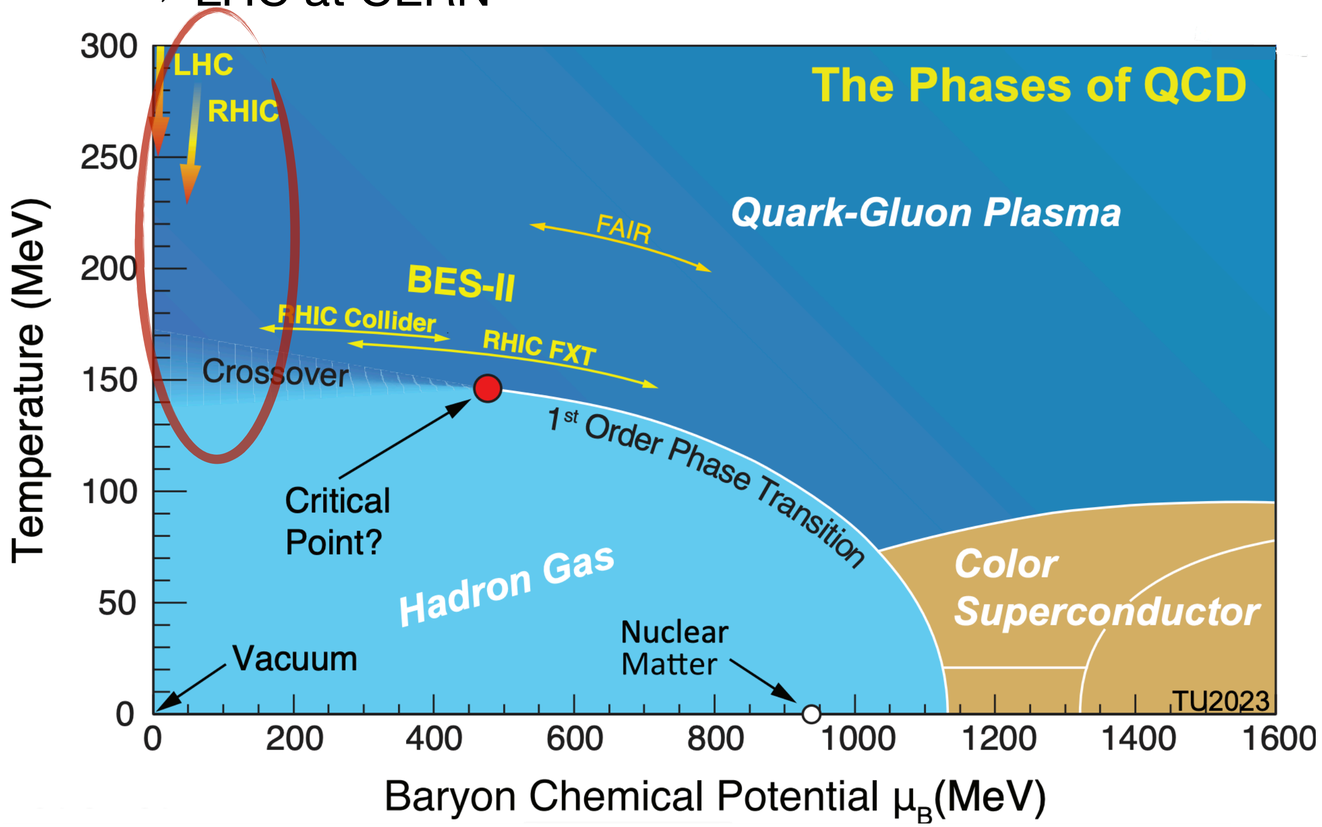
- Phase transition at high temperature or density to deconfined state of quarks and gluons
  - quark-gluon plasma (QGP)

- Created using ultra-relativistic heavy-ion collisions
  → RHIC at BNL
  → LHC at CERN



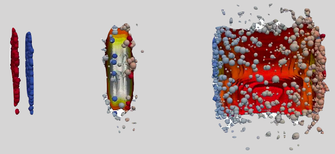
The JETSCAPE collaboration

The tool for comprehensive validation of cutting-edge models with multi-messenger data

→ does a model capture the essential physics?

Heavy-ion event generator

Framework for modelling all aspects of heavy-ion collisions



Statistical toolkit

Bayesian inference for data-theory comparison

$$P(\theta\,|\,\text{data}) = \frac{P(\text{data}\,|\,\theta)P(\theta)}{P(\text{data})}$$

Modular - substitute in different models

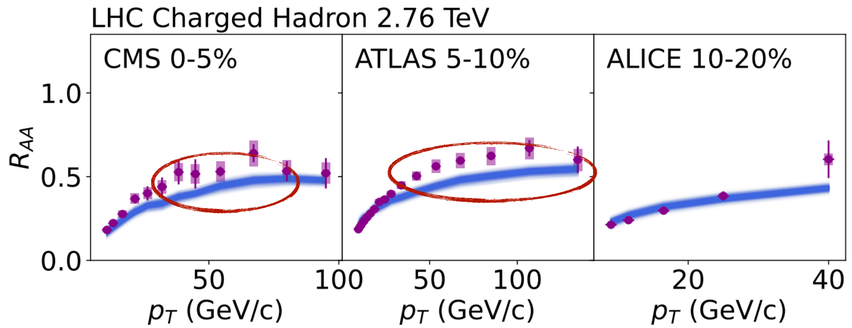
Interdisciplinary collaboration of ~50 (experimentalists, theorists, statisticians)

Computing intensive calculations
- Requires HPC + AI/ML

State-of-the-art:

Constrain QGP properties with comprehensive data-theory comparisons

example: JETSCAPE, *Phys.Rev.C* 111 (2025) 5, 054913

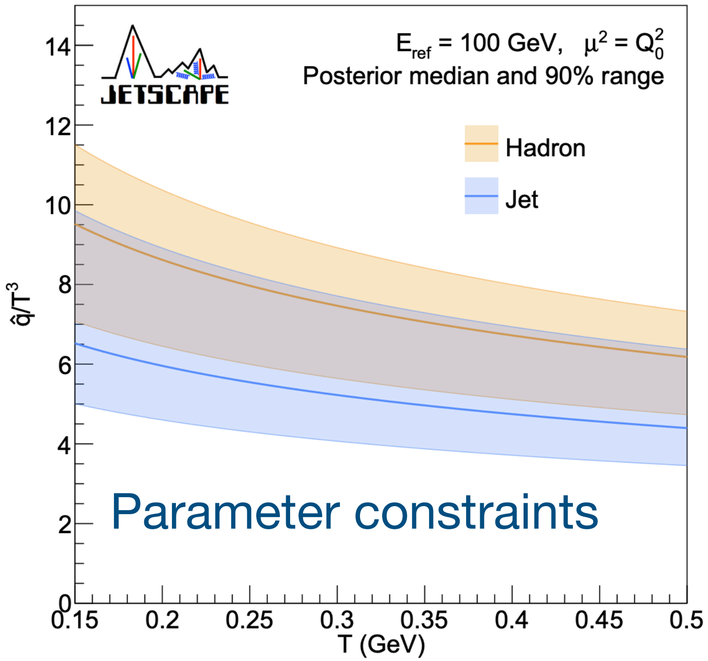


Complete set of experimental measurements

+ simulated data sampling multi-dimensional parameter space
(O(5M) CPU hours on US-based clusters)

Bayesian inference

$$P(\theta\,|\,\text{data}) = \frac{P(\text{data}\,|\,\theta)P(\theta)}{P(\text{data})}$$



jet transport coefficient

$$\hat{q} \sim \frac{< k_T >}{L}$$

See also JETSCAPE, *Phys.Rev.C* 103 (2021) 5, 054904
Phys.Rev.C 104 (2021) 2, 024905
Phys.Rev.Lett. 126 (2021) 24, 242301

Steps towards precise, quantitative characterisation of the QGP… but

→ models incomplete

→ Incorporates data up to ~2022; new data from LHC Run 2 + 3, plus new RHIC experiment sPHENIX

Next steps:

Next generation of Bayesian inference model constraints

- 3 UK-based members of JETSCAPE (primarily US-based), we joined in 2023
  - Liverpool/Daresbury collaboration - involved in ALICE experiment @ LHC since ~2013
- First IRIS allocation on Cambridge CSD3 (*500k CPU hours*) in 2024-2025 allowed us to:
  → benchmark calculations and new theory developments
  → perform first sensitivity studies prior to large-scale calculations
- This years allocation (*12M CPU hours, 100 TB storage*) provide resources for these calculations:
  - Calibration: constrain ‘bulk’ QGP properties incorporating 3D viscous hydrodynamics
  - Connect regimes: Probe how out-of-equilibrium probes (jets) are affected by bulk properties
  - Model discrimination: discriminate and constrain different models of QGP microscopic structure
- Near future - steps towards full model calibration(s)
  - Significant dimensionality increase (~5-6 →~30 free parameters)
    - more resources + ML optimisation required

Will have significant impact in the field of heavy-ion physics → IRIS facilitating this work!