TO-DAY: ALL YOU WANTED TO KNOW ABOUT HEAVY ION COLLISIONS BUT DID NOT DARE TO ASK

TOMORROW: WHY DATA SEEMS TO BE MUCH SIMPLER THAN THE EXPLANATIONS OF IT?

AND PREDICTIONS FOR LHC
QED: One Charge
   Uncharged Photon
   +
   Electrons in Field of Nuclei

QCD: Three Charges (colors)
   Colored Gluons
   +
   3 Families of Quarks

Atoms
   Molecules
   All the matter we see around us

Neutrons, protons, nuclei

?
Crucial Difference Between QED & QCD

At short distances vacuum not important

Asymptotic freedom
Density of hadrons: 500 MeV/fm$^3$
Density of nuclei: 150 MeV/fm$^3$
Heavy Ion Colliders

Bevalac, SIS → AGS → SPS → RHIC → LHC

$\sqrt{s_{NN}}$ 3GeV 5GeV 20GeV 200GeV 5.5TeV

From Tom Roser
~1000 Participants, 
~90 Institutions of 
19 Countries Worldwide
As energy increases mid rapidity tends towards being net baryon free.
proton \rightarrow \text{anti-proton}

\sqrt{s_{NN}} = 130 \text{ GeV}

UA1, 900 \text{ GeV}
SPACE-TIME EVOLUTION OF MULTIPARTICLE PRODUCTION PROCESS
Energy per unit volume:

Effectively the polar angle of produced particle

| E | ~ 0.7 GeV

Therefore total energy released in |η| < 1 is ~1500 GeV

“relevant” initial volume ~ \( \pi R^2 \times (0.1 \text{ fm} - \text{few fm}) \times 2 \)

Initially released energy per unit volume > few GeV/fm³
Note: energy density inside proton \( \approx 0.5 \text{ GeV/fm}^3 \)

Data from: PRL 85, 3100 (2000); PRL 88, 22302 (2002); PRL 91, 052303 (2003); arXiv:nucl-ex/0405027
Experimental Control of Centrality or Impact Parameter

“Spectators”

Zero-degree Calorimeter

“Participants”

Paddle Counter

“Spectators”

200 GeV

ZDC Mean Energy (a.u.)

Paddle Mean (a.u.)

6% Central

200 GeV

Counts

Paddle Mean (a.u.)

6% Central
Azimuthal Angular Distributions

This is direct evidence of collective effects and short time of equilibration
• Same phenomena observed in “gases” of cooled, trapped strongly interacting atoms


The RHIC fluid behaves like this, that is, a strongly coupled fluid

From S. Aronson
Data agrees with calculations for ideal liquid

\( b \approx 6.8 \text{ fm (16-24% Central)} \)

- STAR Data

D. Teaney
The spatial distribution of the interaction points of participating nucleons will vary event-by-event for the same $b$...

...thus the event plane ($\Psi_0$) and eccentricity ($\varepsilon_0$) also varies event-by-event!
Two ways to define eccentricity

Standard Eccentricity

Participant Eccentricity

Participants
Average $v_2/\langle e_{\text{part}} \rangle$ in Cu+Cu and Au+Au
$\sigma(v_2)/\langle v_2 \rangle$ and $\sigma(\varepsilon_{\text{part}})/\langle \varepsilon_{\text{part}} \rangle$ in 200 GeV Au+Au Collisions

Magnitude of $v_2$ fluctuations is in agreement with $\varepsilon_{\text{part}}$ fluctuations!
“X-Ray” of Medium Using Jets

Hadrons

Leading Particle

q

Hadrons

Leading Particle

q

Hadrons

Leading Particle

Leading Particle

Hadrons

Leading Particle
Suppression of High $P_T$ Particles

Peripheral

Central

Phenix

Phenix
Centrality Dependence

- Dramatically different and opposite centrality evolution of Au+Au experiment from d+Au control.
- Jet Suppression is clearly a final state effect.
Jet correlations in proton-proton reactions.
Away side jet disappears for particles $p_T > 2$ GeV.
Strong back to back peaks.
Jet correlations in central gold-gold.
Away side jet reappears for particles $p_T > 200$ MeV.

From Jamie Nagle
EQUILIBRIUM AT CHEMICAL FREEZE-OUT

Model re-fit with all data
T = 176 MeV, $\mu_b = 41$ MeV

Model prediction for
T = 177 MeV, $\mu_b = 29$ MeV

Braun-Munzinger et al., PLB 518 (2001) 41
D. Magestro (updated July 22, 2002)
Limiting Fragmentation (Au+Au)

"Extended Longitudinal Scaling" of all longitudinal distributions
Warning: rapidity $y \neq$ pseudorapidity $\eta$

$$\tanh^{-1} \beta \neq \tanh^{-1} \cos \theta$$

change of reference frame:

$$y \uparrow y + D_y \text{relative}$$

$$\eta \downarrow \eta + \Delta y \text{relative}$$

$$\eta - y = \tanh^{-1} \cos \theta - \tanh^{-1} b$$

$$h - y = \tanh^{-1} \frac{p_l}{p} - \tanh^{-1} \frac{p_l}{E}$$

$$\frac{1}{g}$$
Possible Evidence of Partonic Degrees of Freedom