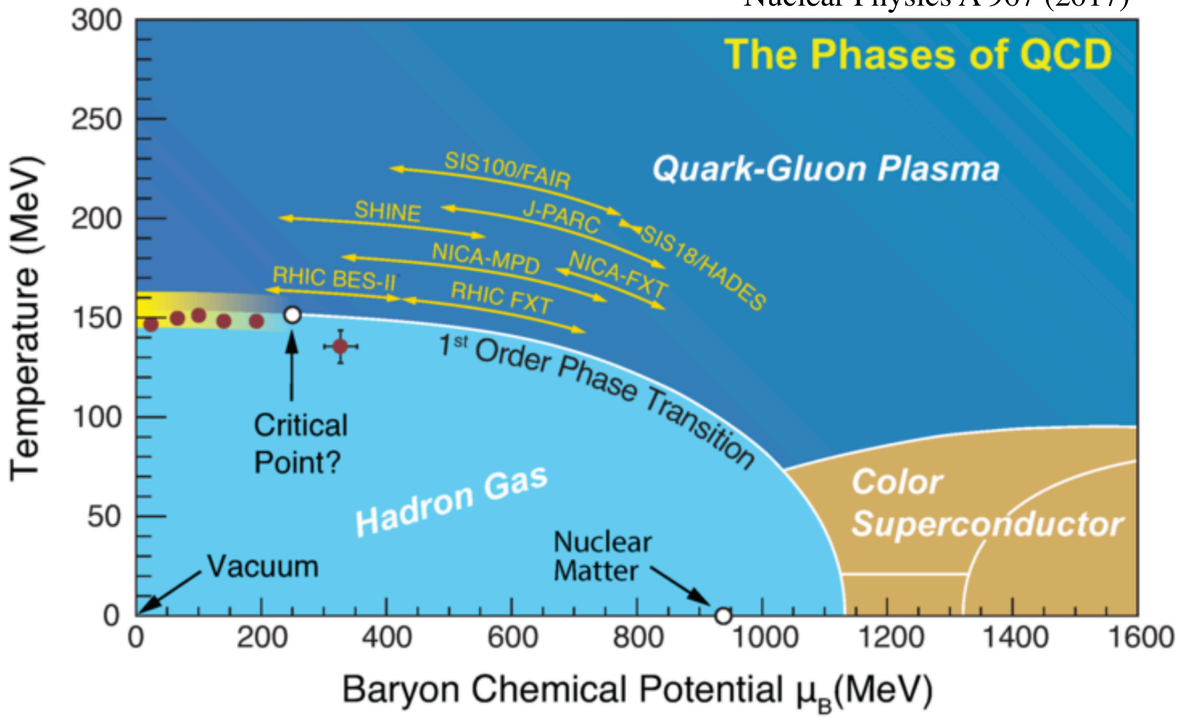
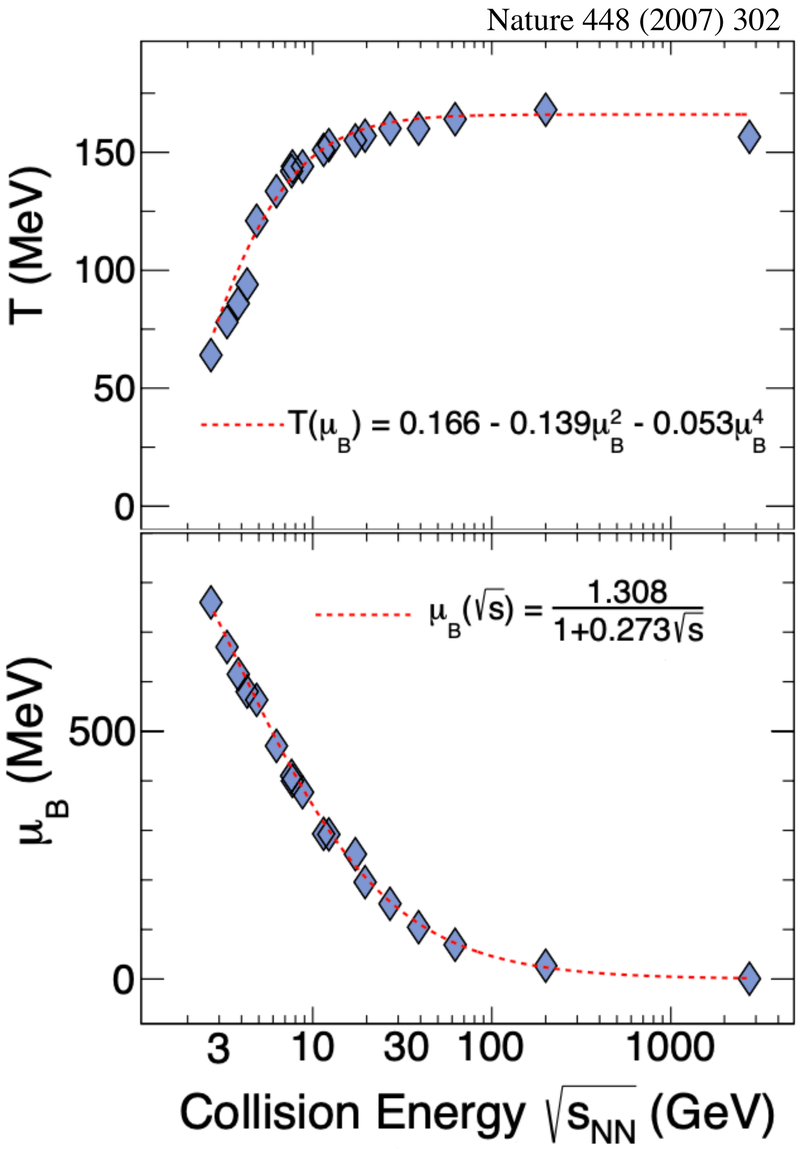
QCD phase diagram

Nuclear Physics A 967 (2017)



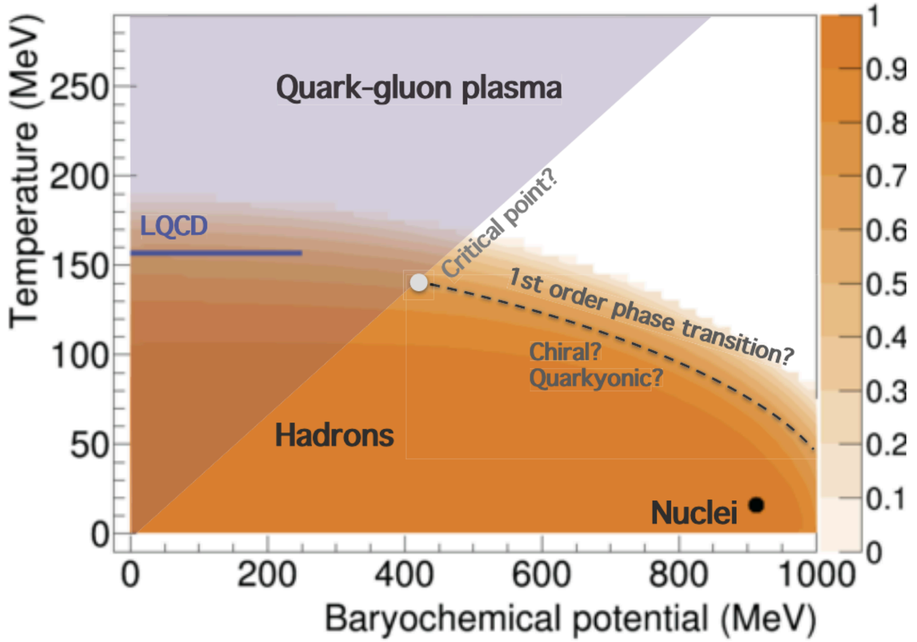
Nature 448 (2007) 302

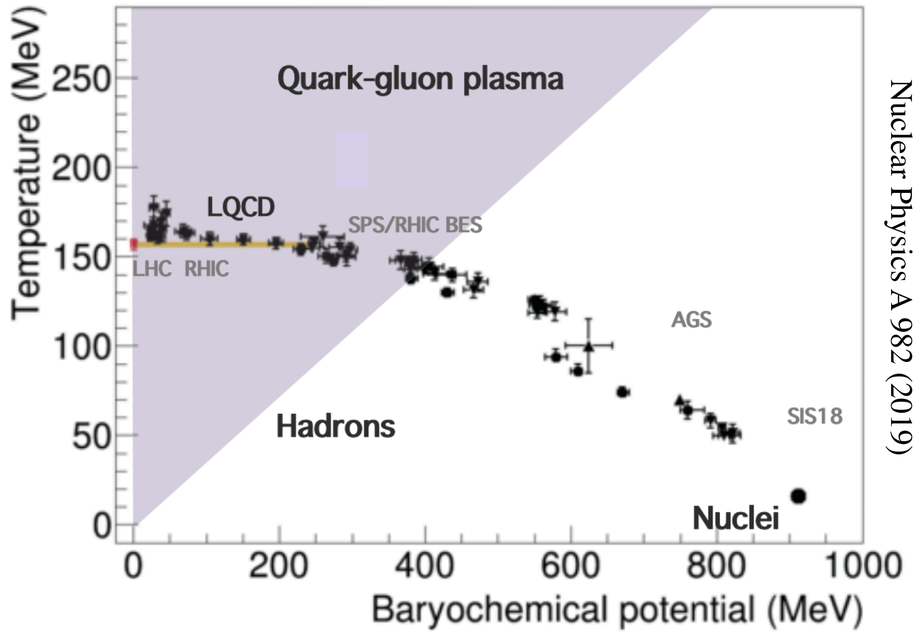


Heavy-ion collisions used as a tool to map the QCD phase diagram by varying the beam energy.

Several experiments/facilities give access to regions that cover cross-over, possible first-order PT and a conjectured CP

Phase structure of QCD





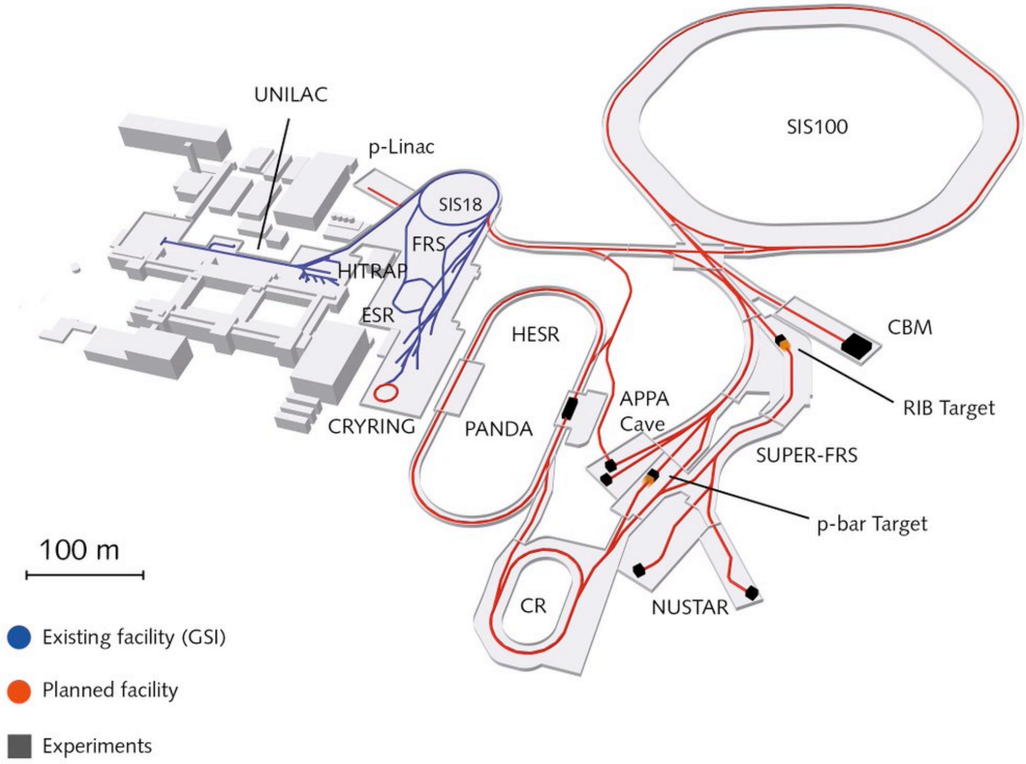
Nuclear Physics A 982 (2019)

- Phase transition does not occur along the freeze-out line
- Reaction dynamics need to be controlled using probes with memory

Organization

- Bulk signatures of QGP — Suppression, elliptic flow
- Thermal radiations and chiral symmetry restoration — Direct photons, dileptons
- Critical phenomenon — fluctuation observables
- Transport properties — heavy flavor
- Sensitivity to large EM fields — spin polarizations
- Light- and hyper-nuclei production

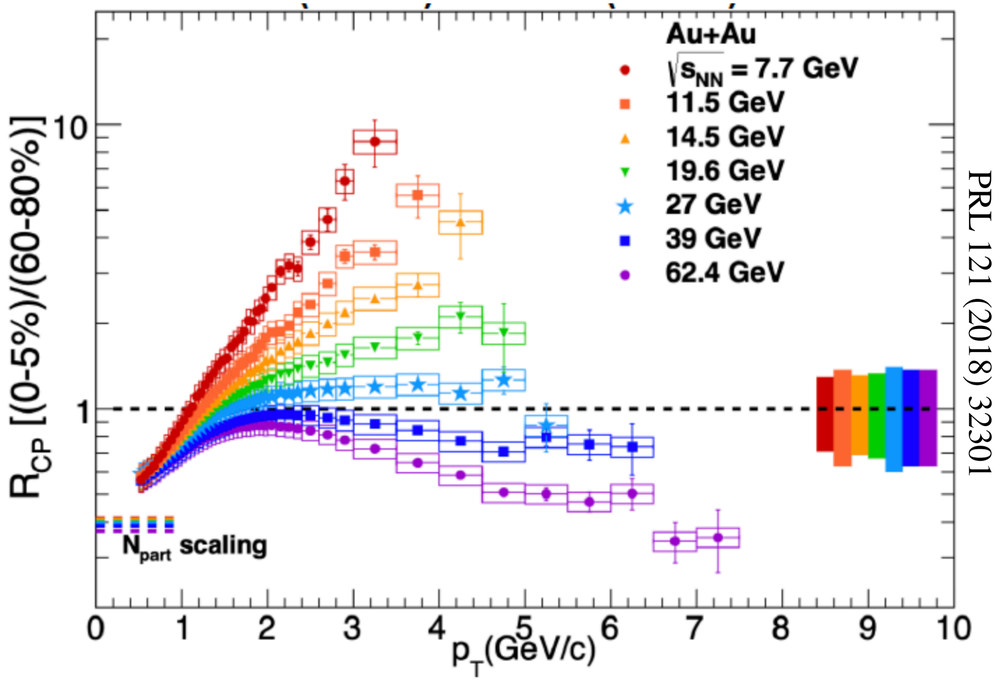
RHIC and FAIR



$\sqrt{s_{NN}}$: 3.0 – 200 GeV

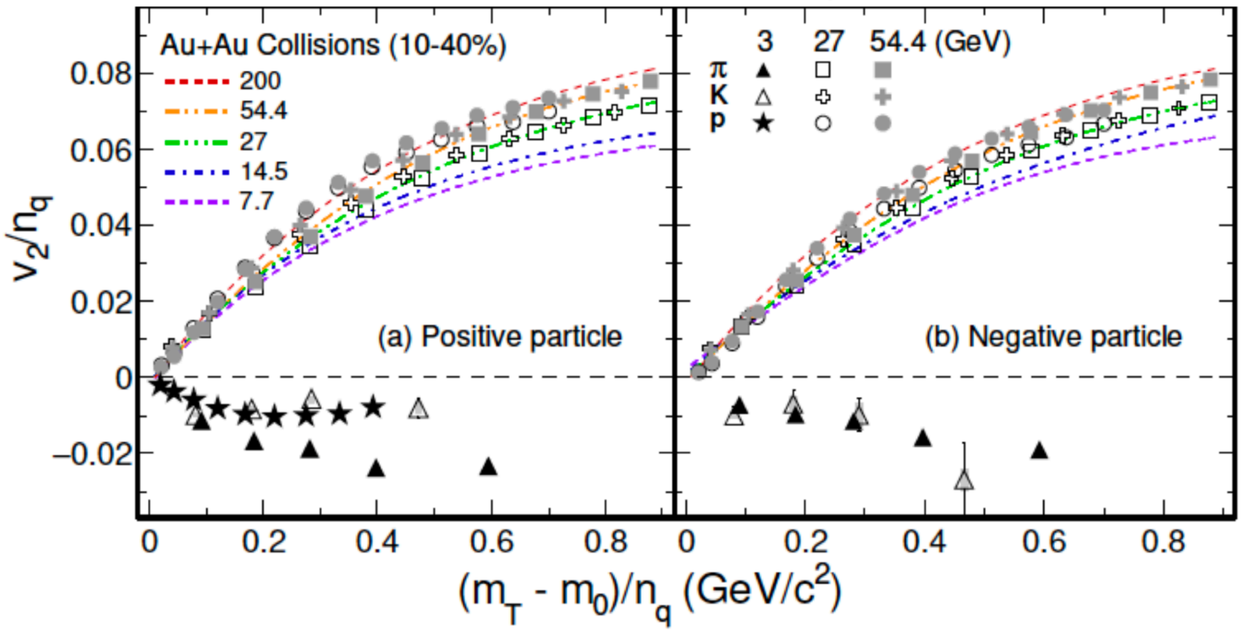
$\sqrt{s_{NN}}$: 2.9 – 4.9 GeV

Evidence for deconfinement



PRL 121 (2018) 32301

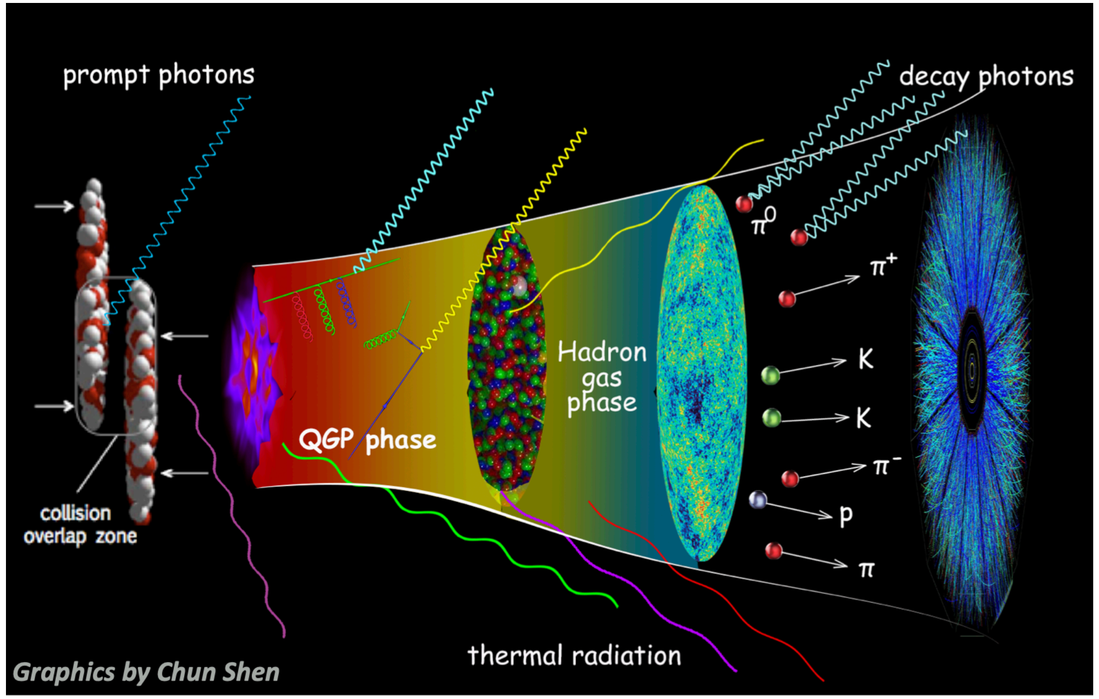
Phys. Lett. B **827** (2022) 137003

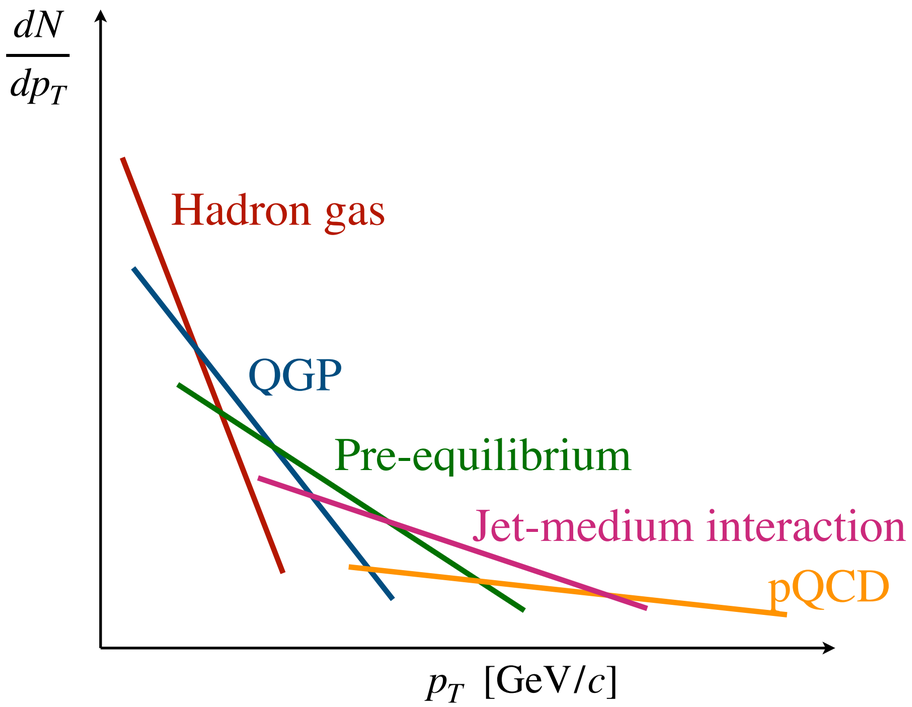


- Suppression due to opaqueness of the deconfined medium
- Enhancement due to dominance of hadronic interactions

- $v_2 > 0$ — formation of QGP
- $v_2 < 0$ — disappearance of partonic collectivity

Thermal radiations

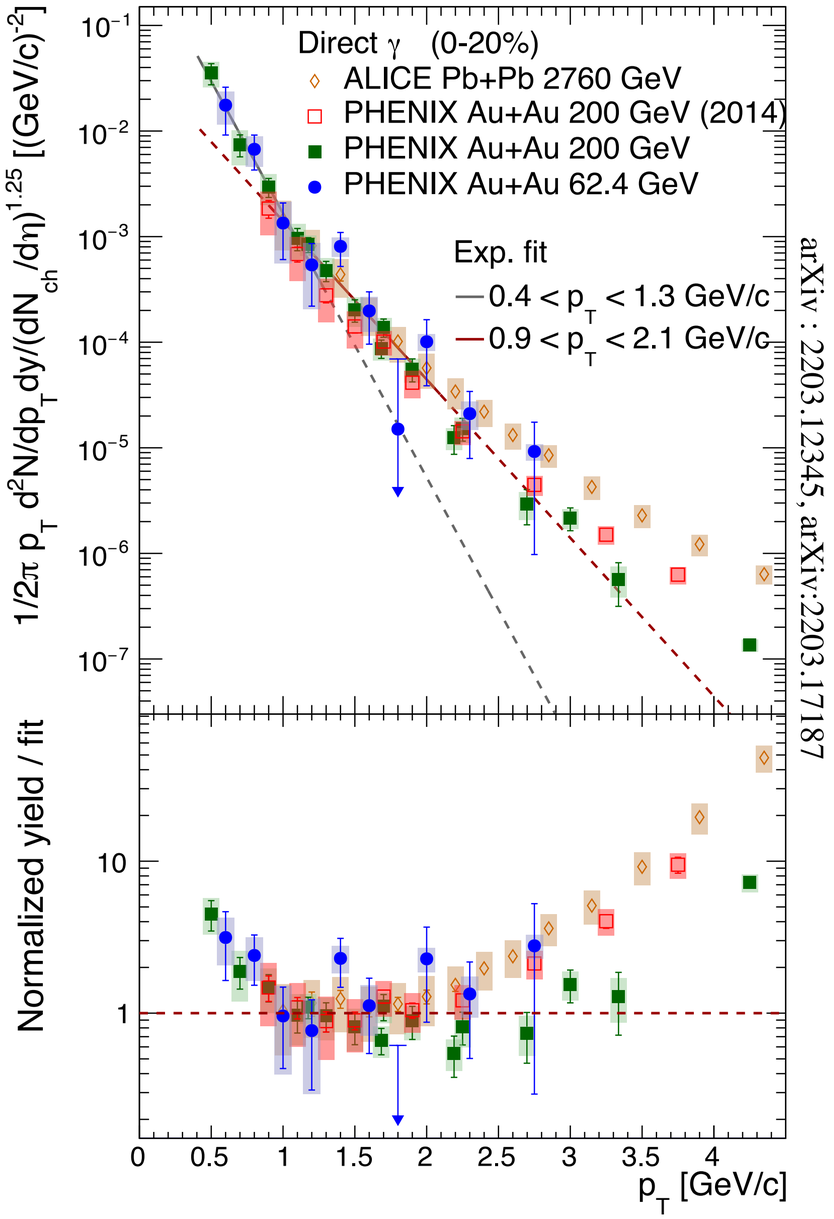


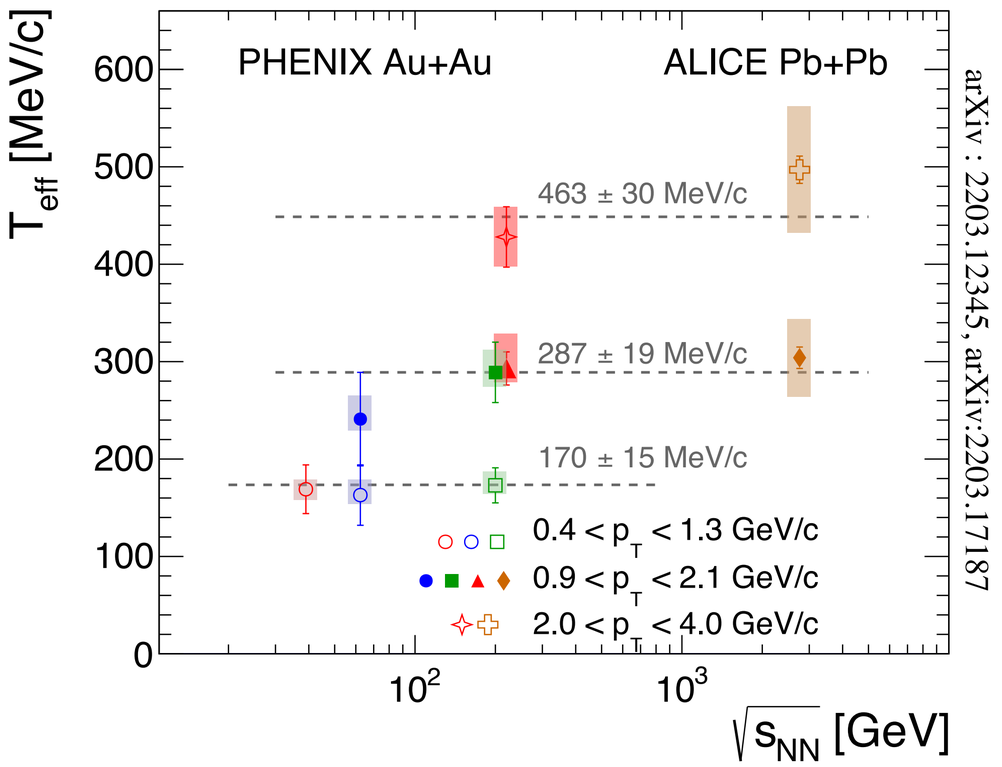


- Sensitive to **space-time evolution** and **temperature** of matter produced in relativistic heavy-ion collisions
- Evidence of thermal radiations from QGP and Hadron Gas
- 80-90% photons are decay photons

Measurement of yield constrains initial conditions, sources, emission rates and space-time evolution

Thermal radiations



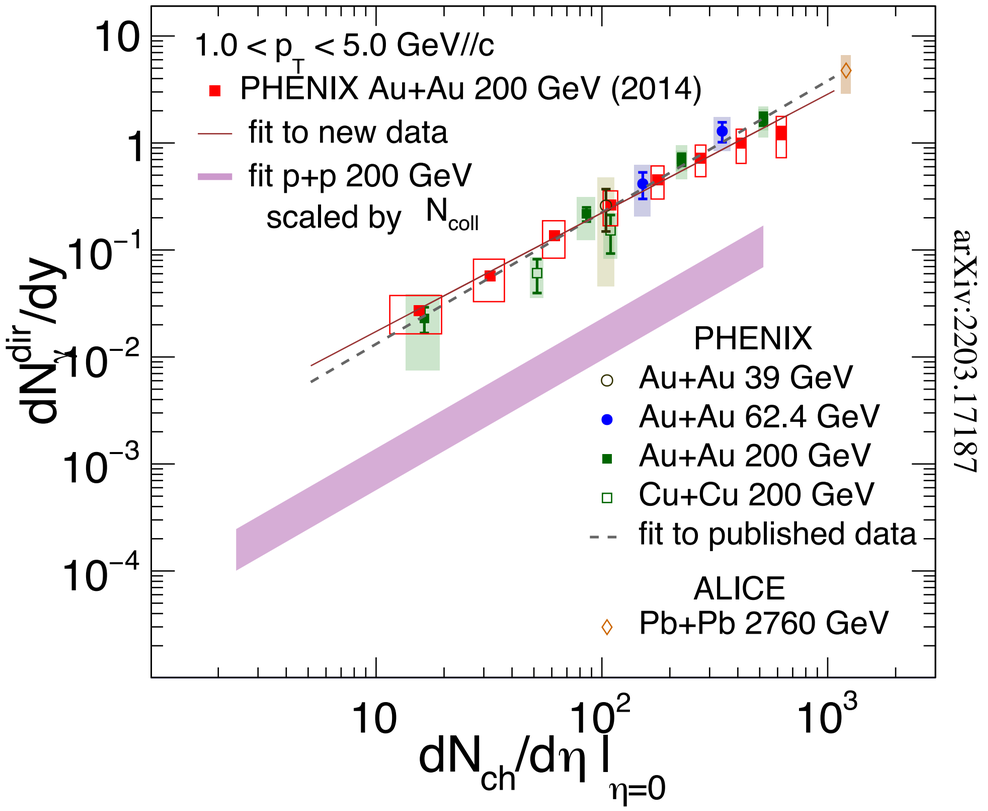


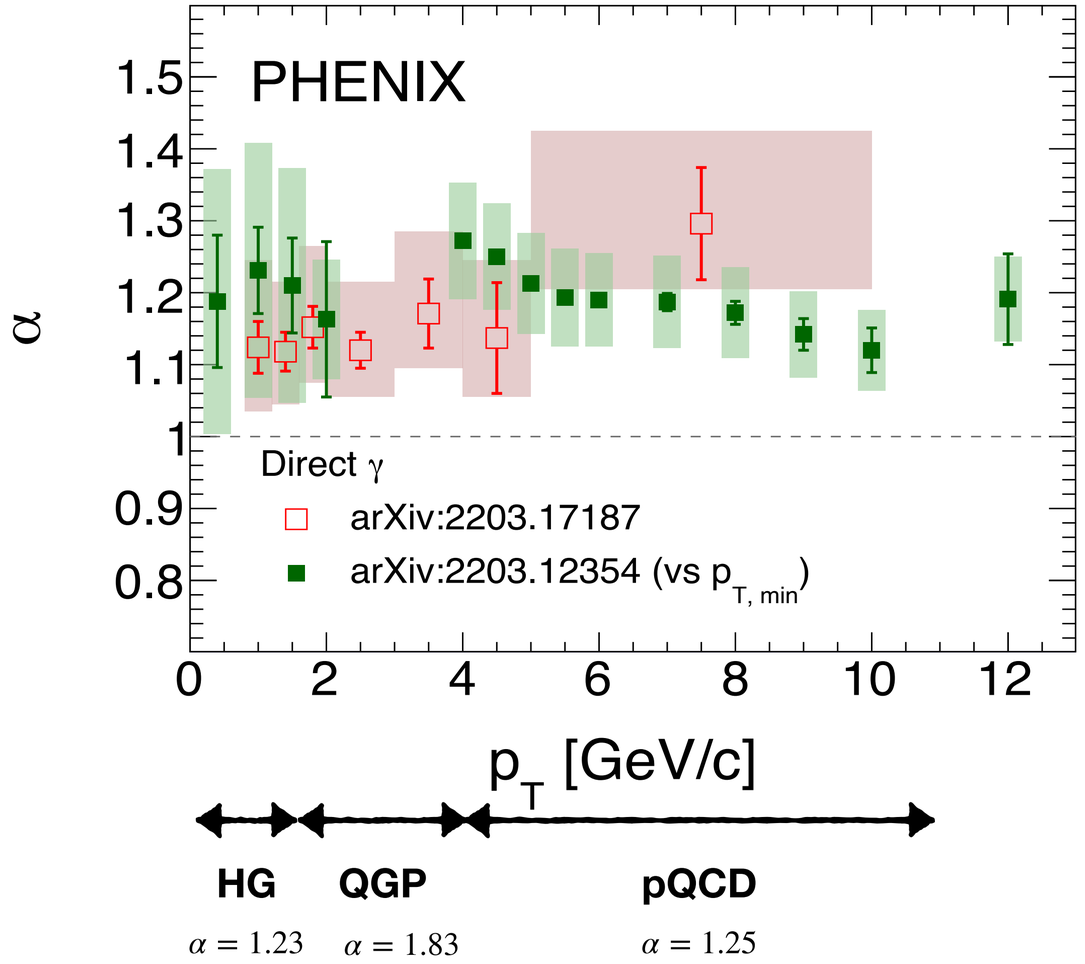
Similar spectra around 2 GeV/c — common source of photon production independent of $\sqrt{s_{NN}}$

Thermal radiations

$$dN_\gamma/dy = A \times (dN_{ch}/d\eta)^\alpha$$

Universal scaling behavior in all A+A systems

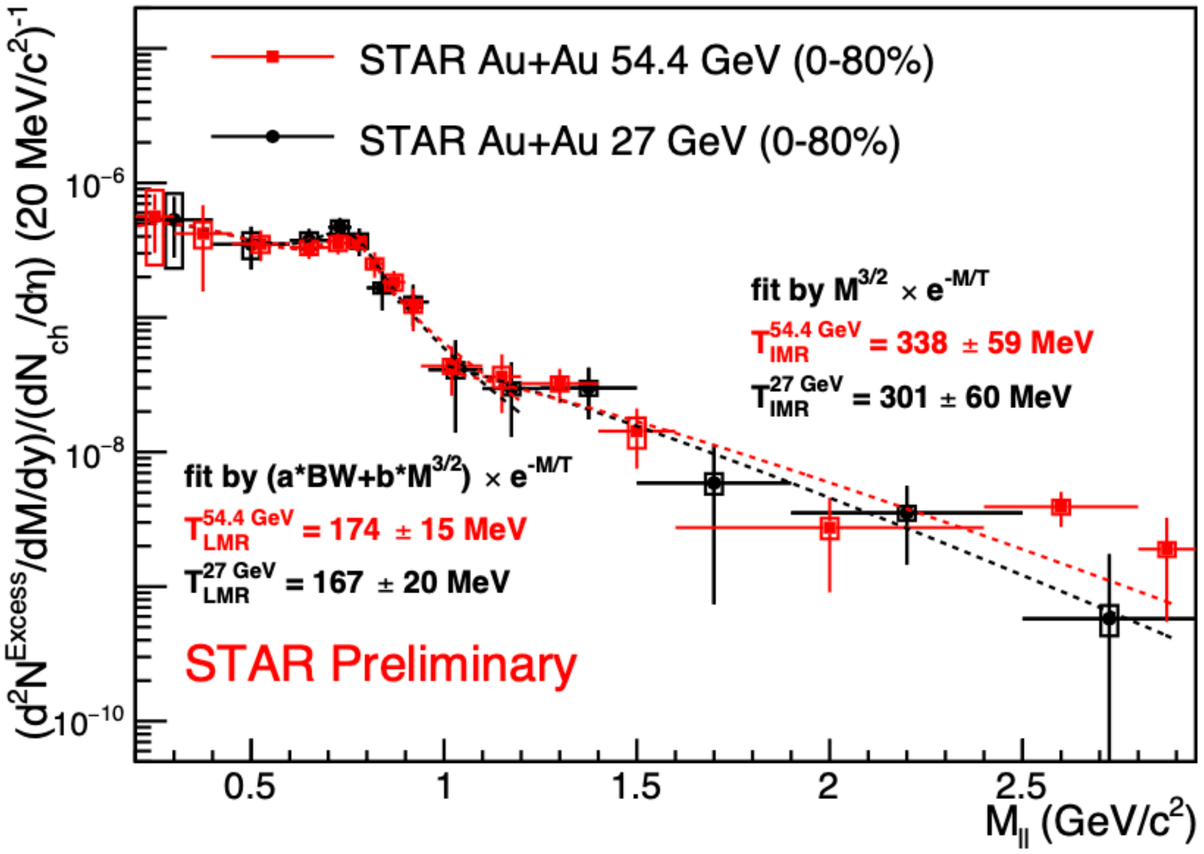




$\alpha > 1$ and independent of p_T

Chiral symmetry restoration

Zaochen Ye, QM2022



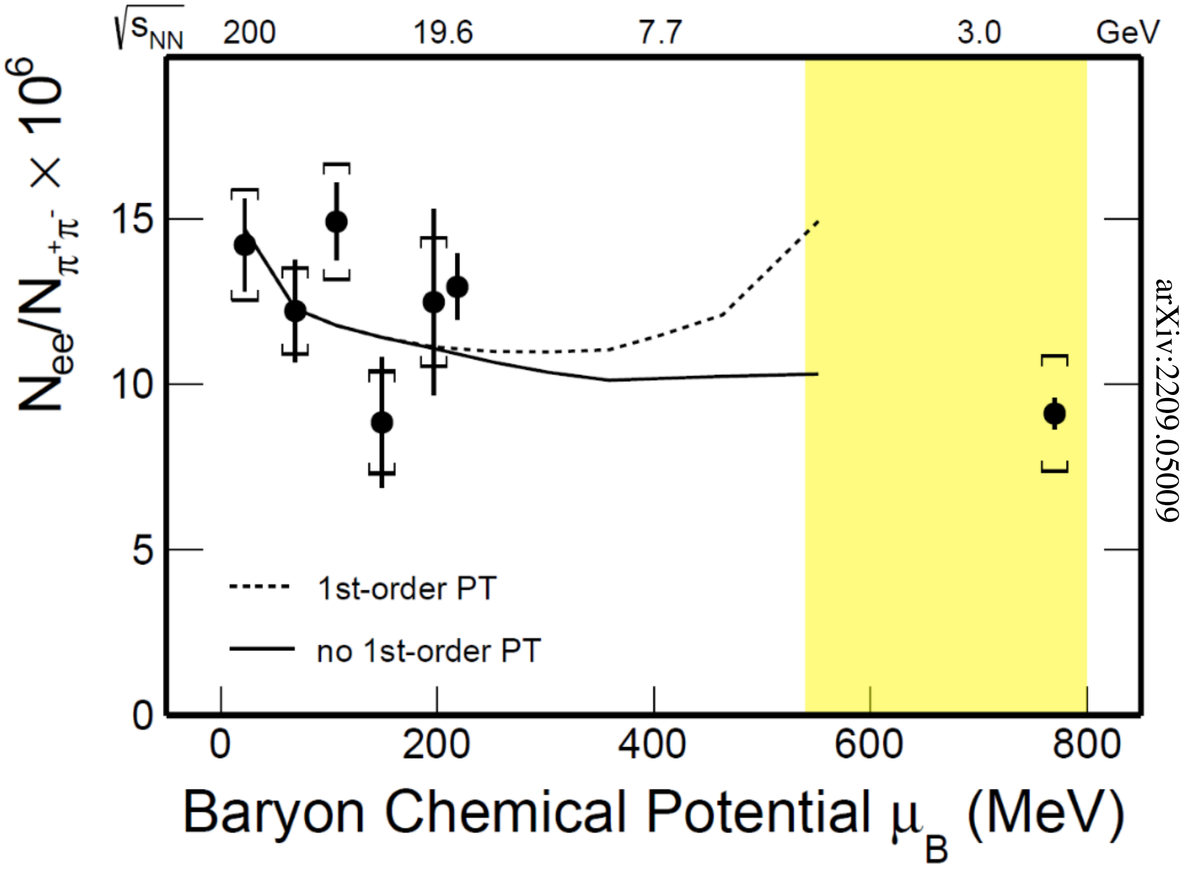
Low Mass Region

- Dilepton excess is consistent with in-medium ρ-broadening
- Extracted temperature ~ T_{ch} implies emissions from hadronic phase

Intermediate Mass Region

- Dilepton excess implies sensitivity to radiations from QGP
- Extracted temperature ~ 300 MeV is surprisingly large

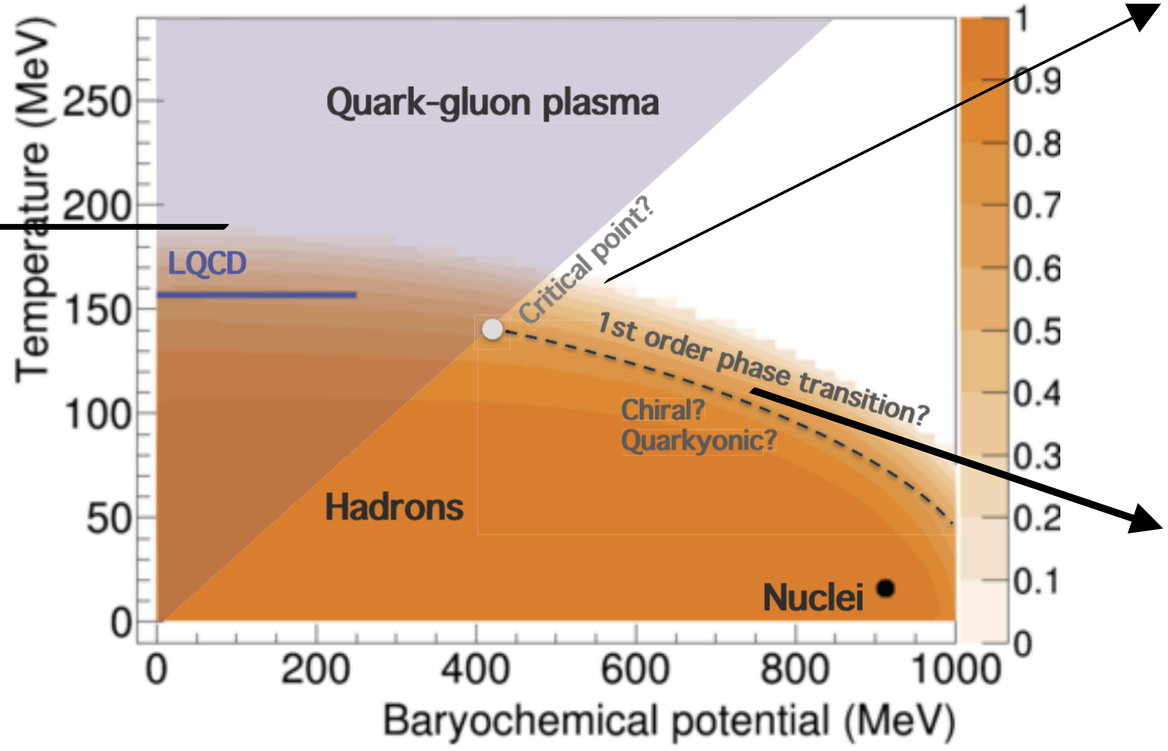
Probing 1st-order transition



- Softening of the EoS due to a first-order phase transition can result in an increase of the low-mass dilepton yield relative to a cross-over scenario

- The slope parameter of the dielectron excess mass spectra, as a measure of the medium temperature, may exhibit a distinct sharp change due to a first-order phase transition

Search for Critical Phenomenon



Cross-over

Negative values for net-baryon C_6/C_2

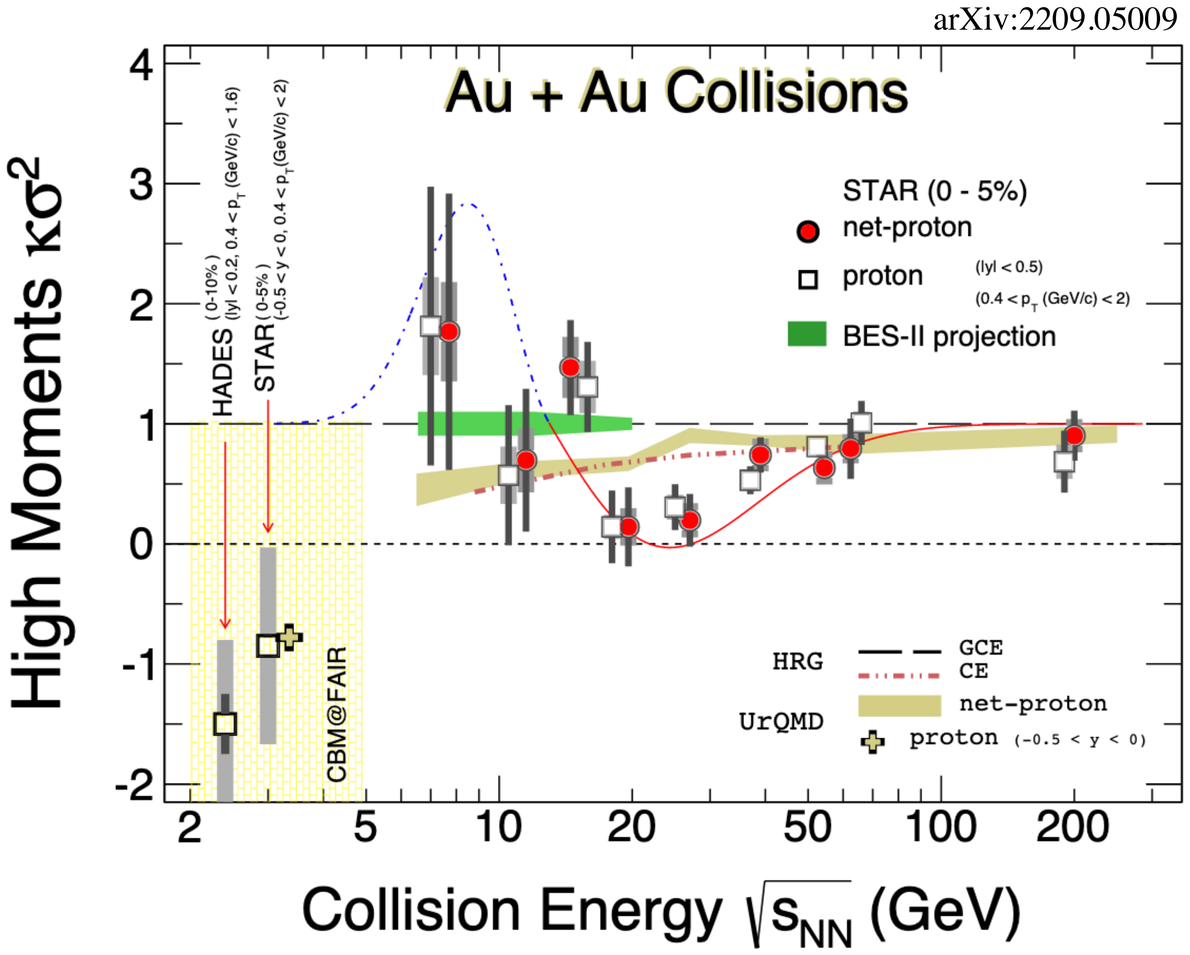
Critical End Point

Non-monotonic trends in net-baryon C_4/C_2 with beam energy

First order transition

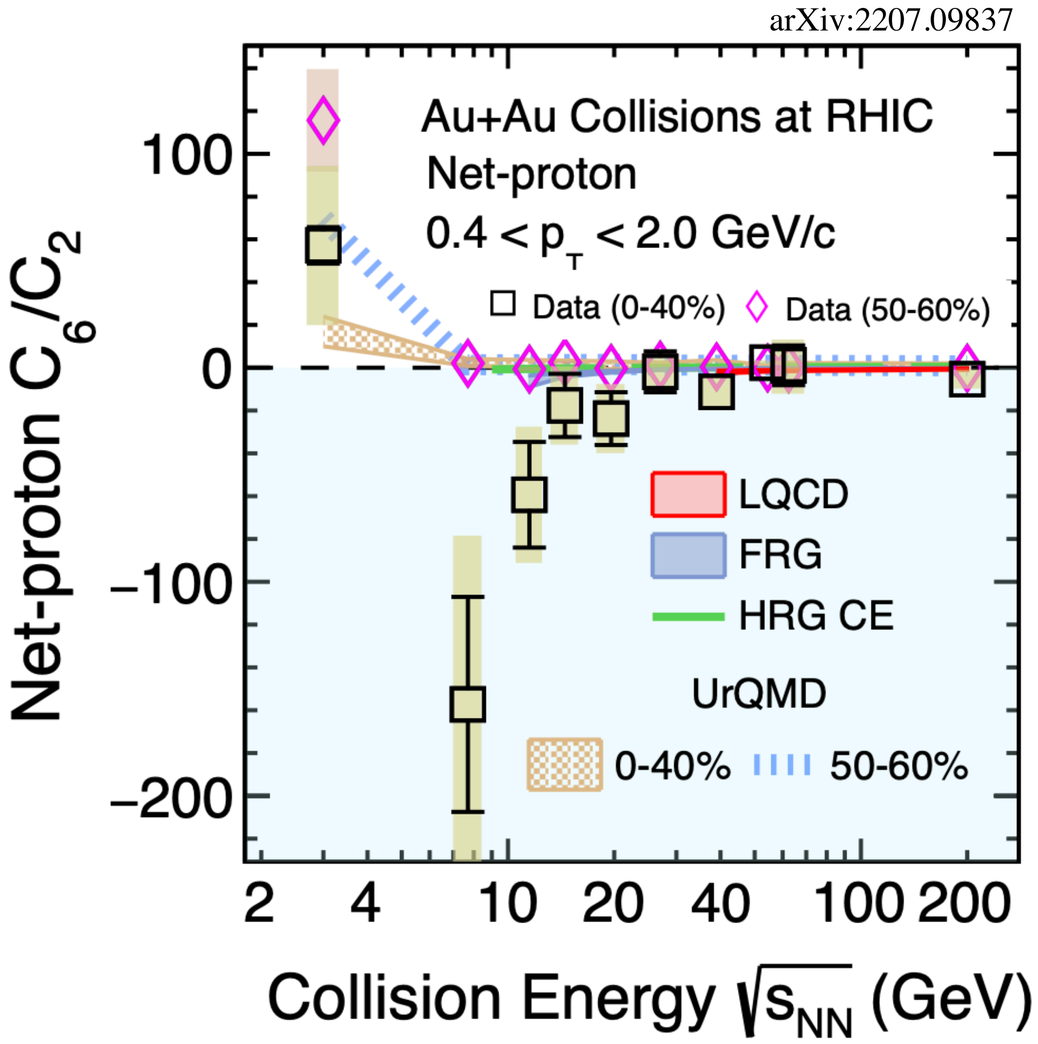
Large proton factorial cumulants (κ_6 and κ_7) with alternating sign

Search for Critical Point



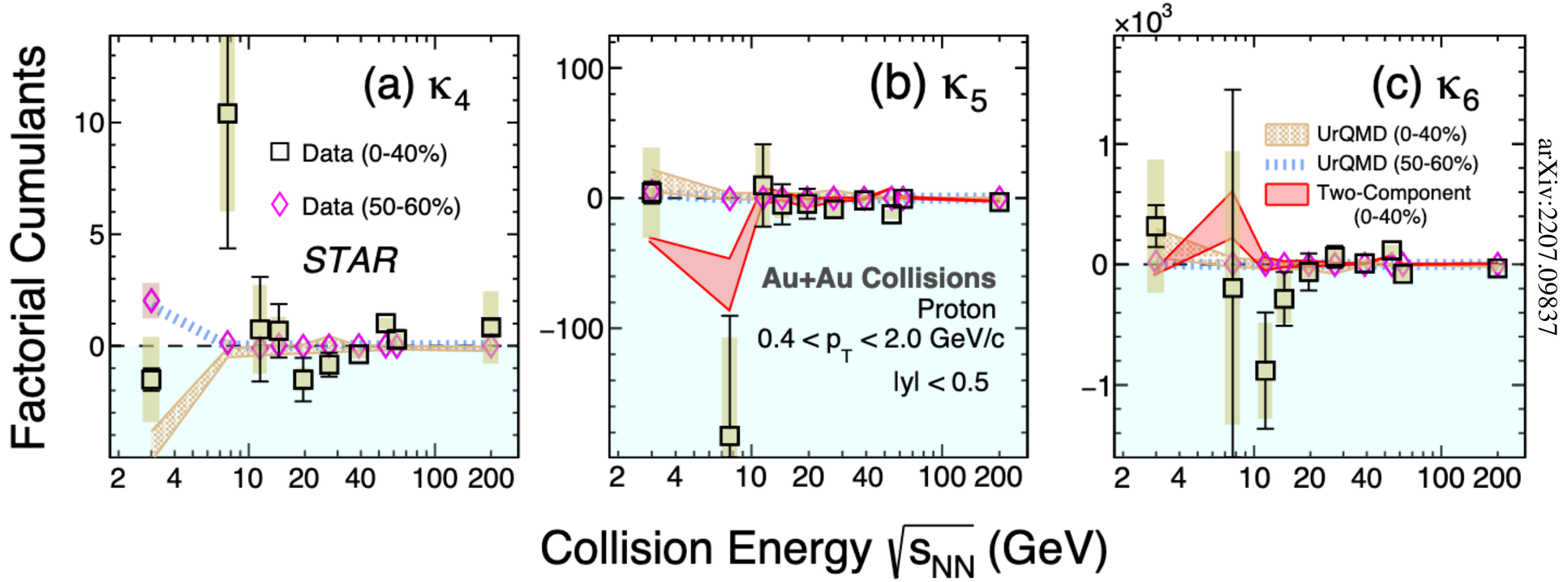
- Non-monotonic collision energy dependence observed for net-proton C_4/C_2 is consistent with CP expectation.
- Non-CP models fail to reproduce the observed trend.
- Measurement at 3 GeV is consistent with UrQMD, implying that the QCD matter created is dominantly hadronic

Search for Crossover



- C_6/C_2 for 0-40% centrality is increasingly negative with decreasing energy, except at 3 GeV where it is positive.
- The negative sign of C_6/C_2 is consistent with QCD calculations ($\mu_B \leq 110$ MeV) that include a crossover quark-hadron transition.
- Peripheral 50-60% data, and calculations from the UrQMD model which does not include any QCD transition, are either positive or consistent with zero.

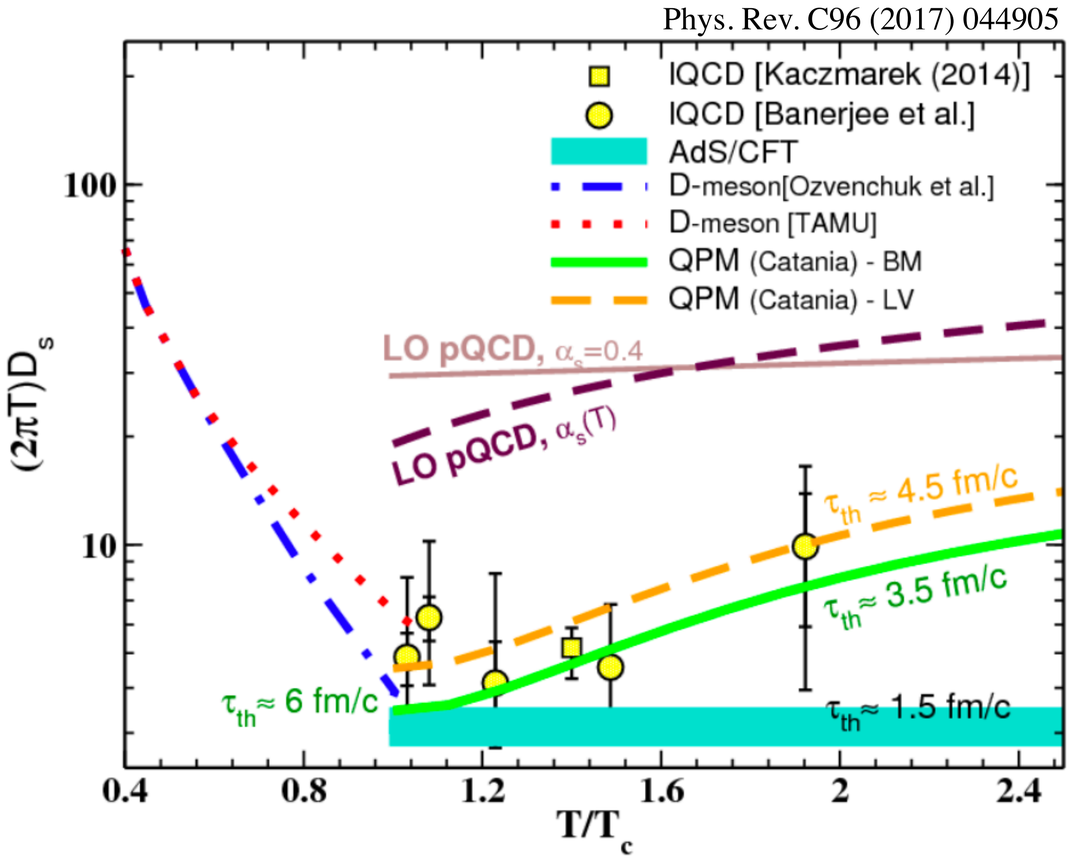
Search for 1storder phase transition



- Prediction : Multiplicity distribution two-component near a 1st order transition. Large factorial cumulants with alternating sign.

- Observation : For $\sqrt{s_{NN}} \geq 11.5$ GeV, the proton κ_n within uncertainties does not support the two-component shape of proton distributions. Possibility of sign change at low energy.

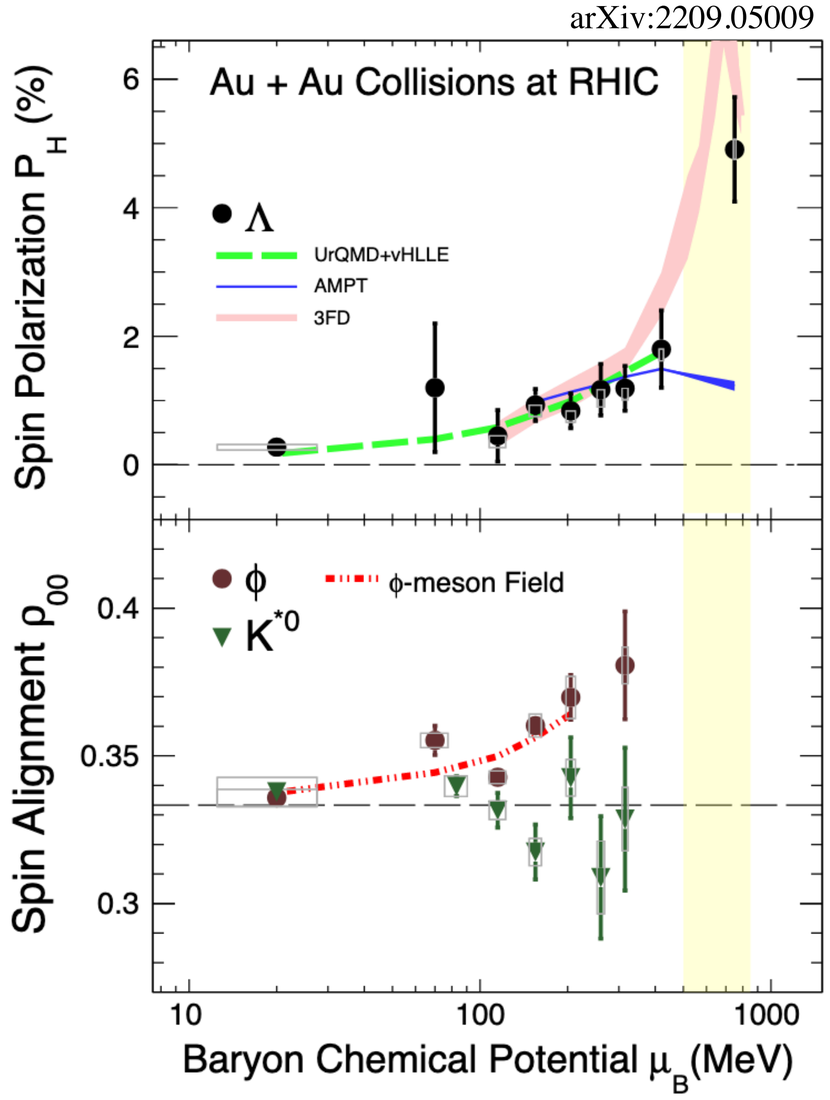
Transport properties



- Spatial diffusion coefficient is expected to be larger in the hadronic phase than in the late QGP phases prior to hadronization — spectra and flow of D-meson

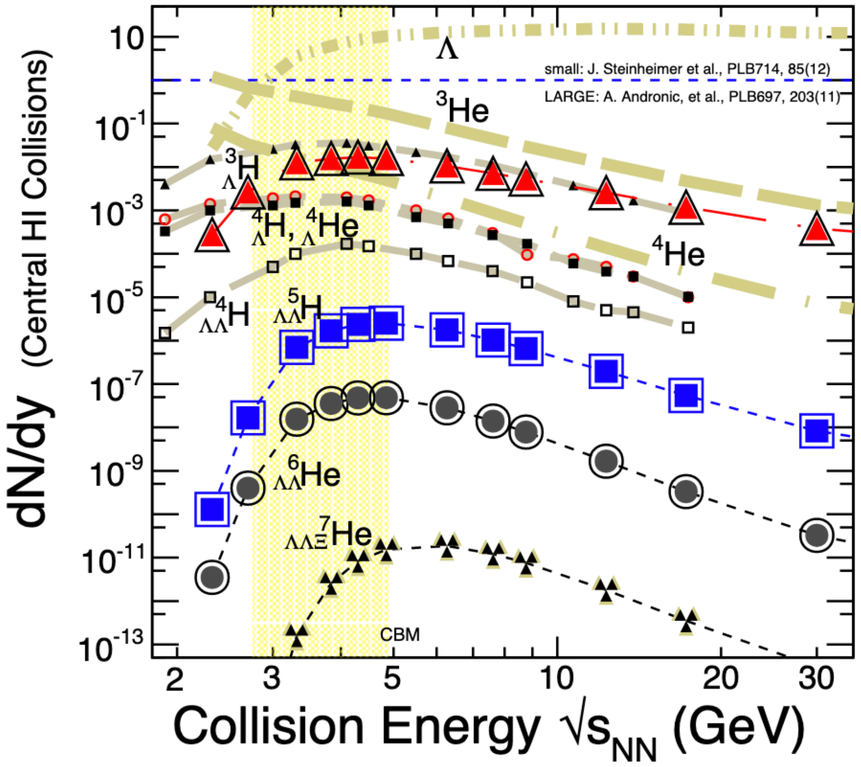
- Measurements of the relative abundances of different charm-hadron species are used to characterize the hadronization mechanisms of charm quarks and the role of quark recombination — Λ_c/D^0

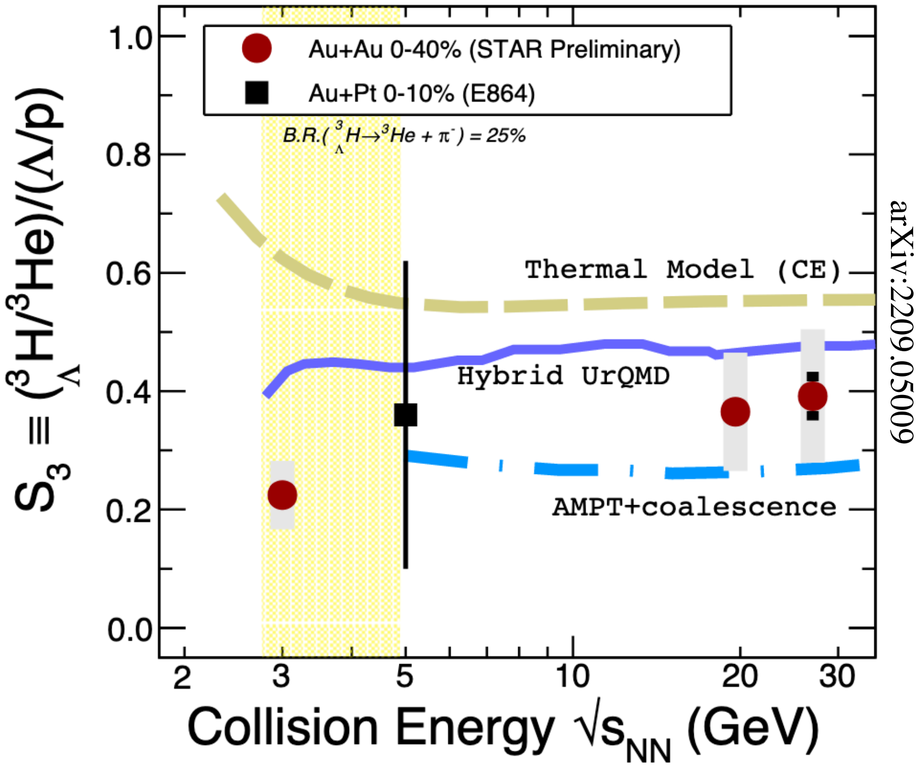
Global spin polarization



- Probe for initial angular momentum and magnetic field
- Polarize quarks and influence different spin polarization for quarks and antiquarks with different magnetic moments
- Consistent with model calculations based on rotational polarization of microscopic particle spin in a vortical fluid, suggesting the presence of a strong vorticity field

Light- and hyper-nuclei production

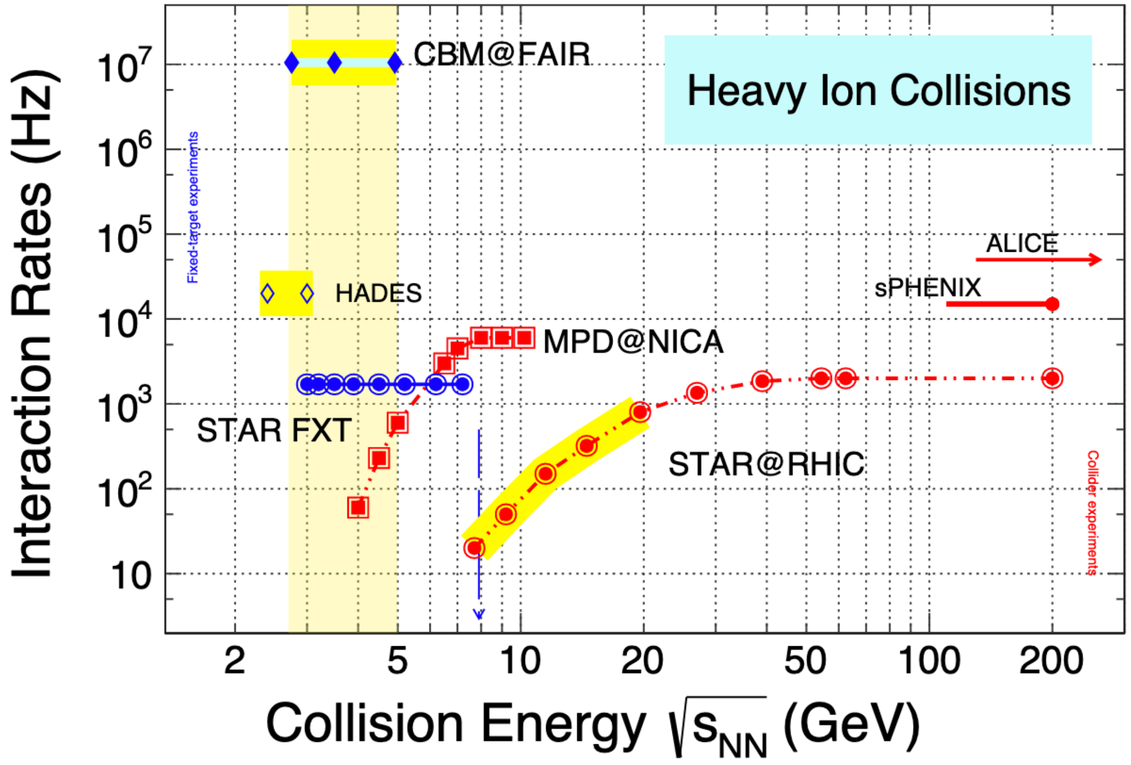




- Provides access to the hyperon–nucleon interaction and strangeness in high density nuclear matter
- Yields of light nuclei and hypernuclei are potentially sensitive to multiple-baryon correlations, which constitute an exquisite test of QCD

Future facilities

arXiv:2209.05009



- Very successful RHIC program comes to an end in 2025
- High μ_B program with FAIR is a natural continuation

Thank you for your attention!