

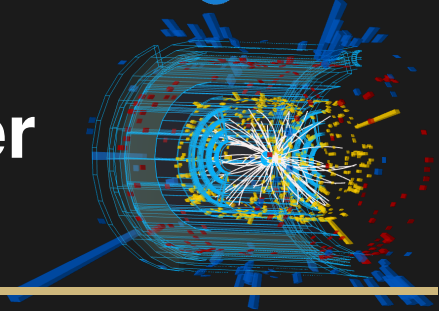
The Hottest Matter in the Universe

From absolute zero to the Quark-Gluon Plasma

Jamie Nagle

University of Colorado Boulder

CU Physics: 100 Years Since the First PhD



A strong tradition of nuclear physics at CU



1960: scale model of the cyclotron with D. A. Lind. Denver Post / Getty Images

The CU Cyclotron

- ▶ 30 MeV protons, 85-ton magnet
- ▶ Lind and Kraushaar:
first beam **1962**

Colorado Cyclotron Facility

MAY 01, 1963

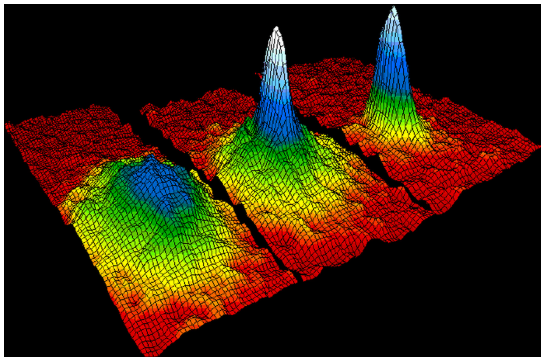
"the only university cyclotron in the Rocky Mountain region"

NSF grant (1963):

\$123,300

≈ \$1.35 million today

Start cold: CU reaches the lowest temperatures



First Bose-Einstein condensate, JILA 1995
(NIST/JILA/CU-Boulder)



Wieman & Cornell

Physics Nobel Prize, 2001

170 nK

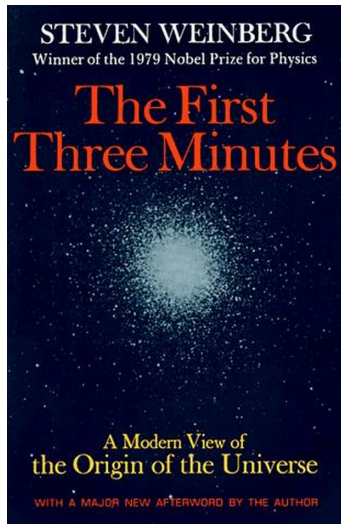
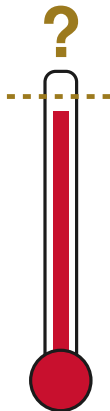
coldest ever, at the time

What about the *highest* temperature?

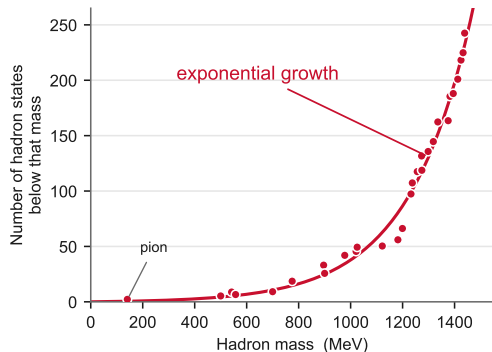
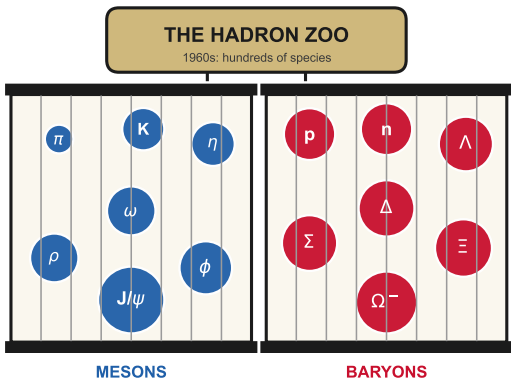
“Ultimate Temperature in the Early Universe”

Huang & Weinberg, PRL
1970

“...a veil, obscuring our view of the very beginning.”



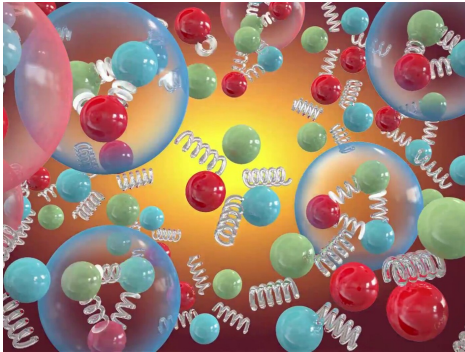
Why a maximum temperature?



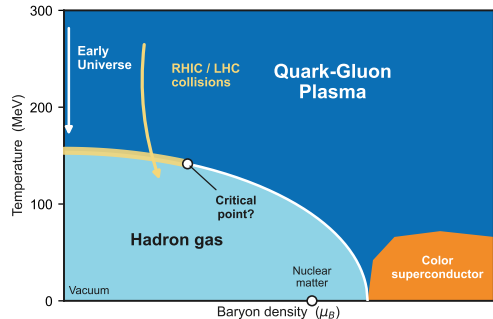
Exponentially many states: more energy $\Rightarrow$ more states, **not** higher T

$$T_{\text{ultimate}} \approx 170 \text{ MeV} \approx \mathbf{2,000,000,000,000 \text{ K}}$$

Beyond the limit: quarks and gluons

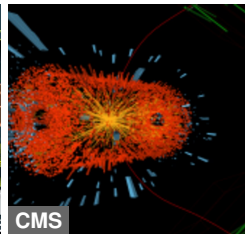
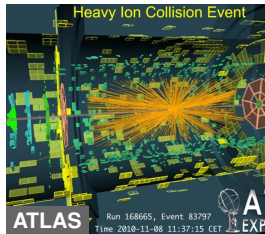
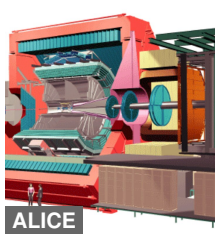
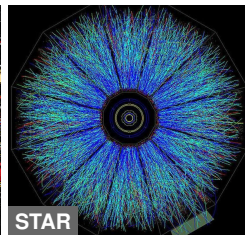
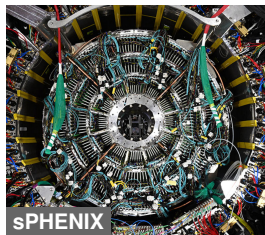
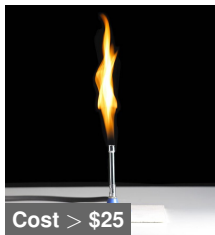


Quarks: confined $\rightarrow$ free

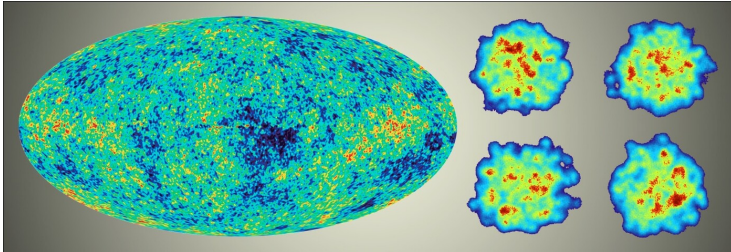


A phase transition: hadron gas $\rightarrow$ Quark-Gluon Plasma

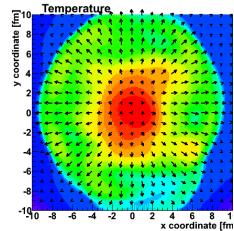
Laboratory “Bunsen burners”



RHIC discovery (2005–06): the Quark-Gluon Plasma



Big Bang (CMB) and “Little Bang” droplets

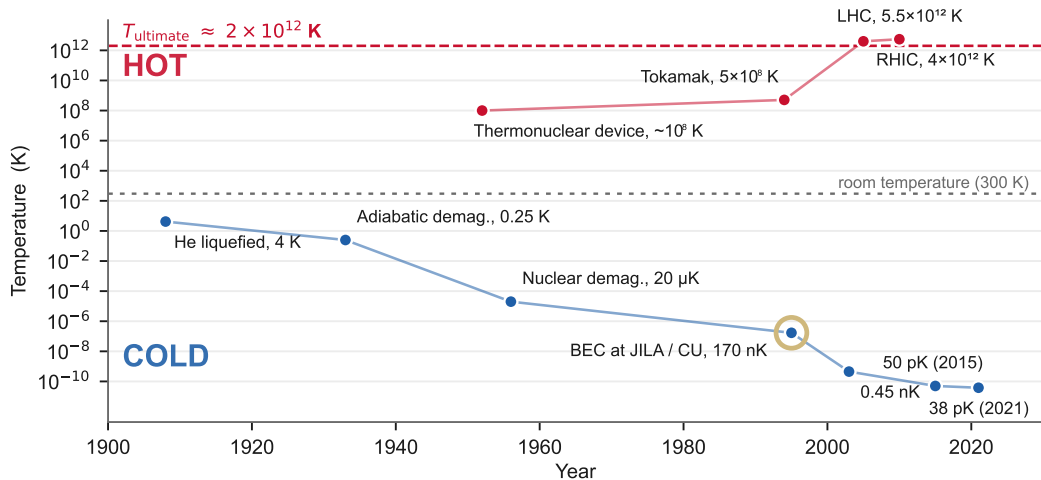


The QGP flows: temperature and velocity

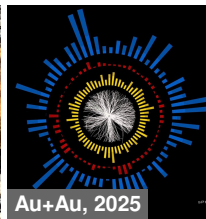
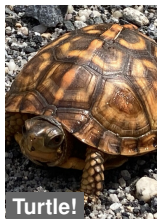
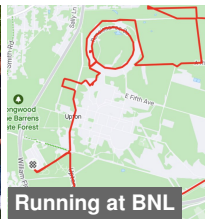
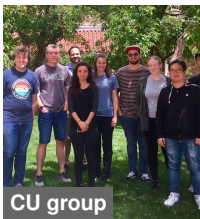
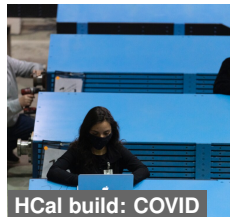
P. Romatschke & U. Romatschke,
Cambridge Univ. Press (2019)

- **Discovery of the QGP:** RHIC White Papers (2005)
- STAR and PHENIX: two of the **five most-cited** nuclear physics papers ever

23 orders of magnitude: 38 pK to 5.5×10^{12} K



sPHENIX: from a napkin to data



Now analyzing data!



RHIC's last day: February 6, 2026

Kevin Coughlin / Brookhaven National Laboratory

The “ultimate temperature”?
New record:
5.5 trillion K
above T_{ultimate}

Congratulations, CU Physics:
100 years of PhDs!

Stay curious
and persevere.

